Remote Sensing and GIS Applications in Mountainous Areas

Editors:
Michel Mulders
Dhruva Pikha Shrestha
Olav Slaymaker
Alfred Zinck

Remote Sensing and GIS Applications in Mountainous Areas

Editors:
Michel Mulders
Dhruba Pikha Shrestha
Olav Slaymaker
Alfred Zinck

Remote Sensing and GIS Applications in Mountainous Areas

Editors:
Michel Mulders
Dhruba Pikha Shrestha
Olav Slaymaker
Alfred Zinck

Proceedings of the IUSS/Working Groups RS and DM International Symposium
“Remote Sensing and GIS for monitoring soils and geomorphic processes to assist integrated development of mountainous land”, Kathmandu, Nepal, 22-29 August 1999
## Contents

Preface  
Michel A Mulders ................................................................. 1

Advances in the application of remote sensing and GIS for surveying mountainous land  
Michel A Mulders ................................................................. 3

The role of remote sensing in geomorphology and terrain analysis in the Canadian Cordillera  
Olav Slaymaker .................................................................... 11

The development of the Alpine Soil Information System  
Luca Montanarella and Thierry Nègre ........................................... 18

Integrated use of satellite images, DEMs, soil and substrate data in studying mountainous lands  
Fabio Giannetti, Luca Montanarella and Roberto Salandin .................. 25

A regional scale soil mapping approach using integrated AVHRR and DEM data  
Endre Dobos, Luca Montanarella, Thierry Nègre and Erica Micheli ................. 30

Mapping and modelling mass movements and gullies in mountainous areas using remote sensing and GIS techniques  
J Alfred Zinck, Jaime López, Graciela I Metternicht, Dhruba P Shrestha and Lorenzo Vázquez-Selem ........................................ 43

Prioritizing erosion-prone areas in hills using remote sensing and GIS: a case study of the Sukhna Lake catchment, Northern India  
S S Shrimali, S P Aggarwal and J S Samra ..................................... 54

The role of GIS and RS in land degradation assessment and conservation mapping: some user experiences and expectations  
Godert W J van Lynden and Stephan Mantel .................................... 61

Soil information system of Arunachal Pradesh in a GIS environment for land use planning  
Amal K Maji, Dulal C Nayak, Nadimpalli D R Krishna, Challa V Srinivas, Kalpana Kamble, Gangalakunta P Obi Reddy and Mariappan Velayutham ........................................ 69

Land use classification in mountainous areas: integration of image processing, digital elevation data and field knowledge (application to Nepal)  
Dhruba Pikha Shrestha and J Alfred Zinck ....................................... 78

Crop area estimation using GIS, remote sensing and area frame sampling  
Sushil Pradhan ...................................................................... 86

Human interactions in soil and geomorphic processes in Nepal: the role of soil fertility in degradation and rehabilitation processes  
Hans Schreier, Sandra Brown, Pravakar B Shah, Bhuban Shrestha, Gopal Nakarmi and Richard Allen ........................................ 93

Identification and accessibility analysis of rural service centers in Kendrapara District, Orissa, India: a GIS based application  
Ranjan Kumar Mallick and Jayant K Routray .................................... 99

Guide to authors ................................................................... 107

Application of the “3S” technologies in sustainable agricultural development and land use planning in mountainous regions  
Zhao Qiguo ........................................................................ 109

Mineralogical analyses and remote sensing for comprehending the role of Himalayan Orogeny in the genesis of salinity in the Indian sub-continent  
Rej-Kumar ........................................................................ 114

Assessment of resources in hilly areas from semi-detailed survey information applying GIS techniques  
M M Rahman .................................................................... 119
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil resources mapping of lower Himalayas</td>
<td>123</td>
</tr>
<tr>
<td>L M Pande, Suresh Kumar and Jitendra Prasad</td>
<td></td>
</tr>
<tr>
<td>Land use dynamics and land degradation in the Jhikhu Khola watershed</td>
<td>129</td>
</tr>
<tr>
<td>Bhuban Shrestha and Gopal Nakarmi</td>
<td></td>
</tr>
<tr>
<td>The use of RS and GIS for monitoring land use in mountainous areas of Myanmar</td>
<td>134</td>
</tr>
<tr>
<td>Myo-Kywe</td>
<td></td>
</tr>
<tr>
<td>The use of the TM thermal band in the study of land cover/use and soil salinity in the mountains of the Iranian deserts</td>
<td>138</td>
</tr>
<tr>
<td>S K Alavi Panah</td>
<td></td>
</tr>
<tr>
<td>Monitoring land use changes in the Sundi Khola micro-watershed, Kavre district, for the sustainable development of agriculture by using geographic information systems</td>
<td>142</td>
</tr>
<tr>
<td>Kamal Sah</td>
<td></td>
</tr>
<tr>
<td>Landscape planning for Mexican mountains: a geo-ecological approach</td>
<td>145</td>
</tr>
<tr>
<td>Alejandro D'Luna Fuentes</td>
<td></td>
</tr>
<tr>
<td>An integrated land evaluation approach of crop planning for lower Himalayan mountainous lands of UP State, India - a case study</td>
<td>148</td>
</tr>
<tr>
<td>D Martin and S K Saha</td>
<td></td>
</tr>
<tr>
<td>GIS application for land use planning in Bhutan</td>
<td>157</td>
</tr>
<tr>
<td>Dungkar Drukpa</td>
<td></td>
</tr>
<tr>
<td>Linking pixels with people for sustainable sloping lands management in Asia</td>
<td>161</td>
</tr>
<tr>
<td>Mohammad Rais</td>
<td></td>
</tr>
<tr>
<td>A short refresher course on the analysis and cartographic presentation of soil data</td>
<td>164</td>
</tr>
<tr>
<td>Jeroen van den Worm and Dhruva Pikha Shrestha</td>
<td></td>
</tr>
<tr>
<td>High spatial resolution for detecting evidences of slope instability: SPOT 5 simulated stereoscopic data</td>
<td>166</td>
</tr>
<tr>
<td>O Rouzeau, F Girault, C King and S Chevrel</td>
<td></td>
</tr>
<tr>
<td>Remote sensing and GIS for mapping erosion susceptibility evolution, coastal Cordillera, Chile</td>
<td>167</td>
</tr>
<tr>
<td>G Delpont, J F Desprats and S Chevrel</td>
<td></td>
</tr>
<tr>
<td>Mapping of vegetation structure as a means of describing chorological variation in land degradation and erosion</td>
<td>168</td>
</tr>
<tr>
<td>J Slurink</td>
<td></td>
</tr>
<tr>
<td>Monitoring changes in arid mountainous rangeland of Morocco with remote sensing data</td>
<td>170</td>
</tr>
<tr>
<td>R Escadafal, J Mégier, S Bouziri and M Zouhri</td>
<td></td>
</tr>
<tr>
<td>Mapping of Sri Lankan soils for land use planning using geographic information systems</td>
<td>171</td>
</tr>
<tr>
<td>R B Mapa, A R Dassanayake and A Senarath</td>
<td></td>
</tr>
<tr>
<td>A 3-D Trekking map of the Langtang valley: the application of RS/GIS techniques for tourist mapping</td>
<td>172</td>
</tr>
<tr>
<td>Anu Rajbhandari Shrestha, Jeroen van den Worm and Dhruva Pikha Shrestha</td>
<td></td>
</tr>
<tr>
<td>Summary of sessions</td>
<td>174</td>
</tr>
<tr>
<td>Results Round Table Discussions</td>
<td>179</td>
</tr>
<tr>
<td>Participants list</td>
<td>183</td>
</tr>
</tbody>
</table>
Preface

The symposium originated from ideas and activities of two working groups of the International Union of Soil Sciences:
- DM or World Soils and Terrain Digital Data Base;
- RS or Remote Sensing for Soil Survey.

The symposium concentrated on the application of remote sensing and GIS in mountainous land. The selection of Nepal, and Kathmandu as symposium site, was made possible by the cooperation with ICIMOD, giving the participants from nearby countries the chance to discuss problems with colleagues from other parts in the world active in the same field. The discussions are supposed to have more impact in an environment reflecting these problems which Nepalese Mountains certainly do.

The aims of the symposium were the following:
- the effective use of databases, GIS and remote sensing to study the mountainous environment;
- the application of these modern techniques to study dynamical geomorphic processes and land degradation due to intensive or marginal land use;
- the application of improved knowledge of environmental processes in land evaluation and in development schemes of mountainous land.

The second aim made input from geomorphological sciences necessary. The International Association of Geomorphologists was willing to fill up the gap and made valuable contributions to the discussions during the symposium.

The symposium was well attended with 40 participants from 15 countries and 31 contributions, dealing with remote sensing, GIS and Data Bases (16 %) and applications of remote sensing and GIS in land use (including change and planning) and geography (19 %), soils (19 %), geology and geomorphic processes (19 %), land evaluation and degradation (16 %) and others (13 %).

Although the results may be regarded as several steps forward in the difficult process of obtaining sustainable land use, there remains much to do. One thing is sure, the many improvements in spatial resolution of the remote sensing tools require the society to prepare itself technically and scientifically to effectively use these new tools.

The proceedings include all papers presented in the symposium. A selected set of these papers was also published in a special issue of the International Journal of Applied Earth Observation and Geoinformation (JAG), Volume 3, Issue 1, 2001.

ACKNOWLEDGEMENTS
First of all thanks are due to the sponsors, who made possible the international symposium "Remote sensing and GIS for monitoring soils and geomorphic processes to assist integrated development of mountainous land":
- International Association of Geomorphologists (IAG);
- International Institute for Aerospace Survey and Earth Sciences (ITC, Enschede);
- International Union of Soil Sciences (IUSS);
- International Centre for Integrated Mountain Development (ICIMOD, Nepal);
- Wageningen University Research Centre (WUR) - Environmental Sciences;
- European Commission (Space Applications Institute and European Soil Bureau);
- Royal Dutch Academy of Sciences, Amsterdam, the Netherlands;
- Committee on Science and Technology in Developing Countries (COSTED - India).

Special thanks are due to the institutes, which made staff available for technical, organisational and scientific aspects of the symposium. These institutes are: ITC, ICIMOD and WUR - Environmental Sciences/Laboratory of Soil Science and Geology.
COMMITTEES

ORGANISING COMMITTEE
Dr. Michel A. Mulders (Chairman IUSS WG-RS, WUR, the Netherlands)
Dr. Richard Escadafal (Vice Chairman WG-RS, JRC, ORSTOM)
Dr. Dhruba P. Shrestha (Secretary IUSS WG-RS, ITC, the Netherlands)
Mr. Pramod Pradhan (Secretary, ICIMOD, Nepal)
Prof. Dr. Olav Slaymaker (President IAG, Univ. of British Columbia, Canada)

LOCAL ORGANISING COMMITTEE
Mr. Pramod Pradhan (Head MENRIS - ICIMOD, Nepal)
Dr. Dhruba P. Shrestha (Secretary WG-RS, ITC, the Netherlands)
Mr. Peter Bitter (RS specialist, MENRIS - ICIMOD, Nepal)
Mr. Pradeep Mool (RS analyst and glaciologist, MENRIS - ICIMOD, Nepal)

INTERNATIONAL SCIENTIFIC COMMITTEE
Dr. M.A. Mulders (Chairman WG-RS, WUR, the Netherlands)
Prof. Dr. Olav Slaymaker (President IAG, Univ. of British Columbia, Canada)
Prof. Dr. J.A. Zinck (ITC, the Netherlands)
Mr. Egbert Pelinck (Director General, ICIMOD, Nepal)

Michel A. Mulders
Chairman of the IUSS Working Group on Remote Sensing
Advances in the application of remote sensing and GIS for surveying mountainous land

Michel A Mulders

Wageningen Agricultural University and Research Centre, Laboratory of Soil Science and Geology P.O. Box 37, 6700 AA Wageningen, the Netherlands (phone: +31 317 482 413; fax: +31 317 482 419; email: Michel.Mulders@Bodlan.BenG.WAU.nl)

KEYWORDS: remote sensing, GIS, GPS, soil, landform, landscape forming processes, land cover, land use, land evaluation.

ABSTRACT

Satellite remote sensing has been practised since 1972, starting with broad channels and moderate ground resolution (Landsat MSS). In the 1980s, Landsat TM and SPOT provided for improved spatial and spectral resolutions. Many satellite images were produced in these two decades, offering a synoptic view of landscapes that were rich in contrast and that included mountainous areas. The present paper describes advances made throughout the 1990s in research on and application of remote sensing and the use of DEMs to identify landforms and landscape forming processes has become an accepted survey technique. Advances were made in the field of multi-factor approaches to spatial prediction of shallow mass movements, the application of multiple endmember spectral mixture analysis to identify land cover types, and the definition of image time series, as well as their use in component identification and monitoring of land cover (including snow). The use of steerable imaging instruments in SPOT, synthetic aperture radar (SAR) and wide scan angles in thermal infrared scanning bring specific geometric problems that have yet to be solved. SAR in particular has received increasing attention in recent research. Examples of research on radargrammetry to correct for geometric distortions in the slant range are discussed. The simulation of SAR data, aided by topographic data (DEM) of mountainous terrain, is a means to obtain better understanding and reach high geometric precision. For thematic interpretation, a variety of techniques are used, including GPS registration for measuring earth crust movements and application of remote-sensing-based vegetation indices as land quality or LAI indicators, acting as basic input for crop growth models. Great impact on the application of remote sensing can be expected in the near future from: (1) improved spatial and spectral resolution for object identification; (2) application of off-nadir viewing in stereo-modelling; and (3) improved temporal resolution, serving the monitoring of land cover (including snow) and thermal conditions.

INTRODUCTION

Natural disasters related to dynamic processes in "mountainous hinterlands" are well known, ranging from volcanic eruptions to disasters such as the heavy rainfalls and mud slides that affected Middle America on the passage of hurricane Mitch in 1998, and including regular flooding of lowlands due to snow melting in the mountains, as well as (snow) avalanches like those that occurred in winter sport areas of the European Alps in 1999. Many of the effects are predictable if proper information is available. For example, it is important to know the location and thickness of snow cover. Policy makers in communities located at the foot of mountainous areas should consider flooding as a possible hazard and settlement on areas subject to flooding and landslide hazards should be avoided. Furthermore, gully erosion is often observed in suburbs, and combative measures should be pursued with more vigour.

Do we have a proper evaluation system that considers environmental processes in the "hinterland"? Flooding is considered in land evaluation as a land characteristic, contributing to the rating of several land qualities such as water availability, oxygen availability and availability of a foothold for roots [Sys et al., 1991]. Key land qualities in land evaluation are site specific [Dumanski et al., 1998] and do not take into consideration natural hazards related to processes in the mountainous hinterland. The answer to the question is therefore that the present evaluation system only partly considers the environmental processes in the "hinterland".

Monitoring the physiography of mountainous land is of great importance for the mountainous area itself, but also for the adjacent lowlands. Since access of mountainous areas is difficult, remote sensing is a valuable alternative to intensive fieldwork and the gathering of data required for GIS manipulations. Satellite remote sensing for earth observation started in 1972, when the USA launched the first Earth Resources Technology Satellite (ERTS, later renamed Landsat), a system with a ground resolution of 80 m. Since then, much data has been acquired about the earth and image processing systems have been developed to create multispectral satellite images in colour that show contrasted landscape scenes, in particular in mountainous areas.

Further developments were directed towards improvement of spatial resolution, which resulted in Landsat TM (Thematic Mapper, 1978), with 30 m ground resolution, and SPOT (Système Probatoire d'Observation de la Terre,
1986) with 20 m ground resolution in a three-band multispectral mode and 10 m ground resolution in a panchromatic mode.

Landsat TM and SPOT also provide amelioration of the spectral resolution: narrower bands and extension of the spectral view from 0.5-1.1 μm (Landsat MS) to 0.45-2.35 μm and to thermal infrared in Landsat TM. Many satellites for earth observation, operating in the visible, infrared or radar ranges were launched in the 1980s by different nations (China, France, India and Japan) and international institutions (European Space Agency). The manned NASA Space Shuttle carried different remote sensing payloads, e.g., a shuttle imaging radar.

Mulders [1987] summarised the development objectives formulated at the end of the 1980s: (1) further improvement of spatial resolution, radiometry and spectral resolution; (2) increased application of synthetic aperture radar (SAR) and thermal infrared radiometers in satellite systems; (3) emphasis on data compression techniques; (4) research on multidirectional observation; and (5) research on spectral bands, for providing specific information.

The present paper deals with the advances made in research and application of remote sensing particularly in the 1990s and especially in relation to mountainous areas. The role of GPS (Global Positioning System) and GIS as research tools also receives attention.

DEM, TERRAIN DATA, RS AND GIS FOR CLASSIFICATION OF LANDFORMS AND INTERPRETATION OF LANDSCAPE FORMING PROCESSES

In the past, manual methods were used for classifying landforms. Hammond [1954; 1964] identified landform types in the USA by moving a square window (9.65 km x 9.65 km) across a 1: 250000 scale topographic map. For each position of the window, Hammond calculated the percentage of the area occupied by slopes of less than 8 percent, local relief and profile type (relative proportion of area with slopes less than 8 percent in upland areas). Five landform types were discriminated: plains, tablelands, plains with hills, plains with mountains and hills, and mountains. Dikau et al. [1991] developed automated procedures of DEM analysis that simulate use of Hammond's method, and which were tested in a study area containing the Southern Alps of New Zealand (Brabyn, 1997). Good resemblance to the landforms of Niemann & Hower [1991] but still without real temporal prediction, since the time recurrence of transient trigger factors, such as abnormal rainfalls, earthquakes or volcanic eruptions, cannot be evaluated.

López & Zinck [1991] digitised existing maps on topography, geology, geomorphology and soils to model spatial prediction of mass movements in the upper Coello river basin (Colombia). This approach is more complete than that of Niemann & Hower [1991] but still without real temporal prediction, since the time recurrence of transient trigger factors, such as abnormal rainfalls, earthquakes or volcanic eruptions, cannot be evaluated.

Multispectral satellite data of Landsat Thematic Mapper (TM), IRS-1C LISS III (Indian Remote Sensing programme) of landscape forming processes. A digital elevation model (DEM) and several morphologic properties (slope, aspect, curvature and upslope drainage area) were used by Niemann & Hower [1991] for slope stability assessment. Their study concerned and considered intrinsic factors for shallow mass movements (sliding and/or flowing, commonly over impermeable substrate) in the Pacific Northwest of British Columbia: (1) topography (slope gradient and shape); (2) hydrological conditions; and (3) properties of overlying soil or surficial materials. In that area, slopes greater than 35 degrees are susceptible to shallow mass movements, concave slopes being more susceptible than convex slopes. The DEM morphologic slope stability classification tended to overestimate terrain with high and moderate hazard, compared to the traditional multifactor approach, which also incorporates other factors such as material type and thickness. Niemann & Hower stated that ideally DEM-derived maps should be used to identify those areas in which more detailed investigations should be conducted.

Mulders [1998] has used a DEM for the analysis of a savannah landscape with granitic rocks in Burkina Faso, using the following steps in physiographic classification:

- elevation zones between relevant contour lines;
- slope classification;
- discrimination of plateaux and footslopes (< 0.5 percent slope);
- identification of broad valley bottoms aided by a TM image;
- identification of physiographic units by evaluation of drainage density and drainage pattern (aided by 5 x 5 window with pixel bounded multiplication factors), percent of area with slopes greater than 5 percent, percent of area occupied by plateaux, position of plateaux within elevation zones, and characterisation of component variability, as well as height of pediments, identified in cross-sections. The physiographic units are described by their soil content, using terrain data located by GPS.

Other research has been directed towards identification of landscape forming processes. A digital elevation model (DEM) and several morphologic properties (slope, aspect, curvature and upslope drainage area) were used by Niemann & Hower [1991] for slope stability assessment. Their study concerned and considered intrinsic factors for shallow mass movements (sliding and/or flowing, commonly over impermeable substrate) in the Pacific Northwest of British Columbia: (1) topography (slope gradient and shape); (2) hydrological conditions; and (3) properties of overlying soil or surficial materials. In that area, slopes greater than 35 degrees are susceptible to shallow mass movements, concave slopes being more susceptible than convex slopes. The DEM morphologic slope stability classification tended to overestimate terrain with high and moderate hazard, compared to the traditional multifactor approach, which also incorporates other factors such as material type and thickness. Niemann & Hower stated that ideally DEM-derived maps should be used to identify those areas in which more detailed investigations should be conducted.

López & Zinck [1991] digitised existing maps on topography, geology, geomorphology and soils to model spatial prediction of mass movements in the upper Coello river basin (Colombia). This approach is more complete than that of Niemann & Hower [1991] but still without real temporal prediction, since the time recurrence of transient trigger factors, such as abnormal rainfalls, earthquakes or volcanic eruptions, cannot be evaluated.
and aerial photographs at scale 1:40,000 were used for detecting geomorphic signatures of active tectonics in the Western Doon Valley, North-West Himalaya, India [Philip & Sah, 1999]. The method included visual interpretation and feature enhancement by digital image processing (e.g., application of filters for line detection). Lineaments and active fault traces, sag ponds, alluvial fans, river terraces and landslides were identified. Faults were detected in the Khara and Sirmuri Tal that were most likely due to co-seismic activity along the ongoing Himalayan tectonic uplift. The co-seismic activity along the faults might have triggered a series of landslides in the Malgi and Basog regions.

Geomorphology is very important in studying the dynamics of mountainous land. Recent developments have been directed towards modelling these dynamics. Tebbens [1999], for instance, used three-dimensional forward modelling to simulate fluvial dynamics over the last 250,000 years, using an initial profile of the Meuse in the Central Ardennes, Terrace Flight and Venlo Graben areas, as well as time variables such as tectonic uplift or subsidence rates, sea-level changes and climatic data.

**IMAGE TIME SERIES TO INTERPRET LAND COVER DYNAMICS AND IDENTIFY LITHOLOGY**

Image time series are often used to identify and monitor land cover dynamics (including snow cover). A principal components transformation of geo-referenced wet and dry season Landsat TM data was used in the Sahelian and Sudanian zones of Mali to differentiate areas with annual grass growth from those with woody cover [Franklin, 1991]. Furthermore, clusters were assigned to vegetation types and density categories. Map accuracy was standard (40-80 percent overall) for detailed vegetation categories but high (90 percent) for vegetation density.

Modelling land cover dynamics in Africa was done with NOAA/AVHRR (National Oceanographic and Atmospheric Administration/Advanced Very High Resolution Radiometer), Landsat MSS and SPOT XS (multispectral mode) satellite data [Mertens & Lambin, 1999]. NOAA/AVHRR data with 1 km x 1 km ground resolution, characterised by its brightness temperature and a vegetation index, were interpreted in terms of land cover change on a yearly basis from 1982 to 1991. Remote sensing data with finer spatial resolution, Landsat MSS and SPOT XS, were used for validation and to achieve a better understanding of the land-cover-change processes in the period 1973–1986 in a study area in the east of Cameroon. Several spatial variables were integrated in GIS: land suitability, distance to the nearest road and nearest town, nearest forest edge, spatial fragmentation of the forest cover and forest cover density. Conclusions were drawn on the type of relationship of deforestation with the spatial variables, e.g., negative logarithmic functions or linear functions, and a multivariate model was developed to account for interaction effects between the different variables.

Snow cover distribution was analysed using a DEM and processing five IRS-1B LISS-II multispectral satellite data sets with ground resolution of 36.25 m that had been obtained in the period December 1993 – September 1994. This was done to study an area located in the Gharwal Himalayas, India [Baral & Gupta, 1997]. The snow cover area at repetitive coverage of IRS 1B LISS-II was computed by density slicing the near-infrared image (DN more or equal to 126). For shadow correction the DEM was used. The shadow map was based on the application of artificial illumination to the DEM, corresponding to the solar position at satellite crossing, and simulation of shadows. The shadow image was laid over the snow cover image. The pixels in the shadow area, lying close to the snow cover, were re-categorised to the snow cover area to produce shadow-corrected data. The snow cover distribution was related to slope and aspect components derived from the DEM analysis. The south-facing facets have the largest number of pixels with snow cover and exhibit the fastest depletion in snow cover area. Snow cover inventory, producing maps on an important dynamic aspect of mountainous land, is served by GIS and remotely-sensed image time series. The latter have a wide field of application, since they are also useful for mapping stable components.

Landsat MSS data have been used for documenting land cover changes in the North American continent. Historical image data (aerial photographs and Landsat MSS) were found to be appropriate for mapping soils and geology in areas of great surface disturbance due to human activities. Image time series can be very useful to study landscape dynamics and to map rocks and soils. Yuan et al [1998] described the image time series by the following function:

\[
DN = F(S, T, R)
\]

where DN = DN value of recorded signal, F = function, generally additive, S = stable components (soil, rock, etc.), T = temporal components (vegetation, land use, etc.) and R = random components (atmosphere, etc.). The image time series obtained through remote sensing is not a simple sum of the individual time series at pixel level. It has interactions at pixel, neighbourhood and scene levels. Four steps are regarded as essential in lithological mapping [Yuan et al, 1998]: (1) albedo conversion/data reduction in spectral dimension, the multichannel image time series being reduced into a single channel image time series; (2) Principal Component Analysis (PCA) for component separation; (3) stable component
identification, using visual identification and separability analysis; (4) lithological classification, using the maximum likelihood classification.

TECHNOLOGICAL ADVANCES WITH EMPHASIS ON THE 1990S

HIGH SPECTRAL RESOLUTION

TERRA-ASTER (launched in 1999) shows improved spectral resolution with 6 channels in the SWIR and 5 channels in the TIR. AirborneVisible – Infrared Imaging Spectrometer (AVIRIS) data of the Santa Monica Mountains were used to test and develop a technique: MESMA (Multiple Endmember Spectral Mixture Analysis) [Roberts et al., 1998]. AVIRIS operates with 224 spectral bands in the 370-2500 nm range with a ground instantaneous view of 17.4 m x 17.4 m from a platform altitude of 20 km. The MESMA technique models remotely measured spectra, called endmembers, while allowing the types and number of endmembers to vary on a per pixel basis. The AVIRIS data were acquired in fall 1994 to map the Southern Californian chaparral, a natural vegetation type with high fire hazard. Candidate members were developed from a library of field and laboratory measured spectra (leaves, canopies and non-photosynthetic materials). In total, 276 three-endmembers were used to reach a final product with seven evergreen classes and nine senescent or drought deciduous classes of natural and introduced vegetation in the study area [Roberts et al., 1998].

HIGH SPATIAL RESOLUTION AND STEREO-VISION

Landsat 7 (launched in 1999), shows improved spatial resolution in the panchromatic band and the thermal band, respectively set on 15 m and 60 m. The TERRA-ASTER has spatial resolution of 15 m in the VNIR and 90 m in the TIR. The 90 m spatial resolution is remarkably high since it has been achieved at the relatively high spectral resolution of 5 bands in the TIR domain (8-12 μm).

Two operational remote sensors with high spatial resolution are the SPOT 2-3 with 10 m ground resolution in the panchromatic channel 0.51-0.73 μm, and the IRS-1C with 5.7 m ground resolution in the panchromatic channel 0.50-0.90 μm [Noordzij, 1996]. Very high ground resolution has been achieved with cameras, eg, the KVR-1000 with 2 m. Satellite scanner/sensor development programmes, directed towards development of very high ground resolution are, for example:

1. panchromatic modes in QuickBird and IKONOS-2 with 0.82 m; IKONOS-1 and OrbView-3 with 1 m; SPOT-5 with 5 m; and
2. XS sensors (4 spectral bands) in the 450-900 nm spectral domain with 3.2-4.0 m [Balsem, 1999].

The launch of IKONOS-2 took place in 1999. Since this launch, a wide range of applications has been realised for IKONOS-2 products.

Most of these systems will get off-nadir viewing capacity to enable stereo-vision. However, the TERRA-ASTER system has a telescope backward viewing band in the NIRS for high-resolution along-track stereoscopic vision.

Experience has been gained with the optional capability of steerable mirrors on the SPOT satellite [Loedeman, 1993]. A pair of SPOT images can be acquired from different orbits 3-4 days apart and with non-identical viewing geometries. Height measurements from a SPOT stereo pair are based on stereo-matching. The height is calculated from the shift in position or parallax of corresponding pixels from the stereo pair. With suitable ground control points, DEMs generated from SPOT at 30 m spacing can be achieved with vertical and horizontal errors of 10-20 m [Vries, 1999]. Slopes steeper than the complement of the incidence angle, exposed in the look direction, are not visible to the SPOT-HRV (High Resolution Visible) imaging instruments. A computer program developed by Nossin & Gorte [1991] calculates the visibility of slopes with specified slope angles and aspects, as well as the state of shade or sunshine on the slope for any combination of look direction, incidence angle and sun elevation. Using this program, image interpretation can be done with more insight.

HIGH TEMPORAL RESOLUTION

NOAA satellites have a high temporal resolution of twice daily for equatorial localities, but a low ground resolution of 1 km x 1 km in the visible and near infrared bands. Application of more than one satellite improves this temporal resolution. The temporal resolution of SPOT can be increased to one passage during daylight every 3-4 days over the same earth locality by using the steerability of the HRV imaging instruments. The IKONOS-2 satellite with very high ground resolution of 0.82 m (mentioned above) has a revisit interval of 1-3 days [Balsem, 1999], although close to the equator the revisit frequency is less within this range. The chances of obtaining images for monitoring processes in the near future are thus good. [COSPAR, 1998].

ACHIEVEMENTS WITH RADAR

Since the 1960s, SAR (Synthetic Aperture Radar) has been used for (1) observing terrestrial areas concealed under thick cloud cover; and (2) extracting terrain elevation data and generating topographic maps and DEMs. Radar altimetry from space has been used since the early 1970s, eg, NASA's Skylab in 1973. GEOS-3 operated in 1976 to measure height differences > 60 cm with an accuracy of 10 cm. This satellite was followed in 1985 by GEOSAT and TOPEX-Poseidon, the latter having an accuracy close to 3-4 cm. Radar altimetry can also be used to...
measure the height of the sea level. For example, warm seawater associated with events like "El Niño" will have a higher sea level and will thus be detectable by radar [Schrampa & Naeije, 1999], demonstrating an important application, namely the detection of warm sea water bodies, which have great impact on climate and climate-related disasters.

Later developments were directed towards improvement of accuracy, detectability and imaging capability. Radarsat was launched in 1985 to survey Antarctica. It can be programmed to capture images of an area as wide as 500 km and can detect objects as small as 8 m [COSPAR, 1997b]. The European Remote Sensing Satellites, ERS-1 and -2, were launched in 1991 and 1995, respectively. ERS-1 SAR achieves accuracies in altimetry of better than 10 cm over oceans and smooth ice surfaces. ERS-1 and ERS-2 have interferometric sensors for extracting 3-dimensional information about the earth’s surface. This is done by relating signals with phase differences from two spatially separated antennas or a single antenna viewing the same surface on two different passes [Vries, 1999]. In the near future, a follow up of ERS is foreseen in the ENVISAT programme, with a launch planned in 2001. Improvements are planned, such as a SAR that will enable more detail at one polarisation or less detail and various polarisations [Jongepier, 1998].

Recent developments aim at correction of geometric distortions in radargrammetry: (1) in the range axis, to compose an algorithm that calculates the elevation of homologous points in SAR images, obtained by parallel same-side facing airborne flight paths (test site Kilauea Volcano, Hawai [Ansant & Thouvenot, 1998]) and using automatic search of homologous points by shape recognition – determined by a threshold in the pixel radiometry gradient; (2) in the slant range (Figure 1) of the 3rd Shuttle Imaging Radar (SIR-C with X-SAR), using multi-frequency and multipolarization SAR. Relief-induced distortions can be corrected by low level radiometric enhancement via PCT or ratio analysis (test site Timna Valley, Southern Israel [Wever & Bodechtel, 1998]).

Chorowicz et al [1998] (test site Montagne Sainte-Victoire, Provence, France) used computer-aided recognition of relief patterns on airborne SAR images Band X (wavelength 3.2 cm; pixel size 2 m x 2 m) by a syntax analysis. Preprocessing involved image filtering, gradient and far-range correction. Processing involved the composition of characteristic profiles and identification of complex patterns through a search of specific successions of symbols using syntax rules. The search was limited to crests, thalwegs, landslides, and structural escarpments and associated lithological boundaries.

A step forward in the improvement of our understanding of radar images is the simulation of such images from known topographic data (DEMs) in mountainous terrain, where image grey values of SAR are mainly influenced by topography rather than thematic content. The main design goal of the SAR simulation program developed by Gelautz et al [1998] was to achieve high geometric precision in terrain with strong relief. Tests were carried out on ERS-1/X-SAR and JERS-1 images (Japanese Earth Resources Satellite-L band-SAR) of the Oetztal area in Tyrol (Austria). Two different backscatter models were employed: (1) a simple cosine reflectance function; and (2) a model that accounts for the effects of different types of land cover. The geometric deviations between the real and the simulated image could be described by an RMS error of less than 25 m.

THERMAL INFRARED WITH LOW SPATIAL RESOLUTION

The forward- and nadir-views of ATSR (Along Track Scanning Radiometer, operating in thermal infrared on ERS) have a wide scan angle and high temporal resolution. Dual data of volcanic lava domes are being used to investigate how geometric effects influence the retrieved thermal anomalies. The effect of increasing pixel size with zenith angle is counteracted by increasing pixel overlap, using two ATSR views in areas where off-nadir obscurcation by crater walls is not significant. The findings will serve future application of MODIS (Moderate Resolution Imagery Spectrometer) on board the NASA Earth Observing System (EOS). MODIS uses a 55-degree scan angle (2330 km wide swath) and is likely to be used in volcanological investigations (test sites Lascar Volcano in Chile and Unzen Volcano in Japan [Wooster et al, 1998]).

RS DATA REDUCTION

PC transform and ratios are means to obtaining data reduction, ie, reduction of raw data into a volume no larger than that required for a particular analysis. I found

![Figure 1: Geometry of radar acquisition](image)
good correlation between the iron content of map units and a TM derived ratio 3-1/3+1 in a savannah area of Burkina Faso. A moderate correlation was obtained between the ratio 7/sum of TM bands, as well as PC1, and the clay content of map units in the same area. These maps and others (e.g., high albedo to indicate areas with white sandy surface) may be used to extract information on terrain units in an early stage of soil survey.

THEMATIC INTERPRETATION

GPS AS A TOOL TO MEASURE EARTH CRUST MOVEMENTS

A network of Global Positioning System (GPS) receivers has been used to measure the movements of the earth's crust along faults. Forty GPS receivers were running in 1997 in Southern California. It was determined that California had continued to move after the earthquake in 1994, which may mean that stress was still being released. Furthermore, the survey data are important for identifying active buried faults [COSPAR, 1997a].

CONTRIBUTIONS OF GIS AND GEOSTATISTICS TO SOIL MAPPING

Fuzzy c-means clustering of attribute data, derived from a DEM, was applied to a hill slope within a drainage basin in Southern Spain to represent transitional zones in the soil landscape. Conventional soil-landscape modelling is enhanced by this method as it allows representation of the fuzziness inherent to soil-landscape units [de Bruin & Stein, 1997].

GIS FOR LAND USE STUDIES

GIS and multivariate analysis of farmer's spatial crop-decision behaviour were used to characterise rugged terrain in Buguias, Northern Luzon in the Philippines [Lawas & Luning, 1998]. Factors used in the analysis were: soil suitability, season, maximum market price at harvesting time, crop growing highest income in a specific period, availability of planting materials, and occurrence of pests and diseases in a particular period.

In evaluating land use in the Atlantic zone of Costa Rica (with volcanic mountain ranges and plains), the GIS capacity of ArcInfo was used to overlay land use patterns with physiographic mapping units (PMUs). For every PMU, the land capability class distribution could be calculated, given its composition of terrain units and associated land capability class. The actual land use was evaluated in terms of over-use and under-use [Huiising et al, 1994].

Airborne remote sensing data were used to evaluate optical (SPOT and Landsat) and microwave (ERS1/2 and JERS-1) satellite configurations for estimating LAI and biomass as input to crop growth models [van Leeuwen, 1996].

Multitemporal MSP (MultSpectral aerial Photography), acquired twice during the growing season of maize in Limagne (France), was expressed in plots with different soils by photo-density values, which were translated into reflectance values with the aid of field reflectance measurements at comparable solar positions. The WDVI (Weighted Difference Vegetation Index) was used as a land quality indicator to arrive at an appraisal of land suitability for maize growth in the Limagne area, France [Mulders & l'Homme, 1997]. The WDVI is expressed by the following formula:

\[ WDVI = \text{NIR} - c \times \frac{\text{R}}{\text{NIR}} \]

where NIR and R are the reflectance values for the crop cover and \( c \) is equal to the \( \text{NIR}/\text{R} \) ratio of the reflectance values for soil.

Airborne optical scanner data have been used to provide quantitative and qualitative information on crop status and development. Field patches with over-fertilisation, light-textured soils and patches with crop damage by snails were identified from remotely sensed data. The remotely sensed images were converted into LAI images and simulation modelling was used to determine time windows for fertiliser application in a decision support system for precision agriculture [Booltink & Epinat, 1999].

CONCLUSIONS

The expectations of future developments of remote sensing that were envisioned in the 1980s have been by and large fulfilled by the advances described in this paper. GIS and applications of DEM-analysis have also had a strong effect on survey techniques, including the prediction of mass movements. GPS has enabled a better registration of field observations and it has become an indispensable tool for linking field data with DEM. Geomorphology can play a key role in the study of landscape forming processes. For human-induced processes of land cover change also to be considered, co-operation between specialists on soils, vegetation and agriculture is required.

It is expected that a number of developments in remote sensing will have great impact on the methods for surveying mountainous land:
- high spectral resolution and MESMA;
- high spatial resolution expected in the near future;
- off-nadir viewing for stereo-vision;
- high temporal resolution of visible and near infrared imaging systems;
- geometric correction of radar images, acquired independently of weather conditions;
- monitoring of thermal condition;
- use of PCA and various ratios to reduce remote sensing data and information extraction;
- use of RS-derived vegetation indices as land quality indicators and as input in crop growth models.

Finally, the application of GIS in multivariate analyses of agricultural systems is well accepted. This is also true for the application of RS-derived data.

The scientific community should prepare itself for future developments in remote sensing, which are bound to accelerate in the first decade of the 21st century. What will be available? What are the possibilities and limitations? What will geo-scientists need? How can the data be improved for application in a pre-fieldwork phase?

Current limitations are:
- Multispectral capability of the very high spatial resolution systems. They are capable of operating in the visible and near infrared domain, but they lack the valuable information obtainable by TM in the bands 5 and 7 (1.55 - 1.75 μm and 2.08-2.35 μm, respectively).
- Limited financial means in developing countries. This limits, for example, investments in PCs, printers and digital storage capacity, as well as opportunities to obtain detailed information of the terrain to be used for coupling of DEM data with soil data or with other ground-truth data.
- Communication. Data should regularly exchanged across national boundaries to cope with natural disasters in mountainous hinterlands and adjacent lowlands. The exchange of knowledge should be people-oriented, i.e., through more frequent contacts between experts, for example in the form of workshops, symposia and short refresher courses. Experts in GIS and remote sensing should be more active in convincing policy makers and planners of the need to study dynamic aspects in mountainous areas and to take these aspects into consideration in agricultural and rural development.

REFERENCES


RESUME

La télédétection à l’ aide d’ images satellites a été pratiquée depuis 1972, en commençant avec des canaux spectraux larges et des résolutions terrain faibles (Landsat MSS). En 1980, Landsat TM et SPOT ont amélioré les résolutions spectrales et spatiales. Beaucoup d’ images satellites ont été produites au cours de ces deux décennies, offrant une vue synoptique de paysages qui étaient riches en contraste et qui comprenaient des zones montagneuses. Le présent article décrit les avancées faites durant les années 90 en matière de recherche et application de la télédétection et de l’ utilisation de MNT pour identifier des formes de terrain et les procédés de formation de paysage est devenu une technique de lever courante. Des progrès ont été faits dans le domaine des approches multifacteurs pour la prédiction spatiale de mouvements en masse superficiels, de l’ application d’ analyse multivariate et d’ analyse spectrale pour identifier les types d’ occupation des sols et la définition de séries temporelles d’ images, ainsi que leur utilisation dans l’ identification de composant et le suivi de l’ occupation du sol (y compris la neige). L’ utilisation d’ instruments images pouvant être dirigés tels que SPOT, Radar à antenne synthétique (SAR) et le scannage grand angulaire dans les images thermiques infrarouges crée des problèmes géométriques spécifiques qui doivent encore être résolus. SAR en particulier a reçu une attention accrue dans la recherche récente. Des exemples de recherche en radargrammétrie pour corriger les distorsions géométriques dans les distances obliques sont discutées. La simulation de données SAR, appuyées sur des données topographiques (MNT) de terrain montagneux, est un moyen pour obtenir une meilleure compréhension et atteindre une précision géométrique élevée. Pour des interprétations thématiques, des techniques variées sont utilisées y compris des enregistrements GPS pour mesurer les mouvements de l’ écorce terrestre et l’ application d’ indices de végétation basés sur la télédétection comme qualité de paysage ou indicateurs LAI, jouant le rôle d’ entrées de base pour des modèles de croissance des cultures. On peut s’ attendre à un grand impact des applications de la télédétection dans un futur proche: (1) amélioration de la résolution spatiale et spectrale pour l’ identification d’ objets; (2) application de vues non verticales dans la modélisation stéréo; (3) amélioration de la résolution temporelle, définissant le suivi de l’ occupation du sol (y compris la neige) et l’ état thermique.

RESUMEN

Se ha practicado teledetección satelital desde 1972, comenzando con canales anchos y moderada resolución espacial (Landsat MSS). En los años 1980, Landsat TM y SPOT suministraron resoluciones espaciales y espectrales mejoradas. En estas dos décadas, se produjeron muchas imágenes satelitales, que ofrecieron una visión sinóptica de paisajes ricos en contrastes, incluyendo áreas montañosas. Este artículo describe los progresos realizados en investigación y aplicación de la teledetección en el transcurso de los años 1990, mientras que los modelos digitales de elevación (MDE) pasaron a ser una técnica aceptada de levantamiento para identificar formas de terreno y procesos formadores de paisaje. Se hicieron progresos en el área de los enfoques multi-factoriales para predecir la ocurrencia espacial de movimientos en masa superficiales, en la aplicación del análisis de mezcla espacial de componentes múltiples para identificar tipos de cobertura de la tierra, y en la definición de series temporales de imágenes y el uso de estas para identificar componentes y monitorear la cobertura de la tierra (incluyendo nieve). Todavía falta por resolver problemas geométricos específicos planteados por el uso de instrumentos direccionales para la toma de imágenes en SPOT, por el uso del radar de apertura sintética (SAR), y por el uso de ángulos de barrido anchos en el infrarrojo térmico. SAR en particular ha recibido una creciente atención en investigación reciente. Se discuten ejemplos de investigación en radargrammétrie para corregir distorsiones geométricas en ángulo oblicuo. La simulación de datos SAR, apoyada por información topográfica (MDE) en terreno montañoso, permite obtener un mejor entendimiento y alcanzar una alta precisión geométrica. Se utiliza una amplia variedad de técnicas para interpretación temática, incluyendo registros GPS para medir movimientos de la corteza terráquea y la implementación de índices de vegetación basados en teledetección como indicadores de calidad de las tierras o de LAI, usados en modelos de crecimiento de cultivos. En un futuro cercano, se puede esperar que varios factores van a tener un impacto considerable en la aplicación de la teledetección, incluyendo: (1) una mejor resolución espacial y espacial para la identificación de objetos; (2) la utilización de imágenes tomadas fuera del nadir para modelización estereoscópica; y (3) mejor resolución temporal para seguir cambios en la cobertura (nieve incluida) y la condición térmica de la tierra.
The role of remote sensing in geomorphology and terrain analysis in the Canadian Cordillera

Olav Slaymaker

Department of Geography, University of British Columbia, Vancouver, BC, V6T 1Z2, Canada (phone: +604 822 2663; fax +604-822-6150; email: olav@geog.ubc.ca)

KEYWORDS: Remote sensing; terrain analysis; geomorphology; Canadian Cordillera; geoscience registration

ABSTRACT

Geomorphology, soil science and remote sensing are closely related fields of enquiry through their common interest in the five state-factors of environmental systems: climate, organisms, relief, parent material, and time. Remote sensing, from aerial photography to satellite imagery, constitutes a powerful tool for improving accuracy and precision of extensive large-scale geomorphological surveys, making it possible to investigate previously untestable ideas. Remote sensing is transforming geomorphology into a more global science, and it is influencing the development of environmental policy with respect to geomorphological problems. An instructive example is the evolution of remote sensing applications to terrain analysis in British Columbia over the past 25 years. Applications of geomorphology to land management, resource development planning, land use planning and project planning as well as natural hazards policy are illustrated.

INTRODUCTION

Geomorphology, soil science and remote sensing are closely related fields of enquiry. Jenny's 'clorpt' equation [Jenny, 1941] provides one useful way of illustrating the fundamental links between the three fields. If soil science is seen as an analysis of the soil response to climate, organisms, relief, parent material and time, geomorphology can be viewed as an analysis of landform response to climate, organisms, relief, parent material and time. Geomorphologists tend to emphasize parent material, climate, relief and time; and they frequently subsume these factors under the trilogy 'structure, process and stage' [Chorley et al., 1984]. In practice, the biggest difference in emphasis between the two fields is probably the stronger emphasis on geological time scales in geomorphology and the stronger emphasis on ecological factors (i.e., organisms sensu lato) in soil science. Remote sensing can be defined as the process of obtaining information on four of the state-factors close to the Earth's surface by measuring electromagnetic radiation, the observations being made from a considerable height above the target [Massom, 1991]. A more general definition is provided by Avery & Berlin [1992], who see it as the measurement of a property of an object by a device not in direct contact with the object of study. Common remote sensing platforms are illustrated in Figure 1.

REMOTE SENSING AND DIGITAL TERRAIN MODELS

AERIAL PHOTOGRAPHY

If we adopt the more general definition of remote sensing, then conventional aerial photography is highly relevant to our discussion. Aerial photography has been demonstrated to be a powerful tool to generate information on lithology, drainage patterns and a whole...
range of fluvial, coastal, glacial and eolian landforms. It is a routinely applied technique in terrain stability assessment [eg, Howes & Kenk, 1997], and it allows the researcher to examine large areas in remote terrain which would otherwise present insurmountable financial and logistical obstacles.

REPEAT PHOTOGRAPHY
In Canada, aerial photographs dating from the late 1920's are available for some regions. Photographic records of rivers and associated landforms are more complete than any other type of record [Kellerhals et al, 1976]. Sundborg's classic study [1956] of the River Klaralven in Sweden illustrates the innovative and quantitative way in which repeat photography can be used. There are, however, numerous technical problems in using photographs of differing levels of scale and resolution. Ham & Church [2000] have 'solved the problem of scale changes for historic sequences of air photos by georeferencing imagery with common ground control points using an analytic stereoplotter. The advantage of using this approach is that the stereoplotter rectifies the stereo image, removes parallax distortion and magnifies the view, thereby enhancing interpretation reliability. It also provides a mathematically derived error of fit between each control point and its real world equivalent' [Ham, personal communication 2000]. Repeat photography is commonly available at annual to decadal time scales. In this sense it is admirably suited to the time scale of channel changes along large rivers and discrete geomorphological events like large landslides. But many geomorphic changes that occur at shorter intervals or with greater frequency cannot be captured in this way. Because of the combination of historic coverage, high spatial resolution and accurate mapping capabilities, repeat photography will continue to be a powerful geomorphological tool.

LAND COVER CHANGE
For the last thirty years, remote sensing techniques at broad spatial scales together with sequential maps have been used to model and monitor land cover change [Lambin, 1997]. Perhaps the most dramatic illustration of the value of this approach is in the context of desertification processes as, for example, in Burkina Faso [Lundqvist & Tengberg, 1993] and Botswana [Sefe et al, 1996]. The unique capacity of satellite imagery to provide consistent and complete data about very large areas is illustrated by a study of landscape changes in the interior of British Columbia by Sachs et al [1998]. They used Landsat Thematic Mapper and Multi-spectral Scanner (TM and MSS) imagery to map forest cover and detect major disturbances between 1975 and 1992 for a 4.2 million hectare area. An independent estimate from forest inventory data was similar to that achieved by image-based estimates. This approach provides important information not only on geomorphology [eg, Jones & Grant, 1996], but also on forest management effects on landscape patterns [Franklin & Forman, 1987]. Indeed there have been growing demands that forest management should be based on ecosystem or landscape management principles in all forest lands [Galindo-Leal & Bunnell, 1995].

DIGITAL TERRAIN MODELS
The numerical representation of ground surface relief and pattern has traditionally been referred to as terrain analysis, quantitative geomorphology or geomorphometry. However, a new term, digital terrain modeling, is increasingly preferred [Pike, 2000] as a result of the explosive growth of computing capacity and widespread application of digital elevation models. The computation of basin hydrographs, estimation of soil erosion, mapping of landslide susceptibility, prediction of groundwater movement and visualization of topography are all aided by digital terrain modeling [Florinsky, 1998]. Automated software tools to extract accurate terrain models from conventional aerial photographs are now available for the desktop computer [Chandler, 1999]. Synthetic Aperture Radar interferometry uses phase changes of radar pulses from two different antenna positions to derive digital terrain models. If the antennae are separated by time rather than space, subtle changes in surface morphology can be detected. This technique has proved particularly valuable in the study of glaciers and ice sheet motion [Kwok & Fahnestock, 1996; White, 1997].

HYDRO-GEOMORPHOLOGY
Experimentation with fully automated approaches to extracting stream networks and drainage basins from digital terrain models has led to new understanding of the scale dependency of stream networks, notably their degree of self-similarity as expressed by fractal measures. The idea of self-organized criticality goes some way towards explaining the spatial orderliness of stream patterns in terms of principles of energy dissipation, characterized by fractal scaling in space and time. This automatic extraction of river networks from satellite images allows for controls on drainage patterns to be analysed [Kimothi & Juyal, 1996; Deroin & Deffontaines, 1995]. Synthetic Aperture Radar data can be used for estimating width and discharge of braided rivers [Smith et al, 1996].

SOIL-LANDSCAPE RELATIONS
Measuring the fine to micro-scale geometry of field surfaces to model soil-landscape relations is traditional in agricultural engineering, but assessment of soil resources from broad-scale terrain geometry is new. For example, from a 10m digital elevation model relations have been established between spatial patterns of terrain and patterns of a color index associated with hydric soils
Terrain analysis in the Canadian Cordillera

(Gleysols). Slope gradient, profile curvature and local relief can explain up to 68 percent of the color index variation [Galvao et al., 1995].

**LANDSCAPE ECOLOGY**

Quantification of landscape structure is facilitated by incorporating digital terrain model based variables into land unit classification. Measures such as contiguity, interspersion, nesting and adjacency complement slope profile curvature. Ultimately, patches, land components and terrain facets can be objectively identified in this way [Pike, 2000]. It is also argued that the increasing use of satellite imagery, combined with digital terrain modeling, is transforming geomorphology into a more global science - a science that is more able to respond to the questions of global environmental change [Slaymaker & Spencer, 1998].

**GENERAL OBSERVATIONS ON REMOTE SENSING IN GEOMORPHOLOGY**

Higgitt & Warburton [1999] have argued that remote sensing techniques are providing fresh insights in geomorphology in four main ways:

a) They provide new applications for geomorphology.
b) They provide new and improved accuracy of measurement.
c) They provide new data that allow investigation of ideas that were previously untestable.
d) They involve development of data processing capability.

It is important to pay attention to the appropriateness of the remote sensing platforms utilized, especially with respect to the scale of the study (Figure 2). But it is also clear that real progress in understanding of the value of remote sensing to geomorphology will only be achieved through careful field data collection, ground truthing and field checking alongside the increasing use of remote sensing technologies.

**THE EXAMPLE OF TERRAIN ANALYSIS IN THE CANADIAN CORDILLERA**

One of the problem areas in which this relation between remote sensing and geomorphology is well illustrated is that of terrain analysis. Terrain analysis and its relation to land use was explored by Sidle et al [1985] and a wide range of applications was discussed. Recent developments in the Canadian Cordillera, especially in British Columbia (BC) but also in western Alberta, western North-West Territories and Yukon Territory, demonstrate the necessity for close collaboration among scientists to address questions of land management, resource development planning, land use planning and project planning in a mountainous region.

A dramatic increase in research and a renewed debate over natural hazards policy in British Columbia were stimulated in part by an editorial in the BC Professional Engineer [Farquharson et al., 1976]. Prior to 1976, natural hazards policy, such as it was, related almost exclusively to high magnitude, low frequency events such as huge floods and unpredictable landslides. The only practical response to such extreme geophysical events was a structural one. The role of geomorphology, soil science and remote sensing experts was seen as ex post facto – one of interpretation after the event. Interestingly enough, it was an extreme hydrologic event on the Queen Charlotte Islands in 1978 [Schwab, 1983] that reinforced the natural hazards policy debate. One three-day storm in October 1978 triggered over 500 landslides; of these, landslides on previously logged slopes were particularly severe. An inter-governmental research initiative (The Fish–Forestry Interaction Program) was established in 1981, with a 10-year budget. The following concerns were rapidly incorporated into the discussion: the relation between resources, population growth and environment [Eisbacher, 1982]; ecological concerns over fish-forestry interactions [Church, 1983]; implications of potential climate change [Slaymaker, 1990] and international pressure directed towards our inefficient timber harvesting practices [Ellis, 1989]. The net result was that the whole emphasis of the natural hazards and land use planning debate shifted towards widely distributed high frequency, low magnitude events which can, in principle, be predicted, enabling precautionary practices and avoidance measures to be carried out. The fundamental change in approach was due to the realization that slope failures are a ‘normal’ feature of over-steepened, glaciated slopes subjected to intense precipitation. The new

![FIGURE 2: Size scales and appropriate remote sensing platforms](image-url)
Terrain analysis in the Canadian Cordillera

The challenge is to locate these conditionally unstable slopes and identify types of terrain that are most susceptible to failure. When such concerns become significant to policy makers, geomorphologists, soil scientists and remote sensing specialists assume a new level of importance and responsibility in society.

The shift of emphasis during the past two decades can be exemplified by the following research developments:

(a) Aerial photograph inventory of forested and clear-cut terrain [Rood, 1984; 1990]. The first of these landmark studies established that the average density of landslides larger than 0.02 ha on the Queen Charlotte Islands is about 8 per km². The actual sediment yield estimated by Rood led to the conclusion that clearcut logging and associated road construction increased the frequency of mass wasting events by 34 times and the volume of eroded soil by 35 times compared with adjacent unlogged terrain. Sediment delivery to stream channels in logged areas was increased by 23 times. Jakob [2000] provided data on landslide frequency as a function of area logged per watershed on Vancouver Island (Figure 3).

(b) Terrain stability in sediment budget studies [Roberts & Church, 1986; Jordan & Slaymaker, 1991]. These two studies dealt with small, forestry-impacted basins on the Queen Charlotte Islands from 3.9 to 12.6 km² in area [Roberts & Church, 1986] and with an intermediate-scale (3,800 km²), glacierised and debris-flow-dominated basin [Jordan & Slaymaker, 1991]. The use of a sediment budget approach provided some powerful new insights into the need for greater attention to terrain analysis and the importance of sediment storage effects within river basins. On the Queen Charlotte Islands, Roberts & Church demonstrated, at one level, the conventional effect of logging, namely a ten-fold acceleration in sediment transport. At another level, their results were quite novel. Because of the build up of 'sediment wedges' in the stream channels, in-channel sediment residence time increased by a factor of 100. On the one hand, this results in a poor aquatic habitat; but on the other hand, the downstream impact of logging is strongly buffered. In the Lillooet River basin, Jordan & Slaymaker demonstrated the high rate of sediment delivery to the delta, resulting from glacier and mass wasting sources upstream. Nevertheless, best estimates of contemporary sediment production rates can account for no more than 50 percent of the mass of sediment accumulating at the delta. It appears probable then that sediment presently delivered at the delta is a response to channel straightening carried out between 1948-51. A 50-year time lag associated with rearrangement of the floodplain is also possibly combined with a longer time lag of accelerated sediment production from the Little Ice Age of the 18th and 19th centuries. Detailed terrain analysis of the major storage areas is needed to provide more precise estimates.

(c) Effects of terrain instability on fish [Hartman & Scrivenor, 1990]. This is just one example from a wealth of literature on the ecological complexity of salmonid life history strategies and forest harvesting impacts. Not the least of these complexities is that each salmonid species (of which there are seven in the coastal BC region) uses streams in a different manner. Therefore, forest harvesting affects each species differently. Three groups of effects must be analyzed separately as they operate on different time frames: the regrowth of watershed vegetation, the impact of which begins immediately after logging; the occurrence of large floods, whose impacts are felt within 5-10 years; and structural and habitat changes that may appear within 10-20 years, but will probably continue throughout a forest rotation.

(d) Predictive studies of slope instability [Rollerson, 1992]. Clearcut landslide frequency is related to surficial material, bedrock lithology, horizontal slope curvature, soil type, slope angle, slope position and slope morphology. Combinations of these variables were used to develop landslide risk classifications. The study was restricted to logged areas that were 6-15 years old and it included 28 randomly selected logged areas within the physiographic unit Skidegate Plateau of the Queen Charlotte Islands.

(e) Applications of GIS to terrain stability analysis [Niemann & Howes, 1992]. In this paper, algorithms that describe hill slope shape in terms of gradient, two-dimensional curvature and distance from drainage divide and that relate these parameters to landslide incidence were successful in predicting...
Terrain stability and the forest industry [Ryder et al., 1995]. In this publication, Ryder et al. pointed out that the new BC Forest Practices Code makes it mandatory for appropriate levels of terrain stability assessment to be carried out prior to various stages of forestry development. The three levels of terrain stability assessment currently used are: (1) reconnaissance terrain stability mapping; (2) detailed terrain stability mapping and (3) on-site assessment of terrain stability. In reconnaissance terrain stability mapping, airphoto interpretation, from photos at scales of 1:15,000 to 1:40,000, is the primary tool. Three stability classes are recognized: unstable, potentially unstable and stable. In detailed terrain stability mapping, two steps are recognized: terrain mapping and interpretation of terrain data for slope stability. Terrain mapping is carried out according to the Terrain Classification System for British Columbia [Howes & Kenk, 1997] following Guidelines and Standards for Terrain Mapping in British Columbia. Five stability classes are recognized, of which classes IV and V are approximately equivalent to the potentially unstable and unstable classes of the reconnaissance system above. The mapping is based on interpretation of 1:15,000 to 1:20,000 scale airphotos, later verified by field checking. Interpretation is based on expected performance of slopes after logging has taken place, a largely qualitative exercise.

On-site assessment of terrain stability is equivalent to the traditional engineering practice of 'reconnaissance'. Areas requiring on-site assessment are those shown as unstable and potentially unstable on detailed and/or reconnaissance terrain stability maps. Available information is reviewed and airphoto interpretation completed before the field work begins. An overview by vehicle is performed, and logged and unlogged slopes are checked. Foot traverses are usually made by the terrain stability expert in the company of forestry staff; observations of visible surface characteristics are the criteria used. Dense road networks and a long history of logging give higher confidence levels than unlogged areas without roads.

Publication of guidebooks for a new and environmentally sensitive Forest Practices Code [BC Ministry of Forests, 1995]. These guidebooks are one of the four components of the Code. The Forest Practices Code of BC Act, the regulations, the standards and the guidebooks were all implemented in 1995. These guidebooks were developed to support the regulations, but they are not part of the legislation. Recommendations in the guidebooks are not mandatory, but they describe procedures, practices and results that are consistent with the legislated requirements of the Code. Such topics as mapping and assessing terrain stability, forest road engineering, soil conservation, gully assessment, hazard assessment keys for evaluating site sensitivity to soil degrading processes, fish-stream identification and coastal and interior watershed assessment procedures are all addressed in separate guidebooks. These guidebooks that interpret the BC Forest
The explosive growth of computing capacity has given rise to a new field, known as digital terrain modeling. This new field links the fields of geomorphology, soil science and remote sensing more closely than at any previous stage in their respective histories. Because all three fields are interested in different aspects of the characterization of ground surface relief and patterns, and because digital terrain modeling is the best tool available, not only for modeling but also for importing data from other automated systems that provide remotely sensed data, it is anticipated that this linkage will continue to grow. At the same time, traditional techniques of field mapping, aerial photography, repeat photography and mapping of land cover change will continue to provide important ground truth. It seems fair to say that because of the greater precision over larger spatial scales achievable by digital terrain modeling, the dynamic and interdisciplinary aspects of geomorphology, soils and landscape ecology will be most directly advanced by these developments.

Developments in British Columbia, a large, resource-rich province in Canada, reflect the implications of these technical developments rather well. Digital terrain analysis has become an essential skill in land and forest management in the Canadian Cordillera. Remote sensing specialists, with geomorphic and soil science understanding, have become increasingly central to improved land management implementation. At the same time, the focus of natural hazards policy has shifted towards increasing slope failures. Forest Practices Codes and educational programs of professional geoscience registration have initiated in the 1990s in order to regulate this trend.

Based on these conclusions, we draw the following conclusions:

1. Greater efforts should be made to accelerate the cross fertilization of ideas between geomorphology, soil science and remote sensing.
2. Digital terrain modeling is the essential linking tool.
3. As a result of the incorporation of DTM courses into the curricula of these fields, we anticipate increased demand for the services of geomorphologists, soil scientists and remote sensing specialists in the resource management professions.

REFERENCES

RESUME
La Géomorphologie, la science des sols et la télédétection sont des champs d'investigation étroitement liés à travers leur intérêt commun dans les cinq facteurs décrivant l'état des systèmes environnementaux: climat, organismes, relief, matériau de départ et temps. La télédétection, partant des photos aériennes jusqu'aux images satellites, constitue un outil puissant pour améliorer l'exactitude et la précision de levés géomorphologiques à grande échelle, rendant possible l'investigation d'idées qui ne pouvaient être testées antérieurement. La télédétection est en train de transformer la géomorphologie en une science plus globale et influence le développement de la politique environnementale par rapport aux problèmes géomorphologiques. Un exemple instructif est l'évolution des applications de la télédétection aux analyses de terrain dans la Colombie Britannique durant les 25 dernières années. Des applications de la géomorphologie à la gestion des terres, la planification du développement des ressources, la planification de l'utilisation des terres et la planification d'un projet ainsi la politique des risques naturels sont expliqués.

RESUMEN
La geomorfología, la ciencia del suelo y la teledetección son áreas de investigación estrechamente relacionadas debido a su interés común en los cinco factores de estado de los sistemas ambientales: clima, organismos, relieve, material parental, y tiempo. La teledetección, desde las fotografías aéreas hasta las imágenes satelitales, constituye un poderoso instrumento para mejorar la exactitud y la precisión de levantamientos geomorfológicos realizados a pequeña escala sobre grandes extensiones, lo que permite investigar ideas que se consideraban previamente como imposibles de probar. La teledetección está transformando la geomorfología en una ciencia más global y está influyendo en el desarrollo de una política ambiental con respecto a los problemas geomorfológicos. Un ejemplo instructivo es la evolución en las aplicaciones de la teledetección al análisis de terreno en British Columbia durante los últimos 25 años. Se ilustran aplicaciones de la geomorfología al manejo de tierras, a la planificación del desarrollo de recursos, a la planificación del uso de las tierras, a la planificación de proyectos y a la política de riesgos naturales.
The development of the Alpine Soil Information System

Luca Montanarella¹ and Thierry Nègre¹

¹ European Commission, Directorate General JRC – Joint Research Centre, Space Applications Institute, Agriculture and Regional Information Systems, European Soil Bureau TP 262, I-21020 Ispra (VA), Italy (phone: +39 0332 78 61 02; fax: +39 0332 789930; e-mail: luca.montanarella@jrc.it)

KEYWORDS: soil, information systems, Alps, European Soil Bureau, database

ABSTRACT

The recent adoption of the protocol on soil protection (Bled 20/10/98), within the Alpine Convention, sets new goals for the European Soil Bureau (ESB). Currently, the only harmonised soil database covering the Alps is available at the ESB within the framework of the European Soil Information System (EUSIS). The soil information available within that system is at small scale (1:1,000,000) and is therefore not suitable for regional scale applications as required by the Alpine Convention. In particular, Article 11 of the newly signed soil protection protocol calls for the establishment of a soil erosion risk database in order to delineate areas at high risk. This will require further work towards the establishment of a more detailed soil information system for the Alps. To integrate the on-going activities at European level, the scale should be compatible (1:250,000) with the future geo-referenced soil database for Europe, currently under development at the ESB. The future structure of the Alpine Soil Information System (ALSIS) follows essentially the structure of the geo-referenced soil database for Europe. The establishment of this information system will rely heavily on the use of remote sensing data, digital elevation models and existing geological maps.

INTRODUCTION

Soils play a central role in the ecology and development of mountainous lands. They provide a vital substratum for humans, animals, plants and micro-organisms. They are a key component of the mountainous ecosystems, in particular for water and nutrient cycling. In addition, they constitute a major genetic reservoir and they are the location of major regulation and transformation processes. As a central element of the mountainous landscape, soils have always occupied a central position in the cultural and economic life of human communities. In particular, they constitute the basis for agriculture, including forestry and livestock raising, and a major component for recreational and tourist activities. It is therefore essential to promote the conservation and sustainable use of the soil resource, taking into account the specific sensitivity of mountainous soils to degradation and weathering processes.

DESCRIPTION OF THE ALPINE CONVENTION

The Alps represent one of the most sensitive ecosystems in Europe because of aggressive development in the recent past, huge numbers of tourists and severe environmental damage. In awareness of the fact that the Alps are one of Europe's largest inter-related natural regions and that, due to their specific and diverse nature, culture and history, they represent an excellent location for habitation and the execution of economic, cultural and recreational activities situated in the heart of Europe, an Alpine Convention was established following the results of the first Alpine Conference of the Ministers of the Environment held in Berchtesgaden in 1989. Members of the Alpine Convention are Germany, France, Italy, Slovenia, Liechtenstein, Austria, Switzerland and the European Community (Figure 1).

The Alpine Convention stipulates in Article 2, Paragraph 1, that "The Contracting Parties shall pursue a comprehensive policy for the preservation and protection of the Alps by applying the principles of prevention, payment by the polluter (the "polluter pays" principle) and co-operation, after careful consideration of the interests of all the

FIGURE 1: Application area of the Alpine Convention
Alpine States, their Alpine regions and the European Economic Community, and through the prudent and sustained use of resources. Trans-border co-operation in the Alpine region shall be intensified and extended both in terms of the territory and the number of subjects covered. Article 2 also stipulates that “in order to attain the objective specified under Paragraph 1”, the parties to the agreement shall take appropriate measures in particular in the following fields: population and culture, regional planning, maintaining air cleanliness, soil conservation, water economy, protection of nature and maintenance of the landscape, mountain agriculture, mountain forests, tourism and recreation, traffic, energy and waste management.

Furthermore, the contracting parties shall also ensure that the public is regularly kept informed in an appropriate manner about the results of research, monitoring and actions taken. This means that the dissemination of information should not be restricted to individuals immediately concerned, or public organisations and research institutions, but that the media will be used to ensure that a wider section of the public, both within the alpine areas and outside, will be appropriately informed.

PROTOCOL ON SOIL PROTECTION
The recent adoption of the protocol on soil protection (Bled, 20 October 1998) sets new goals in the framework of the Alpine Convention. Articles 10, 11 and 20 of the protocol explicitly call for the establishment of a coherent soil information system for the Alps. Currently, the only harmonised soil database covering the Alps is the Soil Geographical Database of Europe at scale 1:1,000,000 (Figure 2). It is available at the European Soil Bureau (ESB) and has been developed within the framework of the European Soil Information System (EUSIS). The soil information available within that system is at small scale (1:1,000,000) and is therefore not suitable for regional scale applications as required by the Alpine Convention.

Particularly Article 11 of the newly signed soil protection protocol calls for the establishment of a soil erosion risk database in order to delineate areas at high risk. This will require further work towards the establishment of a more detailed soil information system for the Alps. To integrate the on-going activities at European level, the scale should be compatible (1:250,000) with the future geo-referenced soil database for Europe, which is currently under development at the ESB.

**FIGURE 2:** The Alpine area in the only available trans-national soil information system: the Soil Geographical Database of Europe at scale 1:1,000,000 (CEC, 1985; Platou et al, 1988; King et al, 1994, King et al, 1995)
THE GEO-REFERENCED SOIL DATABASE FOR EUROPE

In most European countries, systematic soil surveys started in the 1950s against the background of an urgent need for increased agricultural production. The methodologies, classification systems, scales and coverage of the surveys varied widely in the different countries. It was soon realised that co-operation and correlation would allow exchange of experience and know-how and would greatly favour an overall European approach. On the initiative of a number of European soil scientists responsible for soil survey programmes in their respective countries, a meeting was held in Gent, Belgium, in 1952, with the purpose of discussing the possibility of unifying the different systems of soil classification and nomenclature. As a result, a request was submitted to the Director-General of the Food and Agriculture Organisation of the United Nations (FAO) to sponsor this harmonisation within the framework of the FAO European Working Party on Land Utilisation and Conservation. In response to this request, FAO established in 1955 the Working Party on Soil Classification and Survey, affiliated with the Subcommission on Land and Water Use of the European Commission on Agriculture.

The first session of the Working Party took place in Bonn in 1957. It was realised that the most effective way to harmonise the soil survey activities in the different European countries would be the joint preparation of a unified soil map of Europe. The Working Party considered the technical aspects of the preparation of such a map at scale 1:2,500,000. This relatively small scale was justified by the uneven density or even lack of soil survey information in certain parts of the continent. It was decided that the map would show the major soil groups and include data on terrain type and parent materials. The Working Party nominated a Correlation Committee and agreed that the material and information collected in different countries would be centralised in the Soil Survey Centre at Gent University.

A first draft of the Soil Map of Europe at a scale of 1:2,500,000 was presented at the second meeting of the Working Party held in Oxford in 1959. Co-operation was obtained from soil scientists from Eastern European countries who made available the soils data necessary to assure the continuity of soil boundaries in Central Europe.

A further step to a common European endeavour was the preparation of the 1:5,000,000 Soil Map of the World, jointly undertaken by FAO and UNESCO. The project was initiated in 1961 and publication started in 1971. The two map sheets covering Europe were issued in 1981 [FAO, 1981]. The FAO/UNESCO Soil Map of the World incorporated the European systems of soil classification into an internationally recognised legend, which enhanced co-operation and enabled a harmonised overview of the soil cover, both at continental and global level. However, the broad composition of the soil associations at scales of 1:2,500,000 and 1:5,000,000 did not provide an appropriate basis for land use planning. Conscious of its responsibilities with regard to the practical application of soil data, the Working Party on Soil Classification and Survey decided, in 1965, to include the preparation of a Soil Map of Europe at scale 1:1,000,000 in its programme. Four sessions of the Working Party (Montpellier in 1967, Varso in 1969, Helsinki in 1971, Gent in 1973) were devoted to the construction of the legend, in accordance with the FAO/UNESCO Soil Map of the World, and to the harmonisation of the map units across national boundaries. By 1973, the basic material for the preparation of the 1:1,000,000 Soil Map of Europe had been assembled and correlated [FAO, 1973]. However, the publication did not immediately materialise because of budgetary restrictions.

In 1978 the Land and Water Use Steering Committee of the European Communities (EC) proposed that a soil map of the EC be prepared and published. Advantage was taken of the preparatory work already carried out and of the material assembled in the framework of FAO's European Commission on Agriculture. The EC Soil Map, at scale 1:1,000,000, was prepared at Gent University and published in 1985 on the initiative and with the support of the Directorate General for Agriculture of the Commission of the European Communities [CEC, 1985]. As a part of the CORINE project, the EC Soil Map was digitised in 1986 [Platou et al., 1986] in order to establish a geographical database for environmental protection work in the EC. In 1987 the European Commission launched a programme to monitor agriculture by remote sensing, MARS [Meyer-Roux, 1987]. The programme was entrusted to the Institute for Remote Sensing Applications, Joint Research Centre of the European Communities at Ispra, Italy. In the framework of this project agro-meteorological models were developed, including soil and climatic data. The EC Soil Map of Europe at scale 1:1,000,000 served as a first database. Additional parameters for plant growth and environmental objectives were added, as derived from the original material and from updates by national experts. In 1994, the ongoing soils database activity was upgraded to establish a Soils Information Focal Point (SIFP) in charge of addressing the broader needs of the European Communities. These efforts led to an improved version of a 1:1,000,000 geographical soil database of Europe. It is now one out of only two existing harmonised databases at continental scale (the other one being on forest soils) and it can satisfy demands for broad information in the domains of agriculture and environmental protection. It is also the only harmonised and coherent soil information system covering the entire Alps (Figure 2).
However, with the development of more advanced applications and models, the scale and precision of the 1:1,000,000 database no longer suffice to ensure the harmonisation in methodology between the various soil survey organisations and to meet the needs for specific soil information. The Task Force of the European Environment Agency, DG XI of the European Commission, therefore initiated a study on the feasibility of creating a soil map of Europe, at scale 1:250,000 [Dudal et al., 1993]. The study concluded that the preparation of such a map was feasible and desirable. Meetings of the heads of soil surveys of the European Union, which took place in Silsoe in 1989 [Hodgson, 1991] and Orléans in 1994 [Le Bas & Jamagne, 1996], recommended and endorsed the preparation of a geo-referenced soil database for Europe at scale 1:250,000. The implementation of this recommendation was ensured by a Soil Information System Development Working Group (SISD) and subsequently entrusted to the European Soil Bureau which was created within the JRC in 1996 [Montanarella, 1996]. The objective of the geo-referenced soil database at scale 1:250,000 is to provide the required soil parameters, combined with terrain, climatic, vegetation and lithological data, at a resolution which is suitable for regional planning and in a way which ensures compatibility and comparability of datasets of different national or regional institutions.

A major difference between the present project and previous approaches is that the geo-referenced database will not be limited to a representation of data in the form of maps. Cartographic outputs, in order to be readable, have to be simplified, which results in a loss of information. The use of soil classification units only, based on a restricted number of taxonomic criteria, limits the interpretation value of the maps because certain parameters, needed for currently demanded applications, are not recorded [Vossen & Meyer-Roux, 1995]. Therefore, the geo-referenced database will have a computerised structure, allowing for the storage of a maximum of soil information needed for the solution of specific problems. This structure reaches beyond the all-purpose nature of traditional surveys. The 1:250,000 geo-referenced soil database of Europe will allow for the preparation of thematic outputs to address a broad range of land use issues [van Ranst & Gellinck, 1999]. The suitability of the scale has been shown by a number of applications in different European countries, such as the protection of groundwater quality, the assessment of soil erosion risks, the assessment of drought hazards, the evaluation of land capability, the delineation of lands vulnerable to nitrate leaching, the assessment of risks of agrochemical pollution and the monitoring of forest ecosystems. In addition, the soil database will provide precise and harmonised soil information for the Directorate Generals of the European Commission, for the European Environment Agency, for interested institutions in member governments and for international organisations. It will allow for an effective exchange of data, for standardisation of methodologies of data storage and retrieval, and for establishing co-operation towards rational land use across national boundaries [King & Thomasson, 1996].

The overall organisation of this new soil information system is represented in Figure 3. At the basis of the system is a delineation of the European soil regions [Giannetti et al., 2001; Figure 4] that allows a broad definition of homogeneous areas from the point of view of geology, climate and landform. This broad delineation at 1:5,000,000 scale allows for a coherent view of the European soils. Projects implemented in this context need to follow this delineation across administrative boundaries. Indeed, experience with the 1:1,000,000 soil database of Europe has demonstrated that later harmonisation of soil units between different countries is extremely difficult, and sometimes impossible because of differences in legends, soil classification systems and analytical methods. This is clearly visible in Figure 2, which shows that there are still some evident problems of harmonisation between Switzerland and the bordering countries.

The new geo-referenced soil database at scale 1:250,000 is being built in a stepwise approach starting from the soil regions of Europe. Several projects are currently underway in Central and Southern Italy, Northern France, Po river plains, etc. A new project has also been proposed in the context of the Alpine Convention: The Alpine Soil Information System. The detailed description of the database can be found in the Manual of Procedures [European Soil Bureau Scientific Committee, 1998] available through the European Soil Bureau.

![FIGURE 3: Simplified structure of the European soil database](image-url)
THE GEO-REFERENCED SOIL DATABASE OF THE ALPS PROJECT AREA
As previously mentioned, the realisation of the geo-referenced soil database of Europe at scale 1:250,000 follows the delineation of the European soil regions at scale 1:5,000,000.
The Alps are covered by the following three soil regions (Figure 4), which closely match the area determined by the Alpine Convention (Figure 1).

1. Leptosol-Region (34.2) of the Northern and Western Alps (LPk, LPq)
   Mesozoic calcareous rocks (limestone)
   Mean annual temperature: 5.2 - 6.3°C
   Mean annual precipitation: 900 - 1300 mm
   Months of highest precipitation: July - August
   Months of drought: none
   Months with temperatures below zero: November - March
   Mountainous land between 750 m amsl and 3100 m amsl

2. Leptosol-Region (34.3) of the Southern Alps (LPk, LPq)
   Mesozoic calcareous rocks (dolomite, limestone),
   Mean annual temperature: 7.5 - 9.5°C
   Mean annual precipitation: 600 - 1000 mm
   Months of highest precipitation: May and October
   Months of drought: none
   Months with temperatures below zero: December - February
   Mountainous land between 750 m amsl and 3300 m amsl

3. Leptosol-Region (37.1), with Podzols and Cambisols of the Central Alps, partly with permanent snow cover or glaciers (LPu, LPq, PZb, CMd)
   Igneous and metamorphic rocks (granite, gneiss, schist)
   Mean annual temperature: 4.5 - 5.7°C
   Mean annual precipitation: 1000 - 1250 mm
   Months of highest precipitation: May - October
   Months of drought: none
   Months with temperatures below zero: November - March/April
   Mountainous land between 750 m amsl and 4800 m amsl

IMPLEMENTATION PROCEDURE
Development of metadatabase
The metadatabase should describe all existing information relevant to the project. This includes maps, profile databases, aerial photographs, satellite data, etc. Types of maps to be included are soil, geologic, topographic, forest, vegetation and geomorphological maps. The Manual of Procedures [European Soil Bureau Scientific Committee, 1998] advises to introduce in the metadatabase only the contours and contents of the existing maps, and not the maps themselves. Metadata include projection and scale of the available maps, a reference to the legend used, density of the observations on which the maps were based, references to eventually constructed digital databases with maps and point data, year of survey, etc. Sources of metadata are to be found at national and regional levels. The most recent inventory of national soil data sources in EU countries was published by Le Bas & Jamagne [1996].

Work in areas with existing soil data
- Screening, aggregation and use of existing data
  The screening of existing data is done by evaluating maps by their scales, and the legends by their fitness to be harmonised. Also, soil profile data are screened by comparing the data with a number of requirements.

  - Determining usability of maps
    A soil map may be appropriate to build a 1:250,000 database if the map scale is between 1:25,000 and 1:100,000. It is also necessary to know which map projection was used and how the map was made (e.g., the observation density, the survey method). The legend of the map needs to be checked against the criteria used to define soil bodies and soilscapes. For instance, the soil classes included in the map units must be able to be reclassified according to the FAO revised legend [FAO, 1998]. If the available maps and associated data do not allow for a conversion of the legend into the FAO-revised legend, additional sampling is required. If so, additional sampling schemes should be defined at this stage.

  - Recognition of soil bodies and delineation of soilscapes
    If appropriate soil maps at detailed scales exist, an ascending method can be applied to define and characterise soil bodies and to define and delineate soilscapes. Ascending methods generalise large-scale inventories.
Work in areas without existing soil data

- Data acquisition

In areas where no soil maps and databases yet exist, a combination of ascending and descending mapping methods is necessary. A typical sequence of activities would be:

(i) Consultation of basic documents such as the soil region map 1:5,000,000, topographic, geological, forest and vegetation maps, DEM, aerial photographs and satellite data (SPOT, Landsat). These documents allow the subdivision of the area into large soil-landscapes.

(ii) Use of geomorphological maps and DEM, etc., in combination with field survey to define and delineate soilscape.

(iii) Systematic field survey with surface and soil profile observations to improve the delineation and definition of soilscape and to investigate which soil bodies occur in a soilscape.

Information acquisition to characterise soil bodies, including soil profile sampling to a depth of at least 1.5 m or to a lithic contact if shallower. The 1.5 m criterion covers most of the depth criteria in the World Reference Base for Soil Resources [FAO, 1998], except for argic horizon, ferralic horizon, spodic horizon, secondary carbonates and permafrost, for which the criterion is deeper, namely 2.0 m.

- Recognition of soil bodies and delineation of soilscape

Phases (i) and (ii) correspond to a descending mapping method. In descending methods, information is collected at a large target scale to recognise and delineate spatial units. Delineation of soilscape should be done in a reproducible manner. One way to achieve this is to use the 30 arc seconds DEM of Europe as a first recognition of the physiography of the landscapes and the main drainage basins. This recognition can then be improved by using a field survey to better locate soilscape limits and by adding geomorphological criteria and parent material differences to subdivide units if the scale permits. Phases (iii) and (iv) use ascending methods in small reference areas, with soil survey at detailed scales (e.g., 1:25,000). Alternatively, phases (iii) and (iv) may also cover the whole pilot area.

- Observation and sample density

The amount of observations needed in the phase of systematic survey at scale 1:250,000 depends on the soil variability. As a rule of thumb, at high variability, 1 observation per km² may be necessary; while at low variability, one observation per 6 km² may be realistic. The minimal number of sampled profiles is two per soil body. Thus in the case of a pilot area of 7500 km² containing two soil regions each with 40 soilscape and five soil bodies per soilscape, about 800 profiles have to be analysed. Statistical methods can be applied to estimate the number of samples needed to obtain a mean value with fixed precision. These methods have the disadvantage that they deal with only one variable at a time. Soil variability can also be estimated by means of standard errors or variograms.

Filling and validating the database

After the soil bodies and soilscape have been defined and the soilscape have been delineated, the database can be filled. At this stage, when the database partly consists of existing data, it may be necessary to sample additional data. Complementary data are collected whenever the existing data are harmonised to the acceptable level according to expert judgement, but are not adequate or sufficient. This may lead to additional analytical determinations or more complete soil profile characterisation. Complementary determinations can be made for sites previously sampled or for individual samples in the case of relatively stable soil and land properties such as CEC, particle size distribution, parent material, slope, aspect or drainage. New profiles should be described and sampled where existing data do not meet the requirements described above.

The data set used for the validation of the database has to be different from the one used to define soil bodies and soilscape, e.g., the validation set must be independent and should be verified in pilot areas.

APPLICATIONS DERIVED FROM THE GEO-REFERENCED SOIL DATABASE

The systematic collection, storage and retrieval of soil information is a great effort requiring expert skills, enthusiasm and financial means. Nevertheless, building soil databases is never a goal in itself. The database is intended to be used for as great a variety of applications as possible. In general, a geo-referenced soil database can be used for two types of applications: (1) to delineate areas in which the soil acts or reacts in a unique manner towards its environment; and (2) to quantify the behaviour of soils in a certain area.

Results of any interpretation of soil data in combination with other data can be added to the database in tabular or thematic map form. These data augment the database’s usefulness and facilitate its application. Such tables and maps refer, for instance, to the suitability of soils for major classes of land use, their environmental functions, sensitivity to degrading influxes, hydrological contribution and land capability classification.

Interpretation tables referring to soil bodies may be more specific in rating those bodies for various uses and management practices, such as potential productivity, erodibility or suitability for irrigated agriculture and given land utilisation types (sanitary landfills, dwellings, pond reser-
voirs, roads, recreational areas, and buildings, among others). Such soil ratings are qualitative and are to be derived through expert systems, available or to be developed for each pilot area on the basis of available research data, pedotransfer functions and rules, and experience.

Possible applications relevant to the Alps are evaluation of soil erosion risk, landslide risk, agricultural suitability, hydrological modelling, forestry suitability, and soil degradation (contamination, sealing, etc.) and design of a soil monitoring network.

REFERENCES


The Federal Republic of Germany, the French Republic, the Italian Republic, the Republic of Slovenia, the Principality of Liechtenstein, the Republic of Austria, the Swiss Confederation and the European Economic Community, 1991. Alpine Convention, Salzburg. Austrian State archives.


RESUME

L’adoption récente du protocole sur la protection du sol (Bled 20/10/98), dans le cadre de la Convention Alpine, établit de nouveaux objectifs pour le Bureau Européen du Sol (ESB). Actuellement, la seule base de données mise en conformité couvrant les Alpes est disponible au ESB au sein de l’infrastructure du Système Européen d’Information du Sol (EUSIS). L’information sur les sols disponible dans ce système est à petite échelle (1:1,000,000) et ne convient donc pas à des applications à échelle régionale comme le demande la Convention Alpine. En particulier, dans l’article 11, du protocole de protection nouvellement signé, il est demandé l’établissement d’une base de données sur les risques d’érosion du sol afin de délimiter des zones à haut risque. Ceci exigera d’autres travaux pour l’établissement d’un système d’information sur les Alpes plus détaillé. Pour integrer des activités durables au niveau européen, l’échelle devrait être compatible (1:250,000) avec la base de données des sols géoréférencée pour l’Europe, actuellement en développement au ESB. La structure future du Système Alpin d’Information du Sol (ALSIS) suit essentiellement la structure de la base de données de sol géoréférencée pour l’Europe. L’établissement de ce système d’information dépendra fortement de l’usage de données de télédétection, des modèles numériques de terrain et des cartes géologiques existantes.

RESUMEN

La reciente adopcion del protocolo sobre la protection de los suelos (Bled 20/10/98), dentro de la Convención Alpina, plantea nuevos objetivos a la Oficina Europea de Suelos (European Soil Bureau, ESB). Presentemente, la única base de datos de suelos armonizada cubriendo los Alpes se encuentra en el ESB en el marco del Sistema Europeo de Información de Suelos (EUSIS). La información de suelos disponible en este sistema es a pequeña escala (1:1.000.000) y, por lo tanto, no es apta para aplicaciones a nivel regional como lo requiere la Convención Alpina. En particular, el Artículo 11 del recién firmado protocolo sobre la protección de los suelos pide la elaboración de una base de datos sobre riesgos de erosión de suelos con fines de delinear áreas de alto riesgo. Esto va a requerir trabajo adicional para establecer un sistema de información de suelos más detallado para los Alpes. Para integrar las actividades en marcha a nivel europeo, la escala debería ser compatible (1:250.000) con la futura base de datos de suelos geo-referenciada para Europa, la cual está siendo desarrollada actualmente en el ESB. La futura estructura del Sistema Alpino de Información de Suelos (ALSIS) sigue esencialmente la estructura de la base de datos de suelos geo-referenciada para Europa. La elaboración de este sistema de información va a depender considerablemente del uso de datos de tele-detección, de modelos digitales de elevación y de mapas geológicos existentes.
Integrated use of satellite images, DEMs, soil and substrate data in studying mountainous lands

Fabio Giannetti¹, Luca Montanarella² and Roberto Salandin¹

¹ Istituto per le Piante da Legno e l’Ambiente (IPLA) S.p.A., Corso Casale 476, 10132 Torino, Italy (phone +39-011-8998933; fax +39-011-8989333; e-mail ipla@ipla.org)
² Joint Research Centre, Space Applications Institute, European Soil Bureau, Ispra, Italy

KEYWORDS: satellite images, soil, northwestern Alps, supervised classification, vegetation indices.

ABSTRACT

A method based on the integration into a GIS of satellite images of different spatial resolution (Landsat TM and SPOT), Digital Elevation Models, geo-lithological maps and some soil-landscape data was developed and applied to a test area on a sector of the Italian northwestern Alps in the Piemonte region (Pellice, Po, Varaita and Maira valleys southwest of Torino). The main working steps performed (using GIS software) in this area were: (1) acquisition of geo-lithological and geomorphological maps available and a first definition of homogeneous zones obtained by joining different classes with pedogenic criteria; (2) processing and classification of satellite images to define homogeneous areas with reference to prevailing land cover, land use pattern, relief shape and spectral characters; (3) integration of the previous two layers to obtain a first set of cartographic units showing a distinctive and often repetitive pattern of land form, land cover and parent material; and (4) processing DEMs (slope and aspect), soil or soil-landscape data in order to refine data and characterise the units. The resulting cartographic units were superimposed on a soil-landscape map realised by means of stereoscopic interpretation of aerial photographs by IPLA at the same scale (1:250,000). This comparison was used to verify the correctness of the satellite image processing steps and consistency with the map scale used. A larger scale application was also developed for grassland at 1:50,000 scale to demonstrate the practical use of remote sensing and GIS data in assisting mountainous land development.

INTRODUCTION

Any analytical approach to mountainous areas, aimed at evaluating their resources and promoting their sustainable development, requires objective knowledge of the territory – based on maps and linked geographical databases. Information extracted from satellite images, DEMs and lithological data from the northwestern Alps was integrated into a GIS to meet such goals and to define eco-pedological units at a 1:250,000 scale. Operational earth observation satellites such as Landsat TM and SPOT are very useful for studying mountainous areas at this scale. In particular the synoptic view of the terrain and the geometric resolution of 20–30 m makes it possible to map the main environmental characteristics and monitor dynamic aspects by multi-temporal sequence analysis [Allan, 1980].

This paper presents a method for defining eco-pedological cartographic units in mountainous areas. The work described was carried out by IPLA and the European Soil Bureau at Ispra as a preliminary step in the project "Eco-pedological map of Italy".

STUDY AREA

The study area includes a sector of the northwestern Alps in the Piemonte region, from the Pellice valley in the north to the Maira valley in the south. The area is located southwest of Torino, the main town of the region (Figure 1).

This area has undergone considerable deformation and metamorphosis during the different phases of alpine orogenesis and it is characterised by a great variety of lithologies belonging to different tectonic zones. The crystalline massif of the Dora-Maira, the Piedmontese zone and the Brianconnaise zone are the tectonic zones encountered when moving from the inner part of the chain towards the meso-european foreland.

FIGURE 1: Location of the study area in northern Italy. Main physiographic characteristics of the study area are represented in DEMs.
Integrating data sources for studying mountainous lands

Geologica Italiana, 1992]. Acid rocks such as mica schists and gneiss are the main rock types of the Dora-Maira massif. The mica schist rocks have undergone considerable weathering in the Quaternary, resulting therefore in a smooth morphology and deep soils. The gneiss rocks are less weathered and mainly covered by shallow soils.

The Piedmontese zone is composed of series of lime schists and some large ophiolitic sheets. The lime schists are particularly weatherable and, because of the long period of snow cover, often give rise to neutral soils. Ophiolitic rocks, less weathered and more erosion-resistant than lime schists, often produce subalkaline soils. Quartzitic, calcareous and dolomitic rocks cover the limited outcrop area of the Brianconnaise zone in this sector of the northwestern Alps.

The Quaternary deposits in the study area are represented mainly by terraced fans in the lower valleys and by some moraines. These deposits cover only a limited portion of the area.

The Italian boundary of the Alps in this sector is very steep with no more than 30-35 km between the basin ridges, elevations of around 2700-3000 m a.s.l., and river debouchments onto the Po plain at altitudes ranging from 250 m to 400 m.

MATERIALS
The following materials were used: (1) SPOT 4 images of 05/07/1998 and 18/09/98; (2) LANDSAT TM images of 15/09/92; (3) a DEM with a grid of 250 m x 250 m converted into a raster layer; (4) a DEM with a grid of 50 m x 50 m on grassland area; and (5) geolithological, geomorphological and soil-landscape maps of the study area at 1:250,000 scale.

The images were first georeferenced (nearest neighbour algorithm) by means of ortho-rectification using about 40 ground control points with an averaged bias of about 10 m in their x and y coordinates. All image processing was done on the SPOT 4 image acquired in July 1998 as this was the most suitable period. The other two images were used to confirm the results obtained through interpretation and statistical processing of the SPOT 4 July image. The work was carried out using “Cartha for Windows”, Italian software that integrates image processing and GIS functions.

CARTOGRAPHIC UNIT DEFINITION – SYSTEMS
In this paper we have defined systems as eco-pedological units characterised by a homogeneous pattern of lithological, landscape and morphological characteristics [Finke et al, 1998] and we propose a method to delineate them at 1:250,000 scale. Preliminary systems delineation originates from a GIS integration of two layers: the first concerning geological substrates; and the second the result of processing and interpretation of satellite images.

The work was conducted in several steps. The first step concerns integration in a GIS of a geo-lithological map of 1:250,000 scale. This kind of data is essential to define the distribution of substrates of pedogenic characteristics. The pedogenic value of the substrates is derived mainly from the lithological composition of each geological formation. It is therefore necessary to obtain a preliminary re-interpretation of the geological legend to join the different geological formations in three groups: basic, acid and neutral substrates.

Each group can be further divided in two subgroups if there are differences in weatherability (Figure 2). In this case, differences in intensity of pedogenic processes enable the formation of deeper or shallower soils.

For the second step, the main landscape components, considered as one of the factors related to soil forming processes in mountainous areas, were extracted from satellite images and grouped into six classes (Figure 3): (1) rock outcrop, fresh debris fan and landslides (mineral zones almost absent of soil and vegetation); (2) areas of low-density vegetation in which vegetation of scattered and poor development, indicates the presence of discontinuous shallow soils (such as lithosols); (3) deciduous forest (broadleaf); (4) evergreen forest (coniferous); (5) herbaceous cover zones (alpine and subalpine grassland). (6) Arable zones and grasslands of the valley bottoms.

The first two classes can be best derived from computations of the NDVI vegetation index, which is a normalised difference of near infrared and red bands. As

FIGURE 2: Geological map of the examined area. Geological formations are combined into 5 groups according to pedogenic characteristics and rock weatherability
Integrating data sources for studying mountainous lands

Rock outcrops
Low density vegetated areas
Deciduous forest
Evergreen forest
Herbaceous cover

FIGURE 3: Main landscape components extracted from processing of satellite images (supervised classification and NDVI). Arable zones and grasslands of the valley bottoms are not shown in the legend.

This index is very sensitive to the presence of photosynthetic biological matter [Schowengerdt, 1997], it is possible to discriminate, by means of thresholds, areas with no vegetation cover from those with poor photosynthetic activity.

Some attempts were made in order to distinguish the other classes through utilisation of NDVI and other vegetation indices, such as Infrared Index (normalised difference between near infrared and medium infrared bands), which is particularly sensitive to the water content of vegetation. Forest and herbaceous vegetation are easily separable using the Infrared Index to identify their different moisture status. However, discrimination between broadleaf and conifer trees is not possible with this index.

The best solution seems to be a supervised classification (maximum likelihood algorithm) based on comprehensive large sample areas of all the different morphological locations in which each class can be retrieved. Classification was carried out using synthetic bands like arithmetic indices and statistical processing, such as Principal Component Analysis, to minimise the influence of illumination differences [Richards, 1994]. Comparison between the classification layer obtained and other land-use or land cover data that was available for some parts of the study area confirmed the reliability of our results.

Some problems were faced in correctly differentiating arable lands that in narrow and steep-profile valleys are often so small that they cannot form a significant, clearly distinguishable training sample of the class for running the classification algorithm. In such cases we decided not to include them in the classification and, if allowed by cartographic scale, to delineate these zones by a simple visual interpretation based on the geometric shapes of the fields and a spectral characterisation of the crops.

After a first delineation of the systems that integrate main landscape components and pedogenic substrates (Figure 4), these units were refined and characterised by the following techniques: (1) slope and aspect computing from DEMs; (2) video interpretation of satellite image RGB compositions useful in differentiating distinctive patterns of relief features or landforms; and (3) comparison and integration with a soil-landscape map realised by IPLA at the same scale by means of stereoscopic interpretation of aerial photographs.

DEM and interpretation of RGB composite images led to further subdivisions of the previous units based on slope, aspect and/or general physiographic aspects [Calzolari et al, 1996; Dubuq et al, 1991]. The third refining step was useful for validating the resulting units and for verifying the consistency with the map scale.

FIGURE 4: SPOT 4 image of 05/07/98 (RGB = 3, 4, 2) with superimposed limits of the systems
ANALYSIS OF GRASSLAND AREAS AT 1:50,000 SCALE
A sub-alpine grassland area located on the Po valley head was chosen to verify the possible use of instruments such as satellite images and DEMs for a more detailed analysis of grassland resources at 1:50,000 scale. The area of interest was extracted from the SPOT 4 July image and techniques developed for the characterisation of the main landscape systems at 1:250,000 scale were applied at a finer scale (1:50,000). The following results were obtained: (1) Principal Component Analysis revealed its utility in stretching differences among the main elements of the image (different kinds of herbaceous cover, shrub cover, alders colonisation, rocks, debris fans, etc.); (2) NDVI and Infrared Index are useful to show differences in density of vegetation cover and water content; and (3) application of the redness index can help in identifying areas with erosion in progress.

Integration of the satellite-derived information with a more detailed DEM (50 m x 50 m grid) gave a better understanding of the relation between slope, aspect and soil distribution in the area examined. Soil profile data, flora inventory, measurement of ligneous-herbaceous cover percent, etc., in some sample areas should then be collected for better knowledge of the area. Once acquired, these data can be spatially organised by raster information, leading to a pastoral resource map.

CONCLUSIONS
The potential of integrated use of satellite images, DEMs and soil and substrate data within a geographic information system was shown. This approach contributed significantly to the elaboration of a common, uniform 1:250,000 scale eco-pedological map of the Italian northwestern Alps.

Output of this nature will not create only a cartographic document, useful to delineate main landscape elements related to soil distribution in an alpine environment, but it also represents an open database that can be updated by satellite images, allowing dynamic processes such as soil erosion and the expansion or contraction of wooded areas to be monitored and compared with the extension of pastoral land.

ACKNOWLEDGEMENTS
We would like to thank Dr. Thierry Negre of Joint Research Centre for his careful revision of this paper.

REFERENCES

RESUME
Une méthode basée sur l’intégration dans un SIG d’images satellitaires de résolutions spatiales différentes (Landsat TM et SPOT), de Modèles Numériques de Terrain, de cartes géo-lithologiques et certaines données du sol et du paysage a été développée et appliquée sur une zone test dans un secteur nord-ouest des Alpes italiennes dans la région du Piémont (Pellice, Po, Varaita, et les valées Maira au sud-ouest de Turin). Les principales étapes de travail réalisées (en utilisant un logiciel SIG) dans cette zone ont été : (1) l’acquisition de cartes géo-lithologiques et géomorphologiques disponibles et une première définition de zones homogènes obtenues en assemblant différentes classes avec des critères pédogéniques ; (2) traitement et classification d’images satellite afin de définir des zones homogènes en référence aux occupations dominantes des terres, aux modèles d’utilisation des sols, aux formes du relief et aux caractères spectaux ; (3) intégration des deux couches antérieures pour obtenir une première série d’unités cartographiques montrant un modèle distinctif et souvent répétitif de forme de terrain, de couverture de sol et de matériel de base ; (4) traitement MNT (petites et orientation), données de sol ou de sol et paysage afin d’affiner les données et de caractériser les unités. Les unités cartographiques résultantes ont été superposées sur une carte sol et paysage réalisée au moyen d’interprétation stéréoscopique de photographies aériennes par IFLA à la même échelle (1:250,000). Cette comparaison a été faite afin de vérifier la correction des phases de traitement d’image satellite et la consistance avec l’échelle de carte utilisée. Une application à une plus grande échelle a été également développée pour une prairie à l’échelle du 1:50,000 pour démontrer l’utilisation pratique de la télédétection et de données SIG comme aide au développement des terres de montagne.

RESUMEN
Se desarrolló un método basado en la integración en un SIG de imágenes satelitales de diferente resolución espacial (Landsat TM y SPOT), de modelos digitales de elevación, de mapas geo-litologicos y de algunos datos sobre el paisaje edáfico. Se aplicó este método a un área de prueba en un sector de los Alpes italianos noroccidentales, en la región de Piemonte (valles de Pellice, Po, Varaita y Maira, al suroeste de Torino). Los pasos metodológicos más importantes efectuados en esta área (usando SIG) fueron: (1) adquisición de mapas geo-litológicos y geomorfológicos disponibles y una primera definición de zonas homogéneas obtenidas por agrupación de diferentes clases basadas en criterios pedogenéticos; (2) procesamiento y clasificación de imágenes satelitales para definir áreas homogéneas con respecto a cobertura dominante del terreno, patrón de uso de las tierras, forma del relieve y características espectrales; (3) integración de las dos capas anteriores para obtener un primer
conjunto de unidades cartográficas mostrando un patrón distintivo y frecuentemente repetitivo de la forma del terreno, de la cobertura de las tierras y del material parental; y (4) procesamiento de MDE (pendiente y exposición), de datos de suelos o de datos de paisaje edáfico, con fines de mejorar la información y caracterizar las unidades. Las unidades cartográficas resultantes se han sobrepuestas a un mapa del paisaje edáfico realizado mediante interpretación estereoscópica de fotografías aéreas por IPLA a la misma escala (1:250,000). Se usó esta comparación para verificar la adecuación de los pasos de procesamiento de las imágenes satelitales y la compatibilidad con la escala de mapa usada. Se desarrolló también una aplicación para prados a la escala de 1:50,000 con fines de demostrar la utilización práctica de los datos de teledetección y SIG para apoyar el desarrollo de tierras en montañas.
A regional scale soil mapping approach using integrated AVHRR and DEM data

Endre Dobos¹, Luca Montanarella², Thierry Nègre² and Erika Micheli³

1 University of Miskolc, Department of Physical Geography and Environmental Sciences, Miskolc-Egyetemváros, 3515 Hungary (phone: +36-565-111-2314; e-mail: ecodobos@gold.uni-miskolc.hu)
2 European Commission, Directorate General, Joint Research Center, Space Applications Institute, Agriculture and Regional Information Systems, European Soil Bureau, I-21020, Ispra (VA), Italy
3 Gödöllő Agricultural University, Department of Agrochemistry and Soil Science, Gödöllő Páter K. 1, 2100 Hungary

KEYWORDS: Soil mapping, DEM, AVHRR, Remote sensing

ABSTRACT

There is an increasing need for reasonably accurate small-scale soil databases. The compilation of a continental or global-scale soil database requires a lot of spatially and thematically accurate soil data. The aim of this study was to test a method for small-scale soil mapping in Italy using Advanced Very High Resolution Radiometer (AVHRR) and digital elevation data. This method was employed in an earlier study in Hungary for a much smaller area and a significantly different soil-forming environment. An integrated, 45-layer AVHRR-terrain database was used for the study, including a digital elevation model (DEM), slope, curvature, aspect, potential drainage density, and the five bands of AVHRR data for eight different dates. The data were processed using the Discriminant Analysis Feature Extraction (DAFE) function, which is based on a canonical analysis procedure. Two types of images (basic and transformed) were classified using the maximum likelihood classifier. Two training sets were chosen that have identical geographic coverage, but differ in the level of soil classification. One set was based on the soil units (SU) of the FAO-revised legend, while the other set represented major soil groupings (MSG). The best 10, 15, 20, 25, 30, 35, 40 and 45 layers were selected using the Bhattacharyya feature selection method and were then classified. The results of the different sets were compared. The performance of the purely AVHRR and purely terrain-data-based images, respectively, were also interpreted. The results indicate that the terrain descriptors alone are not sufficient for soil classification. However, the feature selection algorithms always selected the DEM and its derivatives among the first ones, highlighting their importance for soil-landscape characterization. When using AVHRR data alone, test class performances of 49.8 percent (MSG) and 48.6 percent (SU) were achieved. Integration of terrain data into the AVHRR database produced relatively small improvements (4.6 and 2.8 percent). The best test class performances were achieved when all available channels were used for the classification, namely 51.4 for the FAO’s SUs and 54.4 for the MSGs on the basic image, and 51.7 and 54.4 respectively on the DAFE-transformed images. The most informative AVHRR bands were found to be from the spring period (April-May), while the most abundant bands were the visible-red (band 1) and bands 3 and 4.

INTRODUCTION

To support many aspects of our lives, we need good quality information on natural resources. Agriculture, forestry, the food production industry, and the preservation of environmental quality, for example, all require an extensive range of data. Governmental and international agencies also have a strong interest in global and regional, reliable, up-to-date information on numerous natural resources. Decision-making relies to a great extent on the existence and quality of information. Furthermore, long-term scientific studies and natural resource monitoring systems need to acquire earth observation data to build models at various scales.

The growing demand for consistent and comprehensive information on environmental resources has instigated numerous global and continental activities, including for instance the International Geosphere and Biosphere Program (IGBP) [Townshend et al, 1994], Mission to Planet Earth (MTE) [USGCRP, 1993], Global and National Soils and Terrain Digital Databases (SOTER) [ISRIC, 1993], US Global Change Research Program (USGCRP) [USGCRP, 1993], Earth Observation System (EOS), Centre for Earth Observation (CEO) [SAI, 1998], Co-ordination of Information on the Environment (CORINE) [Mégier & Winkler, 1996], Monitoring Agriculture by Remote Sensing (MARS) [SAI, 1998], Tropical Forest Monitoring (TREES) [SAI, 1998], the Fire in Global Resource and Environmental Monitoring (FIRE) [SAI, 1998], Forests Information from Remote Sensing (FIRS) [SAI, 1998] and the 1:1,000,000 and 1:250,000 European Soil Database [ESB, 1998].

The European Soil Database (which provides the background and also a potential source for continuation of this work) was initiated under an EU program known as MARS. It focused initially on the development of a harmonized and corrected geographical database for the soil cover of 18 European nations, at a scale of 1:1,000,000. It was developed as part of the institutional support from the Joint Research Center to Directorate General VI - Agriculture and the European Statistical Office. Work is ongoing and the coverage of this database will be extended to 26 West, Central and East European coun-
Mapping soils using AVHRR and DEM data

JAG • Volume 3 - Issue 1 - 2001

tries, mainly those that are members of or wish to join the EU and their neighboring countries. Long-term intentions of the project to extend its database development activities to include all countries in the world [King & Thomasson, 1996]. The nomenclature used in this project was developed for the FAO "Soil Map of the World."

This database has been successfully used for monitoring crop performance [Vossen & Meyer-Roux, 1995] and estimating environmental degradation risks [Giordano et al., 1991]. However, the uncertainties attached to the 1:1,000,000 scale should be estimated to identify areas with inadequate information and to avoid misuses of the information.

Due to the limitations of this small-scale database, a new mapping program at a scale of 1:250,000 was proposed by the scientific advisory committee of ESB. It is still unclear whether this larger-scale database needs to cover all of Europe or just concentrate on priority regions and representative "windows." An even larger-scale soil database, at 1:50,000 scale, is being discussed by the committee, because more detailed soil information is required for many situations.

The work described in this paper aimed to test a method using integrated AVHRR and DEM data for deriving small-scale soil maps in support of the European Soil Database. The final product can be used parallel to the one created with the conventional method or as complementary information to help delineate patterns on soil maps. Comparison of the conventionally made database and the one created through the use of AVHRR-terrain data can highlight areas with potentially inadequate information and help solve problems that occur along national borders due to the lack of successful harmonization.

BACKGROUND INFORMATION

Natural resource inventories are conventionally done using ground-based and aerial surveys. However, collecting national, regional or global-scale land information becomes increasingly time consuming and expensive using traditional methods, while database consistency is also difficult to maintain due to varying mapping approaches of contributing field surveyors. Thus, small-scale databases are rarely based on primary (field) data collection, but on the generalization of existing larger-scale maps. However, such an approach entails difficulties. First of all, a method of data generalization has to be developed and then the compilation problems arising from data dissimilarity must be solved. Lack of data compatibility and the missing data limit the comprehensiveness of the database. Both issues call for more soil information, which may require too much effort. A potential shortcut is the use of secondary (non-soil) data sources, which have to meet the following requirements: they have to (1) contain extractable soil information; (2) have global coverage; and (3) be consistent and comprehensive both in time and space. A review of literature reveals two possible data sources: coarse spatial resolution satellite data and digital elevation data. These data have worldwide coverage and provide support to characterize the soil-forming environment.

THE USE OF COARSE SPATIAL RESOLUTION SATELLITE IMAGES FOR SOIL MAPPING

The coarse spatial resolution satellite data are provided by the Advanced Very High Resolution Radiometer (AVHRR). Recently, a new European instrument called Vegetation was launched (Table 1) and, in the near future, the Moderate Resolution Imaging Spectroradiometer (MODIS) will be operational. These will provide better spectral resolution and absolute location accuracy. Therefore, this study is not only about the evaluation of AVHRR data, but also a preliminary study of the potential use of these new kinds of satellite data.

Numerous studies have been carried out to evaluate the potential use of AVHRR data for soil pattern recognition on a small scale [Vettorazzi et al., 1995; Dobos, 1998;
The thermal bands are often superior to the vegetation indices for which the AVHRR instrument was designed. Yang et al. [1997] used NDVI for ecoclimatic mapping in Nebraska. They concluded that all five channels have found some level of use for land cover studies. The AVHRR/NDVI data are the most commonly used. In particular, the multitemporal NDVI data sets have been widely used to describe vegetation phenology. Thermal bands have also been employed for surface temperature mapping and land cover discrimination, especially in tropical rainforests. The thermal bands are often superior to the vegetation indices for land cover discrimination.

The spatial and temporal variations in NDVI have been studied by numerous researchers and were found to be linked with temperature and precipitation regimes [Schultz & Halpert, 1993; Di et al, 1994; Yang et al, 1997], plant evapotranspiration [Cihlar et al, 1991; Yang et al, 1997], root zone soil moisture [Narasimha et al, 1993] and soil physical properties [Lozano-García et al, 1991; Yang et al, 1997].

Yang et al [1997] used NDVI for ecoclimatic mapping in Nebraska. They concluded that NDVI-climate relations are stronger where vegetation developed on soils with low root-zone-available water-holding capacity and high permeability. Temporal variability of NDVI was found to be linked closely to the temperature regime, while the NDVI-precipitation and the NDVI-evapotranspiration relationships exhibited time lags.

Vettorazzi et al [1995] studied the utility of AVHRR data to characterize regional soil patterns using the two reflective bands and the NDVI. They performed several unsupervised classifications and concluded that AVHRR data are useful in the delineation of small-scale soil patterns. They used one image from April and one from the peak of the growing season at the time of maximum crop canopy. The results indicated that the NDVI has less importance than the first two bands. However, with respect to the mid-summer AVHRR image (maximum crop canopy), the NDVI provided useful supplemental information related to soil patterns.

Dobos [1998] carried out a statistical analysis of the soil-AVHRR relationship. He found that the amount of extractable information depends on the spectral characteristics of the band, the acquisition date of the image and the environmental conditions of the observed area at the time of data acquisition. The thermal bands (particularly band 3) and the vegetation index were found to be the best for predicting soil classes. He concluded that the thermal conditions of the scene, the type and condition of the vegetation and their spatial variability have a significant effect on the spectral response. Due to the large pixel size of 1 km x 1 km, much primarily non-soil information is incorporated into the pixel response and this makes an important contribution to the soil class identification.

AVHRR-type data have not been used routinely for soil characterization. However, the utility of the data in differentiating between kinds of parent materials (using the thermal bands), and kinds of vegetation (through the vegetation indices) has been demonstrated [Short & Stuart, 1982; Zhu & Evans, 1994; Foody et al, 1996].

Foody et al [1996] reported high correlation between remotely sensed radiation and the biophysical properties of tropical forests, particularly with the middle- and thermal-infrared channels (~0.87, ~0.88 correlation coefficient with tree density). Vegetation indices containing data acquired in the middle- and thermal-infrared channels performed better than the widely used NDVI.

Parent material and vegetation refer to two of Jenny's soil forming factors [Jenny, 1941]. Some spectral variation could be due to the physiographic characteristics of an area, which could produce different results even for the same natural phenomenon. Integrating terrain information with the AVHRR data can eliminate this problem on a certain level.

The time factor, which refers to the age of the soil surface, is mainly a function of the age of the deposit or “time zero,” when the exposure of the surface began. The latter directs the erosion and depositional processes. This factor could significantly influence the kind and condition of vegetation, so the NDVI may reveal some information related to parent material, vegetation and time if an integrated database of satellite and DEM data is used, only the macroclimatic factor, among Jenny's soil forming
Mapping soils using AVHRR and DEM data

JAG • Volume 3 - Issue 1 - 2001

factors, is missing. However, the spatial variation of the vegetation can explain some of the climate variation as well. If the area of the study site is "small enough" to assume the macroclimatic effects to be homogeneous, then the integrated database will allow delineation of areas characterized by the same soil-forming environment.

Remotely sensed data are greatly influenced by terrain variability. However, these data still do not represent all the soil variability that occurs in the landscape. As has been suggested by many researchers [Franklin, 1987; Lee et al., 1987; Frank, 1988; Leprieur et al., 1988; Yuan et al., 1995], satellite data have to be complemented with terrain information to correct satellite data distortions arising from topographic variations of the landscape and to provide additional data for soil-landscape modeling. Both data sources, the satellite and the digital elevation data (DEM), have worldwide coverage and help to characterize the soil-forming environment.

THE USE OF DIGITAL TERRAIN DATA FOR SOIL MAPPING

Digital terrain data have been used for soil feature prediction by many researchers [Moore et al., 1993; Bell et al., 1994; Gessler et al., 1995; Chaplot et al., 1998; Florinsky & Kuryakova, 1998]. Catenary soil development occurs in many landscapes in response to the way water moves through and over the landscape. Terrain attributes can characterize these flow paths and the interactions with the soil attributes. Moore et al. [1993] found significant correlation between quantified terrain attributes and measured soil attributes. Slope and wetness indices were the terrain attributes most highly correlated with surface soil attributes. They accounted for about one-half of the variability in A horizon thickness, organic matter content, pH, extractable P, and silt and sand contents.

Bell et al. [1994] combined a statistically based soil-landscape model and a geographic information system (GIS) to create soil drainage class maps. The landscape attributes used were parent material, terrain and surface drainage feature variables. The model produced drainage class maps with an accuracy of 67 percent at a scale of 1:20,000. Gessler et al. [1995] developed a statistical soil-landscape model to predict soil attributes. They used different terrain attributes, such as plane curvature, compound topographic index, and upslope mean plane curvature to predict the depth of the A horizon and the solum, and the absence or presence of E horizon in an area with a uniform geology and geologic history. The reduction in deviation was around 65 percent on average.

Biggs & Slater [1998] carried out a medium-scale soil survey with the use of digital elevation model. They used a 15 m DEM and its derivatives, namely the slope, curvature, topographic wetness index (TWI), relative elevation and slope position. They produced a soil attribute map at a scale of approximately 1:100,000, which enhanced field validation and increased mapping confidence. Until recently, no low spatial resolution DEM data were used for small-scale soil mapping.

Odeh et al. [1995] compared geostatistical methods with classical statistical methods by integrating soil-landform interrelationship. They found that regression kriging generally performs best. However, there is no single best method for all predicted variables. Due to the flexibility of the regression kriging, more ancillary information (e.g., parent material, vegetation, etc.) can be included in the model and thus the accuracy of the predicted variables can be increased.

THE USE OF INTEGRATED SATELLITE AND TERRAIN DATA FOR SOIL MAPPING

Many attempts have been made to complement the satellite data sources with topographic information for mapping natural resources [e.g., Weismler et al., 1977; Shasby & Carnegie, 1986; Franklin, 1987; Lee et al., 1988; Frank, 1988; Leprieur et al., 1988; Yuan et al., 1995].

Loveland et al. [1991] suggested that the effect of physiographic variation on spectral data can be reduced through stratification of a large region into smaller areas. Zhu & Evans [1994] used this technique in the production of the "U.S. forest type and percent forest cover map." A similar physiographic stratification technique was used in the classification of potential old growth forests in the Pacific Northwest of the United States [Congalton et al., 1993]. The disadvantage of this method is the need for edge matching and refinement of final classes and categories. Along the edges of the stratification units, some unconformity is likely to occur due to the lack of absolute classification categories and possible incoherence of class interpretation within the different classification units.

Another weakness of this approach of data integration is that the gradually changing natural phenomena are represented with boundaries, and thus the possibility to use continuous surface information as a whole is missing. The rapid development of GIS in the last two decades has made "direct" data integration possible, when data sources of different origin are used simultaneously. This permits a much better exploitation of the DEM data. Weismler et al. [1977] used Landsat and topographic data to make a soil inventory in Missouri. However, they did not attempt to relate soil cover to soil type. Franklin [1987] reported a 46 to 75 percent improvement of classification accuracy when he used Landsat MSS data with DEM-derived landscape descriptor layers for classification of landscape classes.

In our study, the primary objective was to evaluate the use of integrated satellite and terrain data for global-scale
soil inventories. Previous studies have demonstrated the potential use of AVHRR data for small-scale soil pattern delineation [Dobos, 1998, Dobos et al, 2000, Odeh et al, 2000]. In this paper, we focus on the use of integrated AVHRR-terrain data, emphasize the potential improvement of the final classification results and highlight the problems that can occur in small-scale soil inventories based on remotely sensed and digital elevation data.

MATERIALS AND METHODS

STUDY AREA

The study covers an area of 1160 km × 1425 km (1,650,000 km²), of which 48.8 percent is sea. It represents the entire area of Italy and Slovenia and parts of France, Switzerland, Austria, Hungary, Croatia and Bosnia-Herzegovina. The area is dominated by temperate and Mediterranean climates. The soils of the Mediterranean regions are mainly Cambisols, Leptosols and Luvisols, with some Vertisols, Andosols, Fluvisols and Regosols. In the temperate region dominant soils are Cambisols, Luvisols and Phaeozems. The dominant soils in the Alps are Podzols, Podzoluvisols, Luvisols, Leptosols and Cambisols.

THE DATA

AVHRR data

The primary data used in this project are from the AVHRR of the National Oceanic and Atmospheric Administration (NOAA) polar orbiting weather satellites. The characteristics of the NOAA/AVHRR system are shown in Table 2. Selected 10-day composite images were produced. All five spectral bands were used. No filtering or off board calibration was applied to the data. The pixel value range was set to 0-255 in order to reduce the size of the database. A pixel value of 255 was assigned to all water pixels. The 10-day composites were made up of picture elements of the certain channel (pixels) that have maximum NDVI value in the 10-day period (Maximum Value Composite-MVC). Data selection was based on the following requirements: free of clouds and snow cover; coverage of different stages of vegetative growths; and soil moisture contents near to field capacity. According to Dobos [1998], the separability of soils with the use of AVHRR band 3 is best when the image was acquired no more than a few days after copious rainfall, with soils at or near field capacity. The periods of 10-day composite data chosen for this study and their identification numbers are shown in Table 3. Eight different dates were selected between 1995 and 1998. The AVHRR data have an original resolution of 1.1 km. The images were resampled to a 1 km resolution with the use of the nearest neighbor method. The data were then stacked into a 45-layer image data set (40 AVHRR and five terrain descriptors). The geographic projection was the Albers Equal Area projection.

Digital elevation data

The digital elevation data cover the same study area with a resolution of 1 km² per pixel. The European DEM data are derived from the 30", DEM data set for Europe from the EROS Data Center (EDC). This data set is based on the 1° × 1° Digital Terrain Elevation Data (DTED) of the US Defense Mapping Agency (DMA) and the Digital Chart of the World (DCW) (scale 1:1,000,000,000).

The data were transformed from geographical co-ordinates (latitude/longitude) to the standard Gisco projection system (Lambert Azimuthal Equal Area projection). The elevation value is the average elevation taken for an area of 1 km². Finally, the data were re-projected into the Albers Equal Area projection to reach a common platform with the AVHRR data.

1,000,000 scale European Soil Database

The 1:1,000,000 scale European Soil Database (ESD) was the training and test (reference or “ground truth”) database used for the AVHRR-terrain classification. The data structure of the ESD was organized into three hierarchical levels. The first level consists of Soil Mapping Units (SMU) - only general descriptive attributes of SMU are stored, for instance minimum and maximum altitudes and land-use. Due to the scale and the resolution, these SMU correspond to soil associations and not directly to soil types (soil units). The second level is the Soil Typological Unit.

<table>
<thead>
<tr>
<th>TABLE 2: AVHRR instrument features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Characteristics</td>
</tr>
<tr>
<td>Spectral Bandwidth</td>
</tr>
<tr>
<td>1. 580-680 nm</td>
</tr>
<tr>
<td>2. 735-1100 nm</td>
</tr>
<tr>
<td>3. 3550-3930 nm</td>
</tr>
<tr>
<td>4. 10300-11300 nm</td>
</tr>
<tr>
<td>5. 11500-12500 nm</td>
</tr>
<tr>
<td>Radiometric Resolution</td>
</tr>
<tr>
<td>10 bits (1024 levels)</td>
</tr>
<tr>
<td>IFOV (Nadir)</td>
</tr>
<tr>
<td>1.1 km</td>
</tr>
<tr>
<td>View Angle</td>
</tr>
<tr>
<td>55.4° (IFOV = 6 km at swath edge)</td>
</tr>
<tr>
<td>Swath Width</td>
</tr>
<tr>
<td>2700 km</td>
</tr>
<tr>
<td>Platform Characteristics</td>
</tr>
<tr>
<td>Orbit</td>
</tr>
<tr>
<td>Near-polar, Sun-synchronous</td>
</tr>
<tr>
<td>Altitude</td>
</tr>
<tr>
<td>833-870 km</td>
</tr>
<tr>
<td>Inclination</td>
</tr>
<tr>
<td>98.7</td>
</tr>
<tr>
<td>Period</td>
</tr>
<tr>
<td>102 min</td>
</tr>
<tr>
<td>Equator crossing time (ii)</td>
</tr>
<tr>
<td>0730 and 1930 (even numbered satellites)</td>
</tr>
<tr>
<td>1400 and 0200 (odd numbered satellites)</td>
</tr>
<tr>
<td>Repeat cycle</td>
</tr>
<tr>
<td>12 hours</td>
</tr>
<tr>
<td>Global Frequency Coverage</td>
</tr>
<tr>
<td>1-2 days</td>
</tr>
</tbody>
</table>

(i) The most usable within the swath of 2700 km is the area within +/- 15°. At 15°, the area covered by a pixel is approximately 1.5 km and the repeated coverage for this reduced swath width is about 6 days.

(ii) Greenwich standard time (1430 ascending and 0230 descending (local time)).
TABLE 3: Layer identification numbers and the corresponding band or terrain data

<table>
<thead>
<tr>
<th>Layer ID</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DEM</td>
</tr>
<tr>
<td>2</td>
<td>SLOPE</td>
</tr>
<tr>
<td>3</td>
<td>ASPECT</td>
</tr>
<tr>
<td>4</td>
<td>CURVATURE</td>
</tr>
<tr>
<td>5</td>
<td>PDD</td>
</tr>
<tr>
<td>6</td>
<td>98 May 08-17 Band 1</td>
</tr>
<tr>
<td>7</td>
<td>98 May 08-17 Band 2</td>
</tr>
<tr>
<td>8</td>
<td>98 May 08-17 Band 3</td>
</tr>
<tr>
<td>9</td>
<td>98 May 08-17 Band 4</td>
</tr>
<tr>
<td>10</td>
<td>98 May 08-17 Band 5</td>
</tr>
<tr>
<td>11</td>
<td>98 June 20-29 Band 1</td>
</tr>
<tr>
<td>12</td>
<td>98 June 20-29 Band 2</td>
</tr>
<tr>
<td>13</td>
<td>98 June 20-29 Band 3</td>
</tr>
<tr>
<td>14</td>
<td>98 June 20-29 Band 4</td>
</tr>
<tr>
<td>15</td>
<td>98 June 20-29 Band 5</td>
</tr>
<tr>
<td>16</td>
<td>97 August 22-31 Band 1</td>
</tr>
<tr>
<td>17</td>
<td>97 August 22-31 Band 2</td>
</tr>
<tr>
<td>18</td>
<td>97 August 22-31 Band 3</td>
</tr>
<tr>
<td>19</td>
<td>97 August 22-31 Band 4</td>
</tr>
<tr>
<td>20</td>
<td>97 August 22-31 Band 5</td>
</tr>
<tr>
<td>21</td>
<td>97 April 01-10 Band 1</td>
</tr>
<tr>
<td>22</td>
<td>97 April 01-10 Band 2</td>
</tr>
<tr>
<td>23</td>
<td>97 April 01-10 Band 3</td>
</tr>
<tr>
<td>24</td>
<td>97 April 01-10 Band 4</td>
</tr>
<tr>
<td>25</td>
<td>97 April 01-10 Band 5</td>
</tr>
<tr>
<td>26</td>
<td>96 May 29-June 07 Band 1</td>
</tr>
<tr>
<td>27</td>
<td>96 May 29-June 07 Band 2</td>
</tr>
<tr>
<td>28</td>
<td>96 May 29-June 07 Band 3</td>
</tr>
<tr>
<td>29</td>
<td>96 May 29-June 07 Band 4</td>
</tr>
<tr>
<td>30</td>
<td>96 May 29-June 07 Band 5</td>
</tr>
<tr>
<td>31</td>
<td>95 October 07-16 Band 1</td>
</tr>
<tr>
<td>32</td>
<td>95 October 07-16 Band 2</td>
</tr>
<tr>
<td>33</td>
<td>95 October 07-16 Band 3</td>
</tr>
<tr>
<td>34</td>
<td>95 October 07-16 Band 4</td>
</tr>
<tr>
<td>35</td>
<td>95 October 07-16 Band 5</td>
</tr>
<tr>
<td>36</td>
<td>95 July 06-15 Band 1</td>
</tr>
<tr>
<td>37</td>
<td>95 July 06-15 Band 2</td>
</tr>
<tr>
<td>38</td>
<td>95 July 06-15 Band 3</td>
</tr>
<tr>
<td>39</td>
<td>95 July 06-15 Band 4</td>
</tr>
<tr>
<td>40</td>
<td>95 July 06-15 Band 5</td>
</tr>
<tr>
<td>41</td>
<td>95 May 01-10 Band 1</td>
</tr>
<tr>
<td>42</td>
<td>95 May 01-10 Band 2</td>
</tr>
<tr>
<td>43</td>
<td>95 May 01-10 Band 3</td>
</tr>
<tr>
<td>44</td>
<td>95 May 01-10 Band 4</td>
</tr>
<tr>
<td>45</td>
<td>95 May 01-10 Band 5</td>
</tr>
</tbody>
</table>

(STU), which refers to a certain soil type. At this level, each STU belonging to a SMU is described with its percentage of representation within the SMU. The STU provides the descriptive soil attributes (e.g., topsoil texture, parent material). The nomenclature used in this project was developed for the FAO "Soil Map of the World." The polygons have no direct soil unit (SU) information assigned to them, but rather a predefined soil association. In order to simplify the database for our purposes, the dominant SU, that is, of largest spatial extent within the polygon, was selected and assigned to the polygon. This generalization results in some loss of information. However, since many soil types within the soil associations are in close genetic relationship, the loss of information is not really relevant.

The European Soil Database is stored in a polygon format, which was converted into a 1 km resolution grid format and reprojected to the Albers Equal Area projection to make the overlay possible with the AVHRR-terrain data.

A soil profile database is connected to the polygon database. This data contains the exact geographic location and all the main descriptive information of the soil profile. These profiles were also used for training the data.

METHODS

The work was done in five main steps: (1) database construction; (2) training and test set selection; (3) feature extraction and reduction of dimensionality; (4) supervised classification; and (5) accuracy assessment.

Database construction

Forty AVHRR bands (five bands for eight different dates) and five terrain descriptor layers, (DEM, slope, aspect, curvature and the potential drainage density) were integrated and a 45-layer, 1 km pixel size AVHRR-terrain image set was formed. The slope, aspect and the curvature layers were created using the slope, aspect and curvature functions of the Unix platform ARC/INFO's GRID package Version 7.0.3. [ESRI, 1997]. The potential drainage density (PDD) layer was created by following the method described by Dobos [1998] (Figure 1). The image set was projected onto the Albers Equal Area projection. For constructing and processing the database, the ARC/INFO and ERDAS Imagine software were used.

FIGURE 1: The Potential Drainage Density (PDD) image of Italy
Two training and test sample sets were selected. In the first phase, the SU level of the FAO-revised legend was used and 56 classes were formed. In the second phase, the major soil grouping (MSG) level was used and the classes selected in the first phase were grouped into 17 MSG classes. In both cases, the same pixel set was used to secure comparability of the results.

This part of the study was done with the use of the MultiSpec software developed at the Department of Electrical Engineering, Purdue University, Indiana, U.S.A. Both the training and the test sample sets were selected based on the 1:1,000,000 European Soil Database. The training sample set selection was done in two steps. First, all the representative profiles (from the soil profile database) falling into the study area, with known geographic coordinates, were selected and overlaid on the polygon database. In the second step, all profiles matching the SU of a given polygon were selected together with the neighboring cells for training purposes. In the case of under-represented classes, more training samples were selected from larger-scale maps (1:250,000) and the 1:1,000,000 European Soil Database. Overall, 34,888 training pixels were selected, which represent 2.13 percent of the entire image.

The test samples were taken from the 1:1,000,000 European Soil Database using the inner part of the polygons. In total, 9160 samples were selected, making up 0.56 percent of the entire image.

Based on the results reported by Dobos [1998], the Discriminant Analysis Feature Extraction (DAFE) method, based on a canonical analysis procedure [Richards, 1993] was used to reduce the dimensionality of the data from the original 45 and to increase the separability for the classes. This linearly transformed image was later used as a basis for the classification.

Several maximum likelihood classifications were performed on the basic image using the training set selected by the method described above. The data were classified using successively the best 10, 20, 25, 30, 35, 40, and, finally, all the available layers. The best layers for these classifications were selected with the Bhattacharyya step-wise feature selection method [Richards, 1993]. Classifications were also performed using only the terrain data (5 layers) and then only the AVHRR data (40 layers).

In the second phase, the classifications were performed on the DAFE transformed image. The first 10, 15, 25, 35 and 45 features were used for the maximum likelihood classifications and these were compared later.

For assessing the classification performance, 0.56 percent of the total number of pixels (9160) were selected as test pixels, based on the 1:1,000,000 European Soil Database. This test database was the best available option, although its accuracy is not exactly known. Its limitations have to be considered later when the results are interpreted. Four different ways of assessing the accuracy were used: (1) test class performance (producer's accuracy): the probability that the classifier has properly labeled the image pixel "B", given that the actual class (test pixel or ground truth) is "B"; (2) user's accuracy: the probability that the actual class (the class in the 1:1,000,000 European Soil Database) is "B", given that the pixel has been labeled "B" on the thematic map by the classifier; (3) Kappa Statistics described by Hudson & Ramm, 1987] and Congalton [1991]; and (4) likelihood probability image: the pixels of the image are assigned the likelihood value of the most likely class.

RESULTS AND DISCUSSION
ACCURACY ASSESSMENT OF THE REFERENCE DATABASE

Two of the most critical factors for image classification are the quality and quantity of the training and test data sets. Field data collection, particularly in small-scale studies, is always expensive. This motivates the resource surveyor to search for alternative sources of less expensive, reliable data for use in the mapping process. The most commonly used ground-truth data are the existing thematic maps and databases. Such maps may be of good quality, but their statistical accuracy is rarely known.

The term taxonomic purity of a mapping unit or a database means the degree or percentage to which soil profiles sampled at random match the mapping unit description in which they occur. Burrough et al. [1971] found mapping purity ranges from 45 to 63 percent for a soil survey map with a scale of 1:63,360 and between 65 to 86 percent for a map of 1:25,000 scale, depending on the complexity of the area mapped. Bascomb & Jarvis [1976] concluded that in the larger scale maps (up to 1:25,000 scale) soil differences occur at lower categorical (taxonomic) levels and that the impurities often arise only in minor definitive features and do not require different management. Therefore the taxonomic purity values of large-scale maps do not necessarily limit the use of the data to such a degree that this could be interpreted from the purity value itself.

Dobos [1998] estimated the taxonomic purity of the HunSOTER database [Várallyay et al, 1994] and found it to be 49.5 percent. This database, like the ESDB, was created using the traditional, expert-knowledge-based method. One explanation for this low value is the generalization procedure used in HunSOTER, in which the origi-
inal soil association was replaced with the dominant soil type and the soil type was assigned to the entire mapping unit. The accuracy of the original (non-modified) HunSOTER database is probably much higher, but generalization was necessary to allow for spatial comparison.

The reference base of this study was the 1:1,000,000 scale ESD, which was modified for the purposes of this study in the same manner as the HunSOTER was modified in Dobos' study [1998]. The dominant soil type, instead of the original soil association, was assigned to the entire mapping unit. Taxonomic purity of the ESDB was estimated (not calculated) to be between 45 and 55 percent on the basis of the similarity between HunSOTER and the ESD in terms of scale, data structure and the method of data modification. This fact must be considered when interpreting the classification accuracy of the different test schemes. Because of the lack of better quality data, the ESD was used in this study for testing the results.

RESULTS OF THE CLASSIFICATIONS
Two different training and test data sets were used in the framework of this study, one representing SUs according to FAO-revised legend, and the second representing MSGs [FAO, 1994]. The two data sets cover the same areas, so that the results were comparable. In the first phase of the study, classifications were performed on the basic image, while in the second phase the original image was linearly transformed with the DAFE function. In both cases the best results were achieved when all available channels were used for the classification, namely 51.4 for the SU level and 54.4 for the MSG level on the basic image, and 51.7 and 54.4 respectively on the DAFE transformed images. The classified image of the MSG level is shown in Figure 2. Dobos [1998] has reported that the use of DAFE can significantly increase the classification result. In this study, we found little or no increase with the use of the DAFE. However, the increase in classification accuracy due to the increasing dimensionality was much higher in the lower dimensions and reached the top values much earlier than the ones obtained without using DAFE.

The higher the number of channels involved in the classification, the better the separability within the classes. Every new channel that is used for the classification provides new information and more chances to make the training classes more distinguishable. However, higher training field performance does not necessarily mean higher test performance. As the number of the channels increases, more statistics have to be estimated with the same number of training pixels, which can decrease the accuracy of the estimates, and the percentage of correctly classified test pixels. This effect decreases the test performance when the number of training pixels is not high enough to achieve accurate estimates of class statistics (Hughes phenomenon). In this study, we used 2.13 percent of the image pixels for training the classifier to avoid a severe occurrence of the Hughes phenomenon.

FIGURE 2: Classified image of the SU level (A) and the 1:1,000,000 European Soil Database (B) of Italy
However, at SU level, where the training pixels were divided into 56 classes, the shape of the classification curve showed a saturation trend and a lower increase when adding more channels to the set used for the classification. In the MSG case, the saturation trend was less expressed, because the number of training pixels per class needed to estimate the second order class statistics was much higher, minimizing the Hughes phenomenon (Figure 3).

When examining the results, it was found that the Podzoluvisol, Fluvisol and Vertisol classes showed the lowest accuracy, the pixels belonging to these classes were classified mainly into the Cambisol class. The Cambisol is a very heterogeneous class, with soils varying a lot in physical and chemical properties. It acts as a collector class, absorbing all other classes with no distinct class statistics due to spectral similarities or an insufficient number of training pixels. In the case of the Podzoluvisol class, a significant portion of the test pixels were classified to the Luvisol class, a relatively close class in terms of genesis. The best classification accuracy was obtained for the classes of Chernozem, Phaeozem, Podzoluvisol, Fluvisol and Vertisol classes showed the significant increases in user's accuracy (over 15 percent) when this technique is used. Such low figures reflect not only the limitation of the methods and the data, but also the quality of the test database.

In this study, we used the Bhattacharyya feature selection method to assess the usefulness of the individual layers. Except when the “sea” (or background) class was used, the most important layers were the DEM and its terrain descriptor derivatives, the slope, curvature and PDD. These layers were neglected when the “sea” class was added to the class set. The most informative AVHRR bands were band 1 (visible-red) and the three thermal bands (bands 3-5) (Table 5).

These trends were recognized when the best layer combinations were selected for the classification. In general, the first layers selected by the layer selection algorithm were the DEM and its derivatives. In the SU case, all terrain descriptor layers were selected, while on the MSG level only the DEM and PDD layers were selected. Most of the selected AVHRR layers were from the spring peri-

The effect of integrating terrain data into the AVHRR database was also studied in both the SU and the MSG levels. Three supervised classifications were performed using the same training set. First the terrain descriptor layers (layers 1-5) and the AVHRR channels (layer 6-45) were used in two separate data sets, while in the second phase the 45-layer integrated AVHRR-terrain data were employed for classification. The results indicate that the terrain descriptors alone are not sufficient for soil classification (Figure 6). Test class performances of 49.8 percent (MSG) and 48.6 percent (SU) using AVHRR data alone were achieved. After the integration of terrain data into the AVHRR database, the performance slightly increased by 4.6 and 2.8 percent, respectively. The most significant increases in user’s accuracy (over 15 percent) were found in the classes of Regosol, Arenosol, Planosol and Histosol (Table 4).

SEPARABILITY STUDIES
This study, we used the Bhattacharyya feature selection method to assess the usefulness of the individual layers. Except when the “sea” (or background) class was used, the most important layers were the DEM and its terrain descriptor derivatives, the slope, curvature and PDD. These layers were neglected when the “sea” class was added to the class set. The most informative AVHRR bands were band 1 (visible-red) and the three thermal bands (bands 3-5) (Table 5).

These trends were recognized when the best layer combinations were selected for the classification. In general, the first layers selected by the layer selection algorithm were the DEM and its derivatives. In the SU case, all terrain descriptor layers were selected, while on the MSG level only the DEM and PDD layers were selected. Most of the selected AVHRR layers were from the spring peri-
Mapping soils using AVHRR and DEM data

FIGURE 4: Probability images of the MSG level (A) and the SU level (B) (red, yellow and blue indicate high, intermediate and low probability values, respectively)

FIGURE 5: Test class performance and the Kappa values for the basic images

FIGURE 6: Test class performance of AVHRR, DEM (terrain descriptors) and AVHRR-DEM images
Mapping soils using AVHRR and DEM data

TABLE 4: Producer's and user's accuracy of the MSG level

<table>
<thead>
<tr>
<th>Class name</th>
<th>User's accuracy</th>
<th>Producer's accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leptosols</td>
<td>69.9</td>
<td>47.9</td>
</tr>
<tr>
<td>Luvisols</td>
<td>54.4</td>
<td>57.5</td>
</tr>
<tr>
<td>Cambisols</td>
<td>63.8</td>
<td>43.6</td>
</tr>
<tr>
<td>Fluvisols</td>
<td>10.3</td>
<td>56.0</td>
</tr>
<tr>
<td>Chernozems</td>
<td>79.8</td>
<td>71.4</td>
</tr>
<tr>
<td>Gleysols</td>
<td>27.6</td>
<td>61.8</td>
</tr>
<tr>
<td>Podzols</td>
<td>32.3</td>
<td>49.4</td>
</tr>
<tr>
<td>Podzoluvisol</td>
<td>19.0</td>
<td>39.5</td>
</tr>
<tr>
<td>Regosols</td>
<td>29.3</td>
<td>13.7</td>
</tr>
<tr>
<td>Arenosols</td>
<td>72.5</td>
<td>78.7</td>
</tr>
<tr>
<td>Planosols</td>
<td>72.8</td>
<td>79.2</td>
</tr>
<tr>
<td>Phaeozems</td>
<td>61.8</td>
<td>94.9</td>
</tr>
<tr>
<td>Andosols</td>
<td>45.1</td>
<td>57.5</td>
</tr>
<tr>
<td>Vertisols</td>
<td>10.5</td>
<td>14.7</td>
</tr>
<tr>
<td>Histosols</td>
<td>33.9</td>
<td>62.3</td>
</tr>
<tr>
<td>Solonchaks</td>
<td>Results not available</td>
<td></td>
</tr>
<tr>
<td>Background</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

TABLE 5: The best 20 layers in terms of class separability (when used individually)

<table>
<thead>
<tr>
<th>Soil Unit level</th>
<th>Major Soil Grouping level</th>
<th>Layer ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without the use of &quot;sea&quot; class</td>
<td>With the use of &quot;sea&quot; class</td>
<td></td>
</tr>
<tr>
<td>1 DEM</td>
<td>DEM</td>
<td>CH1-95MAY</td>
</tr>
<tr>
<td>2 SLOPE</td>
<td>SLOPE</td>
<td>CH1-95OCT</td>
</tr>
<tr>
<td>3 CURVATURE</td>
<td>CURVATURE</td>
<td>CH1-96MAY</td>
</tr>
<tr>
<td>4 CH1-95MAY</td>
<td>CH1-95MAY</td>
<td>CH1-95JULY</td>
</tr>
<tr>
<td>5 PDD</td>
<td>PDD</td>
<td>CH1-97AUG</td>
</tr>
<tr>
<td>6 CH1-95OCT.</td>
<td>CH1-97APRIL</td>
<td>CH1-98MAY</td>
</tr>
<tr>
<td>7 CH1-95JULY</td>
<td>CH5-95OCT.</td>
<td>CH1-97MAY</td>
</tr>
<tr>
<td>8 CH4-95OCT.</td>
<td>CH3-95IULY</td>
<td>CH1-98IUNE</td>
</tr>
<tr>
<td>9 CH1-97APR.</td>
<td>CH4-95OCT.</td>
<td>CH2-95OCT</td>
</tr>
<tr>
<td>10 CH1-97AUG.</td>
<td>CH4-95OCT.</td>
<td>CH2-95OCT</td>
</tr>
<tr>
<td>11 CH1-96MAY</td>
<td>CH3-95OCT.</td>
<td>CH5-95OCT</td>
</tr>
<tr>
<td>12 CH1-98MAY</td>
<td>CH1-98MAY</td>
<td>CH4-95OCT</td>
</tr>
<tr>
<td>13 CH1-95OCT.</td>
<td>CH3-97AUG.</td>
<td>CH2-95MAY</td>
</tr>
<tr>
<td>14 CH5-95OCT.</td>
<td>CH1-95OCT.</td>
<td>CH2-96MAY</td>
</tr>
<tr>
<td>15 CH3-95JULY</td>
<td>CH1-96MAY</td>
<td>CH2-97AUG</td>
</tr>
<tr>
<td>16 CH4-95JULY</td>
<td>CH4-95IULY</td>
<td>CH3-95OCT</td>
</tr>
<tr>
<td>17 CH3-97AUG.</td>
<td>CH1-97AUG.</td>
<td>CH5-95IULY</td>
</tr>
<tr>
<td>18 CH5-98MAY</td>
<td>CH5-65MAY</td>
<td>CH2-97APR</td>
</tr>
<tr>
<td>19 CH4-98MAY</td>
<td>CH4-95MAY</td>
<td>CH5-97AUG</td>
</tr>
<tr>
<td>20 CH4-95MAY</td>
<td>CH4-97AUG.</td>
<td>CH4-95JULY</td>
</tr>
</tbody>
</table>

od (April-May), while the most abundant bands were the visible-red (band 1) and bands 3 and 4. These results coincide with those reported by Dobos et al [1998], who studied the statistical relationship between soil types and AVHRR data. They found that the thermal bands (particularly band 3) and the vegetation index were the best for predicting soil classes. They also studied the correlation between each of the AVHRR channels and found that NDVI shows a relatively high correlation with channel 1 of AVHRR. Therefore, NDVI was not used in the current study, although the integration of NDVI into the database could have slightly improved the final result.

CONCLUSIONS

The results of this study show that AVHRR data and DEM derivatives, from national to continental level surveys, are promising tools for geographers and soil surveyors. AVHRR data are often used in land cover studies, but their usefulness in soil studies has not yet been proven. This study demonstrates their "power" for characterizing the soil-forming environment and delineating soil patterns, particularly when other ancillary data, capable of describing the soil-landscape such as DEM, slope, curvature and PDD, are used together. The predictive power of AVHRR and similar low spatial resolution satellite data could be further improved with the development of soil sensitive filters. Potential improvements can be expected when using better quality data provided by satellites that have been launched recently (Vegetation, MODIS). NOAA/AVHRR was originally designed for meteorological purposes and its application to Earth observation is hampered by system limitations. For instance, the pixel size is not uniform across the entire FOV; geometric distortion affects multi-date registration; the loss of radiometric accuracy due to atmospheric absorption is significant. The Vegetation instrument provides a more advanced data source, designed specially for monitoring the Earth's environment and natural resources. Better data quality may significantly improve the performance of low spatial resolution satellite data in small-scale soil inventories. Performance can also be improved by using better spectral resolution data, such as with MODIS. The 36 bands of MODIS represent a wide range of land information that may be used for soil inventories, among other applications.

REFERENCES


Mapping soils using AVHRR and DEM data


RESUME

Il y a un besoin croissant de bases de données des sols à petite échelle d’une précision correcte. La compilation d’une base de données des sols continentale ou à une échelle globale exige un tas de données spatiales et thématiques précises. Le but de cette étude était de tester une méthode pour une cartographie des sols à petite échelle en Italie utilisant un radiomètre de très haute résolution en technologie avancée (AVHRR) et des données numériques d’altitude. La méthode a été employée dans une étude antérieure en Hongrie pour une zone beaucoup plus petite et un environnement de formation de sol différent. Une base de données intégrée AVHRR-terrain de 45 couches a été utilisée pour l’étude, y compris un modèle numérique du terrain (MNT), pente, courbure, orientation, densité du potentiel de drainage et les données AVHRR de cinq bandes pour huit dates différentes. Les données ont été traitées en utilisant la fonction d’Extraction de Détails par Analyse du Discriminant (DAFE), basée en un procédé d’analyse canonique. Deux types d’images (de base et transformée) ont été classées en utilisant la méthode de Bhattachryya pour la sélection des détails de la base intégrée avec 45 capas combinando datos de AVHRR y de terreno, incluyendo un modelo digital de elevación (MDE), pendiente, curvatura, exposición, densidad potencial de drenaje, y las cinco bandas de datos AVHRR para ocho fechas diferentes. Se procesaron los datos mediante una función de extracción de rasgos por análisis discriminante (Discriminant Analysis Feature Extraction, DAFE), basada en un procedimiento de análisis canónico. Se clasificaron dos tipos de imagen (básico y transformado) usando el clasificador de máxima verosimilitud. Se escogieron dos conjuntos de prueba con idéntica cobertura geográfica, pero con distinto nivel de clasificación de suelos. Un conjunto estaba integrado por unidades de suelos (SU) de la leyenda revisada de la FAO, mientras que el otro conjunto representaba las agrupaciones de suelos mayores (MSG). Se seleccionaron y clasificaron los mejores conjuntos de capas, incluyendo 10, 15, 20, 25, 30, 35, 40 y 45 capas respectivamente, mediante el método de Bhattachryya para la selección de rasgos. Se compararon los resultados de los diferentes conjuntos. Se interpretaron también los rendimientos obtenidos con las imágenes AVHRR solas y con las imágenes basadas únicamente en datos de terreno, respectivamente. Los resultados indican que los descriptors de terreno solos no son suficientes para clasificación de suelos. Sin embargo, los resultados de selección de rasgos siempre seleccionaron el MDE y sus derivados entre los primeros, lo que subraya su importancia para la caracterización del paisaje edáfico. Cuando se utilizaron solamente datos AVHRR, las clases de prueba rindieron 49.8% para los MSG y 48.6% para los SU. La integración de datos de terreno en la base de datos AVHRR produjo mejoramientos relativamente pequeños (4.6% y 2.8%). Los mejores rendimientos con las clases de prueba se obtuvieron cuando se utilizaron todos los canales disponibles para la clasificación, con 51.4% para los SU de la FAO y 54.4% para los MSG en la imagen básica, y con 51.7% y 54.4% respectivamente en las imágenes transformadas mediante DAFE. Las bandas AVHRR con mayor importancia eran las obtenidas en primavera (abril-mayo), mientras que las bandas más abundantes resultaron ser la banda 1 (rojo visible) y las bandas 3 y 4.

RESUMEN

Hay una necesidad creciente de bases de datos de suelos a pequeña escala pero razonablemente precisas. La compilación de una base de datos de suelos a escala continental o global requiere una gran cantidad de datos de suelos que sean precisos desde los puntos de vista espacial y temático. El objetivo de este estudio fue el de probar un método de cartografía de suelos a pequeña escala realizada en Italia mediante uso del radiómetro avanzado de muy alta resolución (Advanced Very High Resolution Radiometer, AVHRR) y datos antiguales en formato digital. En un estudio previo en Hungría, se aplicó este método a un área de mucho menor extensión y con un ambiente de formación de suelos significativamente diferente. Para el presente estudio se usó una base integrada con 45 capas combinando datos de AVHRR y de terreno, incluyendo un modelo digital de elevación (MDE), pendiente, curvatura, exposición, densidad potencial de drenaje, y las cinco bandas de datos AVHRR para ocho fechas diferentes. Se procesaron los datos mediante una función de extracción de rasgos por análisis discriminante (Discriminant Analysis Feature Extraction, DAFE), basada en un procedimiento de análisis canónico. Se clasificaron dos tipos de imagen (básico y transformado) usando el clasificador de máxima verosimilitud. Se escogieron dos conjuntos de prueba con idéntica cobertura geográfica, pero con distinto nivel de clasificación de suelos. Un conjunto estaba integrado por unidades de suelos (SU) de la leyenda revisada de la FAO, mientras que el otro conjunto representaba las agrupaciones de suelos mayores (MSG). Se seleccionaron y clasificaron los mejores conjuntos de capas, incluyendo 10, 15, 20, 25, 30, 35, 40 y 45 capas respectivamente, mediante el método de Bhattachryya para la selección de rasgos. Se compararon los resultados de los diferentes conjuntos. Se interpretaron también los rendimientos obtenidos con las imágenes AVHRR solas y con las imágenes basadas únicamente en datos de terreno, respectivamente. Los resultados indican que los descriptors de terreno solos no son suficientes para clasificación de suelos. Sin embargo, los resultados de selección de rasgos siempre seleccionaron el MDE y sus derivados entre los primeros, lo que subraya su importancia para la caracterización del paisaje edáfico. Cuando se utilizaron solamente datos AVHRR, las clases de prueba rindieron 49.8% para los MSG y 48.6% para los SU. La integración de datos de terreno en la base de datos AVHRR produjo mejoramientos relativamente pequeños (4.6% y 2.8%). Los mejores rendimientos con las clases de prueba se obtuvieron cuando se utilizaron todos los canales disponibles para la clasificación, con 51.4% para los SU de la FAO y 54.4% para los MSG en la imagen básica, y con 51.7% y 54.4% respectivamente en las imágenes transformadas mediante DAFE. Las bandas AVHRR con mayor importancia eran las obtenidas en primavera (abril-mayo), mientras que las bandas más abundantes resultaron ser la banda 1 (rojo visible) y las bandas 3 y 4.
Mapping and modelling mass movements and gullies in mountainous areas using remote sensing and GIS techniques

J Alfred Zinck¹, Jaime López², Graciela I Metternicht³, Dhruba P Shrestha¹ and Lorenzo Vázquez-Selem⁴

¹ ITC, Division of Soil Sciences, PO Box 6, 7500 AA Enschede, the Netherlands (fax: +31-53-4874-379; phone: +31-53-4874-322; e-mail: zincka@itc.nl)
² Apartado Aéreo 5057, Santa Marta, Colombia
³ Curtin University of Technology, GPO Box U1987, Perth, WA 6845, Australia
⁴ UNAM, Instituto de Geografía, Ciudad Universitaria, CP 04510, D.F. Mexico

KEYWORDS: mass movements, gullies, mapping, monitoring, modelling, hazard assessment, remote sensing, GIS

ABSTRACT

Natural as well as human-induced mass movements and gullies are severe environmental hazards. Remote sensing data offer promising possibilities for identification and monitoring. But their effective use in mountainous areas is hampered by cloud effects and relief-controlled factors, which cause geometric distortions and shadow areas, among other constraints. Nevertheless, aerial photographs and satellite images (visible, infrared and microwave bands), or combinations thereof, have been successfully used to discriminate and delineate landslide and gully types. GIS modelling of mass movements and gullies, using ancillary information in combination with remote sensing data, is rapidly developing. The shortcomings of deterministic modelling of such chaotic phenomena as mass movements and gullies highlight the relevance of GIS-assisted approaches to exploratory and predictive modelling. This paper describes practical applications of remote sensing and GIS for mapping, monitoring, exploring cause-effect relationships and assessing hazards of mass movements and gullies in hilly and mountainous areas.

INTRODUCTION

Mass movements and gullies are severe environmental hazards in mountainous areas. Both erosion processes, especially mass movements, cause extensive material and human losses, which are often blamed in official statistics on primary causes such as earthquakes or hurricanes. Mass movements probably constitute the single most widespread hazard on the earth's surface. For instance in New Zealand, one of the few countries that has a countrywide landslide map, 36% of the territory shows formerly or presently active mass movements [Eyles, 1983].

Although the basic processes are fundamentally different, mass movements and gullies share some common characteristics. In both cases, the soil material frequently conditions the initiation and development of the erosion processes and, at the same time, is affected by them. There are also dynamic relationships between gullies and mass movements themselves, since small landslides or earth slumps often convert into gully heads, while gullies frequently expand laterally through mass wasting. Mass movements and gullies are processes of multiple origin/causes and the initiation mechanisms might take place at the terrain surface or beneath. They are chaotic phenomena, triggered by sudden alteration of the environmental equilibrium and generating catastrophic damages. Common factors, such as the complexity of the processes and interactions, the catastrophic character of the events, and the difficulty in predicting their spatial and temporal occurrence, contribute to making deterministic modelling cumbersome in both cases.

However, the development of modern earth observation techniques, in particular the availability of multitemporal remote sensing data, improves the mapping and monitoring possibilities. Similarly, GIS techniques facilitate the integration of multiple data layers and spatial simulation to explore cause-effect relationships. Such issues have been addressed by a number of authors from different perspectives, focussing on mass movements and/or gullies specifically, or environmental hazards in general. In this context, research with significant input of remote sensing and/or GIS has focused on a variety of aspects, including mapping and monitoring approaches [Kienholz et al, 1983; Pike, 1988; McKean et al, 1991; Palacio-Prieto & López-Blanco, 1994; Verstappen, 1995; Chowdhury & Flentje, 1996; Irigaray et al, 1996; Liener et al, 1996; Rosenbaum & Popescu, 1996, Duan & Grant, 2000], the scale at which hazard maps are prepared for regional, local and site planning purposes [Rengers et al, 1992; van Westen, 1993; Leroi, 1996], the synergy obtained from merging different kinds of remote sensing

Our paper addresses some issues related to the use of remote sensing for mapping and monitoring purposes. Further, it describes and illustrates several GIS-assisted approaches to modelling gully and mass movement hazards, using examples drawn from research work developed at ITC by advanced students.

MAPPING

DATA RESOLUTION REQUIREMENTS

The application of remote sensing to environmental studies, including the mapping and monitoring of mass movements and gullies, is controlled by the spatial, spectral and temporal resolutions of the data. Spectral data resolution does not refer only to the number of spectral bands offered by the sensor, but also to the ability of specific portions of the electromagnetic spectrum to provide enough spectral separability amongst surface features related to mass movements or gully formation processes. This requires a good understanding of the interactions between ecosystem characteristics and incoming solar radiation or artificially propagated electromagnetic energy, such as in the case of radar sensors [Lunetta, 1999].

The spatial resolution of the sensor determines the scale at which the data may be useful for mass movement or gully analysis and mapping. The concept of a minimum map unit, which makes it possible to consistently delineate the smallest ground features of interest over a selected area, is an important consideration when establishing spatial data requirements. Lunetta [1999] recognises that remotely sensed data should support a minimum map unit, characteristic of the process or feature being mapped. His view is supported by the current trend of using spatially explicit approaches based on available remote sensing, GIS and digital terrain analysis techniques, which allow researchers to consider local heterogeneity of the landscape, such as discussed by Duan & Grant [2000] and Shroder & Bishop [1998].

Finally, temporal resolution is determined by the revisiting cycle of the sensor. Ideally, the data acquired for mass movement or gully mapping should have a temporal resolution higher than the changes evidenced by the phenomena. For instance, a recent study conducted by Kniveton et al [2000] shows that high temporal resolution data can be used to provide early warning of atmospheric conditions likely to initiate debris flow events.

RELIEF-INDUCED CONSTRAINTS ON THE USE OF REMOTE SENSING DATA

Strong relief variations cause geometric and climatic constraints to the efficient use of remote sensing in mountainous areas. Topography and elevation produce distortions, which are reflected in anomalous height differences, scale differences, relief displacements and shadow areas, among others. They also cause climatic conditions to change from the bottom of the valleys to the summit of the ridges, with effects on temperature, humidity, cloud formation, snow cover and grey tones [Buchroithner, 1995]. The delineation of gullies and mass movements is particularly affected by such geometric and climatic restrictions, as they are usually elongated features, which develop parallel to the slopes over long distances and may cross several bioclimatic elevation belts. A variety of technical solutions including digital elevation and illumination models, multi-seasonal and multi-directional remote sensing data, haze and atmospheric corrections, radar and stereo data, interferometry and GPS, is available to correct for relief, scale, shadow, weather and snow effects (Table 1).

Changes in topographic parameters, such as slope gradient, aspect and orientation with respect to sun elevation, create illumination variations which cause the reflectance values from the same surface cover type to vary. This produces an elongation of the training samples in the feature space plots and induces a bias towards either fully illuminated or fully shaded slopes. Furthermore, the application of multispectral classification algorithms, based on statistical pattern recognition, assumes that the training samples be normally distributed. The latter is generally not the case in areas of rugged topography, with frequent slope gradient and aspect variations causing large illumination differences, and this requires thus some kind of data transformation to approach normality. In a case study of land use classification in the Likhu Khola watershed, Nepal, Shrestha & Zinck [2001] used intensity normalisation of multispectral data to remove the topography-induced constraints for land degradation assessment. This approach solved the problem caused by biased sampling of the training pixels. The effect of data normalisation in the feature space plots is shown in Figure 1.

LANDSLIDE MAPPING

A variety of approaches has been used for landslide mapping, including on-ground monitoring, remote sensing, factor overlay, statistical models, and geotechnical process models [Duan & Grant, 2000]. Singhroy [1995],
TABLE 1: Problem-and-solution matrix regarding relief-induced factors influencing remote sensing data use in high-mountain regions [Buchroithner, 1995].

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>REMOTE SENSING CARTOGRAPHY AND HIGH MOUNTAINS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relief</td>
<td>High acquisition altitude</td>
<td>Displacement, Reduction</td>
</tr>
<tr>
<td></td>
<td>Small FOV</td>
<td>Displacement, Reduction</td>
</tr>
<tr>
<td></td>
<td>Stereo data</td>
<td>Also multi-sensoral</td>
</tr>
<tr>
<td></td>
<td>Digital elevation models</td>
<td>Also from remote sensing. Stereo data</td>
</tr>
<tr>
<td></td>
<td>Shape from shading</td>
<td>SAR application</td>
</tr>
<tr>
<td></td>
<td>Interferometry</td>
<td>Shadow problem. Remains most accurate</td>
</tr>
<tr>
<td></td>
<td>GPS</td>
<td>relief information</td>
</tr>
<tr>
<td>Scale effects</td>
<td>Stereo data</td>
<td>Intrinsic scale changes</td>
</tr>
<tr>
<td></td>
<td>Digital elevation models</td>
<td>Permits mono-ploting, geocoding</td>
</tr>
<tr>
<td>Shadow</td>
<td>Multi-seasonal data</td>
<td>Also multi-sensoral</td>
</tr>
<tr>
<td></td>
<td>Multi-directional radar</td>
<td>Illumination differences</td>
</tr>
<tr>
<td></td>
<td>Digital elevation models</td>
<td>Base for illumination models</td>
</tr>
<tr>
<td></td>
<td>Digital illumination models</td>
<td>CPU-intensive integration</td>
</tr>
<tr>
<td></td>
<td>Grey value ratioing</td>
<td>Simple. Not for completely dark slopes</td>
</tr>
<tr>
<td></td>
<td>Solar noon satellites</td>
<td>Shadow minimisation</td>
</tr>
<tr>
<td>Weather, Haze, Clouds</td>
<td>Multi-seasonal data (high temporal resolution)</td>
<td>Also multi-sensoral</td>
</tr>
<tr>
<td></td>
<td>Haze correction</td>
<td>Simple approach</td>
</tr>
<tr>
<td></td>
<td>Atmospheric correction</td>
<td>Problem of data availability</td>
</tr>
<tr>
<td></td>
<td>Radar</td>
<td>Cloud penetration</td>
</tr>
<tr>
<td>Snow cover</td>
<td>Multi-seasonal data (high temporal resolution)</td>
<td>Also multi-sensoral</td>
</tr>
<tr>
<td></td>
<td>Passive microwaves</td>
<td>Snow type mapping</td>
</tr>
<tr>
<td></td>
<td>Radar</td>
<td>Penetration to ground</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Snow type mapping</td>
</tr>
</tbody>
</table>

among others, has shown that mass movement features in a mountainous environment can be identified from remote sensing data, including the discrimination of different types of landslide (e.g., rock slumps, block slides, debris lobes and slide scars) and the detection of conditioning factors such as faults and rupture lines. The use of airborne SAR data made it possible to recognise geomorphic patterns, while the combination of SAR and TM data added additional information on the vegetation cover.

The comparative advantages of different kinds of remote sensing data and their integration to extract selective information on landslide characteristics (e.g., distribution and classification) and factors (e.g., slope, lithology, geostucture, neotectonics and land use/land cover) are also discussed by Singhroy [1995]. Overall, aerial photos are judged to be the best data source for the identification and mapping of a large number of landslide-related features, while integrated satellite remote sensing data, combining optical and microwave ranges, are superior to the use of individual bands (Table 2). Using study examples from Canada, Singhroy et al. [1998] assessed the usefulness of integrated SAR/TM images and SAR interferometric techniques for landslide inventory and characterisation. They reached the following conclusions applicable to mountainous terrains: (1) RADARSAT SAR incidence angles varying from 40° to 59° provide the most suitable imagery to map landslides; (2) the interferometric SAR technique allows easy recognition of landslide

FIGURE 1: Feature space plots before (a) and after (b) data normalisation (units in reflectance values in eight-bit format), Likhu Khola watershed, Nepal [Shrestha & Zinck, 2001].
TABLE 2: Remote sensing guideline for geohazard assessment [Singhroy, 1995]

<table>
<thead>
<tr>
<th>LANDSLIDES</th>
<th>SPACEBORNE</th>
<th>AIRBORNE</th>
<th>INTEGRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VIR SAR</td>
<td>SAR AIRPHOTOS</td>
<td>SAR/VIR (TM)</td>
</tr>
<tr>
<td>Distribution</td>
<td>P P</td>
<td>E E</td>
<td>E E</td>
</tr>
<tr>
<td>Classification</td>
<td></td>
<td>A</td>
<td>E A</td>
</tr>
<tr>
<td>Factors controlling slope stability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geomorphology of slopes</td>
<td>P P</td>
<td>A</td>
<td>E A</td>
</tr>
<tr>
<td>Lithology</td>
<td>P P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>A A</td>
<td>E E</td>
<td>E E</td>
</tr>
<tr>
<td>Neotectonics</td>
<td></td>
<td>A</td>
<td>E</td>
</tr>
<tr>
<td>Landuse/landcover/infrastructure</td>
<td>E A</td>
<td>A E</td>
<td>E E</td>
</tr>
</tbody>
</table>

E= Excellent; A= Average; P = Poor

features on steep valley slopes; and (3) a combination of airborne SAR and TM images is appropriate to monitor retrogressive slope failures.

GULLY MAPPING

Individual gullies are elongated, narrow features that are difficult to identify at medium and small scales. More often, gullies develop into large ramified badland areas, which are easier to map from remote sensing data. In a case study developed in the intra-mountainous basin of Cochabamba, eastern Bolivian Andes, the possibility of discriminating gullied badlands from other kinds of surface features was assessed using Landsat TM and JERS-1 SAR data [Metternicht, 1996; Metternicht & Zinck, 1998]. Six information classes were considered, referring to terrain surface components spatially intermingled with the gullies: (1) natural vegetation (mainly shrubs), (2) fallow land (bare during dry season), (3) slightly eroded areas (mainly sheet erosion), (4) moderately eroded areas (mainly rill erosion), (5) badlands (mainly gully erosion), and (6) miscellaneous land (ephemeral riverbeds and stone pavements).

In the above study, gullies showed low reflectance in the visible and near infrared. This can be attributed to a shadow effect caused by the depth and surface irregularities of the gullies, which traps the incoming light and reduces the reflectance (Figure 2). In the middle infrared, reflectance remained lower than that of the other features because of the surface roughness component. After merging Landsat TM and JERS-1 SAR data, the energy backscattered by the gullied areas remained rela-

![Figure 2: Digital numbers of selected surface components from Landsat TM bands, Sacaba valley, Bolivia [Metternicht, 1996]. The X-axis represents the visible (1, 2, 3), near infrared (4), middle infrared (5, 7) and thermal (6) bands of the Landsat TM sensor.](image-url)
tively low, but became more variable so that the separability of the gullies from the other erosion features and surface components slightly improved (Figure 3).

The effect of data fusion on spectral class separability was assessed using transformed divergence (TDij), a measure to select the best band combination for pixel labelling. Output values are usually scaled between 0 and 2000. For TDij>1600, good separability between classes i and j can be expected [Richards, 1993]. In the study case [Metternicht, 1996], best between-class separability was obtained when combining JERS-1 SAR (L-band) and TM bands 1, 3, 4, 5, 6 and 7, causing all transformed divergence values to cross the threshold figure of 1600. This is particularly the case between badlands and miscellaneous land, as well as between badlands and moderately eroded areas. The improvement of class separability is also reflected in the spatial distribution of the gullies before and after data merging. With Landsat data alone, gullies appear as large undifferentiated areas. Comparatively, Landsat and JERS-1 SAR data together produce a sharper spatial segmentation of the gullies.

However, in any case of band combination or data fusion, the class accuracy for gullies remained low (54 percent), when compared to the other surface components included in the study. This is because gullies are heterogeneous areas including variable mixtures of natural vegetation, stone pavements and eroded soils. The intricate distribution of branching gullies generates impure pixels, whose spectral reflectances are mixtures of the reflectances of the individual components. Thus the issue is not one of spectral confusion, but one of spectral mixing of the surface components within a single pixel. To solve this problem, a linear mixture model including five pure end-members (n-1), one of them being pure gullies, was applied to a 6-band Landsat TM data set (the thermal range being excluded). The procedure is described in Metternicht & Fermont [1998]. This made it possible to generate an error map from spectral unmixing. The error between the original map and the root-mean-square image representing the best-fit output proportion map was lower than 1 percent in 36 percent of the classified area, and between 1 and 10 percent in 63 percent of the area. Only 1 percent of the classified area had an error greater than 10 percent. These results were further used to improve the image classification.

The efficiency of the different portions of the spectrum (ie, visible, infrared, thermal and microwave) to properly separate gullies from the other selected surface components was assessed using a procedure based on the percentage of spectral confusion, derived from the transformed divergence analysis, in relation to the total number of training samples [Metternicht, 1996]. Applying this criterion to the study case, the different regions of the electromagnetic spectrum performed relatively well when separating gullies from fallow land and from slight-
ly and moderately eroded areas. In contrast, major spectral confusions occurred between gullies and surfaces covered with rock fragments and stone pavements, especially in the visible and infrared ranges. Similarly, the visible and microwave ranges performed poorly in discriminating between gullies and vegetation cover (Figure 4). This study shows that regardless of the satellite sensor, spectral band combinations and/or image classification algorithm applied, accurate detection of gullies requires contextual knowledge to improve the between-class spectral separability. In particular, knowledge about the relationship between gullies, their characteristic surface features, and geomorphic positions is needed.

MODELLING

BOUNDARY CONDITIONS

Attempts to model mass movements and gullies have been made from different perspectives [van Westen & Terlien, 1996]. Ideal modelling would be deterministic, which aims at explaining erosion phenomena through the mechanics of the processes. Mechanistic modelling would allow one to predict the geomorphic response from the properties of the soil or substratum material, thus from its intrinsic susceptibility. For instance, when the micro-fabric of the material is deflocculated, thus in liquid state, the expected geomorphic response would be mudflow. Similarly, with a dispersed micro-fabric and a plastic consistence, the predicted mass movement would be solifluction. An aggregated micro-fabric and semi-solid consistence would promote sliding. In contrast, a flocculated micro-fabric and solid consistence would pro-

vide the conditions for geomorphic stability [Zinck, 1996].

Mass movements, as well as gullies, are chaotic phenomena. They occur when the terms of a meta-stable equilibrium situation drastically and suddenly change. The activating factor might be abnormal rainfall or an earthquake. The conditioning factors include properties of the vegetation cover, topography, geomorphodynamics, geological structure and hydrogeological behaviour. But it is the intrinsic nature of the soil material which determines its propensity to mass wasting, mainly through its mechanical and hydrological properties. The rheological contrast between consecutive soil horizons creates planes susceptible to functioning as shear surfaces. When the actual moisture content of the soil mantle exceeds the water holding capacity and/or the Atterberg limits, a mass movement hazard exists. A simple graphical comparison between water-potential or consistence profiles and the real moisture contents of the soil cover, preferably as time series, allows identification of areas where a mass movement potential builds up during critical periods of the year [Zinck, 1986, 1996]. While deterministic models able to explain and predict mass movement hazards require further elaboration, the simple graphical correlation between consistence and moisture profiles can be used as a basis for designing rheostatic models. To improve the basic conceptual framework for deterministic modelling of mass movements, better understanding of the relationships between the micro-fabric of the soil material and the geomorphic response must still be achieved. As quite some progress is needed

FIGURE 4: Spectral confusion among terrain surface features, Sacaba valley, Bolivia [Metternicht, 1996].
before deterministic modelling of mass movements and gullies can be fully undertaken, the current shortcomings can be partially compensated by GIS-assisted modelling, including exploratory and predictive approaches [Zinck, 1997, 1999].

EXPLORATORY APPROACH
Exploratory models attempt to identify non-explicit cause-effect relationships between environmental hazard types (e.g., soil erosion processes) and affected soil types (i.e., soil map units) in order to predict, from these relationships, soilscape areas potentially exposed to degradation. Because it relies on relatively simple GIS operations, cartographic modelling is an exploratory mode frequently implemented to this end [Bocco et al, 1990]. The overlay of information layers, usually represented by series of thematic single-attribute maps, allows highlighting of areas of coincidence between factors presumably controlling erosion processes and features resulting from these processes.

Erosion features caused by gullies or mass movements are not randomly distributed on the landscape. They develop in response to a combination of controlling factors. The simple overlay of a gully distribution map on top of maps representing environmental factors, such as geoforms, slope gradients, soils, lithologic units and land use types, highlights the degree of spatial coincidence between factors presumably controlling erosion processes and features resulting from these processes.

Cartographic modelling through thematic map overlay was performed in a volcanic area located about one hundred kilometres northeast of Mexico City, in Huasca de Ocampo County [Vázquez-Selem & Zinck, 1994]. Frequency graphs were established for each forming factor to highlight the conditions most favourable to the occurrence of gullies. For example, nearly half of the total gullied area corresponds to a narrow slope gradient range of 4-7 percent (Figure 5). Thus, gully erosion does not increase proportionally to slope gradient and, in this sense, substantially deviates from the principles governing rill and sheet erosion.

Similarly, the overlay of the gully map and the soil map shows that most gullies develop on Alfisols (Figure 6). In fact, about 90 percent of the gullied surface within the study area concentrates on deep Paleustalfs, although these soils account for only 39 percent of the total area. Alfisols in this area are composed of two main layers: a colluvial cover material, 40 to 60 cm thick, which lies on a buried Bt horizon belonging to a truncated subsoil. The surface of discontinuity between the two materials is marked by ancient human artefacts (2400 years BP). The difference of permeability between the well-structured colluvial cover and the highly clay-dispersible subsoil favours horizontal water flow along percolines, from which gullies initiate. In contrast, the areas covered with Mollisols are virtually free of gullies, although these soils occur in conditions of slope and land use similar to those of the Alfisols.

FIGURE 5: Observed gullied areas per slope gradient units at Huasca de Ocampo, Mexico [Vázquez-Selem & Zinck, 1994].

FIGURE 6: Observed gullied areas per dominant soil units at Huasca de Ocampo, Mexico [Vázquez-Selem & Zinck, 1994].
PREDICTIVE APPROACH

Predictive models usually implemented in GIS are based on rules and expert knowledge. Such models lack deterministic capability, because they neither simulate nor explain the mechanisms involved in gully formation or mass wasting. They are built on the results of the exploratory analysis, which identifies cause-effect relationships from the spatial coincidence between observed erosion features (eg, gullies, landslides) and landscape factors. Such models are not able to take into consideration, for the purpose of prediction, the role played by the activating factors (ie, exceptional rainfalls, earthquakes) in triggering the processes. The modelling rules are mainly based on the conditioning factors of the environment (eg, slope, vegetation cover, rock substratum) and a few soil properties. This type of model is able to (1) reproduce the spatial distribution of existing gullies for validation purposes and (2) predict the potential occurrence of gullies in areas with favourable conditions.

To illustrate the above considerations, a set of nested models was developed to confirm observed gullies and assess the hazard of potential gullies in the same Huasca de Ocampo area of central Mexico, where the exploratory models were developed [Vázquez-Selem & Zinck, 1994]. The assessment rules mobilise only the area percentages covered by observed gullies in the units of the thematic maps representing environmental factors. Six environmental factors were selected on the assumption that they contribute, in one way or another, to gully formation: geofoms, lithologic units, slope gradients, slope shapes, dominant soils and land uses. Two criteria were implemented to account for the area percentages: (1) the percentage of area with observed gullies in each thematic map unit, and (2) the percentage that the observed gullied area in each thematic map unit represents in relation to the total extent of gullies (562 ha) within the whole study area (8009 ha). The first criterion was considered more diagnostic than the second one, because it is independent of the total gullied area and thus reflects better the intrinsic susceptibility of each thematic map unit to gully formation. To establish class limits, critical threshold values of area percentages were determined by iteration from the graphics showing the frequency of gullies per classes of environmental factors (eg, Figures 5 and 6).

Using these rules, six models were established with decreasing boundary conditions (Table 3). The first model, for instance, takes into account only the thematic map units with a high percentage of observed gullied area (more than 10 percent or more than 15 percent according to the environmental factor considered). Such a combination of rules is highly selective, since only a few units satisfy the requirements. As a consequence, the gullied area estimated by model 1 is small. But, at the same time, the model is efficient because a large proportion of the calculated gullied area corresponds to existing gullies. The other models operate with less restrictive rules in decreasing order.

The relative efficiency of the various models in corroborating observed gullies is presented in Figure 7. The total gullied surface area of 562 ha is equivalent to 7 percent of the study area. An ideal model would confirm 100 percent of the gullied area with only 7 percent of the study area. Thus, an efficient model is one which approximates this optimum performance. To assess the efficiency of the models, the gullied area calculated by each model was compared to the area percentage of existing gullies properly confirmed. Accordingly, models 2b, 3a, 3b and 4a are the best predictors.

---

**TABLE 3: Rule-based spatial models for gully prediction at Huasca de Ocampo, Mexico [Vázquez-Selem & Zinck, 1994]**

<table>
<thead>
<tr>
<th>Geopedologic map (1)</th>
<th>Lithologic map</th>
<th>Slope gradient map</th>
<th>Slope shape map</th>
<th>Dominant soil map</th>
<th>Landuse map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;15% unit area</td>
<td>&gt;15% unit area</td>
<td>&gt;10% unit area</td>
<td>&gt;15% unit area</td>
<td>&gt;15% unit area</td>
<td>&gt;10% unit area</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[&gt;10% unit area and &gt;10% total gullied area] or &gt;15% unit area</td>
<td>&gt;15% unit area or &gt;30% total gullied area</td>
<td>&gt;5% unit area or &gt;5% total gullied area</td>
<td>&gt;10% unit area or &gt;20% total gullied area</td>
<td>&gt;10% unit area</td>
<td>&gt;5% unit area</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;5% unit area</td>
<td>&gt;5% unit area and &gt;5% total gullied area</td>
<td>&gt;5% unit area or &gt;5% total gullied area</td>
<td>&gt;5% total gullied area</td>
<td>&gt;5% unit area</td>
<td>&gt;3% unit area</td>
</tr>
<tr>
<td>Model 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;2% unit area</td>
<td>&gt;2% unit area</td>
<td>&gt;2% unit area</td>
<td>&gt;2% unit area</td>
<td>&gt;2% unit area</td>
<td>&gt;2% unit area</td>
</tr>
<tr>
<td>Model 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;0% unit area</td>
<td>&gt;0% unit area</td>
<td>&gt;0% unit area</td>
<td>&gt;0% unit area</td>
<td>&gt;0% unit area</td>
<td>&gt;0% unit area</td>
</tr>
<tr>
<td>Model 6</td>
<td>no gullies</td>
<td>no gullies</td>
<td>no gullies</td>
<td>no gullies</td>
<td>no gullies</td>
</tr>
</tbody>
</table>

(1) Only geomorphologic component of the geopedologic map taken into account. 
Example: ">15% unit area" means that only units in which observed gullies cover >15% of the area of the unit are considered in the model's calculations; ">2% total gullied area" means that only units that contain >2% of the total gullied area within the study area are considered in the model's calculations.
Mapping and modelling mass movements and gullies

\[
\text{% of total study area} = \left( \frac{\text{total area calculated by the model}}{\text{total study area}} \right) \times 100
\]

\[
\text{% of total gullied area} = \left( \frac{\text{gullied area calculated by the model}}{\text{total gullied area}} \right) \times 100
\]

- Ideal model
- Type "a" models: including all thematic maps except the geomorphic component of the geopedologic map (see Table 3)
- Type "b" models: based on the geomorphic component of the geopedologic map alone (see Table 3)
- Intersection model of 3-16% slopes and Alfisols
- Intersection model of 5-11% slopes and highly susceptible geoforms

FIGURE 7: Relative efficiency of rule-based models for gully prediction at Huasca de Ocampo, Mexico [Vázquez-Selem & Zinck, 1994].

Gully hazard severity classes
1. Very high
2. High
3. Moderate
4. Low
5. Very low
6. No hazard

FIGURE 8: Observed gullied areas per gully hazard units at Huasca de Ocampo, Mexico [Vázquez-Selem & Zinck, 1994].

In addition to confirming existing gullies, the models can also be used to identify areas that meet conditions favourable to the potential development of gullies. Since the models are organised per decreasing order of constraints, this sequence also represents a decreasing scale of hazard severity. Model 1 identifies areas strongly prone to future gully initiation. Models 2 to 6 indicate decreasing hazard rates (Figure 8).

Instead of operating only on the basis of area criteria, predictive models can directly use concrete parameters to describe the environmental factors and establish hazard severity classes. In the Coello river valley, central cordillera of the Colombian Andes, a model was developed to identify areas favourable to the potential development of mass movements in a volcanic ash cover [López & Zinck, 1991]. Criteria used included slope classes, susceptibility classes of the material on the basis of its physico-mechanical properties, and distribution of observed mass movements. For hazard zoning, a geopedological map was used as vector to extrapolate over the whole basin the causal model established in sample areas (Figure 9). Previous to extrapolation, the structural homogeneity of the soil properties and the spatial homogeneity of the soil units were validated, by testing

FIGURE 9: Mass movement hazard zones in the upper Coello river basin, Colombia [López & Zinck, 1991].
they are difficult to control.

CONCLUSIONS

Gullies and mass movements are severe environmental hazards because of the damages they cause and because they are difficult to control. Remote sensing data substantially contribute to the mapping and monitoring of landslide and gully erosion features, but their use is limited by relief-controlled factors, which cause geometric distortions and atmospheric constraints.

Best results are obtained when improving class separability through the integration of multi-source data (eg, merging visible, infrared and microwave data) and when applying techniques such as linear spectral unmixing to remove spectral confusions caused by the presence of contrasting surface features in single pixels. The complexity of formation and evolution hampers deterministic modelling of gullies and mass movements. More empirical GIS-assisted approaches, based on rules and expert knowledge, make it possible to explore relationships between forming factors and spatial distribution of gullies and mass movements and identify areas potentially exposed to hazards because they meet favourable formation conditions.

REFERENCES


Mapping and modelling mass movements and gullies


Prioritizing erosion-prone areas in hills using remote sensing and GIS – a case study of the Sukhna Lake catchment, Northern India

S S Shrimali¹, S P Aggarwal² and J S Samra¹

¹ Central Soil and Water Conservation Research and Training Institute, 218 Kaulagarh Road, Dehradun, India (e-mail: s_s_shirmali@eudora-mail.com)
² Indian Institute of Remote Sensing, Kalidas Road, Dehradun, India

KEYWORDS: erosion, remote sensing, GIS

ABSTRACT

Traditionally, assessment of productivity of land took priority over all other aspects of evaluating land use performance. Presently, the effects of land use on the quality of the environment and environmental sustainability of production systems have become the major issues. In hills, the terrain conditions aggravate erosion-induced land degradation. Judicious allocation of available resources for sustainable production requires mapping, monitoring and prioritizing the areas based on their susceptibility to degradation. Remote sensing and Geographic Information Systems are effective tools for inventory, monitoring and management of spatially distributed resources. This paper presents a case study of the 42 km² Sukhna Lake catchment in the Shiwalik hills conducted for the delineation and prioritization of erosion-prone areas using RS and Geographic Information Systems. Multi-spectral IRS ID-LISS III data acquired in March 1998 was used for the supervised digital classification of the land use/land cover type. The catchment was classified in six land use classes: forest, agriculture, scrub, barren hills, streambed and settlements. These classes were divided into sub-classes based on the cover characteristics. Using the U.S. Soil Conservation Service curve number method, runoff potential of each delineated hydrologic unit was computed in a grid-based analysis using an ARC/INFO GIS. Erosion-prone areas were classified further by integration of a digital elevation model or DEM-derived slope, aspect and flow length. To get an ordered priority of the erosion-prone areas, a cumulative erosion index was computed from the rating given to the three main causative factors, i.e., slope, soil erodibility, and cover, on a scale of 1-7 for each grid. The cumulative index was further classified in four classes for spatial representation of the erosion-prone areas on the catchment map. The study revealed that 32.9 percent of the catchment area is susceptible to high or very high erosion risk and thus has to be managed with appropriate conservation strategies.

INTRODUCTION

Judicious allocation of available resources for checking erosion-induced land degradation requires mapping, monitoring and prioritizing the areas based on their susceptibility to erosion. The assessment of erosion risk/hazard for prioritization is a specific form of land evaluation, the objective of which is to identify areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss [Morgan, 1986]. At times, when storage structures downstream are threatened by excess incoming sediment from the catchment area, offsite effects demand top priority in preparing a conservation plan. The priority of the treatment then shifts to sediment-producing areas. Since water-induced soil erosion is closely related to vegetation cover, slope and soil, mapping these parameters is a pre-requisite to erosion risk assessment in an area.

Remote sensing techniques [Lillesand & Kiefer, 1994] are operationally used for soil resource inventory and natural resource mapping at a scale of 1:50,000. They provide the real-time and accurate information related to land/soil [Manchanda & Kudrat, 1999]. Multi-spectral remote sensing together with Geographic Information Systems (GISs) helps to integrate information on spatially distributed erosion-causative factors in order to divide regions into areas similar in their degree and kind of erosion hazard. The resulting product becomes a basis for prioritizing and planning soil conservation works.

The study presented in this paper utilized the potential of multi-spectral remote sensing and GISs for mapping land use/land cover and prioritizing erosion-prone areas in the 42 km² catchment in the Shiwalik hills of India.

STUDY AREA – SUKHNA LAKE CATCHMENT

Sukhna Lake was established in the early 1950s at Chandigarh by harvesting the excess monsoon rainfall from a 42 km² catchment area of the Shiwalik hills and ro:ng farm and of the foothills. The area selected for the study, the catchment of the lake, lies between latitudes 30° 44' and 30° 50' N and longitudes 76° 48' to 76° 54' E. The area lies in the two adjoining States of Punjab and Haryana and in the Union Territory of Chandigarh (U.T. Chandigarh). Two major ephemeral streams, Kansal and Nep, locally called Choe, drain into the lake. Since these streams were carrying a large amount of sediment, the
lake lost 70 percent of its water-storing capacity in 17 years [Murthy & Shankaranarayana, 1977]. Several conservation measures were taken to check the siltation of the lake including contour trenches, silt-arresting dams, planting of forest species and grasses, terracing in the agricultural lands and linking of the two major streams to divert the flow away from the boat club at the lake. Though these conservation measures were effective in arresting a large amount of sediment, the lake continues to receive sediment, which is being removed by dredging. The present study was therefore undertaken to prioritize the catchment area in relation to erosion risk for adoption of further conservation measures.

For operational and monitoring purposes, the catchment was divided into three sub-watersheds, ie, Kansal, Nepli, and Ghareri, and the foothill villages (Figure 1). In Figure 1, soil texture or physiography is used to describe the units. In the case of highly variable soil texture, physiographic indications are preferred above those of soil texture. This was done for lake bed and steep hills, the latter also being characterized by shallow soils.

CLIMATE
The climate of the area is sub-humid with a mean maximum temperature of 41.8 °C in June, and a minimum temperature of 5.1 °C in January. The average annual rainfall of the area is 1120 mm, with a maximum of 1976 mm and a minimum of 713 mm. Of the total rainfall per year, 80 percent is received during the monsoon season July to September. Average daily evaporation ranges from 0.9 mm per day in December to 9.5 mm per day in May.

SOILS
The soil of the catchment area is variable within short distances. Murthy & Shankaranarayana [1977] mapped the soils and Grewal & Juneja [1984] characterized the soils of the catchment with respect to their erosion behaviour. The texture of the soil varies from loamy sand to fine loamy to silty clay, depending on location in the catchment. The textural variation is so great that within a small area the sand content may vary from 4.5 to 65 percent, the silt content from 6.6 to 46.7 percent and the clay content from 3.1 to 56 percent. This variation can be explained by the change of parent materials over short distances. Indeed, sandstones and shales occur side by side and alluvial soils show textural changes over short distances. Differences in soil structural stability and strong sealing of pores at the soil surface, especially in soils of silty clay texture, lead to heavy runoff from bare hill slopes. Each soil group was given a code (Table 1) for further analysis in a GIS.

VEGETATION
Natural vegetation consists of trees, shrubs, climbers and grasses. Apart from the natural occurring vegetation,
TABLE 1: Details of soil units and soil codes (given for a GIS)

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Description - Soil type</th>
<th>Soil code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lake bed (water submergence)</td>
<td>700</td>
</tr>
<tr>
<td>2</td>
<td>Alluvial plains and terraces with fine loamy calcareous soils</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>Hill slopes and foothills with gravelly coarse loamy to gravelly fine loam</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>Alluvial plains and terraces with coarse loamy and sandy soil</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Shallow to moderate steep complexes on more than 40 percent hill slopes with silty loam to silty clay loam</td>
<td>400</td>
</tr>
<tr>
<td>6</td>
<td>Steep hills, silty clay to loamy sand</td>
<td>500</td>
</tr>
<tr>
<td>7</td>
<td>River wash, variable stratified soil, generally loamy sand</td>
<td>600</td>
</tr>
</tbody>
</table>

MATERIAL AND METHODS

DATA USED

Remote sensing data – Indian remote sensing satellite IRS – ID LISS III

Digital data – Scale 1:50,000; path 95; row 49; date of acquisition 1 March 1998

Ancillary/Collateral/topographic data – (1) Survey of India (SOI) toposheets No. 53 B/13, 53 B/14; (2) soil map of the catchment area [Murthy & Shankaranarayana, 1977]; (3) general information of catchment and vegetation; (4) soil-related information [Grewal & Juneja, 1984]; and (5) hydrologic information [Bansal & Grewal, 1986] and Department of Forestry, U.T. Chandigarh.

CREATION OF DIGITAL DATA BASE

Topographic – Two toposheets 53 B/13 and 53 B/14 of survey of India (SOI), covering the catchment area at 1:50,000 scale, were used to create the digital data base for the watershed boundary, the drainage system and a contour map (20 m interval) of the catchment in an ARC/INFO GIS. The desired DEM, slope and aspect map were prepared using grid-based GIS analysis.

Soils – The soil map of the catchment area [Murthy & Shankaranarayana, 1977] was used to prepare the digitized soil map. Soils were grouped into seven classes depending on soil properties. The predominant soil textural classes were silty loam and silty clay loam, found in about 45 percent of the catchment area. The streambeds have a loamy to sandy texture, whereas the steep hills comprise yellow and pink shales.

Land use/land cover – A land use/land cover map was prepared using the digital data of an IRS-ID LISS III image. Multi-spectral supervised classification using ERDAS Imagine, followed by smoothing and editing of pixels, was performed to prepare a land use/land cover map of the catchment area.

ANALYSIS OF DATA

Classified slope map (Figure 2) – The DEM-derived slope map was classified into seven slope (percent) classes 0-3, 3-5, 5-15, 15-25, 25-33, 33-100 and >100 based on Tejwani [1976]. These slope groups were used to determine the land capability class. In the present analysis some of the slope groups (eg, 0-1, 1-3) were combined, while keeping the recommendation of the conservation measures in view. Each slope class present in the catchment was given a slope index value on a rating of 1 to 7. Value 7 was given for the highest slope class (>100) and value 1 for the lowest (0-3).
Excluding the gently sloping areas, ie, the slope classes of foothill villages, the catchment of the lake has slopes ranging from 5 to more than 100 percent. The surfaces of areas falling in different slope classes are presented in Table 2.

### TABLE 2: Details of the slope classes in the catchment

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Slope steepness class</th>
<th>Sub-catchments</th>
<th>Area (ha)</th>
<th>Foothill villages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kansal</td>
<td>Nepli</td>
<td>Ghareri</td>
</tr>
<tr>
<td>1</td>
<td>0 to 3</td>
<td>300</td>
<td>326</td>
<td>111</td>
</tr>
<tr>
<td>2</td>
<td>3 to 5</td>
<td>31</td>
<td>36</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>5 to 15</td>
<td>154</td>
<td>176</td>
<td>81</td>
</tr>
<tr>
<td>4</td>
<td>15 to 25</td>
<td>224</td>
<td>262</td>
<td>134</td>
</tr>
<tr>
<td>5</td>
<td>25 to 33</td>
<td>221</td>
<td>261</td>
<td>92</td>
</tr>
<tr>
<td>6</td>
<td>33 to 100</td>
<td>273</td>
<td>425</td>
<td>124</td>
</tr>
<tr>
<td>7</td>
<td>&gt; 100</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1204</td>
<td>1485</td>
<td>560</td>
</tr>
</tbody>
</table>

### MAPPING RUNOFF POTENTIAL OF CATCHMENT

Since surface runoff is the main causative factor for water-induced erosion, mapping of runoff potential of the catchment area can also be used as an indirect method for identifying potential erosion areas. A simple model with modest input requirement can be used to prepare a runoff potential map. In the present study, the SCS [U.S. Soil Conservation Service, 1972] curve number method was used. Map cross or matrix combination of the soil and land use maps resulted in uniform hydrologic units in the catchment. These units were assigned curve numbers using the standard attribute table. The runoff potential map was prepared by classifying the curve numbers into four classes: low, moderate, high and very high. The details of various classes falling in sub-watershed areas are given in Table 3.

### TABLE 3: Runoff potential areas in the catchment

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Runoff potential</th>
<th>Sub-catchments</th>
<th>Area (ha)</th>
<th>Foothill villages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kansal</td>
<td>Nepli</td>
<td>Ghareri</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>5</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>1073</td>
<td>1323</td>
<td>507</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>33</td>
<td>49</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Very High</td>
<td>92</td>
<td>95</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1204</td>
<td>1485</td>
<td>560</td>
</tr>
</tbody>
</table>

### PRIORIZING EROSION-PRONE AREAS

Prioritizing erosion-prone areas in the catchment is essential when financial resources available for executing a conservation plan are limited. The areas most likely to contribute to a large volume of sediment, and which are susceptible to a high degree of erosion, get higher priority in treatment. These areas in the catchment were delineated using information on erosion-causative factors such as slope, soil and land use/land cover type. A GIS provides an effective tool for integrating this spatial information. Though erosion models, the Universal Soil Loss Equation or USLE [Wischmeier & Smith, 1978] and the model developed by Morgan et al [1984] provide quantitative estimates of erosion, the input parameters are often approximated in absence of local validation, thus resulting in highly uncertain soil loss estimates. These models are used in predicting possible impacts of alternative land use/land cover changes. However, when the objective is to prioritize the areas in order to use the limited resources efficiently, a simpler approach can give an equally good result. In our study, the three main causative factors, ie, soil, land use and slope, were used for prioritizing. The prevalent range of these variables were grouped into seven classes and each class was given a rating between 1-7 based on their ranking in relation to erosion (Tables 4-8). A class of a variable having high susceptibility to erosion was rated higher by its index value. A cumulative erosion index (EI) was worked out by summing all individual indices in a GIS. The EI ranging between 3 and 21 was further grouped into five erosion classes from no erosion to slight, low, moderate, high and very high erosion. These classes were spatially represented in the erosion potential map. Areas rated high to very high on the EI get priority of treatment in the conservation plan.

### RESULTS AND DISCUSSION

#### DIGITAL IMAGE CLASSIFICATION FOR THE LAND USE/LAND COVER MAP

Classification of land use/land cover had an overall accuracy of 83 percent, which can be considered as a reasonably accurate classification for hydrological applications. Some classes such as agriculture (terraced), agriculture (fallow), and water body had a classification accuracy of more than 90 percent. The classification of forest into three classes (dense, moderate and open mixed forest) was 85.5 percent accurate. The reason for the percentage of error was signature overlapping of fallow areas with grass cover and overlapping of grass and moderate (dense) forests with open mixed forests. Accuracy could be further improved if the quantification of standing bio-mass in the forest area could be done in the training sets. However, for hydrological applications and erosion assessment, the classification method is considered reasonable. The details of land use and land cover in different sub-watersheds of Sukhna Lake catchment, derived from the digitally classified image, are presented in Figure 2 and Table 8.

### MAPPING RUNOFF POTENTIAL IN THE CATCHMENT

The runoff potential map (see Figure 3 and Table 9) prepared for the catchment area indicates that about 74 percent of the area has moderate runoff potential.
TABLE 4: Land use indices

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Land use</th>
<th>Land use index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Streambed</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Barren hill/land</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Agricultural land</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Scrub</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Open mixed forest</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Moderate forest</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Dense forest</td>
<td>1</td>
</tr>
</tbody>
</table>

TABLE 5: Soil indices

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Soil code*</th>
<th>Soil index**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>600</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>700</td>
<td>1</td>
</tr>
</tbody>
</table>

* See Table 1 for definition of terms.
** Index given based on erosion characteristics of soils, i.e., suspension percent, dispersion ratio, clay-moisture equivalent ratio and erosion rate, as reported by Grewal & Juneja [1984]

TABLE 6: Slope indices

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Slope (%)</th>
<th>Slope index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3 - 5</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>5 - 15</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>15 - 25</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>25 - 33</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>33 - 100</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>&gt; 100</td>
<td>7</td>
</tr>
</tbody>
</table>

TABLE 7: Erosion indices

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Description</th>
<th>Erosion potential index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None to slight</td>
<td>Less than 3</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>3 - 7</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>7 - 12</td>
</tr>
<tr>
<td>4</td>
<td>Very high</td>
<td>16 - 21</td>
</tr>
</tbody>
</table>

TABLE 8: Details of the land use

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Description</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sub-catchments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kansal</td>
</tr>
<tr>
<td>1</td>
<td>Agric. (terraced)</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Agric. (fallow)</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Dense forest</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>Mod. forest</td>
<td>542</td>
</tr>
<tr>
<td>5</td>
<td>Open forest</td>
<td>499</td>
</tr>
<tr>
<td>6</td>
<td>Scrub</td>
<td>43</td>
</tr>
<tr>
<td>7</td>
<td>Streambed</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>Barren hill/land</td>
<td>69</td>
</tr>
<tr>
<td>9</td>
<td>Habitation</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Water body</td>
<td>7</td>
</tr>
</tbody>
</table>

TABLE 9: Runoff potential areas in the catchment

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Runoff potential</th>
<th>Area (ha)</th>
<th>Sub-catchments</th>
<th>Foothill villages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kansal</td>
<td>Nepli</td>
<td>Ghareri</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>5</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>1073</td>
<td>1323</td>
<td>507</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>33</td>
<td>49</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Very High</td>
<td>92</td>
<td>95</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1204</td>
<td>1485</td>
<td>560</td>
</tr>
</tbody>
</table>

FIGURE 3: Runoff and erosion potential map
Villages in foothills, with predominantly agricultural and residential use, have a high runoff potential in comparison to catchments with more moderate to dense forest. A qualitative assessment of runoff will be useful for making decisions in a GIS related to conservation planning.

PRIORITIZING EROSION-PRONE AREAS

The index-based analysis revealed that about 30 percent (1328.45 ha) of the lake catchment area is prone to a high degree of water erosion (53.8 percent is prone to moderate and about 2 percent to a very high degree of water erosion). Most (90-92 percent) of the area in the different sub-watersheds, i.e., Kansal, Nepli and Ghareri, has a moderate to high degree of water erosion (Table 10). These areas are characterized mainly by open scrub and moderate forest on steep slopes.

TABLE 10: Potential erosion areas in the sub-watersheds

<table>
<thead>
<tr>
<th>Soil no.</th>
<th>Erosion potential</th>
<th>Area (ha) Sub-catchments</th>
<th>Foothill villages Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None to slight</td>
<td>0 0 0 25</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>84 73 33 161</td>
<td>351</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>633 789 320 538</td>
<td>2280</td>
</tr>
<tr>
<td>4</td>
<td>High</td>
<td>461 585 196 87</td>
<td>1328</td>
</tr>
<tr>
<td>5</td>
<td>Very High</td>
<td>26 38 10 1</td>
<td>76</td>
</tr>
<tr>
<td>6</td>
<td>Lake</td>
<td>0 0 0 200</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1204 1485 560</td>
<td>1012 4261</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The study indicates that (1) IRS ID LISS III data can be used for land use/land cover mapping with a reasonably good (83 percent in this study) classification accuracy for hydrological and erosion assessment applications, and (2) that a simple index-based approach using three main causative factors, i.e., slope, soil and land use/land cover, can give fairly good delineation of erosion-prone areas for prioritization.

REFERENCES


RESUME

Traditionnellement l'évaluation de la productivité des terres a eu la priorité sur tous les aspects d'évaluation de la performance de l'utilisation des terres. Actuellement les effets de l'utilisation des terres sur la qualité de l'environnement et la durabilité environnementale des systèmes de production sont devenus des problèmes majeurs.

Dans les collines, les conditions de terrain aggravent encore la dégradation des terres causée par l'érosion. Une allocation judicieuse des ressources disponibles pour une production acceptable exige de cartographe, de suivre l'évolution et de fixer des priorités pour les zones susceptibles de dégradation. Télédétection et Systèmes d'Information Géographique sont des outils effectifs pour l'inventaire, le suivi et la gestion de ressources distribuées dans l'espace. L'article présente une étude de cas du bassin versant du lac Sukhna de 42 km² dans les collines de Shivalik pour la délimitation et la détermination de priorités dans les zones à risques d'érosion, en utilisant la télédétection et des Systèmes d'Information Géographique. Des données multispectrales IRS ID-LISS III acquises en mars 98 ont été utilisées pour la classification numérique supervisée des types d'utilisation/d'occupation des sols. Le bassin versant a été classé en six classes d'utilisation des terres, notamment: forêt, broussailles, collines arides, lits des cours d'eau et zones habitées. Ces classes ont été divisées en sous-classes basées sur les caractéristiques de couverture. En utilisant la méthode du nombre de la courbe du SCS (Service de Conservation des Sols, Etats-Unis 1972) le potentiel d'écoulement de chaque unité hydrologique délimitée a été calculée par une analyse à base de mailles à l'aide du SIG d'ARC/INFO. Des zones à risques d'érosion ont été classées plus loin par intégration d'un modèle numérique du terrain ou des dérivés de pente, d'orientation, et de longueur des courants. Pour obtenir un ordre de priorité pour les zones susceptibles d'érosion un index cumulatif d'érosion est calculé à partir de l'estimation obtenue par les trois facteurs principaux: pente, érodibilité des sols et occupation des sols à une échelle 1-7 pour chaque maille. L'index cumulatif est de plus classé en quatre classes pour une représentation spatiale des zones susceptibles d'érosion dans la carte des bassins versants. L'étude montre que le bassin versant présente un risque fort ou très fort pour 32,9 pour-cent de la surface et doit être géré avec des stratégies de conservation appropriées.
RESUMEN

Tradicionalmente, se privilegió la evaluación de la productividad de las tierras por encima de todos aquellos aspectos relacionados con la evaluación del rendimiento del uso de las tierras. Presentemente, se pone énfasis en los impactos del uso de las tierras sobre la calidad del ambiente y la sostenibilidad ambiental del sistema de producción. En áreas de colinas, las condiciones del relieve agravan la degradación de tierras inducida por erosión. Para una juiciosa alocación de los recursos disponibles para producción sostenible es necesario mapear, monitorear y priorizar las áreas de desarrollo en base a su susceptibilidad a la degradación. Teledetección y SIG son instrumentos efectivos para el inventario, seguimiento y manejo de los recursos distribuidos en el espacio geográfico. El artículo presenta un estudio de caso de la cuenca del lago Sukhna con 42 km² de extensión, ubicada en la zona de colinas de Shiwalik, para la delineación y priorización de áreas expuestas a la erosión mediante el uso de la teledetección y de sistemas de información geográfica. Se usaron datos multi-espectrales IRS ID-LISS III adquiridos en marzo de 1998 para la clasificación digital supervisada de los tipos de cobertura y uso de las tierras. La cuenca fue clasificada en seis clases de uso de las tierras, a saber: bosque, agricultura, matorral, colinas con tierras estériles, cauces de ríos y asentamientos humanos. Estas clases fueron divididas en subclases en base a las características de la cobertura. Se calculó el potencial de escurrimiento de cada unidad hidrológica delineada con la aplicación del método de número de curva del SCS (U.S. Soil Conservation Service, 1972), utilizando un análisis de retícula de celdas en ARC/INFO. Adicionalmente, se clasificaron las áreas expuestas a erosión mediante la integración de datos de pendiente, exposición y longitud de flujo derivados de un modelo digital de elevación (MDE). Para obtener el orden de prioridad de las áreas expuestas a erosión, se calculó un índice de erosión acumulativo a partir de la evaluación de los tres factores causales – pendiente, erodabilidad del suelo, y cubertura de las tierras – en una escala de 1 a 7 para cada celda. El índice acumulativo se clasificó en cuatro clases para la representación espacial de las áreas expuestas a erosión en el mapa de la cuenca. El estudio revela que el 32.9% del área de la cuenca tiene una susceptibilidad alta o muy alta al riesgo de erosión y que la cuenca necesita ser manejada con apropiadas estrategias de conservación.
The role of GIS and remote sensing in land degradation assessment and conservation mapping: some user experiences and expectations

Godert W J van Lynden and Stephan Mantel

International Soil Reference and Information Centre (ISRIC), P.O. Box 353, 6700 AI Wageningen, The Netherlands (phone: +31 471 711/735; fax: +31 317 47 17 00; email: vanlynden@isric.nl; website: http://www.isric.nl)

KEYWORDS: land degradation assessment, soil and water conservation inventories, GIS, remote sensing

ABSTRACT

Planning strategies for sustainable land management require solid base line data on natural resources (soils, physiography, climate, vegetation, land use, etc.) and on socio-economic aspects. GIS and remote sensing have an important role in linkage and analysis of such data, in particular for detection (direct or indirect), extrapolation and interpretation, area calculation, and monitoring. More specifically, GIS and/or remote sensing has been or could be used: (1) to identify physiographic units; (2) to serve as a common (physiographic) base map for assessments of different kinds of soils, degradation, and conservation; (3) to overlay data layers for different map units; (4) to make area calculations; (5) to link spatial data with non-spatial but more detailed attribute data; (6) to make georeferenced information easily accessible to non-GIS users; (7) to "bridge the scale gap", ie, upgrade experimental results from small plots to larger areas; (8) to present data in map and other graphic format; (9) to map (temporal and spatial changes in) land cover and land use; and (10) to identify areas of degradation. Located in the Hindu Kush-Himalaya (HKH) region, the International Centre for Integrated Mountain Development (ICIMOD) is in an excellent position to apply GIS and remote sensing in an integrated context, eg, to make a comprehensive inventory of natural resources, degradation status and risk and an inventory of conservation measures being applied, using internationally accepted standardised methodologies described in this paper.

INTRODUCTION

At the local level, various studies and projects in the HKH region have investigated soil conservation activities or causes of degradation. Far less attention has been paid to national or regional inventory of land degradation, despite the possibilities such inventories could offer for conservation and development; nor has enough attention been paid to the basic data required. According to Messerli et al [1993; p.16] for instance, "Information on soils in the Hindu Kush-Himalayas is very weak". Denniston [1995] states that "A fundamental impediment to raising mountains on the agenda of policy makers is lack of knowledge, combined with pervasive scientific uncertainty about the planet's most complex landscapes. Data on mountain areas - whether economic, social, or environmental - are usually incomplete when they exist at all".

The use of GIS and remote sensing for monitoring soils and geomorphic processes has a special importance in the mountainous and remote HKH region. Due to the difficult terrain and its remoteness, field data are often scarce or lacking. Remote sensing and GIS can play an important role in extrapolating existing data and filling the gaps between them. Without an integrating methodology, identification of viable technological and institutional options for the sustainable development of mountain areas will not be possible [ICIMOD, 1999]. Moreover, as stated in the Second Regional Collaborative Programme of the International Centre for Integrated Mountain Development (ICIMOD): "Geo-referenced databases have become powerful tools in decision-making for sustainable development, but it is now time that a shift be made from the formerly ad-hoc and isolated development of databases to a more structured and easily accessible and compatible system" [ICIMOD, 1998].

The extreme conditions of the high mountain regions justify a specific approach that recognises the significance of particular mountain parameters. Jodha & Shrestha [in ICIMOD, 1994] refer in this respect to the mountain perspective as an "understanding and explicit consideration of specific mountain conditions and their imperatives while designing and implementing interventions in these areas". These specific conditions also include non-biological aspects, namely poverty, low level of education, health and poor infrastructure inter alia. The lack of a mountain perspective underlies the majority of failures of conventional development projects in mountain areas. This is also reflected in mapping scales. Where smaller scales might be adequate for general planning purposes in flatter land, the geographic diversity of mountain ranges requires a methodology at more detailed scales, eg, larger than 1:250,000. Valley conditions differ widely from those on higher and steeper adjacent slopes, and
GIS and remote sensing in land degradation assessment

GIS, REMOTE SENSING AND ISRIC DATABASES

The International Soil Reference and Information Centre (ISRIC) in Wageningen, The Netherlands, helps to develop and supports methodologies for establishment of geo-referenced databases on soils and related issues, such as soil degradation, conservation and land use. ISRIC projects include the following:

1. **Global and National Soils and Terrain Digital database (SOTER).** This is a relational database system for storing detailed information on natural resources that can readily be accessed, combined and analysed to determine the resources’ potential for specified uses, including land productivity, environmental impact and conservation needs. SOTER is linked to a Geographic Information System, with attributes on topography, soils, climate, vegetation (optional) and land use (optional), each of which can be displayed as a separate layer or in tabular form [van Engelen & Wen, 1995]. The long-term objective of the global SOTER is to replace the current FAO/UNESCO Soil Map of the World at 1:5,000,000.

2. **Global Assessment of Human-Induced Soil Degradation (GLASOD)** [Oldeman et al., 1991]. Based on the expert judgement of a few hundred scientists worldwide, a map on the status of human-induced soil degradation at an average scale of 1:10,000,000 was prepared. This map was subsequently digitised and its attributes stored in a database.

3. **Assessment of Human-Induced Soil Degradation in South and Southeast Asia (ASSOD)** [van Lynden & Oldeman, 1997] at a scale of 1:5,000,000. The assessment used a modified GLASOD methodology, with more emphasis on the impact of degradation on productivity and on the rate of degradation. A physiographic base map that was compiled according to the SOTER criteria served as a mapping template. Data were provided by national institutions and compiled by ISRIC with technical and financial support from UNEP and FAO. The prepared database was linked to a GIS, enabling preparation of thematic outputs in the form of maps, graphs and tables.

4. **World Overview of Conservation Approaches and Technologies (WOCAT),** co-ordinated by the Centre for Development and Environment of the University of Bern, in which ISRIC participates with various other international and national institutions. WOCAT aims to make an overview of what is actually being done to reduce soil degradation in the world. The WOCAT methodology is described in Liniger et al. [1998; 1999] and in Schwilch & Liniger [1997]. WOCAT has developed three comprehensive questionnaires, one on technologies, one on approaches and one for mapping at a scale of 1:5,000,000 and larger [WOCAT, 1995; 1998a; 1998b]. Together, the questionnaires form a framework for the evaluation of soil and water conservation practices and a methodology for data collection at the same time. Advantages and disadvantages of soil and water conservation (SWC) systems can be analysed and answers can be found as to why technologies were accepted or rejected by local users [Liniger, 1997; Giger et al., 1999]. Data are entered in (ACCESS97) database management and analysis system. This information management system is used to build up a Decision Support System.

Although these databases do not focus on specific ecosystems or landscapes, the standardised methodologies are also relevant for use in mountainous land as they enable comparisons and information exchange between different (mountain) regions. They can be used at different (also larger) scales. Recommended scales for mountain regions are 1:250,000 and larger, but this also depends on sufficient data availability. At a meeting on Global Sustainable Mountain Agricultural Development in Lima, October 1995, ISRIC formulated a specific proposal for a soil and terrain database in mountainous areas. Recently, a joint ICIMOD/WOCAT proposal for an Overview of Conservation Approaches and Technologies in the HKH region (HIMCAT) was drafted for submission to donors.

GIS is an important tool for the ISRIC databases in linking data to maps, in combining different data layers in overlays, and for output preparation, but it is not yet being used to its full capacity. Remote sensing has so far played a smaller role, partly because the potential of its application has not yet been fully explored. Two cases will be discussed below to illustrate the role of GIS and remote sensing in the following projects: one study from Fujian Province in China, the other on productivity impact of degradation in Kenya using national SOTER databases.

**CASE 1: SOIL DEGRADATION ASSESSMENT AND CONSERVATION MAPPING IN FUJIAN PROVINCE, CHINA, AND THAILAND**

Prior to the start of the Assessment of Human-Induced Soil Degradation in South and Southeast Asia, a
A 1:5,000,000 physiographic map was prepared for Asia [FAO, 1994] according to SOTER criteria and on the basis of topographic maps of varying quality and some visual interpretation of satellite images. This map was used as a template for mapping the status of soil degradation in 17 countries in South and Southeast Asia (ASSOD), following guidelines by van Lynden (1995). For each polygon of the base map, data were collected on the relative extent of degradation, its impact on productivity, the rate of degradation, and its causative factors. These data were stored in an attribute database and linked with a GIS through unique polygon labels. The use of an equal area projection enabled for instance the calculation of total surface areas affected by a certain type of degradation (Figure 1) [van Lynden & Oldeman, 1997]. At the same time, various thematic maps on different aspects of degradation could thus be created (Figure 2).

The same mapping template was subsequently used by the WOCAT programme for Thailand and Fujian Province in China for mapping conservation activities [WOCAT, 1998c]. Information for individual polygons was collected through matrix forms on:

- major land use types (extent, trends);
- degradation (like in ASSOD, but differentiated per land use type);
- soil and water conservation (type, extent, effectiveness and trend, period of implementation), and
- productivity (trend, role of SWC, approximate input and output figures).

The attribute data were stored in an ACCESS97 database, which is linked to the (physiographic map) polygons in ARCVIEW through the same unique polygon identifiers. Thematic maps on specific soil and water conservation aspects could thus be prepared (see Figure 3). The WOCAT programme developed a query-and-viewing system for the WOCAT map – using ACCESS and Map Objects Light – which enables the users to view a set of data on the basis of a number of predefined queries, without holding ACCESS or GIS software [Liniger et al, 1999].

The WOCAT mapping exercise was accompanied by a more comprehensive but non-geo-referenced inventory of SWC technologies and approaches. Through a reference field in the map database, access to many more details of a given technology is thus possible.
CASE 2: EROSION RISK AND THE CORRESPONDING YIELD LOSSES UNDER SPECIFIC LAND USE SYSTEMS IN KENYA

The objective of the case study discussed below was to explore potential productivity of land use systems at the national level and estimate land quality changes under erosion scenarios with traditionally cultivated maize in Kenya [Mantel & van Engelen, 1999]. The methodology was also applied in Uruguay and Argentina [Mantel et al., 2000; Mantel & van Engelen, 1997]. For this study, several models were combined to predict the impact on crop performance of change in soil properties induced by removal of topsoil through sheet erosion. Land unit data from the Kenya national (1:1,000,000) Soil and Terrain (SOTER) database were linked to a GIS, permitting spatial analysis. Climatic data were stratified using the Agro-Climatological Zones (ACZ) map of Kenya. The overlay of a climatic map with soils and terrain information created the basic units for evaluation. Only the spatially dominant soil component per ACZ was considered in the analysis. The potential yield under actual conditions and with the inclusion of an erosion scenario of 20 years was calculated for the dominant soils of each mapping unit that had been evaluated as suitable for the land use.

The applied procedures in this study can be summarised as follows:

- definition of Agro-ecological units (AEU: aggregations of ACZ, rainfall zones and soil and terrain units) for assessment of suitability for low-input cultivated maize (Figure 4);
- development of pedo-transfer functions to fill data-gaps for required input parameters, such as hydraulic parameters, bulk density, phosphate content;
- calculation of yield potentials using WOFOST (crop growth simulation model; Figure 5);
- assessment of erosion risk using a parametric model (SWEAP);
- definition of a scenario for potential loss of topsoil over a 20-year period from the erosion risk analysis (Figure 6);
- re-running of the crop growth simulation model based on the topsoil loss scenario (Figure 7);
- comparing yields for actual conditions and the erosion scenario and calculation of the yield declines (Figure 8).

From the overlay of the physical suitability map for maize with the actual land-use map, it was concluded that there is little scope for increasing maize production by expansion of agricultural land. Erosion risk was highest in sloping lands with high rainfall and on soils derived from Basement System rocks. Biophysical production potential is high, but yields simulated under constraint of availability of water and nutrients during the growing season...
GIS and remote sensing in land degradation assessment

FIGURE 7: Potential yield after erosion

FIGURE 8: Yield declines after simulated erosion

were often considerably lower than what is maximally attainable (‘yield gap analysis’). Dominant limitations are low soil fertility, poor soil physical conditions and irregular rainfall patterns. Land qualities in Kenya were sensitive to varying degrees of simulated soil erosion. In the steep patches of land in the central and the central-western part of Kenya, calculated yield decline was more than 50 percent. As a consequence of topsoil loss, yields were generally most affected by nutrient decline. This may be explained by the intrinsic properties of major Kenyan soils, such as soils with an argic-B and Ferralsols, for which the organic top layer largely determines actual fertility conditions. An area of 20 percent of the land suitable for maize production was estimated to have a yield decline of 50 percent or more, relative to the current potential yield. Given the high land pressure in Kenya and the poor prospect for expansion of agricultural land, intensification of maize cropping systems is required to satisfy the growing nutritional needs of an increasing population. Land management technologies needed for intensification must include appropriate soil and water management practices given the high erosion risk and vulnerability. WOCAT maps (currently at a much less detailed scale; more detailed updates are under development) show where those changes are already taking place and which soil and water conservation strategies are appropriate (Figure 9). Since soil erosion impacts differ between Agro-Ecological Units and between management practices, extrapolation of agricultural research and conservation strategies should be climate, terrain and soil specific and must take existing management practices into account. Given the constraint of spatial variation within the mapping units at the given scale, AEU-specific land management recommendations could be given as a general guideline. A stratification of farms based on yield level, and farm size and income within each AEU would be most useful for extension purposes, as profitability and applicability of land management options, such as fertiliser recommendations, depend on farm capital and labour resources [Smaling et al., 1992].

This exploratory study aimed to highlight trends in land production capacity under different conditions, whereby the emphasis should be on the relative differences between scenarios and between land units rather than on the absolute values presented. It could provide answers to questions such as: What is the land potential for a crop such as wheat in this case? Where will erosion be most severe? How will production be affected if...? Assessments at small scale such as these include several sources of uncertainty, such as: (1) the interpolation of...
average climatic data, (2) absence of standard errors for the base data used, (3) inference of data to satisfy unavailable model input requirements, (4) use of global models not validated to the local conditions. For a more in-depth evaluation of the methodology reference is made to Mantel et al [2000] and Mantel & van Engelen [1999]. Although such a regional approach includes many uncertainties and limitations, there is much value in linking models with spatially explicit land unit databases as a way to explore land potentials and generate indicators for sustainability and land management options.

**DISCUSSION**

The cases presented above illustrate some experiences and expectations with regard to GIS remote sensing in the assessment of soil and terrain resources and of degradation and conservation activities in particular. Use of remote sensing to identify physiographic units according to the SOTER criteria. So far this has been done on the basis of topographic maps and visual interpretation of satellite images; e.g., draft 1:5,000,000 physiographic maps of Africa [FAO, 1993a], Latin America [FAO, 1993b] and Asia [FAO, 1994], but the use of DEMs may greatly facilitate the delineation of terrain units on the basis of hypsometry, slope class and landform. This of course is especially relevant for sloping lands. Experiences in Europe for the Corine database, [CEC, 1992] and more recently in South Africa for a SOTER database, have demonstrated however that remote sensing data can only serve as a supplementary — but important — tool and not replace field observations nor the use of good topographic maps. Scale is also a limiting factor: at a 1 km resolution, significant height differences may be overlooked or "spread out": a steep escarpment, e.g., a high vertical rock wall, cannot be distinguished from a rather gradual rise over the same distance. Use of a common (physiographic) base map for assessments of different kinds: soils, degradation, conservation. Using the same mapping template for assessments of different subjects permits - through a GIS - simultaneous examination of attribute data (e.g., physiography, degradation, conservation) for the same polygon, thus enabling the interpretation of a range of interrelated geographical information for the same area. This provides a powerful tool for planning purposes, either directly or through derived applications (see Case 2). Since, in the cases described above, soil degradation and remedial measures are (often) linked to both biophysical properties and socio-economic conditions, it would be useful to have the latter information (now often available for administrative units only — if at all!) also for the same geographic units. Except for areas where physical conditions also determine the socio-economic boundaries (such as in some secluded high mountain valleys) the boundaries of units based on physical or bio-physical criteria and units based on socio-economic criteria rarely coincide. In this respect the following point is relevant.

Use of an overlay of different data layers for different map units, either containing natural resource information (soils, land cover, climate data) or other geo-referenced information (e.g., population density, household size, yield maps). This way different spatial data sets can be combined, as illustrated in Case 2 above. Care has to be taken however in the selection and interpretation of overlays, since an apparent correlation (or rather mapping coincidence) does not necessarily indicate a cause and effect relationship. Recently the UNEP GRID has overlaid the GLASOD map with spatial (point) data on adult female illiteracy, with data on Children Stunted Growth and on Primary School Enrolment. Even if there appears to be a correlation between stunted growth of children or female illiteracy and degradation, that does not necessarily mean that degradation is the cause of these problems, or vice-versa! Many industrialised countries face a range of degradation problems, but generally literacy is quite high, and so is primary school enrolment.

Making area calculations. On the condition that equal-area projections are used, area calculations can be made, for instance for the total surface affected by degradation or the total area under a given kind of soil conservation. The ASSOD and WOCAT databases contain the percentage for each polygon that is affected by degradation or controlled by conservation. Other possibilities include calculating distances to a road, market or distribution centre for seeds or fertiliser, factors that play an important role in sustainable land management. However, there are some dangers with overlaying and area calculations, since often it is not known where certain characteristics occur within a mapping unit.

Linking of spatial data with non-spatial, but more detailed, attribute data. The WOCAT methodology offers comprehensive non-spatial information on soil and water conservation (SWC) technologies. More concise geo-referenced data are collected for mapping purposes. A specific query system was developed to allow researchers to obtain more detailed information on a certain technology that occurs in a given area through a linkage of the (geo-referenced) map database with the (non-geo-referenced) technology or approach database.

Making geo-referenced information easily accessible to non-GIS users. The WOCAT map query-and-viewing system provides a tool that will be generally sufficient for the average user of the WOCAT database. The system will be somewhat expanded in the future to give the user a wider range of query options. For more advanced data handling procedures users will need full GIS and database software. Similarly, a data viewer has been developed for the Latin American SOTER, using Delphi programming, allowing non-GIS users to display and query the geographic information in digital map format. Like...
the WOCAT viewer, it contains various GIS-like features for displaying and querying data.

"Bridging of the scale gap", i.e., upgrading experimental results from small plots to larger areas. While on the one hand small experimental plots help researchers understand various processes better (eg, degradation and soil forming), on the other hand, inventories covering whole countries, regions or continents provide a spatial overview of where the various processes take place. Between these two extremes a gap exists that is not sufficiently bridged. **Extrapolation** of experimental results to larger areas is greatly facilitated by GIS and remote sensing techniques. This can be done by identifying the proper environment to apply certain techniques that have been tested on a small plot and by providing input data for modelling processes that help in the extrapolation. For high-resolution and/or single-value maps, point information may be directly extrapolated to a polygon. Low-resolution (small scale) map polygons often contain more complex components (eg, soil maps on which several soils occur within one polygon).

**Presentation of data in map and other graphic formats.** This is actually one of the most frequent uses of GIS within ISRIC to date. GIS offers much greater flexibility in preparing outputs from the same data source, such as various thematic maps, graphs, tables, etc., than the earlier "manual" methods to produce hard copy maps.

**Monitoring to map (temporal and spatial changes in) land cover and land use.** Land use and land cover are important parameters for degradation assessment in the sense that they determine to a large extent the possible types and impacts of degradation. Annual cropland may be affected by erosion, compaction or fertility decline, while urban/industrial areas may face pollution or loss of productive function. Land use is also a factor to consider in the selection of soil conservation options. It is obvious that forest areas may require different solutions than grazing land or annual cropland. Changes in land use sometimes lead to degradation.

**Identification of areas of degradation,** along with the degree and rate (trend) of degradation. So far, experiences using remote sensing on small scales appear to have been rather limited and have been based on the application of remote sensing data in models like USLE (for erosion) rather than on direct observations. Moreover, many applications are restricted to relatively small test areas. However, Karavanova et al [2000] recently discussed the application of remote sensing for the study of soil salinity for a large area (100,000 ha) in Uzbekistan, while Wessels and Pretorius [2000] reported on an integrated approach for spatial natural resource monitoring using remote sensing in a 80,000 km² province of South Africa. Assuming proper criteria and procedures, the potential strength of remote sensing in assessing degradation lies in monitoring through multi-temporal series.

**CONCLUSIONS AND FUTURE DEVELOPMENTS**

When planning strategies for sustainable management of land, it is essential to have solid base line data on natural resources (soils, physiography, climate, vegetation, land use, etc.) and on socio-economic aspects. These data need to be linked and analysed in an effective manner. It is obvious that GIS and remote sensing play an important (potential) role in this process, as illustrated in the two examples, in particular for detection (direct or indirect), extrapolation, area calculation, and monitoring.

ICIMOD is well equipped (eg, through its MENRIS and Mountain Natural Resources divisions) to apply such studies on degradation assessment and conservation mapping, and would be an excellent co-ordinating centre for implementing an inventory for the HKH region of terrain and soil resources in combination with an assessment of degradation status and of the extent and effectiveness of conservation measures. For the latter part, a proposal already exists. (HIMCAT). The database and its applications resulting from such a study would provide a useful tool to researchers and project managers in the region working in the field of natural resources and sustainable land management.

**REFERENCES**


GIS and remote sensing in land degradation assessment


RESUME

Des stratégies de planification pour une gestion durable des terres exigent de solides données de base sur les ressources naturelles (sols, physiographie, climat, végétation, utilisation des terres, etc.) et sur les aspects socio-économiques. SIG et télédétection ont un rôle (potentiel) important dans les relations et l'analyse de telles données, en particulier pour la détection (directe ou indirecte), l'extrapolation et l'interprétation, le calcul de surfaces et le suivi de l'évolution. Plus spécifiquement, SIG et/ou télédétection a été ou pourrait être utilisé: (1) pour identifier des unités physiographiques; (2) pour servir de carte de base pour la détection (physiographique) commune pour les évaluations des différents types de sols, dégradation et conservation; (3) pour superposer des couches de données pour différentes unités de cartes; (4) pour effectuer des calculs de surfaces; (5) pour relier des données spatiales avec des données non-spatiales mais avec des données attributs plus détaillées; (6) pour rendre l'information géoréférencée facilement accessible à des personnes qui ne sont pas des utilisateurs de SIG; (7) pour réduire l'écart entre les échelles c'est-à-dire la mise à jour de résultats expérimentaux de petits lots vers des grandes zones; (8) pour présenter des données sous forme de cartes et autres formats graphiques; (9) pour cartographier (des changements temporels et spatiaux) dans l'occupation et l'utilisation des terres; (10) pour identifier des zones de dégradation. Situé dans la région Hindu Kush-Himalaya (HKH), le Centre International pour le Développement Intégré des Montagnes (ICIMOD) est dans une excellente position pour appliquer SIG et télédétection dans un contexte intégré, c'est-à-dire pour faire un inventaire étendu des ressources naturelles, l'état de la dégradation et du risque et un inventaire des mesures de conservation à appliquer, en utilisant des méthodologies standard acceptées sur un plan international et qui sont décrites dans cet article.

RESUMEN

Las estrategias de planificación para manejo sostenible de las tierras necesitan sólidos datos básicos sobre recursos naturales (suelos, fisografía, clima, vegetación, uso de las tierras, etc.) y sobre aspectos socio-económicos. Los SIG y la teledetección desempeñan un papel (potencial) importante para relacionar y analizar estos datos, especialmente en lo que se refiere a detección (directa o indirecta), extrapolación e interpretación, cálculo de áreas, y seguimiento. Más específicamente, los SIG y/o la teledetección han sido o podrían ser usados: (1) para identificar unidades fisográficas; (2) para producir un mapa base (fisográfico) común para evaluar diferentes tipos de suelos, degradación y conservación; (3) para superponer capas de datos con fines de generar diferentes unidades cartográficas; (4) para realizar cálculos de áreas; (5) para vincular datos espaciales con atributos no-espaciales, pero más detallados; (6) para hacer la información geo-referenciada fácilmente accesible a los usuarios no-especialistas de SIG; (7) para "llenar la brecha de escala", refiriéndose a la extrapolación de resultados experimentales proveídos de pequeñas parcelas sobre áreas más extensas; (8) para presentar los datos en mapas y otros formatos gráficos; (9) para mapear la cobertura y el uso de las tierras, así como sus cambios temporales y espaciales; y (10) para identificar áreas sometidas a degradación. El Centro Internacional para el Desarrollo Integrado de las Montañas (ICIMOD), ubicado en la región del Hindu Kush-Himalaya (HKH), se encuentra en una excelente posición para aplicar SIG y teledetección en un contexto integrado, por ejemplo, con fines de hacer un inventario comprensivo de los recursos naturales, su estado de degradación y los riesgos a los cuales están expuestos, y un inventario de las medidas de conservación que se están aplicando, mediante el uso de metodologías estandarizadas y aceptadas internacionalmente, las cuales se describen en este trabajo.
Soil information system of Arunachal Pradesh in a GIS environment for land use planning

Amal K Maji, Dulal C Nayak, Nadimpalli D R Krishna, Challa V Srinivas, Kalpana Kamble, Gangalakunta P Obi Reddy and Mariappan Velayutham

National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur-440010, India (phone: +91 712 532 386; fax: +91 712 522 534; e-mail: akmaji@nbsslup.mah.nic.in)

KEYWORDS: soil information system, GIS, RDBMS, land use planning

ABSTRACT

Arunachal Pradesh, the largest mountainous state of India, is situated in the northeastern part of the Himalayan region and characterized by high annual rainfall, forest vegetation and diversity in soils. Information on the soils of the state is essential for scientific land use planning and sustainable production. A soil resource inventory and subsequent database creation for thematic mapping using a Geographical Information System (GIS) is presented in this paper. Physiographically, Arunachal Pradesh can be divided into four distinct zones: snow-capped mountains (5500 m amsl); lower Himalayan ranges (3500 m amsl); the sub-Himalayan Siwalik hills (700 m amsl); and the eastern Assam plains. Soils occurring in these physiographic zones are Inceptisols (37 percent), Entisols (35 percent), Ultisols (14 percent) and Alfisols (0.5 percent). The remaining soils can be classed as miscellaneous. Soil resource inventory studies show that the soils of the warm perhumid eastern Himalayan ecosystem, with a ‘thermic’ temperature regime, are Inceptisols and Entisols; and that they are highly acidic in nature. Soils of the warm perhumid Siwalik hill ecosystem, with a ‘hyperthermic’ temperature regime, are also Entisols and Inceptisols with a high to moderate acidic condition. The dominant soils of the northeastern Purvachal hill ecosystem, with ‘hyperthermic’ and ‘thermic’ temperature regimes, are Ultisols and Inceptisols. Inceptisols and Entisols are the dominant soils in the hot and humid plain ecosystem. Steeply sloping landform and high rainfall are mainly responsible for a high erosion hazard in the state. The soil erosion map indicates that very severe (20 percent of TGA) to severe (25 percent of TGA) soil erosion takes place in the warm per-humid zone, whereas, moderate erosion takes place in the Siwalik hills and hot, humid plain areas. This is evident from the soil depth class distribution of Arunachal Pradesh, which shows that shallow soils cover 20 percent of the TGA of the state. Most of the the state is covered by hills and agricultural practices are limited to valley regions. However, the soils of other physiographic zones (lower altitudinal, moderately hilly terrain) provide scope for plantations, such as orange, banana and tea plantations.

INTRODUCTION

Soil is one of the important non-renewable basic natural resources that support life on the earth. Hence, maintenance of this valuable resource in a state of high productivity, so that it can provide the ever-increasing population with its basic needs, is a primary necessity. Natural erosion cycles and the increasing influence of human-induced processes pose a threat to the conservation of soils. Therefore, knowledge of soils with respect to their extent, distribution, characterization and use potential is very important for optimized land utilization [Maji et al, 1993].

The National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) undertook the task of surveying the soils of Arunachal Pradesh to generate a soil database [Nayak et al, 1996] that could provide information for planning viable land use on a sustainable basis. Similar work has been done for the entire northeastern region, comprising Meghalaya [Singh et al, 1999], Manipur [Sen et al, 1996] and Tripura [Bhattacharya et al, 1996]. A GIS approach was adopted to generate a soil resource database at 1:250,000 scale with soil families as the basic mapping units, and to reclassify the master soil map. Several thematic maps were prepared to provide the basic information needed for land use planning.

STUDY AREA

LOCATION AND EXTENT

The state of Arunachal Pradesh is situated between latitudes of 26°30’ to 29°28’ N and longitudes of 91°25’ to 97°24’ E. It covers an area of 8.37 million hectares (Figure 1). The state is bounded by China and Tibet in the north, Assam in the south, Myanmar and the state of Nagaland in the east, and Bhutan in the west. It has 11 administrative districts, with Itanagar as its capital.

PHYSIOGRAPHY, RELIEF AND DRAINAGE

The study area can broadly be divided into four distinct physiographic regions. These are:

- the greater Himalayas, with snow-capped mountains rising up to 5500 m above mean sea level (amsl);
- the lower Himalayan range, rising up to 3500 m amsl;
- the sub-Himalayan belt, including the Siwalik hills, with elevation up to 1500 m amsl;
- the plains of the eastern continuity of Assam.

through feeder streams. The southern part, adjacent to the Assam plains, is nearly level to very gently sloping. Elevation in the region varies from 80 to 210 m amsl. The various areas are drained by the Siang, Lohit, Dibang, Kamlong, Nao-Dihing, Tirap, Namchik and Manphuk (Buridihing), Dirak and Namsing rivers.

GEOLoGY
The geology of the state is characterized by the presence of sedimentary and metamorphic rocks [Anonymous, 1974]. Some important rock groups are the (1) Sela group, consisting of schist, magnetites, quartzite and amphiboles; (2) Tenga formation, consisting of low grade metamorphic rocks, such as schists, amphiboles, phyllites and sericite, and quartzite; (3) Bichom group of sedimentary rocks, composed of quartzites, phyllites, shales, sandstone, dolomite, etc.

CLIMATE
The climate of Arunachal Pradesh is humid to perhumid subtropical, characterized by the high rainfall and high humidity of the sub-Himalayan belt. However, a temperate climate prevails in the lower Himalayan region and the greater Himalayan region is perpetually covered with snow. The average annual rainfall varies from 1380 to 5000 mm. The minimum temperature is around 0°C in winter months in the Bomdila and Twang areas, while it rises to 35°C during summer months in the Namsai and Tezu areas of Lohit district. The mean annual air temperature is 23.8°C in the plains and 16.2 °C in the hilly regions.

LAND USE AND AGRICULTURE
Land use statistics of Arunachal Pradesh [Anonymous, 1985] indicate that 61.6 percent of the total geographical area (TGA) is under forest, while cultivated land accounts for only 1.4 percent of TGA (Table 1). The land not available for cultivation accounts for 0.4 percent, fallow land covers an area of 2.0 percent of TGA and other uncultivated land excluding fallow land accounts for 2.0 percent of the total area of the state.

TABLE 1: Land use of Arunachal Pradesh

<table>
<thead>
<tr>
<th>Category</th>
<th>Area (10^3 ha)</th>
<th>Percent of TGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total geographical area</td>
<td>8374.3</td>
<td></td>
</tr>
<tr>
<td>Reported area for land utilization</td>
<td>5643.0</td>
<td></td>
</tr>
<tr>
<td>Unreported area</td>
<td>2731.3</td>
<td>32.6</td>
</tr>
<tr>
<td>Forest</td>
<td>5254.0</td>
<td>61.6</td>
</tr>
<tr>
<td>Land not available for cultivation</td>
<td>37.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Uncultivated land</td>
<td>168.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Fallow land</td>
<td>169.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Net area sown</td>
<td>115.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Area sown more than once</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>Net irrigated area</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Area under shifting cultivation</td>
<td>250.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
AGRO-ECOLOGICAL SUB-REGIONS
There are four distinct agro-ecosystems in Arunachal Pradesh [Sehgal et al., 1993], based on the variability of landscape, bio-climate, length of growing period, and soils (Figure 2). Land use patterns in these ecosystems vary widely. The characteristics of these ecosystems and present land use patterns are described below.

**FIGURE 2: Agro-ecological sub-regions of Arunachal Pradesh**

**Warm perhumid, eastern Himalaya ecosystem**
The climate of the region is characterized by mild summers and moderate to severe winters. The mean annual precipitation ranges from 2000 to 5000 mm. Generally, there is no period when the water requirement is greater than the water supply through precipitation. The availability of moisture to the crops generally exceeds 270 days per year. The region is typified by an 'udic' soil moisture regime (soil moisture control section is not dry in any part for as long as 90 cumulative days). The mean annual soil temperature (MAST) varies from 18° C to 22° C. The region thus represents a 'thermic' soil temperature regime. The natural vegetation comprises alpine and sub-alpine, temperate (coniferous), semi-evergreen and tropical moist deciduous forests. Rice, maize, millet, pea, beans, potato and vegetables are grown. Shifting cultivation (with slash and burn techniques, locally known as Jhum cultivation) is followed as a traditional farming practice.

**Warm perhumid, Siwalik Hills ecosystem**
The climate of this region is characterized by mild summers and moderate winters. The mean annual precipitation is about 2000 mm. Precipitation exceeds the potential evapotranspiration (PET) in most years. The region occasionally experiences a short period of water deficit due to seasonal dry spells during the post-monsoon period. The length of the moisture availability (growing) period is about 270 days. The area represents a 'udic' soil moisture regime and 'hyperthermic' soil temperature regime. The natural vegetation comprises wet evergreen and tropical moist deciduous forests. Jhum cultivation is practiced on hillside slopes. Except for a few places where maize and rice are grown, other areas have subtropical to evergreen species varying from open scrubs to thick forest cover. Rice, maize, millet, pineapple and tea are grown on hill terraces.

**Warm perhumid, Purvanchal ecosystem**
The climate of this region is characterized by warm summers and cold winters. The mean annual precipitation varies from 1960 to 3450 mm, which exceeds the PET in most years. The region experiences a short period of water deficit due to seasonal dry spells in the post-monsoon period. The area represents an 'udic' soil moisture regime. The soil temperature regime varies from 'hyperthermic' in valleys and ranges of low hills to 'thermic' in ranges of high hills. The hill slopes are covered with forest vegetation of moist deciduous species. Jhum cultivation is practiced in the region. Maize, millet and vegetables are grown on hill slopes, while rice is cultivated in valleys and hill terraces. Tea, bananas and oranges are also grown on steep foothill slopes.

**Hot humid, plain ecosystem**
The climate of the area is characterized by hot summers and moderately cool winters. The mean annual rainfall varies from 2590 to 3390 mm and it exceeds PET for a greater part of the year. The soils remain dry only for about a month or so. The soil moisture regime is 'udic' and the area has a 'hyperthermic' soil temperature regime as the MAST is 22° C or higher. The natural vegetation comprises semi-evergreen and moist deciduous forests. Rainfed agriculture is the traditional farming system. Rice as well as mustard, potato and tapioca are cultivated in the rabi (autumn to spring) season. Horticultural crops like oranges and areca nuts are found in the region.

**METHODOLOGY**
**SOIL SURVEY AND MAPPING**
A soil survey was undertaken that followed a three-tier approach comprising image interpretation, field surveys and laboratory analysis [Sehgal et al., 1987]. Landsat images (1:250,000 scale) were interpreted for landform analysis and then transferred onto Survey of India toposheets to prepare the base physiographic map for the soil survey. The soil survey was carried out following sample strip, grid and random observations. Sample strips were examined with 30 samples of profiles for in-depth soil information. Grid samples were taken at 10 km intervals. Random observations were taken for unrepresented physiographic units. In total, about 350 observations were recorded (in accessible areas only) per toposheet. Soil samples, collected per soil horizon, were analysed on various morphological and physio-chemical properties. Soils were characterized, classified as per Soil Survey Staff [1992] and mapped.
GENERATION OF SOIL RESOURCE INFORMATION
The soil information system is a computerized database management system, which in addition to simple storage and retrieval for reporting includes other functions such as manipulation and dissemination of information to various users. It basically constitutes a set of files in a Geographic Information System (GIS) comprising spatial and attribute data under a Relational Database Management System (RDBMS). It is capable of delivering accurate, useful and timely information for various applications.

The data on soils and their properties formed the basic database. The database format was developed for all site, soil and physico-chemical properties and was made available in MS Excel for further interfacing to GISs. To generate a spatial soil information system, the soil association units identified on 1:250,000 scale toposheets were digitized in ARC/INFO.

The adjacent vector soil layers were edge-matched, polygon topology was built and identification numbers (IDs) were assigned to the polygon layer. The cover was projected to real world coordinates in a polyconic projection system, with geographic extents in latitude/longitudes. Items were added in the Polygon Attribute Table (PAT) for all the soil attributes. Using AML script, properties such as pH, depth, texture, soil taxonomic class, erosion and physiography, with their respective classes, were assigned to the soil association units. These items were subsequently reclassified to prepare thematic layers. Area analysis was performed for these layers using a statistical module. Map compositions were prepared in an ARC PLOT environment with suitable layouts, pallets and paper scales. A flow chart for thematic map generation is depicted in Figure 3 [Maji et al, 1998].

RESULTS AND DISCUSSION
SLOPE
Slope is an important consideration in mountainous land use options. The slope map (Figure 4) of Arunachal Pradesh shows that a major part of the state has very steep slopes (26.5 percent of TGA) followed by moderately steep (24.5 percent of TGA) and steep slopes (12 percent of TGA). Very gently sloping landforms account for only 6 percent, while gentle sloping lands covers 2 percent of the area.

LANDFORMS
Landform analysis (Figure 5) shows that the state is dominated by ridges (37 percent) and escarpments (33 percent), while undulating lands account for 4 percent...
Soil information system in a GIS environment for land use planning

JAG · Volume 3 - Issue 1 - 2001

Areas with level to nearly level and gently sloping lands, where traditional cereal crops are grown, cover only 4 percent of TGA. Dissected lands account for 9 percent of TGA and rocky lands occupy about 11 percent of TGA.

SOIL RESOURCE INFORMATION

To assess the potential and problems of different soils, and to develop rational land use options for optimizing agricultural production, we need consistent and comparable information about soils. Different kinds of soils are present in Arunachal Pradesh, due to a wide variability in factors (climate, physiography, geology and vegetation) that influence the ecosystems. Data revealed that 86 soil family associations are spread over the state. Four soil orders predominate. Inceptisols are dominant (covering 37 percent of TGA), followed by Entisols (35 percent), Ultisols (14 percent) and Alfisols (0.5 percent). Information on site characteristics, physical and morphological properties, and soil chemical properties of both dominant and sub-dominant soils of each map unit form the major database. These datasets were used to generate various thematic maps. A soil map (with 19 units) is presented in Figure 6. The 45 soil map units, referred to in Tables 3-6, represent associations of dominant and sub-dominant soil classes, occurring in different physiographic zones (Table 2).

TABLE 2: Soils of Arunachal Pradesh

<table>
<thead>
<tr>
<th>Map Unit (% TGA)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 (16.4)</td>
<td>Shallow, excessively drained, loamy-skeletal Lithic Udorthents; with moderately deep, somewhat excessively drained, loamy-skeletal Typic Udorthents</td>
</tr>
<tr>
<td>02 (6.2)</td>
<td>Deep, somewhat excessively drained, loamy-skeletal Entic Haplumbrepts; with moderately shallow, excessively drained, sandy-skeletal Typic Udorthents</td>
</tr>
<tr>
<td>03 (7.8)</td>
<td>Shallow, excessively drained, loamy-skeletal, Lithic Udorthents</td>
</tr>
<tr>
<td>04 (4.0)</td>
<td>Shallow, excessively drained, loamy-skeletal; with moderately deep, somewhat excessively drained, sandy-skeletal soils, sandy-skeletal Typic Udorthents</td>
</tr>
<tr>
<td>05 (3.1)</td>
<td>Very deep, well-drained, fine soils, Humic Hapludults; with very deep, well-drained, fine-loamy Umbric Dystrochrepts</td>
</tr>
<tr>
<td>06 (2.2)</td>
<td>Shallow, excessively drained, sandy-skeletal Lithic Udorthents; with moderately deep, excessively drained, loamy-skeletal Typic Eutrochrepts</td>
</tr>
<tr>
<td>07 (6.1)</td>
<td>Very deep, somewhat excessively drained, fine Typic Palehumults; with moderately shallow, excessively drained, fine, Typic Haplumbrepts</td>
</tr>
<tr>
<td>08 (2.3)</td>
<td>Moderately shallow, somewhat excessively drained, loamy-skeletal Typic Udorthents; with moderately deep, somewhat excessively drained, fine-loamy Typic Eutrochrepts</td>
</tr>
<tr>
<td>09 (6.1)</td>
<td>Deep, well-drained, fine Typic Kanhaplohumults with very deep, well-drained, fine-loamy Pachic Haplumbrepts</td>
</tr>
<tr>
<td>10 (4.0)</td>
<td>Very deep, somewhat excessively drained, fine-loamy Umbric Dystrochrepts; with very deep, well-drained, fine-loamy Pachic Haplumbrepts</td>
</tr>
<tr>
<td>11 (5.2)</td>
<td>Very deep, well-drained, fine-loamy Pachic Haplumbrepts; with very deep, well-drained, fine Typic Palehumults</td>
</tr>
<tr>
<td>12 (2.9)</td>
<td>Very deep, well-drained, fine Typic Kandihumults; with deep, somewhat excessively drained, fine Pachic Haplumbrepts</td>
</tr>
<tr>
<td>13 (0.1)</td>
<td>Very deep, poorly drained, fine Humaqueptic Fluvaquents; with very deep, imperfectly drained, fine Humic Haplaquepts</td>
</tr>
<tr>
<td>14 (0.7)</td>
<td>Very deep, well-drained, fine Typic Kanhaplohumults; with deep, somewhat excessively drained, loamy-skeletal Umbric Dystrochrepts</td>
</tr>
<tr>
<td>15 (1.4)</td>
<td>Very deep, well-drained, fine Typic Paleudults; with deep, well-drained, fine Umbric Dystrochrepts</td>
</tr>
<tr>
<td>16 (0.3)</td>
<td>Very deep, well-drained, fine-loamy Typic Dystrochrepts; with very deep, well-drained, fine-loamy Typic Paleudalfs</td>
</tr>
</tbody>
</table>

THEMATIC MAPPING

Several thematic maps were generated using the soil survey data. The attributes chosen were those that influence land use relationships. The maps of landform, soil depth, texture, erosion, and soil reaction (pH) were prepared using reclassification techniques in a GIS.

DEPTH

Effective soil depth is an important soil parameter, as it determines the growth and performance of crops. Among the five depth classes, shallow soils cover about 20.7 percent and moderately shallow soils about 6.7 percent of the total area of the state. The soils in these depth classes in different map units are given in Table 3. The spatial distribution of different depth classes is shown in Figure 7.

FIGURE 6: Soil map of Arunachal Pradesh

Map Unit (% TGA) Description
SOILS OF GREATER HIMALAYAS

01 (16.4) Shallow, excessively drained, loamy-skeletal Lithic Udorthents; with moderately deep, somewhat excessively drained, loamy-skeletal Typic Udorthents
02 (6.2) Deep, somewhat excessively drained, loamy-skeletal Entic Haplumbrepts; with moderately shallow, excessively drained, sandy-skeletal Typic Udorthents
03 (7.8) Shallow, excessively drained, loamy-skeletal, Lithic Udorthents
04 (4.0) Shallow, excessively drained, loamy-skeletal; with moderately deep, somewhat excessively drained, sandy-skeletal soils, sandy-skeletal Typic Udorthents
05 (3.1) Very deep, well-drained, fine soils, Humic Hapludults; with very deep, well-drained, fine-loamy Umbric Dystrochrepts
06 (2.2) Shallow, excessively drained, sandy-skeletal Lithic Udorthents; with moderately deep, excessively drained, loamy-skeletal Typic Eutrochrepts
07 (6.1) Very deep, somewhat excessively drained, fine Typic Palehumults; with moderately shallow, excessively drained, fine, Typic Haplumbrepts
08 (2.3) Moderately shallow, somewhat excessively drained, loamy-skeletal Typic Udorthents; with moderately deep, somewhat excessively drained, fine-loamy Typic Eutrochrepts
09 (6.1) Deep, well-drained, fine Typic Kanhaplohumults with very deep, well-drained, fine-loamy Pachic Haplumbrepts
10 (4.0) Very deep, somewhat excessively drained, fine-loamy Umbric Dystrochrepts; with very deep, well-drained, fine-loamy Pachic Haplumbrepts
11 (5.2) Very deep, well-drained, fine-loamy Pachic Haplumbrepts; with very deep, well-drained, fine Typic Palehumults
12 (2.9) Very deep, well-drained, fine Typic Kandihumults; with deep, somewhat excessively drained, fine Pachic Haplumbrepts
13 (0.1) Very deep, poorly drained, fine Humaqueptic Fluvaquents; with very deep, imperfectly drained, fine Humic Haplaquepts
14 (0.7) Very deep, well-drained, fine Typic Kanhaplohumults; with deep, somewhat excessively drained, loamy-skeletal Umbric Dystrochrepts
15 (1.4) Very deep, well-drained, fine Typic Paleudults; with deep, well-drained, fine Umbric Dystrochrepts
16 (0.3) Very deep, well-drained, fine-loamy Typic Dystrochrepts; with very deep, well-drained, fine-loamy Typic Paleudalfs
SOILS OF SUB HIMALAYAN REGION - SIWALIK HILLS

17 (1.6) Deep excessively drained, loamy-skeletal Umbric Dystrochrepts; with moderately deep, excessively drained, fine-loamy Typic Dystrochrepts
18 (1.0) Very deep, well-drained, fine-loamy Typic Dystrochrepts; with deep, well-drained, loamy-skeletal Dystric Eutrochrepts
19 (1.5) Deep, somewhat excessively drained, loamy-skeletal Typic Udorthents; with deep, somewhat excessively drained, fine-loamy Typic Dystrochrepts
20 (0.8) Deep, somewhat excessively drained, loamy-skeletal Typic Udorthents; with deep, well-drained, fine-loamy Typic Dystrochrepts
21 (0.6) Deep, somewhat excessively drained, loamy-skeletal Typic Udorthents; with very deep, well-drained, fine-loamy Umbric Dystrochrepts
22 (0.6) Deep, somewhat excessively drained, loamy-skeletal Typic Udorthents; with deep, somewhat excessively drained, fine-loamy Typic Dystrochrepts
23 (1.2) Deep, well-drained, coarse-loamy Typic Dystrochrepts; with moderately deep, somewhat excessively drained, loamy-skeletal Typic Dystrochrepts

SOILS OF LOWER HIMALAYAN RANGES (PURVACHAL)

24 (1.5) Very deep, well-drained, fine Typic Palehumults; with very deep, well-drained, fine Typic Dystrochrepts
25 (0.6) Very deep, well-drained, fine Typic Dystrochrepts; with deep, well-drained, clayey-skeletal Typic Haplhumults
26 (0.2) Very deep, well-drained, fine Fluventic Haplumbrepts; with deep, imperfectly drained, fine-loamy Aerie Haplaquepts
27 (0.2) Very deep, well-drained, fine Typic Haplumbrepts; with deep, well-drained, fine Typic Haplumbrepts
28 (0.6) Very deep, well-drained, fine Typic Kandihumults; with very deep, well-drained, fine Pachic Haplumbrepts
29 (0.4) Moderately deep, somewhat excessively drained, loamy-skeletal Typic Dystrochrepts; with deep, well-drained, clayey-skeletal Umbric Dystrochrepts
30 (0.1) Moderately deep, well-drained, fine Pachic Haplumbrepts; with moderately deep, well-drained, fine-loamy Typic Dystrochrepts
31 (0.6) Deep, well-drained, loamy-skeletal Pachic Haplumbrepts; with deep, well-drained, fine-loamy Typic Dystrochrepts
32 (0.2) Deep, well-drained, loamy-skeletal Fluventic Haplumbrepts; with deep, well-drained, loamy-skeletal Typic Dystrochrepts
33 (0.5) Moderately deep, well-drained, clayey-skeletal Pachic Haplumbrepts; with deep, well-drained, fine Pachic Haplumbrepts
34 (0.6) Deep, somewhat excessively drained, clayey-skeletal Typic Dystrochrepts
35 (1.4) Shallow, excessively drained, loamy-skeletal Lithic Udorthents; with moderately deep, somewhat excessively drained, loamy-skeletal Pachic Haplumbrepts

SOILS OF PLAINS OF EASTERN CONTINUITY OF ASSAM

36 (0.9) Moderately shallow, well-drained, loamy-skeletal Typic Udorthents; with moderately deep, well-drained, coarse-loamy Entic Haplumbrepts
37 (1.2) Very deep, well-drained, coarse-loamy Umbric Dystrochrepts; with deep, well-drained, coarse-loamy Dystric Eutrochrepts
38 (0.5) Very deep, well-drained, fine Typic Dystrochrepts; with very deep, well-drained, fine Typic Kandihumults
39 (0.3) Very deep, well-drained, fine Typic Kandihumults; with deep, well-drained, clayey-skeletal Typic Dystrochrepts
40 (0.4) Very deep, well-drained, fine-loamy Typic Dystrochrepts; with very deep, moderately well-drained, fine-loamy Fluventic Dystrochrepts
41 (0.7) Very deep, imperfectly drained, coarse-loamy Aerie Haplaquepts; with very deep, imperfectly drained, fine-silty Typic Haplaquepts
42 (0.2) Very deep, moderately well-drained, coarse-loamy Typic Udifluvents; with deep, well-drained, coarse-loamy Typic Dystrochrepts
43 (0.3) Deep, well-drained, coarse-loamy Typic Udifluvents; with moderately deep, somewhat excessively drained, sandy Aquic Udipsammets
44 (1.1) Deep, imperfectly drained, coarse-silty Aerie Fluvaquents; with very deep, moderately well-drained, coarse-loamy Fluventic Dystrochrepts
45 (0.4) Moderately shallow, somewhat excessively drained, coated Typic Udipsammets
46 (11.4) Rocky mountains covered with perpetual snow and glaciers

TABLE 3: Soils under limiting* depth classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Agro-eco sub-region</th>
<th>Soil map units covered</th>
<th>Area covered 10^3 ha (% of TGA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow (25-50 cm)</td>
<td>Warm eastern Himalayas</td>
<td>per-humid 1, 3, 4, 6</td>
<td>1655.0</td>
</tr>
<tr>
<td></td>
<td>Warm Purbanchal</td>
<td>per-humid 35</td>
<td>79.3</td>
</tr>
<tr>
<td>Moderately shallow (50-75 cm)</td>
<td>Warm Eastern Himalayas</td>
<td>per-humid 2, 7, 8</td>
<td>485.9</td>
</tr>
<tr>
<td></td>
<td>Hot humid plains</td>
<td>per-humid 36, 45</td>
<td>76.6</td>
</tr>
</tbody>
</table>

* Critical to support optimum crop growth
TEXTURE
Texture is an important soil physical characteristic, which controls soil water retention and availability, workability of soil, infiltration and drainage conditions. Three textural groups identified in Arunachal Pradesh are clayey, loamy and sandy. Data indicate that a substantial area is covered by gravelly loam soils, which accounts for about 48.6 percent of TGA. Clayey surface soils cover an area of 12.0 percent, whereas, sandy soils cover only 2.8 percent of total area (Table 4).

EROSION
Soil erosion is the major soil degradation process among the various kinds of soil problems being faced. In Arunachal Pradesh steep lands with high rainfall are often subjected to soil loss by water erosion and landslides. The soils of the area were grouped into four erosion classes, eg, slight, moderate, severe and very severe (Figure 8). Very severe erosion occurs in an area of 1.83 million hectares (21.9 percent of TGA). Severe erosion occurs in 31.8 percent of the area; and about 25.7 percent of the total area is affected by moderate erosion (Table 5). Jhum cultivation and indiscriminate deforestation leads to accelerated soil erosion in Arunachal Pradesh.

![FIGURE 7: Soil depth map of Arunachal Pradesh](image)

![FIGURE 8: Soil erosion status of Arunachal Pradesh](image)

<table>
<thead>
<tr>
<th>TABLE 4: Soils under limiting textural classes (surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Sandy</td>
</tr>
<tr>
<td>Gravelly loam</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Clayey</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 5: Soils under limiting erosion classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Very severe</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Severe</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Moderate</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
SOIL REACTION (pH)

Soil reaction is also an important limiting factor in crop growth. It governs the uptake of nutrients held in exchange sites of soil colloids. In Arunachal Pradesh, the majority of the soils are acidic in nature. Soil acidity is caused by loss of base due to intensive leaching by high rainfall and the presence of an appreciable amount of exchangeable aluminium. The data indicate that extremely acidic (pH <4.5), very strongly acidic (pH 4.5-5.0) and strongly acidic (pH 5.1-5.5) soils cover an area of 1.4, 21.9 and 39.3 percent, respectively. Moderately acidic (pH 5.6-6.0) and slightly acidic (pH 6.1-6.5) soils cover an area of 12.2 and 10.1 percent, respectively. Neutral to slightly alkaline soils (pH ranging between 7.0 to 7.5) account for only 4.3 percent of the TGA of the state (Figure 9). The limiting soil reaction (pH) classes (extremely acidic to moderately acidic) occurring in soil map units under different agro-eco sub-regions are presented in Table 6. These soils need immediate attention for amendment by applying lime or adopting tolerant crops.

CONCLUSION

Information technology has opened up new avenues for making adequate use of resource information in land use planning. Soil has always been considered as an important bio-physical factor and as one of the most critical in land use planning. Conducting a soil resource inventory in mountainous terrain in India is entirely different from doing the same in the rest of the country: it involves huge amounts of money and extraordinary efforts. The primary data have been generalized in view of land use planning, where production systems and socio-economic scenarios are typical. The area is different from the rest of the plains of the country where the lands are productive and systematic agriculture is practised. Whereas this region is thinly populated with little infrastructure hinders normal agricultural practice. Apart from these the area is rugged and remotely located. Data availability in these regions is scanty and proper database creation is immensely important for users such as planners, decision-makers and non-governmental agencies involved in developmental planning in terrain such as the eastern Himalayan eco-system.

REFERENCES


FIGURE 9: Soil reaction (pH) status of Arunachal Pradesh

TABLE 6: Soils under limiting soil reaction (pH) classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Agro-eco sub-region</th>
<th>Soil map units covered</th>
<th>Area covered 10^4 ha (% of TGA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely acidic</td>
<td>Warm per-humid Siwalik</td>
<td>19</td>
<td>71.2 0.8</td>
</tr>
<tr>
<td></td>
<td>Warm per-humid Purvanchal</td>
<td>24, 33</td>
<td>50.5 0.6</td>
</tr>
<tr>
<td>Very strongly acidic</td>
<td>Warm per-humid eastern Himalayas</td>
<td>5, 7, 9, 11, 13, 16</td>
<td>1291.3 15.4</td>
</tr>
<tr>
<td></td>
<td>Warm per-humid Siwalik</td>
<td>17, 18, 21, 22</td>
<td>193.6 2.3</td>
</tr>
<tr>
<td></td>
<td>Warm per-humid Purvanchal</td>
<td>25, 27, 29, 32, 34, 35</td>
<td>210.9 2.5</td>
</tr>
<tr>
<td></td>
<td>Hot humid plains</td>
<td>36, 38, 41</td>
<td>139.3 1.7</td>
</tr>
<tr>
<td>Strongly acidic</td>
<td>Warm per-humid eastern Himalayas</td>
<td>1, 5, 7, 10, 11, 14, 16</td>
<td>2671.3 31.9</td>
</tr>
<tr>
<td></td>
<td>Warm per-humid Siwalik</td>
<td>17, 19, 20, 22, 23</td>
<td>255.8 3.0</td>
</tr>
<tr>
<td></td>
<td>Warm per-humid Purvanchal</td>
<td>24, 27, 30, 33, 35, 36</td>
<td>178.6 2.1</td>
</tr>
<tr>
<td></td>
<td>Hot humid plains</td>
<td>36, 38, 40, 41</td>
<td>188.2 2.2</td>
</tr>
<tr>
<td>Moderately acidic</td>
<td>Warm per-humid eastern Himalayas</td>
<td>1, 2, 8</td>
<td>911.6 10.9</td>
</tr>
<tr>
<td></td>
<td>Warm per-humid Siwalik</td>
<td>20, 23</td>
<td>68.1 0.8</td>
</tr>
<tr>
<td></td>
<td>Hot humid plains</td>
<td>42, 44</td>
<td>47.5 0.5</td>
</tr>
</tbody>
</table>
Soil information system in a GIS environment for land use planning

RESUMEN

Arunachal Pradesh, el mayor estado montañoso de la India, se encuentra en el noreste de la región del Himalaya y se caracteriza por tener lluvia anual alta, vegetación de bosque y gran diversidad de suelos. La información sobre los suelos es esencial para la planificación científica del uso de las tierras y la producción sostenible. El artículo presenta un inventario del recurso suelo y la creación de una base de datos de suelos para cartografía temática con el uso de un sistema de información geográfica (SIG). Desde el punto de vista fisiográfico, Arunachal Pradesh puede ser dividido en cuatro zonas distintas: montañas cubiertas de nieve (5500 msnm); serranías inferiores del Himalaya (3500 msnm); las colinas Siwalik del sub-Himalaya (700 msnm); y las planicies del Assam oriental. Los suelos que ocurren en estas zonas fisiográficas son Inceptisoles (37%), Entisoles (35%), Ultisoles (14%) y Alfisoles (0.5%). Los demás suelos pueden ser clasificados como misceláneos. Los estudios de inventario del recurso suelo muestran que los suelos en el ecosistema cálido perhúmedo del Himalaya oriental, con un régimen de temperatura "termico", son Inceptisoles e Entisoles, y que estos son altamente ácidos. Los suelos en el ecosistema cálido perhúmedo de las colinas Siwalik, con régimen de temperatura "hipertermico", son también Entisoles e Inceptisoles, altamente a moderadamente ácidos. Los suelos dominantes en el ecosistema colinso del Purvachal nororiental, con regímenes de temperatura "hipertermico" y "termico", son Ultisoles e Inceptisoles. Los suelos dominantes en el ecosistema de planicies muy cálidas y húmedas son Inceptisoles e Entisoles. Relieve escarpado y lluvia abundante son mayormente responsables por crear un alto riesgo de erosión en el estado. El mapa de erosión de suelos indica que la erosión de suelos es muy severa (20% del TGA) a severa (25% del TGA) en la zona cálida perhúmeda, mientras que la erosión es moderada en las colinas de Siwalik y en las planicies húmedas muy cálidas. Esto queda evidenciado por la distribución de las clases de profundidad de suelos en Arunachal Pradesh, la cual muestra que el 20% de TGA del estado se encuentra cubierto por suelos delgados. La mayor parte del estado corresponde a colinas, mientras que la producción agrícola queda restringida a los valles. Sin embargo, los suelos de las otras zonas fisiográficas (terrenos moderadamente colinosos a menor altitud) se prestan para plantaciones con cultivos tales como naranja, banana y té. El turismo también ofrece un gran potencial para el estado.
Land use classification in mountainous areas: integration of image processing, digital elevation data and field knowledge (application to Nepal)

Dhruba Pikha Shrestha and J Alfred Zinck

International Institute for Aerospace Survey and Earth Sciences (ITC), P.O. Box 6, 7500 AA Enschede, The Netherlands (phone: +31 53 4874 264; fax: +31 53 4874 379; e-mail: shrestha@itc.nl)

KEYWORDS: land use classification, mountainous lands, GIS, remote sensing, sun illumination

ABSTRACT
Remote sensing data help in mapping land resources, especially in mountainous areas where accessibility is limited. In such areas, land degradation is a main concern. Land is degraded not only by natural processes but also by human activities through inappropriate land use practices. Land cover and land use mapping is thus very important for evaluating natural resources. Classification of remote sensing data in mountainous terrain is problematic because of variations in the sun illumination angle. This results in biased reflectance data, the distribution of which does not fulfill normality as required by the maximum likelihood classifier. In the present work the topographic effect is corrected by normalising the spectral bands by the total intensity. Classification results are further refined by using ancillary data and expert knowledge of the area. The integration of image processing and spatial analysis functions in GIS improves the overall classification result from 67 to 94 percent (a 27 percent increase).

INTRODUCTION
Land degradation is a common phenomenon in mountainous regions. Although causal factors are mainly natural, inappropriate land uses enhance the degradation processes. Land use practices have a direct effect on soil losses and mass movements [Kienholz et al., 1983; Kienholz et al., 1984; Hurni, 1990; Shah et al., 1991]. Land use and land cover mapping is thus very important for resource evaluation. Remote sensing data help in mapping land cover and land use through multispectral classification. This is especially useful in areas where accessibility is a major issue.

CONSTRAINTS TO LAND USE CLASSIFICATION IN MOUNTAINOUS REGIONS
Various algorithms are available for land cover classification, each having its own limitations and applicability in different environments. Apart from conventional classification algorithms, fractals, neural networks and linear unmixing techniques have been applied [Mulder & Spreeuwers, 1991; De Jong, 1994; Kressler & Steinnocher, 1999]. But in areas with strong topographic variations, results obtained by running a classification are not satisfactory for mapping land cover and land use. The main reasons are elevation differences, illumination variations, effect of topographic shadow and parcel size. Variations in topography have an effect on microclimates, which may influence land cover and land use patterns. Spectral classification alone is not sufficient for extracting land cover/use data. Even in areas without topographic distortions, the accuracy of land cover mapping can be increased by integrated processing of remote sensing and ancillary data in a GIS environment [Molenaar & Janssen, 1991].

The amount of reflected solar radiation received by sensors aboard satellites depends not only on the type of earth surface features but also on sun elevation and topography (Figure 1). Sun-facing slopes receive more illumination. Relief lines perpendicular to the light direction are emphasised, and the ridges or valleys may be over- or under-emphasised depending on their orientation [Hobbs, 1999]. Thus, slope gradient and aspect influence surface reflectance. Full topographic shadow results in the absence of data.

![FIGURE 1: Effect of topography on the amount of sun illumination](image)
Considering the very short time required to scan a full satellite scene (e.g., 28.7 seconds for a Landsat scene of 185 km x 185 km), the sun angle can be considered constant. If the surface cover type is the same, any variation in reflected energy received by the sensor can be attributed to variations in topography, resulting in illumination differences due to slope gradient and aspect. Assuming all other factors are constant, the amount of energy received by the sensor depends on slope gradient and exposition with respect to sun elevation. This results in elongated clusters of the training samples (Figure 2) with degree of elongation depending on the locations where samples are taken. This causes bias and results in non-normal distribution of the training samples, which is not ideal for classification.

In conventional classification of multispectral data, the maximum likelihood classifier is considered to provide the best results since it takes into account the shape, size and orientation of a cluster. Based on the class mean and the variance-covariance matrix, an unknown pixel is assigned to the most likely class. To downgrade the effect of any outlying training sample, which may influence the class mean and variance-covariance matrix, the Mahalanobis distance function can be implemented [Campbell, 1980]. The technique of principal component analysis can be applied to reduce the number of spectral bands [Mulder & Hempenius, 1974; Donker & Mulder, 1977]. This may be important since the maximum likelihood algorithm takes considerable processing time if several spectral bands are used. The classification method assumes that the training samples are normally distributed. This ideal situation, however, may not occur in mountainous areas. Within a given cover type, variations in reflected energy might be considerable due to variations in illumination, resulting in non-normal distribution of the training samples (Figure 3). The distribution of the training samples may be biased towards either fully illuminated or shaded slopes. Thus, the procedure of conventional classification cannot be directly applied in mountainous regions. Conese et al [1993] proposed principal component analysis to overcome the topographic effect. Lees & Ritman [1991] used decision-tree rules to map vegetation in hilly areas.

In the present paper intensity normalisation of the individual spectral bands is implemented for removing the variations in the solar illumination angle. The intensity normalisation technique is also used for natural colour coding of multispectral data. Mulder [1981] demonstrated that decomposition into intensity variation and spectral colour variation can be used meaningfully for feature extraction.

Elevation differences between ridges and valley bottoms cause climatic variations, which influence the land cover and land use types. In studying such areas, a combination of ancillary data and expert knowledge of the area is needed to improve spectral classification, as demonstrated below using an example from Nepal.

STUDY AREA

The study area belongs to the watershed of the Likhu Khola river, in the Middle Mountain region of Nepal (Figures 4 & 5). The watershed occupies about 160 km² and lies between the co-ordinates 27°48'15" and 27°53'55" north and between 85°13'01" and 85°27'51" east. The river Likhu Khola flows from east to west and is joined by many tributaries from both sides. Mountain ridges are mainly east-west oriented. The valley is narrow and elongated, but widens downstream. Elevation varies from 780 m above mean sea level at the valley floor to 2600 m above mean sea level at the highest mountain.
Land use classification in mountainous areas

JAG · Volume 3 - Issue 1 - 2001

ridge. Due to the east-west orientation of the ridges and the elevation differences between valley bottom and mountain summits, the variations in sun illumination between north- and south-facing slopes are considerable.

The climate varies from subtropical at lower elevations (main valley and foothills) through warm temperate at mid-elevations to cold temperate in the high mountains. In the lowlands, the average summer temperature is 26°C (May) and the average winter temperature is 15°C (December). At higher elevations, the average summer temperature is 19°C and average winter temperature is 11°C. Annual precipitation also varies according to elevation from 1000 mm in the lowlands (Chhahare, 780 m above mean sea level) to 2800 mm at higher elevations (Kakani, 2064 m above mean sea level). The average annual rainfall increases by 104 mm for every 100 m increase of elevation [Shrestha, 1997]. Most of the rainfall falls from May to September.

Vegetation changes according to elevation, due to its effect on climate. At higher elevations, land cover is mainly forest with chir pine (*Pinus roxburghii*) and broad leaf trees (*Schima wallichii*). Rainfed maize and millet are the cultivated crops. At lower elevations, the forest is dominated by sal trees (*Shorea robusta*). Cultivation normally takes place on contour terraces. Irrigated rice and rainfed maize and millet are the main crops. For the cultivation of rice, level terraces are made for retaining the water, while sloping terraces (10 to 15 percent) are built for rainfed cultivation. The slope and width of the terraces are determined by the topography: the steeper the topography, the higher the slope gradient of the terrace and the narrower the width. The width of the sloping terraces varies from 2 to 3 m, making the parcel size quite small. Rice is cultivated on level terraces, if irrigation water is available and the temperature is suitable. Elevation, which controls climate, determines the variations in land cover and land use types.

Maximum soil losses occur on steep slopes under rainfed conditions, followed by bare land and degraded forest [Kunwar, 1995; Shrestha, 1997]. Mass movement processes are related to land use types. For example, slumping is common in rice fields, while debris slides seem to occur more in degraded forests and on rangeland than in cultivated areas [Shrestha & Zinck, 1999]. Thus, land use mapping helps in assessing erosion susceptibility and land-use-induced mass movement hazards.

REMOTE SENSING DATA PROCESSING
PRE-PROCESSING
Landsat TM data, acquired on 12 October 1988, were geo-referenced using control points from the 1:25,000 topographic map of the area (sheets 2785 01B, 2785 02C and 2785 02D, edition 1994). Nearest neighbour
interpolation was followed during resampling. All the spectral bands, excluding TM band 6, were used. To
minimise the effect of illumination differences on the surface reflectance, spectral bands were normalised by the total
intensity as follows:

$$\text{NB}_i = 255 \left( \frac{\text{OB}_i}{\sum \text{OB}_i} \right) \quad i = 1 \text{ to } n$$  (1)

where $\text{NB}_i$ is the band normalised by total intensity and $\text{OB}_i$ is the original spectral band. The constant (255) is
used to fit the data in a byte range of 0-255. The resulting bands have the property that the sum of any pixel
values is 255 due to normalisation. In Figure 6, the hypothetical location of water, vegetation and soil is shown in
a two-dimensional feature space. After normalisation, the location of these objects is projected onto a diagonal
line of uniform intensity (Figure 7), indicating that the objects are free from intensity variation.

**CLASSIFICATION PROCEDURE**

Training samples from the original TM bands result in elongated clusters due to topographic effect (Figure 8). After normalisation of the bands, the elongation effect disappears and the training samples can be assumed to be approximately normally distributed (Figure 9). The maximum likelihood algorithm is applied, which calculates the distance from each feature vector (pixel to be classified) to the class means. The within-class variability is taken care of by adding a factor, which is a function of the variance-covariance matrix of that class. The formula used [Mather, 1987] reads:

$$D(X) = \ln |V_i| + (X - M_i)^TV_i^{-1}(X - M_i)$$  (2)

in which: $D(X)$ = distance between pixel vector $X$ and a class mean based on probabilities; $X$ = pixel vector $X$; $M_i$ = mean vector of the class considered; $V_i$ = the variance-
covariance matrix of the class considered; \( V_i^{-1} \) = the inverse of \( V_i \); \( |V_i| \) = determinant of the variance-covariance matrix \( V_i \); \( (X - M_i) \) = the distance towards a class mean; and \( (X-M_i)^T \) = the transposition of \( (X - M_i) \).

During classification, the shortest distance to a class mean is found and the pixel is class-labelled if the distance is smaller than the threshold value.

**CLASSIFICATION RESULTS**

The classification results were checked against a set of test pixels, showing 97 percent accuracy for low altitude forests, 98 percent accuracy for bare surfaces and 93 percent accuracy for rice fields (Table 1). Classification of rainfed agriculture was found only 76 percent correct since 21 percent of the test pixels were mis-classified as bare land. Similarly, high altitude forests were confused with low altitude forests: only 65 percent of the test samples were correctly classified; the rest (35 percent) were classified as low altitude forests. Mean classification accuracy was 87 percent and the overall classification accuracy was 67 percent. The results clearly demonstrate the difficulty in classifying high altitude forests and rainfed agriculture.

**IMPROVING FOREST CLASSIFICATION**

Except for the protected forests and the forests located far from the villages and the foot-trails, the forests in general in the study area are degraded because of the collection of firewood and the collection of tree branches and leaves for cattle fodder and household use. Under degraded forest, soil erosion takes place because of reduced canopy and litter cover. Annual soil loss from the degraded forests can be up to 9 t/ha, while it is less than 1 t/ha under dense forest [Shrestha, 1997]. It was thus important to separate the forest types into dense forest and degraded forest, using the canopy density as an indicator of forest degradation. For this purpose, the intensity normalised difference vegetation index (NDVI) was generated from the spectral bands in the near-infrared and red portions of the spectrum (Landsat TM bands 4 and 3), using the following calculation:

\[
\text{NDVI} = 127\left(\frac{\text{TM4} - \text{TM3}}{\text{TM4} + \text{TM3}}\right) + 127 \quad (3)
\]

The normalised difference of near-infrared and red bands was multiplied by 127 to convert the fractional values into integer numbers, and the constant 127 was added to the result to avoid a possible negative value. From the resulting image three vegetation density classes, based on sample pixels, were generated: low density (less than 40 percent canopy), moderate density (40 - 70 percent canopy) and high density (more than 70 percent canopy).

Using the vegetation indices, it was possible to divide the forest types into various subclasses, by means of conditional ("IF, THEN, ELSE") and logical ("AND") statements. The resulting classes are degraded sal forest, moderately dense sal forest and dense sal forest. Similarly, the high altitude forest type was also further divided into degraded high altitude forest, moderately dense high altitude forest and dense high altitude forest. Table 2 shows forest cover classification improvement.

**TABLE 1** Contingency table of classification results

<table>
<thead>
<tr>
<th>Low altitude forest</th>
<th>Bare land/ landslide area</th>
<th>Rainfed agriculture</th>
<th>Rice fields</th>
<th>Water body</th>
<th>High altitude forest</th>
<th>No. of test pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low altitude forest</td>
<td>971 (97%)</td>
<td>5</td>
<td>6</td>
<td>14</td>
<td>0</td>
<td>996</td>
</tr>
<tr>
<td>Bare land/ landslide area</td>
<td>0 (100%)</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>313</td>
</tr>
<tr>
<td>Rainfed agriculture</td>
<td>0 (100%)</td>
<td>119 (21%)</td>
<td>426 (76%)</td>
<td>1</td>
<td>11 (2%)</td>
<td>557</td>
</tr>
<tr>
<td>Rice fields</td>
<td>37 (6%)</td>
<td>0</td>
<td>0</td>
<td>559 (93%)</td>
<td>7</td>
<td>603</td>
</tr>
<tr>
<td>Water body</td>
<td>0 (100%)</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>104 (96%)</td>
<td>108</td>
</tr>
<tr>
<td>High altitude forest</td>
<td>579 (31%)</td>
<td>8</td>
<td>62 (3%)</td>
<td>1</td>
<td>0</td>
<td>1196 (65%)</td>
</tr>
</tbody>
</table>

**TABLE 2** Classification improvement for the forest cover

<table>
<thead>
<tr>
<th>NDVI class 1 (up to 40% canopy)</th>
<th>NDVI class 2 (40 – 70% canopy)</th>
<th>NDVI class 3 (more than 70% canopy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low altitude forest (sal forest)</td>
<td>Degraded low altitude forest</td>
<td>Moderately dense low altitude forest</td>
</tr>
<tr>
<td>High altitude forest (association of pine, quercus and chilaune)</td>
<td>Degraded high altitude forest</td>
<td>Moderately dense high altitude forest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dense low altitude forest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dense high altitude forest</td>
</tr>
</tbody>
</table>
MASKING OF CLOUD AND SHADOW AREAS
The Landsat TM image included cloud-covered and cloud shadowed areas, the latter enlarged because of the rugged topography. As no information could be extracted from these areas, they were masked and replaced by the classification result obtained from a Landsat MSS image acquired on 28 October 1976.

INTEGRATION OF SPATIAL ANALYSIS FUNCTIONS IN GIS
PROXIMITY ANALYSIS
Since rice is a staple as well as a cash crop, farmers prefer to grow rice more than other cereals. If the climate is suitable and water is available, up to two rice crops are harvested in a year. Rice is planted in level terraces along the contours. Terracing has been practised in Nepal since ancient times to make cultivation possible on very steep slopes. A small bund of about 10-15 cm high is made on the outer edge to store water. Irrigation water is diverted from the streams and allowed to pass from one terrace to another. As the average effective distance for irrigation is approximately 200 m from a stream, areas close to streams are readily converted into rice fields if the temperature is favourable. Rice fields are susceptible to slumping because of continued soil saturation and the extra weight caused by standing water. The classification and mapping of the areas cultivated with rice were improved using a distance function from the streams.

USE OF ELEVATION DATA
Sal forest does not develop at higher elevations, while the forests consisting of pine, quercus, chilaune and utish do not occur at elevations lower than 1100 m above mean sea level. Digital elevation data at 20 m resolution, based on SPOT panchromatic images (Right HRV2, 7 Nov 1986; Left HRV1, 12 December 1986) and the topographic map of Nepal at a scale of 1:50,000, were used to improve the classification by means of conditional statements as follows:

\[
\text{IF land cover} = \text{"high\_altitude\_forest" AND elevation < 1100} \\
\text{THEN land cover} = \text{"low\_altitude\_forest"} \\
\text{ELSE land cover} = \text{"high\_altitude\_forest"}
\]

It was also found that, above elevation 2200 m above mean sea level, the forest type is dominated by quercus species (essentially Quercus semicarpifolia). This made it possible to further improve forest classification.

Because of spectral confusion, riverbeds were originally misclassified as rainfed agriculture. Field knowledge was mobilised to improve the classification. Firstly, rainfed agriculture normally does not develop along rivers. Secondly, riverbed width and configuration change with elevation. At higher elevations, riverbeds are restricted to entrenched and narrow incisions, while at lower elevations, approximately below 700 m above mean sea level, riverbeds widen into an intricate network of braided channels; the latter allows better spectral discrimination and facilitates mapping. Consequently, proximity to main rivers and elevation data were used to decide whether to classify a given area as rainfed agriculture or not. At elevations lower than 700 m, the land cover class was riverbed; at elevations above 700 m it was considered to be rainfed agriculture.

FINAL CLASSIFICATION RESULTS
The final map reflects the integration of remote sensing data processing and spatial analysis, making use of digital elevation data and calculation of distances from the streams and the main rivers in the valley (Figure 10). The areas of the various land cover types are shown in Table 3. Accuracy assessment was carried out using test samples and leading to the confusion matrix of Table 4. Data synergy considerably improved the land use classification. The mean accuracy of the final classification is 97 percent and the overall classification accuracy increased to 94 percent.

<table>
<thead>
<tr>
<th>Land cover/use</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense high altitude quercus forest</td>
<td>358</td>
</tr>
<tr>
<td>Dense high altitude mixed forest</td>
<td>1235</td>
</tr>
<tr>
<td>Dense low altitude sal forest</td>
<td>131</td>
</tr>
<tr>
<td>Moderately dense high altitude mixed forest</td>
<td>2568</td>
</tr>
<tr>
<td>Moderately dense low altitude sal forest</td>
<td>1402</td>
</tr>
<tr>
<td>Degraded high altitude quercus forest</td>
<td>248</td>
</tr>
<tr>
<td>Degraded high altitude mixed forest</td>
<td>1598</td>
</tr>
<tr>
<td>Degraded low altitude sal forest</td>
<td>801</td>
</tr>
<tr>
<td>Rainfed agriculture</td>
<td>4950</td>
</tr>
<tr>
<td>Rice fields</td>
<td>2349</td>
</tr>
<tr>
<td>Bare land/landslide area</td>
<td>106</td>
</tr>
<tr>
<td>River/streams</td>
<td>415</td>
</tr>
</tbody>
</table>

One-third (31 percent) of the watershed area is used for rainfed agriculture. The area under degraded forest is 17 percent. Thus nearly half of the watershed area is exposed to topsoil removal by sheet erosion. The area covered by rice fields is 15 percent, with only 1 percent located in the floodplain of the Likhu Khola river. The rest (14 percent) corresponds to terraces that are built on steep slopes and are therefore highly susceptible to slumping.
CONCLUSIONS
Variations of the solar illumination angle can be easily corrected by normalisation of the individual bands by the total intensity. This is indispensable, if the classification algorithm assumes normal distribution of the training samples. Land use classification can be further refined by using digital elevation data in areas with high topographic variation. Expert knowledge of the area considerably improves classification accuracy.

ACKNOWLEDGEMENTS
The reviewers of this paper are gratefully acknowledged.

TABLE 4 Confusion matrix

<table>
<thead>
<tr>
<th></th>
<th>Low altitude forest</th>
<th>Bare land/landslide area</th>
<th>Rainfed agriculture</th>
<th>Rice fields</th>
<th>Water body</th>
<th>High altitude forest</th>
<th>No. of test pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low altitude forest</td>
<td>971 (97%)</td>
<td>5</td>
<td>6</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>996</td>
</tr>
<tr>
<td>Bare land/landslide area</td>
<td>0</td>
<td>307 (98%)</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>313</td>
</tr>
<tr>
<td>Rainfed agriculture</td>
<td>1</td>
<td>10 (2%)</td>
<td>538 (97%)</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>557</td>
</tr>
<tr>
<td>Rice fields</td>
<td>30 (5%)</td>
<td>0</td>
<td>0</td>
<td>569 (94%)</td>
<td>4</td>
<td>0</td>
<td>603</td>
</tr>
<tr>
<td>Water body</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>104 (96%)</td>
<td>0</td>
<td>108</td>
</tr>
<tr>
<td>High altitude forest</td>
<td>0</td>
<td>0</td>
<td>37 (2%)</td>
<td>0</td>
<td>0</td>
<td>1809 (98%)</td>
<td>1846</td>
</tr>
</tbody>
</table>

REFERENCES

FIGURE 10: Land cover and land use mapping of the Likhu Khola watershed
Land use classification in mountainous areas


RESUME

Des données télédétection se révèlent une aide précieuse dans la cartographie des ressources naturelles, particulièrement dans les zones montagneuses où l'accès est limité. Dans de telles zones, la dégradation des terres est un souci principal. Les terres sont dégradées non seulement par des processus naturels mais aussi par des activités humaines à travers des pratiques impropre d'utilisation des terres. La cartographie de l'occupation et de l'utilisation des terres est donc très importante pour l'évaluation des ressources naturelles. La classification des données de télédétection est problématique dans les terrains montagneux, à cause de l'angle d'éclairement du soleil. Ceci se traduit par des données de reflectance biaisée, dont la distribution ne satisfait pas à la normalité requise par une classification selon le maximum de vraisemblance. Dans le présent travail l'effet topographique est corrigé en normalisant les bandes spectrales par l'intensité totale. Des résultats de classification sont encore améliorés en utilisant des données auxiliaires et des connaissances expertes de la zone. L'intégration du traitement d'image et les fonctions d'analyse spatiale dans un SIG améliore le résultat de la classification totale de 67 à 94 pour-cent (une augmentation de 27 pour-cent).

RESUMEN

Los datos de teledetección ayudan en el mapeo de los recursos naturales, especialmente en áreas montañosas de limitada accesibilidad. En tales áreas, la degradación de tierras es una preocupación mayor. Las tierras se degradan no solamente por procesos naturales, pero también por las actividades humanas debido a prácticas inapropiadas de uso de las tierras. Por esta razón, la cartografía de la cobertura y del uso de las tierras es muy importante para la evaluación de los recursos naturales. La clasificación de los datos de teledetección en relieve montañoso es problemática debido a variaciones en el ángulo de iluminación solar. Esto causa alteración de los datos de reflectancia, cuya distribución no cumple con la condición de normalidad como lo requiere el clasificador de máxima verosimilitud. En este trabajo se corrige el efecto topográfico mediante normalización de las bandas espectrales por la intensidad total. Además, se analizan los resultados de clasificación con datos auxiliares y conocimientos expertos en la zona. La integración del procesamiento de imágenes con funciones de análisis espacial en SIG mejora el resultado general de la clasificación, haciéndolo pasar de 67 a 94% (un incremento de 27%).
Crop area estimation using GIS, remote sensing and area frame sampling

Sushil Pradhan

KEYWORDS: crop area estimation, area frame sampling, GIS, remote sensing

ABSTRACT
This paper presents an approach towards the development of a Geographic Information System (GIS) for crop area estimation to support crop forecasting systems at a regional level. The overall system design aimed at supporting crop area estimation through area frame sampling (AFS), remote sensing, and a combination of AFS and remote sensing. However, the detailed design was carried out to support AFS only. Later, a system was realized which can support AFS survey design, field work, data processing as well as quality assessment of the input data. Based on this, two prototype systems were designed, the so-called CAEIS - I and CAEIS - II. CAEIS - I was developed using the Arc Macro Language (AML) of UNIX-based Arc/Info software, and CAEIS - II was developed using Microsoft Access on a PC environment. Later, the functions of the system were tested and evaluated, using field data collected from Razan township in Hamadan province of the Islamic Republic of Iran during the summer of 1997. The results showed a satisfactory match between the area of major agricultural commodities derived through the developed system and those areas derived by Agricultural Statistics Information Division (ASID) of the Ministry of Agriculture, I.R. of Iran.

INTRODUCTION
Information on changes in land cover/use is of particular importance when such changes could result in progressive land degradation. Derivation of land cover/use and estimation of agricultural production through classical methods are costly, time consuming, and subject to a variety of errors in terms of types and sources. Recent developments in GIS and remote sensing technologies and crop modelling have created promising opportunities for improving agricultural statistics systems [Aronoff, 1989; Burrough, 1986; Laurini & Thompson, 1992; Molenaar 1998; Buiten & Clevers, 1990; MacLean,1995; Sharifi, 1992]. Techniques in crop inventory systems that are based on the application of GIS, remote sensing and agro-ecological models provide examples of developments in each discipline [Gallego et al, 1997; Sharifi et al, 1997]. Several processes, such as derivation of improved land cover/use, crop production estimation, and data handling, are involved in each discipline and are the main components in the estimation and forecasting of agricultural production [Maru, 1997; Sharifi & De Meijere, 1997].

Crop area estimation performed by integration of the Area Frame Sampling (AFS) technique and classification of satellite images is the GIS and remote sensing application that has become most widely used today in many countries. The crop estimation process entails four independent components: a ground survey of randomly sampled areas based on the AFS method; a multi-temporal classification of satellite images covering the entire area; a combination of these two; and aggregation/dis-aggregation to different administrative levels (Figure 1).

The objective of this study was to develop a geo-information system for the estimation of crop areas from ground data based on AFS, which was implemented in Hamadan province of the Islamic Republic of Iran.

METHODOLOGY
SAMPLE DESIGN
A frame of the study area was designed by identifying the minimum and maximum X, Y coordinates to deter...
mine the limits of the study area. Then the coordinates of each point, in both X and Y directions, at an interval of 10 km (the size of the block) was calculated using the UTM coordinate system. A spatial layer of the square frame was generated using these coordinates. The size of the segments was determined to be 1 km by 1 km, and, therefore, each block was again subdivided into 1 km by 1 km cells; ie, each square block contained 100 segments. The segments (points) associated with each square block were assigned a unique code from 1 to 100 as shown in Figure 2.

<table>
<thead>
<tr>
<th>Code</th>
<th>Strata</th>
<th>Intensity</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Irrigated agriculture area</td>
<td>High intensity</td>
<td>490.40</td>
</tr>
<tr>
<td>30</td>
<td>Rainfed agriculture area</td>
<td>Medium intensity</td>
<td>1066.56</td>
</tr>
<tr>
<td>60</td>
<td>Mixed agriculture area</td>
<td>Low intensity</td>
<td>525.60</td>
</tr>
<tr>
<td>40</td>
<td>Pasture (rangeland)</td>
<td>Very low intensity</td>
<td>465.25</td>
</tr>
</tbody>
</table>

TABLE 1: Area of strata

SELECTION OF POSSIBLE SEGMENTS

After the square grid was defined, the most practical method for locating or selecting sample segments was to locate the maximum number of segments (depending upon the chosen maximum sample rate) that could be in any strata. Some of them were later discarded for specific reasons, eg, a lower sample rate for a strata, or a segment was located on the border of a region with less than 50 percent of its area falling inside the region, etc. A systematic, aligned sampling method with a 3 km distance threshold was applied for random selection of the segments. These segments were referred to as possible segments. So, the whole segment selection procedure consisted of selecting possible segments and then selecting final segments.

The possible segments were overlaid on the stratification map, and it was observed that few segments crossed over region and strata boundaries (Figure 4). There are at least three alternative ways to deal with a segment that straddles the stratum boundary and is shared by two strata [Gallego, 1995]: (1) the segment can be assigned to the stratum with which it most overlaps; (2) border segments can be split into pieces that belong to different strata; and (3) the largest piece of the segment located in one stratum can be kept and all other pieces can be discarded.
According to Gallego [1995], the first alternative is the easiest to manage, but may introduce some bias. The second alternative seems to keep the largest amount of information and might prove to be the best in future, but tests have not given convincing results. The third alternative gives the best practical results, although it is not supported by solid theoretical evidence, which still needs to be developed. So, considering the importance of the largest amount of information, the first alternative was selected in this study.

SELECTION OF FINAL SEGMENTS

After dealing with the straddle boundaries and overlap of segments in two strata, final selection of segments was made (Figure 5) by defining a sample rate for each stratum. The sample rates can only be equal to or less than the maximum sample rate. In this study, the maximum sample rate was \( \frac{5}{100} = 5 \text{ percent} \) (100 segments in a block, five of which are chosen as possible segments). The sample rates for each stratum were chosen depending upon the intensity of crop production in the area. In this study, the irrigated area was an intensive agricultural area, and, therefore, the sample rate, 4 percent, was chosen; i.e., a maximum of four segments per block for the irrigated area. So, out of the total possible segments, four segments were randomly selected in a block for the irrigated area by generating four random numbers and defining a rule – if the possible segments having the code of the four random numbers generated above occur on the irrigated land, select only those segments and otherwise delete others. Similarly, sample rates of 3 percent, 2 percent, and 1 percent were chosen for rainfed, mixed, and pasture areas, respectively, and the segments were randomly selected for each strata and replicated in each block. Note the difference in location of sample points between Figures 3 and 5. This was the final selection for the sample survey. The real sample rate for each stratum was calculated by the system shown in Table 2.

<table>
<thead>
<tr>
<th>Code</th>
<th>Strata</th>
<th>No. of Sample Segments</th>
<th>Area (km²)</th>
<th>Sample Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Irrigated agriculture area</td>
<td>20</td>
<td>490.40</td>
<td>4.08</td>
</tr>
<tr>
<td>30</td>
<td>Rainfed agriculture area</td>
<td>32</td>
<td>1066.56</td>
<td>3.35</td>
</tr>
<tr>
<td>60</td>
<td>Mixed agriculture area</td>
<td>11</td>
<td>525.60</td>
<td>2.09</td>
</tr>
<tr>
<td>40</td>
<td>Pasture area</td>
<td>2</td>
<td>465.25</td>
<td>0.86</td>
</tr>
</tbody>
</table>

CREATION OF SAMPLE MAP

Aerial photographs on a scale of 1:40,000 were used to create sample maps (Figure 6). The scale of the photographs was too small to use them directly for drawing tracts. Hence, the photographs had to be enlarged before being used. The general method applied for creating representation of sample maps is:

FIGURE 5: The use of aerial photographs to create sample maps
Crop area estimation

- finding the centre coordinate of a segment on the 1:50,000 scale map;
- comparing the features on the map and photos to find the matching patterns;
- scanning the whole photo at a resolution of 600 dpi to easily find control points;
- selecting the control points (a minimum of four) on the map, calculating the coordinates with the help of rulers, and using these coordinates to geo-correct the photograph;
- cutting out a geo-corrected photo of required size depending upon the size of segments (extending the area of the segment by about 50 to 100 metres is preferable);
- printing the cut-out photo on an A4-size paper, covering as much area as possible;
- printing the scanned photo at a very high resolution to be used during field work.

GROUND SURVEY
Field work was carried out in each segment to produce an accurate map of crops and other land cover (Figure 7). In some cases, crop yields were estimated. Finding the exact location of a segment was the most difficult part. The relevant landmarks shown on the map and the aerial photographs were used to locate a segment. In many cases, a GPS was used to find and verify the exact location (coordinates) of segments. The field boundaries depicting each crop type were drawn on tracing paper. The crop codes for each polygon were indicated on the tracing paper. Features such as roads, paths, rivers, hedges, and streams were also indicated.

DATA PROCESSING
Data processing and preparation of the data required two types of data: segment specifics that involved tracts and tract numbers; and crop specifics that involved area codes of all crops. Data processing and preparation consisted mainly of digitization of segments mapped during fieldwork and entry of recorded data into questionnaires. Arc/Info was used to digitize the mapped segments, and the crop attribute data were entered in dBase III+. Later these data were managed in Arc/Info DBMS.

AREA ESTIMATION
Another major objective of the study was to build a prototype system for area estimation during the implementation phase. The resulting Crop Area Estimating Information System (CAEIS) is subdivided into CAEIS-I and CAEIS-II. CAEIS-I was developed for selecting the final segments to obtain ground truth and CAEIS-II was developed to estimate the area of major crops identified.

FIGURE 6: Overview of the field observation

FIGURE 7: An overview of CAEIS-II system
Crop area estimation per segment per strata. For these estimates, field data were used that had been collected from Razan township in Hamadan province of the Islamic Republic of Iran during the summer of 1997. The formulas used to calculate the estimated areas and the coefficient of variance [Gallego, 1995] are given below. According to Gallego, if \( Z_{hc} \) is the area of cover type \( c \) in the stratum \( h \) of the total area \( D_h \), and \( y_{hc} = Z_{hc}/D_h \), we get the estimators:

\[
\bar{y}_{hc} = \frac{1}{n_h} \sum_{i=1}^{n_h} y_i
\]

\[
Z_{hc} = D_h \bar{y}_{hc}
\]

\[
\text{Var}(\bar{y}_{hc}) = \left(1 - \frac{n_h}{N_h}\right) \frac{1}{n_h(n_h-1)} \sum_{i=1}^{n_h} (y_i - \bar{y}_{hc})^2
\]

\[
\text{Var}(Z_{hc}) = D^2 \text{Var}(\bar{y}_{hc})
\]

For the whole region:

\[
\bar{y}_c = \frac{1}{N} \sum_{h=1}^{H} N_h \bar{y}_{hc}
\]

\[
\text{Var}(\bar{y}_c) = \frac{1}{N^2} \sum_{h=1}^{H} N_h^2 \text{Var}(\bar{y}_{hc})
\]

\[
CV(Z_c) = \frac{\sqrt{\text{Var}(Z_c)}}{Z_c}
\]

where:

- \( y_i \) = the proportion of segment \( i \) covered by cover \( c \) in stratum \( h \)
- \( N \) = total number of segments in the region
- \( n \) = number of segments in sample
- \( n/N \) = the sample fraction (proportion of the region)
- \( D_h \) = area of stratum \( h \)
- \( i \) = segment (1 to \( n \))
- \( Z \) = estimated area
- \( Z_{hc} \) = estimated area of cover type \( c \) in stratum \( h \)
- \( y_{hc} \) = estimated proportion of stratum \( h \) covered by cover type \( c \)
- \( \text{Var} \) = Variance
- \( \bar{y}_c \) = estimated proportion of total area (sum of all strata) covered by crop \( c \)
- \( CV \) = coefficient of variance

A substantial part of the study involved building the prototype system CAEIS-II for area estimation during the implementation phase. CAEIS-II was developed using the database software Microsoft Access in a PC environment for the area estimation process. The advantages of building a system in a PC environment are that it is not as complicated as in a UNIX environment, for example, and most of the users familiar with database concepts in a PC environment can easily handle the system. An overview of CAEIS-II is given in Figure 8. The detailed statistical formula and the data model used in this system can be found in Pradhan [1998].

FIGURE 8: Relationship of CV(%) to area of crops (ha)

RESULTS AND DISCUSSION

The results given in Table 3 are derived from the prototype system CAEIS-II. To assess the accuracy and reliability of the system, the results were compared with results derived by the Agricultural Statistics Information Division (ASID) of the Ministry of Agriculture of I.R. of Iran from the same data. The overall accuracy was 99.8%, which was very satisfactory; it can be concluded that the reliability and the accuracy of the system is acceptable.

The coefficient of variance (CV) is a measure of the accuracy of unbiased area estimates from the ground survey and is given by:

\[
CV(\%) = \frac{\sqrt{\text{Var}(Z_c)}}{Z_c} \times 100
\]

Results obtained from the system were pooled to produce Figure 9, which shows the relationship between the CV and the total estimated area of the crop in the region. The CV decreased with increasing size of the crop area because the standard error, \( SE = \sqrt{\text{Var}(Z_c)} \), decreased. Main crops typically cover areas between 0 and 15,000 ha at this level. From this, it can be concluded that the system works well for the large areas.
Crop area estimation

<table>
<thead>
<tr>
<th>CROP_CODE</th>
<th>DESCRIPTION</th>
<th>IRRIGATED</th>
<th>Area[ha]</th>
<th>CV(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>102</td>
<td>Wheat</td>
<td>Y</td>
<td>15739</td>
<td>30.17</td>
</tr>
<tr>
<td>103</td>
<td>Wheat</td>
<td>N</td>
<td>41310</td>
<td>16.64</td>
</tr>
<tr>
<td>104</td>
<td>Barley</td>
<td>Y</td>
<td>7846</td>
<td>42.13</td>
</tr>
<tr>
<td>105</td>
<td>Barley</td>
<td>N</td>
<td>3831</td>
<td>43.69</td>
</tr>
<tr>
<td>112</td>
<td>Beans</td>
<td>Y</td>
<td>929</td>
<td>67.46</td>
</tr>
<tr>
<td>114</td>
<td>Chickpea</td>
<td>Y</td>
<td>1047</td>
<td>48.16</td>
</tr>
<tr>
<td>115</td>
<td>Chickpea</td>
<td>N</td>
<td>364</td>
<td>95.09</td>
</tr>
<tr>
<td>116</td>
<td>Lentil</td>
<td>Y</td>
<td>95</td>
<td>69.52</td>
</tr>
<tr>
<td>117</td>
<td>Lentil</td>
<td>N</td>
<td>158</td>
<td>95.09</td>
</tr>
<tr>
<td>144</td>
<td>Sugarbeet</td>
<td>U</td>
<td>9</td>
<td>95.09</td>
</tr>
<tr>
<td>154</td>
<td>Melon</td>
<td>U</td>
<td>258</td>
<td>91.16</td>
</tr>
<tr>
<td>156</td>
<td>Watermelon</td>
<td>Y</td>
<td>648</td>
<td>91.16</td>
</tr>
<tr>
<td>160</td>
<td>Cucumber</td>
<td>Y</td>
<td>14</td>
<td>91.16</td>
</tr>
<tr>
<td>162</td>
<td>Squash</td>
<td>U</td>
<td>22</td>
<td>91.16</td>
</tr>
<tr>
<td>166</td>
<td>Other veg.</td>
<td>U</td>
<td>296</td>
<td>55.62</td>
</tr>
<tr>
<td>170</td>
<td>Potato</td>
<td>Y</td>
<td>772</td>
<td>44.28</td>
</tr>
<tr>
<td>172</td>
<td>Onion</td>
<td>Y</td>
<td>45</td>
<td>70.31</td>
</tr>
<tr>
<td>174</td>
<td>Tomato</td>
<td>Y</td>
<td>23</td>
<td>91.16</td>
</tr>
<tr>
<td>176</td>
<td>Pea</td>
<td>U</td>
<td>39</td>
<td>95.09</td>
</tr>
<tr>
<td>202</td>
<td>Alfalfa</td>
<td>Y</td>
<td>11658</td>
<td>34.30</td>
</tr>
<tr>
<td>203</td>
<td>Alfalfa</td>
<td>N</td>
<td>609</td>
<td>66.09</td>
</tr>
<tr>
<td>204</td>
<td>Clover</td>
<td>U</td>
<td>123</td>
<td>91.16</td>
</tr>
</tbody>
</table>

Y = Irrigated, N = Not Irrigated, U = Unknown

CONCLUSIONS

CAEIS is an information system that assists in the design and implementation of an area frame, selection of the sample areas within the frame, and estimation of the areas of major crops. The main advantages of the system include:

The concept of GIS is employed to support spatial information management, analysis of spatial data combined with related thematic data to support the decision-making process, and finally to allow the presentation of results of various processes in a manageable and easily understandable form. Spatial presentation is a natural way of approaching any spatial problem. Visualization of results using GIS technology is one of the most comprehensive and effective forms of presentation and communication.

Using the geographic information concept allows us to combine various forms of information from many different sources and relate them through a common spatial location.

The integration of different data from various sources into a single system improves the function, operation, and performance of the system.

The CAEIS is actually a combination of three different systems - AFS, remote sensing, and CAE. The system uses different types of data from various sources, involves many processes, and, thus, becomes very complex. The CAEIS is based on GIS, which also incorporates remote sensing. All spatial data, including digitized thematic maps, remote sensing images, and tabular data have to be integrated into a single information system to improve the functionality, applicability, and performance of the system as a whole. Hence, the integration of GIS and remote sensing is a very complex task because of the differences in their data acquisition processes and the structure of these data.

REFERENCES


RESUME

Cet article présente une approche vers le développement d'un Système d'Information Géographique (SIG) pour une estimation des surfaces de récoltes afin d'assister des systèmes de prédiction des récoltes au niveau régional. La conception du système vise à aider l'estimation des zones de récoltes au moyen d'échantillonnage sélectif de surfaces (AFS), télédétection et une combinaison de AFS et télédétection. Cependant, le concept détaillé a été exécuté pour aider AFS seulement. Plus tard, un
Crop area estimation

systeme a été réalisé qui peut assister un lever AFS, des travaux de terrain, le traitement de données ainsi que le contrôle qualité des données d’entrée. Sur ces bases deux prototypes systèmes ont été développés, appelés CAEIS - I et CAEIS - II.

CAEIS - I a été développé en utilisant le “Arc Macro Language” (AML) d’Arc/Info dans un environnement UNIX, et CAEIS - II a été développé en utilisant Microsoft Access sur PC. Plus tard, les fonctions du système ont été testées et évaluées, en utilisant des données terrain collectées à Razan dans la province de Hamadan de la République islamique d’Iran pendant l’été 1997. Les résultats ont montré un accord satisfaisant entre la zone de produits agricoles principaux dérivés du système développé et des zones obtenues de la Division de l’Information des Statistiques Agricoles (ASID) du Ministère de l’Agriculture, I.R. d’Iran.

RESUMEN
Este artículo presenta un enfoque para el desarrollo de un sistema de información geográfica (SIG) con fines de estimar áreas cultivadas para apoyar sistemas de predicción de cultivos a nivel regional. El diseño general del sistema tuvo como objetivo el de ayudar a estimar áreas de cultivos mediante muestreo selectivo de áreas, teledetección, y una combinación de muestreo y teledetección. Se elaboró un diseño más detallado para apoyar especialmente el muestreo de áreas. Posteriormente, se realizó un sistema capaz de apoyar específicamente el diseño del muestreo de áreas, trabajo de campo, procesamiento de datos y evaluación de la calidad de los datos de entrada. En base a esto, se diseñaron dos prototipos de sistema, llamados CAEIS-I y CAEIS-II. El sistema CAEIS-I fue desarrollado con el lenguaje Arc Macro Language (AML) del programa Arc/Info basado en UNIX, y el sistema CAEIS-II fue desarrollado con Microsoft Access en PC. Posteriormente, se probaron y evaluaron las funciones del sistema con datos de campo recogidos durante el verano de 1997 en el municipio de Razan, provincia de Hamadan de la República Islámica de Irán. Los resultados muestran una buena concordancia entre el área de cultivos principales obtenida con el sistema que se desarrolló y las áreas estimadas por la división de información estadística agrícola (ASID) de Ministerio de Agricultura, República Islámica de Irán.
Human interactions in soil and geomorphic processes in Nepal: the role of soil fertility in degradation and rehabilitation processes

Hans Schreier\textsuperscript{1}, Sandra Brown\textsuperscript{1}, Pravakar B Shah\textsuperscript{2}, Bhuban Shrestha\textsuperscript{2}, Gopal Nakarmi\textsuperscript{2} and Richard Allen\textsuperscript{1}

\textsuperscript{1} Institute for Resources and Environment, University of British Columbia, Vancouver, BC V6T1Z3, Canada (phone: +604 822 4401; fax: +604 822 9250; e-mail star@interchange.ubc.ca)

\textsuperscript{2} PARDYP Project, International Centre for Integrated Mountain Development (ICIMOD), G.P.O. Box 3226, Katmandu, Nepal

KEYWORDS: Soil erosion, nutrient losses, sediments, phosphorus, land use change, land degradation, nutrient decline, nutrient budgets, rehabilitation processes, GIS, Himalayas.

ABSTRACT

A GIS approach was used in the determination of soil fertility status in the Jhikhu Khola watershed. The watershed was stratified by topography, climate, soil type and land use using GIS overlay techniques. A (2 \times 2 \times 2 \times 4) factorial approach served as the sampling framework to produce single and combined nutrient deficiency GIS maps. Soil acidity, phosphorus availability and lack of base cations were identified as the key soil fertility issues, with forests having the poorest overall soil nutrient status, followed by rangeland, rainfed agriculture and irrigated agriculture. Nutrient budget calculations revealed significant annual deficits in phosphorus for maize rotations but only minor deficits for rice rotations. The effect of inherited biophysical conditions on nutrient deficits were analyzed statistically and displayed using the GIS overlay method. Poor fertility and annual deficits were linked to erosion and sedimentation by documenting annual erosion losses from rainfed agriculture and degraded areas. Over a 7 year period, typical erosion from maize rotations in rainfed agriculture averaged 19 t/ha annually, while erosion from degraded sites were 75-100 percent higher. Significantly different sediment rating curves were obtained from two micro-watersheds, one with 14 percent and the other 25 percent degraded areas. Annual sediment contributions to the micro-watersheds confirmed that degraded sites increase the suspended sediment load, particularly under lower stream flow conditions. The discharge-sediment regression line was significantly higher during the pre-monsoon period than during the monsoon season. GIS tools were found to be useful in all parts of the analysis.

INTRODUCTION

Resource dynamics were examined in the Bela catchment, a 1,930 ha sub-watershed of the Jhikhu Khola basin, located in the Middle Mountains of Nepal, 40 km east of Katmandu, Nepal. A long-term study is underway there to determine soil fertility dynamics under increasing population growth and (as a result) land use intensification. In previous work [Schreier et al, 1995; Brown, 1997] it was shown that over the past 15 years land use intensification had increased from an average of 1.8 annual crop rotations to 2.6. At the same time, agricultural expansion into marginal land has increased by 5 percent. The question of maintaining soil fertility in both intensive and marginal agriculture needs to be raised because inputs are usually insufficient and erosion due to cultivating marginal lands results in high nutrient losses. In general, soil fertility decline leads to decreases in productivity and lowers vegetation cover, which leads to increased erosion. The aims of this paper are to document the status of soil fertility under different biophysical and management conditions, to relate management problems to erosion, and to show the effects of erosion on sediment transport in watersheds. The GIS overlay technique, nutrient budget analysis methods, erosion plot measurements and suspended sediment determination in micro-watersheds were used to link soil fertility decline and erosion/degradation processes.

The Jhikhu Khola catchment represents one of the most intensively used watersheds in Nepal and while the majority of the population work as subsistence farmers, a new trend has developed over the past 10 years with the introduction of tomato and potato. Market access to Banepa and Katmandu has resulted in a significant change from subsistence farming to cash crop production. While these developments have many positive aspects, concerns have to be raised about maintaining soil fertility as these new crops have high nutrient demands and inputs such as manure and fertilizers are limited. Long-term declines in soil fertility lead to loss in productivity and ultimately land degradation. Data from our study suggest that conditions in the watershed are reaching a threshold level where interventions are needed to prevent further decline that might lead to more widespread land degradation, with serious concerns for future food production.
Much has been written about Himalayan degradation and as noted by Ives & Messerli [1989] the myth persists that poor management of the resources is responsible for extensive flooding in the lowlands. Recent scientific evidence has shown clearly that human impact on large Himalayan rivers is insignificant [Messerli & Ives, 1997; Hoffer & Messerli, 1997], and that only at the < 20 km$^2$ micro-scale watershed level can human impact be identified. Even at that scale impacts are delayed and not obvious. Only after long-term studies is it possible to document decline in soil fertility, which leads to declines in productivity, increased soil erosion, and ultimately higher sediment loads in streams, which have off-site impacts. While this process has serious impacts on the livelihood of the local population in the mountains, there is no evidence that this type of human impact in the mountains affects land use and flooding in the Ganges lowland. Therefore it is rehabilitation of the nutrient pool that is critical, if we hope to sustain productivity in Nepalese mountain agro-forestry systems.

METHODS AND TECHNIQUES

The key factors that affect soil development in Nepal include climatic and topographic conditions, parent materials, length of soil forming processes, land cover and land management. These factors need to be considered in the sampling design in order to conduct a diagnostic soil fertility survey, particularly if we hope to determine the relative importance of inherited conditions versus those created by management. A comprehensive GIS database was developed for key resource factors and with GIS overlay techniques the watershed was divided into two elevation classes (< and > than 1200 m) and two aspect classes (dominantly north facing vs. dominantly south facing), which together account for the topographic/climatic factors. The parent material factor was isolated by dividing the watershed into areas dominated by red soils (mostly on phyllite and metamorphosed schist) and the non-red soils dominated by silicarich rocks (quartzite, sandstone, siltstone). The red soils represent the oldest and the most leached soils of the landscape and reflect the time formation factor. The land management factor was isolated by dividing the landscape into four land use classes consisting of irrigated and rainfed agriculture, and range land and forests, and by obtaining input and production information from farm interviews.

Using GIS and overlay techniques the watershed was stratified into a $2 \times 2 \times 2 \times 4$ factorial classification, which theoretically resulted in 32 unique combinations of factor polygons. Since forests are limited to a few selected areas, irrigation is only feasible in the lower gently sloping areas and red soils are restricted to the lower elevations, only 22 of the possible 32 combinations of factors were observed in the watershed. For each of the 22 combinations, 10 soil samples were selected at random from 10 different polygons in the watershed; these served as a basis to characterize the overall conditions. A further subdivision on the basis of slope was considered but would have resulted in an unmanageable sample set of 660 samples. However, as a result of selecting the 10 samples in each factor combination class, slope variations were large. The Mann Whitney U-test and analysis of variance was used to determine the effect and contribution of each factor to the overall variability. At the same time, land management data for the agricultural land uses were obtained through 75 farm interviews.

Well-mixed bulk soil samples, consisting of 10 sub-samples, were collected in each of the 220 field, grass and forest sites. The 0-15 cm soil depth layer was analyzed for pH, carbon, phosphate, exchangeable captions, CEC and base saturation using standard methods described by Page et al [1982]. Soil fertility maps were produced using the GIS factor maps combined with the soil chemical data. The mean values for each factor type were used to determine soil fertility status, and a nutrient budget model described by Brown [1997] and Brown et al [1999] was used to determine the extent of nutrient deficit for the common staple crops of the watershed. Comparisons were then made between nutrient deficits and soil fertility.

Soil erosion has been measured in five agricultural fields since 1992 and in two plots on degraded sites since 1997. The plots are approximately 100 m$^2$ and their runoff and soil loss is collected in storage containers below each plot after every major storm.

Two sediment sampling stations in two sub-watersheds were used to compare sediment loads from a well-managed and a degraded sub-watershed of similar size. A sediment rating curve was established for the Andheri (530 ha) and the Dhap Khola (570 ha) sub-watersheds for both the pre-monsoon and the monsoon seasons. In addition, the link with soil fertility decline was made by analyzing the phosphorus content in a number of sediment samples from between the two seasons. The Bray extraction was used to compare the phosphate values in the soils, the erosion plot samples, and the stream sediments.

RESULTS

SOIL FERTILITY STATUS

The soil fertility conditions in the watershed are shown in Table 1. The results show that soil acidity, phosphorus content and base saturation are the key limiting factors for optimum plant production. Elevation, aspect and soil type all have a significant effect on soil conditions and
sites under forest were poorest, followed by rangeland and rainfed agricultural sites. Only irrigated fields showed values that are considered moderately adequate for most of the staple crop production. In the early 1950s many forested areas were converted to agriculture and as shown by Schreier et al (1994) the soil fertility of these converted sites improved while the fertility of the remaining forests declined due to excessive removal of firewood, fodder and litter.

The differences between the 22 combinations of factors were determined using the Mann Whitney U-test and analysis of variance; the mean values where then assigned to each of the GIS factor classes to generate pH, phosphorus and base saturation maps for the watershed. A combined soil fertility deficiency map was produced for the pH-P-BS combination using the GIS overlay technique (Figure 1). Each variable was divided into low, medium and high classes, and sites were combined into: low in all three variables; low in at least one of the three variables; and medium-high, and high in all three variable categories. The resulting GIS analysis revealed that 39 percent of the watershed fell into the deficiency class for all three variables, and only 13 percent of the watershed showed satisfactory values in all three variables.

SOIL PHOSPHORUS DEFFICITS AND SURPLUSES
The soil fertility status maps only reveal a snapshot of conditions and do not reflect the dynamic cycling of soil nutrients. To document the dynamics, an annual nutrient budget was calculated for the 114 agricultural fields for which input and management data had been collected. If the inputs equal crop uptakes and nutrient losses, then there should be neither a nutrient surplus nor a deficit over the annual cropping cycle. A significant annual deficit implies that the nutrient pool is being depleted, leading to long term decline in soil productive capacity. (Details of the budget model and the rates used are provided by Brown (1997) and Brown et al (1999)). Only the phosphorus calculations are provided in this paper. The surplus/deficit calculations were made for maize and rice production systems and the results are shown in Table 2 and Figure 2.

As shown in Table 2, significant deficits were observed in the maize production system, where insufficient inputs and losses by erosion resulted in annual median deficit values per 15cm soil depth of between 34 kg/ha and 98 kg/ha. Inherent biophysical factors such as aspect, elevation and soil type have a significant impact on biomass productivity and consequently the annual deficits. Sites with higher elevations, southern exposures and red soils had the greatest imbalance.

The spatial distribution of annual P-deficits indicates that about 50 percent of all agricultural fields have annual deficits per 15 cm soil depth > 35 kg/ha, and these are to be predominantly found on rainfed upper elevation sites where inputs are limited and erosion is more significant.

### Table 1: Soil fertility conditions stratified by soil factors investigated (mean values)

<table>
<thead>
<tr>
<th>Soil factor</th>
<th>Elevation</th>
<th>Aspect</th>
<th>Soil type</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1200 meters</td>
<td>&gt;1200 meters</td>
<td>N</td>
<td>S</td>
</tr>
<tr>
<td>pH</td>
<td>4.9</td>
<td>4.7</td>
<td>4.8</td>
<td>4.9</td>
</tr>
<tr>
<td>CEC (cmol/kg)</td>
<td>10.1</td>
<td>11.2</td>
<td>11.0</td>
<td>10.6</td>
</tr>
<tr>
<td>Exch. Ca (cmol/kg)</td>
<td>3.10</td>
<td>4.18</td>
<td>4.09</td>
<td>3.40</td>
</tr>
<tr>
<td>Exch. Mg (cmol/kg)</td>
<td>1.14</td>
<td>1.56</td>
<td>1.19</td>
<td>1.60</td>
</tr>
<tr>
<td>Exch. K (cmol/kg)</td>
<td>0.28</td>
<td>0.28</td>
<td>0.33</td>
<td>0.23</td>
</tr>
<tr>
<td>Base saturation (%)</td>
<td>46.7</td>
<td>55.1</td>
<td>53.2</td>
<td>50.2</td>
</tr>
<tr>
<td>Carbon (%)</td>
<td>1.02</td>
<td>0.98</td>
<td>0.88</td>
<td>1.11</td>
</tr>
<tr>
<td>Available P (mg/kg)</td>
<td>19.6</td>
<td>14.5</td>
<td>20.9</td>
<td>12.2</td>
</tr>
</tbody>
</table>
TABLE 2: Annual phosphorus deficits (kg/ha per 15 cm soil depth annually) in maize and rice cropping systems by site factor conditions (median values).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Maize No. of Farms</th>
<th>Phosphorus deficits</th>
<th>Rice No. of Farms</th>
<th>Phosphorus deficit/surplus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern aspect</td>
<td>35</td>
<td>-48</td>
<td>30</td>
<td>-3</td>
</tr>
<tr>
<td>Southern aspect</td>
<td>30</td>
<td>-98</td>
<td>19</td>
<td>-16</td>
</tr>
<tr>
<td>Elevation &lt; 1200 m</td>
<td>31</td>
<td>-41</td>
<td>39</td>
<td>-14</td>
</tr>
<tr>
<td>Elevation &gt; 1200 m</td>
<td>34</td>
<td>-89</td>
<td>10</td>
<td>+5</td>
</tr>
<tr>
<td>Soil type red</td>
<td>30</td>
<td>-78</td>
<td>20</td>
<td>#</td>
</tr>
<tr>
<td>Soil type non-red</td>
<td>35</td>
<td>-34</td>
<td>29</td>
<td>-7</td>
</tr>
</tbody>
</table>

Based on Mann Whitney-U test between pairs; significance level * p = 0.1, ** p = 0.05

# No rice was grown on red soils

FIGURE 2: Spatial distribution of P deficit/surplus

SOIL EROSION
Erosion from agriculture is particularly of concern in rainfed systems on sloping land; the results of the erosion plot study over the past 7 years are shown in Figure 3. What is clearly apparent is that the variability in erosion between sites was of the same order of magnitude as year-by-year variation. The results from four agricultural plots with similar slope angles revealed erosion rates that differed by one order of magnitude due to differences in infiltration and percolation rates. These differences are similar to the within-plot year-by-year variability, which ranged between 1 t/ha per year and 38 t/ha per year. From Figure 3 it is evident that on moderately drained sites (plots 2 and 3) erosion from rainfed agricultural land averaged between 18 t/ha per year and 20 t/ha per year. Two plots on degraded sites were added to the monitoring program in 1997 and the results show that at least during the first year of monitoring the erosion from these sites was twice that on rainfed agricultural sites. In addition, it was found that 60-80 percent of annual erosion occurs in two of the major storms that predominantly occur during the pre-monsoon season – at the end of the dry season, when vegetation cover is at a minimum. This implies that pedological and topographic conditions, vegetation cover, and pre-monsoon rain are key indicators of the erosion risk. Soil fertility status and nutrient deficit are contributing factors because they affect productivity. As vegetation cover decreases, the erosion risk increases and once sites are degraded they become very difficult to rehabilitate [Schreier et al, 1998, 2000]

FIGURE 3: Annual erosion rates (kg/ha per 15 cm soil depth annually) from erosion plots under rainfed agriculture and degraded site (average value over 7 years from agricultural fields only)

SUSPENDED SEDIMENT RATING CURVES IN MICRO-WATERSHEDS
Concern for sediment losses and annual sediment budgets demands consideration of sediment sources, transport processes, deposition, and losses of suspended sediment from the micro-watershed. Degraded sites are the source of major volumes of sediments as the erosion plot study shows. However, the plot study cannot be used directly to calculate annual sediment loads at the micro-watershed scale because re-deposition of sediments occurs within the channel system and through water diversions to irrigated rice fields. To document the effect of degraded sites on the suspended sediment load at the outlet of micro-watersheds, we compared the sediment rating curves of two similar size micro-watersheds (Table 3).

A GIS land use map was produced for each of the two micro-watersheds and the extent of degraded area (defined as surfaces with little permanent vegetation cover and with evidence of rill and gully erosion) was delineated on 1:15,000 scale aerial photos through aeri-
These data show that the link between soil fertility, decline, landscape degradation, erosion and sediment decline can be made effectively by combining field measurements with GIS and budget modeling techniques. Interestingly, the phosphorus content in the suspended sediments reveals a negative relationship with discharge ($r^2 = -0.56$, Schreier et al [1998] and Carver [1997]) and this suggests that the lower storm conditions during the pre-monsoon season are likely more critical in terms of phosphorus loss than the high-flow conditions. The change in sediment particle size (more silt and clay fractions at low flow and a higher sand fraction at high flow) is likely to be the cause of this negative relationship since phosphorus is more strongly attached to the clay fraction.

Finally, the soil-fertility-degradation-erosion-sediment transport cycles are likely to be restricted to micro-scale watersheds in which the human impact can be isolated. At the meso- to macro-watershed scale these relationships become very difficult to isolate, because cumulative effects and compounding factors affect the processes of re-deposition and distribution of sediments and nutrients.

**CONCLUSIONS**

The results of this research showed that GIS techniques could be used effectively as a tool in investigations linking soil fertility to land degradation, erosion and sediment transport. At the micro-watershed scale our research shows that the human impact on soil fertility was clearly evident in that the overall nutrient status was poor with most soils falling into the low pH, low available phosphorus and low base saturation ranges. Rainfed agriculture suffers from insufficient nutrient input, particularly on sites at higher elevations, with a southern aspect and red soil in maize-dominated rotation systems. Nutrient budget calculations that account for nutrient uptake, losses and inputs into agriculture were used to determine farm balances. As shown for phosphorus, median annual deficits per 15 cm soil depth of 34-98 kg/ha were common in the watershed.

Such conditions lead to decline in productivity and will enhance erosion as was documented in the comparison of erosion rates between agricultural sites and degraded sites. The latter have 75-100 percent higher erosion rates than on rainfed agricultural plots. Site conditions, vegetation cover, and the timing of storms are considered as the key factors determining erosion rates. The pre-monsoon season presents the greatest risk for erosion. The impact of degraded areas on sediment loads at the micro-watershed level was documented by comparing two watersheds of similar size. The results showed that both monsoon and pre-monsoon sediment rating curves were significantly higher under low-flow conditions in the watershed with a 25 percent degraded surface area than in the watershed with degraded sites of 14 percent. Human impact on nutrient cycling, erosion and sediment transport was successfully documented in this micro-scale watershed study. However, we postulate that human impact becomes less important and is difficult to document as one moves from the micro-scale to meso- and macro scale watersheds.
REFERENCES

RESUME
Une approche SIG a été utilisée dans la détermination de l’état de fertilité du sol dans le bassin Jhikhu Kholo. Le bassin a été stratifié par la topographie, le climat, le type de sol, et l’utilisation des sols à l’aide des techniques de superposition SIG. Une approche factorielle (2 x 2 x 2 x 4) servait de cadre d’échantillonnage pour produire des cartes SIG simples et combinées représentant des déficiences en d’éléments nutritifs. L’acidité du sol, la disponibilité de phosphore et le manque de cations de base ont été identifiés comme les problèmes clés de la fertilité des sols; c’est dans les forêts que l’on trouve l’état de nutrition global du sol le plus pauvre, suivi par les pâturages extensifs, l’agriculture sèche et l’agriculture irriguée. Des calculs de quantités d’éléments nutritifs ont révélé des déficits annuels significa-

RESUMEN
Se utilizó un enfoque de SIG para evaluar el estado de la fertilidad de suelos en la cuenca del Jhikhu Khol. Se estratificó la cuenca por topografía, clima, tipo de suelo y uso de las tierras mediante técnicas de superposición en SIG. Se aplicó un esquema factorial de 2x2x2x4 como marco de muestreo para producir mapas en SIG mostrando deficiencias individuales y combinadas de nutrientes. La acidez de suelo, la disponibilidad de fósforo y la falta de cationes básicos se identificaron como los problemas clave de la fertilidad de suelos. Los bosques tienen el nivel general de nutrientes más pobre, seguidos por los pastos, la agricultura de secano y la agricultura de riego. Los cálculos de balance de nutrientes revelaron déficits anuales significativos de fósforo en rotaciones de maíz, pero déficits menores en rotaciones de arroz. Se analizó estadísticamente el efecto de las condiciones biophysiques heredadas sobre los déficits de nutrientes y se desplegaron los resultados mediante el método de superposición en SIG. Se relacionaron la baja fertilidad y los déficits anuales de nutrientes con erosión y sedimentación a partir de la medición de las pérdidas anuales de suelo por erosión en áreas de agricultura de secano y áreas degradadas. En base a mediciones durante un periodo de siete años, el promedio de la pérdida de suelo en rotaciones de maíz de secano era de 19 t/ha por año, mientras que la erosión en áreas degradadas era 75-100% mayor. Se obtuvieron curvas de estimación de sedimentos significativamente diferentes en dos micro-cuencas, una con 14% de áreas degradadas y la otra con 25%. La producción anual de sedimentos en las dos micro-cuencas confirmó que los sitios degradados incrementaban la carga de sedimentos en suspensión, particularmente en condiciones de bajo flujo fluvial. La pendiente de la línea de regresión entre caudal y sedimentos era significativamente más pronunciada durante el periodo pre-mozónico que durante la estación monzónica. Las herramientas de SIG resultaron ser útiles en todas las partes del análisis.
Identification and accessibility analysis of rural service centers in Kendrapara District, Orissa, India: a GIS-based application*

Ranjan Kumar Mallick and Jayant Kumar Routray

Regional and Rural Development Planning, School of Environment, Resources and Development, Asian Institute of Technology (AIT) Bangkok, PO Box 4, Klong Luang, Pathum Thani 12120, Thailand (phone: +66 2 524 5604; fax: +66 2 524 6431; e-mail: routray@ait.ac.th; e-mail: ranjan@gg.iitkgp.ernet.in)

KEYWORDS: service center planning, rural development, accessibility, GIS application, India

ABSTRACT

The methodology in this study is based on fieldwork, primary and secondary data collection, and analysis and displaying of the results. GIS was used in different ways, such as in preparing coverage for interpretation and in planning and decision-making. Different categories of distance were used to determine the delineation of service area of selective functions. The result shows that within a 5 km radius most of the study area is covered except for a few functions such as market, health and multi-nodal centers. The gap between served areas is small. However, there are some pockets of unserved areas that need immediate service facilities. GIS was particularly useful in creating a database required for spatial planning. It is applied more and more in developed countries as a main tool in the field of urban and regional planning.

INTRODUCTION

Developing rural areas is a major concern for almost all governments in developing countries of the world. Most of the population in rural areas is dependent on agriculture and allied activities for its livelihood. Rural areas are typically not only poverty stricken but also backward in fulfilling basic minimum needs in terms of education, health, and a variety of community facilities and service functions. It is commonly not possible to provide adequate institutional and service facilities in rural areas due to financial resource constraints. Such institutional and service facilities support and promote production functions, agricultural marketing, extension and other activities, and improving access to central places having those facilities is an important task of many development agencies at present.

The debate on urban functions in rural development versus location and allocation of services in the context of rural development has been an ongoing issue among researchers since the late 1970's. So far action taken has concentrated on supporting and strengthening the rural development process through a network of service centers for production, consumption and service functions. Service centers are thus defined as central places that serve surrounding settlements and population by providing various social and economic functions and delivering goods and services that are not ubiquitous.

The broad objective of this study is, using GIS-related methods and techniques, to identify and make an accessibility analysis of existing service centers for the purpose of planning the distribution of social and economic functions and services. Specifically, this paper attempts to analyze the distribution of settlements with central functions and services, assess the hierarchy of settlements, identify the service centers and unserved areas based on people's interaction and accessibility, and finally to formulate a development strategy in order to meet the service gaps and strengthen overall rural development of the district.

There is already a large number of research-outputs, review and case studies available that address the theoretical, conceptual, methodological and operational issues of rural service center planning in the context of rural development. It is not intended here to make a fresh review to illustrate the role of rural service centers. Some of the interesting research contributions addressing different aspects of service centers made by Rondinelli [1984], Sarma et al [1984], Kammeier & Meheta [1985], Kammeier [1986], Routray & Singh [1987], Ruston [1993], Rietveld [1993] and Tewari [1992 & 1995] are worth mentioning here. These works have provided the orientation on and familiarity with the current situation of research in this area, and further helped in preparing appropriate methods for carrying out our research in a systematic way.

* This paper is based on part of an MSc thesis by Mallick [1998] carried out at AIT, Bangkok.
DATA AND METHODS

An attempt has been made in this study to collect data from both primary and secondary sources. Primary data comprised mobility of people and interaction with selected functional-cum-nodal centers in the district (in this case nine centers are currently functioning as sub-district headquarters). Secondary data mainly included the collection of 1:50,000-scale base maps that mark the location of settlements, administrative boundaries, and functional attributes covering education, health, market, bank, administration, veterinary, post and telecommunication, bus stops and other services. The population size of settlements was also collected and used for analysis.

The digital spatial database of the district was created for location and polygonal analysis. The attribute database by settlement was prepared for functional hierarchy analysis. The sociogram (people’s mobility and interaction with the centers), accessibility and functional gap analyses were attempted to assess the functional needs and identification of service centers for the purpose of analysis. ArcInfo was used to establish the database and ArcView was used for map preparation and analysis.

STUDY AREA

Kendrapara district, one of the coastal districts of Orissa State in India, was chosen for this study. The district has a geographical area of 2180 km² and a population (in 1991) of 1,104,501, which constitutes 3.63 percent of the state population. The population density is 460 persons per square kilometer as against 203 for the state as a whole. Administratively, the district is divided into nine blocks (sub-districts). Physiographically the district is part of a fertile coastal plain, dissected by a number of distributaries of the major river systems of the Brahmani, Baitarani and Mahanadi, which hinder the establishment of road connectivity among the major settlements of the district.

The economy of the district is primarily rural and based on agriculture and allied activities. More than 75 percent of the total population earn a livelihood from the primary sector. Agricultural activities are frequently prone to flood and are occasionally affected by drought and cyclones. There are 1389 inhabited rural settlements in the district with populations ranging from less than 200 to more than 5000.

The provision of services in rural areas of the district is limited due to various factors. Poor quality and inadequacy of the transportation network make access to places difficult. Low level of demand, a low level of threshold of population needed to support services and, finally, inadequate budgets for supporting facilities and services limit opportunities for efficient use of existing facilities.

<table>
<thead>
<tr>
<th>TABLE 1: Distribution of Sample Settlements by Size of Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Size Class</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>&lt; 200</td>
</tr>
<tr>
<td>200-500</td>
</tr>
<tr>
<td>500-1000</td>
</tr>
<tr>
<td>1000-2000</td>
</tr>
<tr>
<td>2000-5000</td>
</tr>
<tr>
<td>Above 5000</td>
</tr>
<tr>
<td>All Classes</td>
</tr>
</tbody>
</table>
The major functional categories chosen for study cover attributes that include education, market, bank, administration, veterinary, post and telecommunication, bus stops and other services; there are 29 functional attributes (Table 2). A large proportion of settlements (93 percent of the total) had less than five functional attributes. The remaining settlements (7 percent) had a minimum of five functional attributes and in few cases as many as 25.

**TABLE 2**: Central functions, functional categories and number of functional units under each category.

<table>
<thead>
<tr>
<th>Broad Functional Category</th>
<th>Functional Types</th>
<th>Number of Functional Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>1. High School</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td>2. College</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>3. City Training</td>
<td>2</td>
</tr>
<tr>
<td>Health</td>
<td>4. Primary Health Centers</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>5. Community Health Centers</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>6. Upgraded Primary health center</td>
<td>3</td>
</tr>
<tr>
<td>Market</td>
<td>7. Periodic Market</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>8. Daily market</td>
<td>10</td>
</tr>
<tr>
<td>Bank</td>
<td>9. Bank</td>
<td>4</td>
</tr>
<tr>
<td>Administrative center</td>
<td>10. Gram Panchayat</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>11. Revenue In Charge</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>12. Block Headquarters</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>13. Tahasil</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>14. Police Station</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>15. Police Outpost</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>16. Police Circle in Charge</td>
<td>3</td>
</tr>
<tr>
<td>Veterinary Dispensary</td>
<td>17. Livestock Aid centers</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>18. Veterinary Dispensary</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>19. Artificial Insemination</td>
<td>14</td>
</tr>
<tr>
<td>Post and Telecom.</td>
<td>20. Sub Post Office</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>21. Telephone</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>22. Public Call Office</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>23. Head and Sub post office</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>24. Telephone Exchange</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>25. Bus Stop</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>26. Medicine Store</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>27. Sports Centers</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>28. Agricultural Extension Center</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>29. Fire Station</td>
<td>3</td>
</tr>
</tbody>
</table>

**FUNCTIONAL COMPOSITE INDEX AND HIERARCHY OF SETTLEMENTS**

To understand the relative importance and to establish the functional hierarchy of settlements, it is essential to prepare a composite index based on occurrence of functions with frequency of functional units/establishments distributed by settlement. Through different studies in the past, several methods of computing a functional composite index have evolved, all of which are well explained by Sarma et al [1984]. The technique of computing a composite index as adopted in this study is:

\[ C_j = \frac{\sum W_i F_i}{\sum F_i} \]

Where:
\( C_j \) = functional composite index of the jth settlement,
\( W_i \) = weight of the ith subfunction,
\( F_i \) = number of functional establishments under ith subfunction,

\( i = 1 \ldots 29 \)

The weight \( W_i \) is calculated as the ratio of mean threshold population of the ith subfunction to the least mean threshold of population occurring among the selected attribute types of subfunction. The mean threshold of population is taken as the mean population of settlements having ith function. This is applied for all other functions used for this study. Table 3 presents functional weights for all 29 sub-functions. The police outpost function has the unit weight (1), which is the least among all the functions and the telephone exchange function has the highest weight (38.82).

With the above technique and mathematical formula, the functional composite indices were computed for all the settlements. The composite index value of settlements ranges from 1.17 to 4.54. The settlements were further categorized in six groups, based on composite index value to which a mean and standard deviation grouping technique was applied. The results are presented in Table 4.

It is evident that 95 percent of the selected settlements have very limited functions and appear in the lower orders. There are only three higher order centers, one in each of the 4th, 5th and 6th orders. There are 15 centers in the 3rd order but these are very important in fulfilling most of the requirements at present. In reality all 18 centers ranging from 3rd to 6th orders serve higher order functions. The higher centers are usually known as multifunctional centers. Out of the eighteen higher order centers, nine of them belong to existing administrative-cum-functional nodal centers. The classification of settlements into different groups/orders thus helps firstly in establishing their relative importance and status in the context of the total settlement system, and secondly guides the selection of a few of them for strengthening as service centers in order to promote rural development in the district.

**MOBILITY OF PEOPLE AND INTERACTION WITH MULTIFUNCTIONAL SERVICE CENTERS**

A primary survey was conducted in nine centers (existing sub-district/block headquarters) to understand and assess the concentration of numbers of commercial establishments by types broadly categorized as retail and personal, agricultural, repairs and other services operating at present (Table 5). The total number of functional units of
all types is a simple indicator of importance of these nodal centers. About 36 percent of the total commercial establishments were found in the district headquarters (Kendrapara), followed by Pattamundai (15 percent) and Aul (11 percent). These three centers obviously emerge as prominent nodal centers. Kendrapara, the district headquarters, has the largest number of commercial establishments and serves the whole district including the center itself. Garadapur, Rajkanika and Rajnagar are the next lowest order centers in terms of commercial activities. The primary survey also assessed the frequency of the mobility of people to these centers. People from villages within 2-5 km of distance interact most frequently, either by walking or bicycling. These centers get crowded during the evenings with people from nearby villages who have finished their daily agricultural and household work. The purpose of interaction is obviously linked to meeting their day-to-day consumption, production-related, personal and other service needs. In general the daily commuters that frequently interact with these centers are limited to distances of 5 km, with the maximum distance extending perhaps to 10 km. This gives on the one hand a fair idea about the range of goods and services, and also indicates the willingness of people to commute by foot and bicycle. The spatial picture of interaction is presented in a ray diagram in Figure 1, from which it is evident that a major part of the district seems to be unserved. Further analysis is made to identify served and unserved areas of the district.

TABLE 3: Assigned functional weights by mean threshold population method

<table>
<thead>
<tr>
<th>Function</th>
<th>No. of Functional Units</th>
<th>Mean Population</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Agricultural Extension Center</td>
<td>16</td>
<td>1377</td>
<td>1.52</td>
</tr>
<tr>
<td>2. Artificial Insemination Center</td>
<td>14</td>
<td>1642</td>
<td>1.82</td>
</tr>
<tr>
<td>3. Bank</td>
<td>59</td>
<td>1801</td>
<td>1.99</td>
</tr>
<tr>
<td>4. Block Headquarters</td>
<td>9</td>
<td>1233</td>
<td>1.36</td>
</tr>
<tr>
<td>5. Bus Stop</td>
<td>50</td>
<td>1511</td>
<td>1.67</td>
</tr>
<tr>
<td>6. Community Health Center</td>
<td>4</td>
<td>1126</td>
<td>1.24</td>
</tr>
<tr>
<td>7. College</td>
<td>27</td>
<td>1641</td>
<td>1.81</td>
</tr>
<tr>
<td>8. Teachers’ Training School</td>
<td>2</td>
<td>1412</td>
<td>1.56</td>
</tr>
<tr>
<td>9. Daily Market</td>
<td>10</td>
<td>5133</td>
<td>5.69</td>
</tr>
<tr>
<td>10. Fire Station</td>
<td>3</td>
<td>12889</td>
<td>14.2</td>
</tr>
<tr>
<td>11. Gram Panchayat</td>
<td>205</td>
<td>1538</td>
<td>1.70</td>
</tr>
<tr>
<td>12. Head and Sub-Post Office</td>
<td>8</td>
<td>1502</td>
<td>1.66</td>
</tr>
<tr>
<td>13. High School</td>
<td>262</td>
<td>1468</td>
<td>1.62</td>
</tr>
<tr>
<td>14. Livestock Aid Center</td>
<td>29</td>
<td>1286</td>
<td>1.42</td>
</tr>
<tr>
<td>15. Medicine Store</td>
<td>28</td>
<td>2605</td>
<td>2.88</td>
</tr>
<tr>
<td>16. Police Outpost</td>
<td>6</td>
<td>902</td>
<td>1.00</td>
</tr>
<tr>
<td>17. Public Call Office</td>
<td>9</td>
<td>5358</td>
<td>5.94</td>
</tr>
<tr>
<td>18. Periodic Market Center</td>
<td>25</td>
<td>3401</td>
<td>3.77</td>
</tr>
<tr>
<td>19. Primary Health Center</td>
<td>42</td>
<td>1651</td>
<td>1.83</td>
</tr>
<tr>
<td>20. Police Circle Office</td>
<td>3</td>
<td>2229</td>
<td>2.47</td>
</tr>
<tr>
<td>21. Sub Post Office</td>
<td>43</td>
<td>1368</td>
<td>1.51</td>
</tr>
<tr>
<td>22. Sports Center</td>
<td>18</td>
<td>1709</td>
<td>1.89</td>
</tr>
<tr>
<td>23. Tahsil Office</td>
<td>7</td>
<td>1286</td>
<td>1.42</td>
</tr>
<tr>
<td>24. Artificial Insemination Center</td>
<td>1</td>
<td>35015</td>
<td>38.82</td>
</tr>
<tr>
<td>25. Telegraph Office</td>
<td>18</td>
<td>1599</td>
<td>1.77</td>
</tr>
<tr>
<td>26. Veterinary Dispensary</td>
<td>15</td>
<td>1718</td>
<td>1.90</td>
</tr>
<tr>
<td>27. Daily Market</td>
<td>10</td>
<td>5133</td>
<td>5.69</td>
</tr>
<tr>
<td>28. Fire Station</td>
<td>3</td>
<td>12889</td>
<td>14.2</td>
</tr>
</tbody>
</table>

TABLE 5: Types and number of commercial establishments/functional units in selected multifunctional nodal centers

<table>
<thead>
<tr>
<th>Name of nodal center</th>
<th>Population*</th>
<th>Retail and personal services</th>
<th>Agricultural services</th>
<th>Total number of establishments</th>
<th>Population per establishment</th>
<th>% of total establishments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aul</td>
<td>123,291</td>
<td>294</td>
<td>4</td>
<td>68</td>
<td>337</td>
<td>11.0</td>
</tr>
<tr>
<td>Derabis</td>
<td>116,657</td>
<td>113</td>
<td>2</td>
<td>22</td>
<td>851</td>
<td>4.0</td>
</tr>
<tr>
<td>Garadpur</td>
<td>90,922</td>
<td>232</td>
<td>5</td>
<td>84</td>
<td>283</td>
<td>9.0</td>
</tr>
<tr>
<td>Kendrapara</td>
<td>121,256</td>
<td>947</td>
<td>10</td>
<td>309</td>
<td>96</td>
<td>36.0</td>
</tr>
<tr>
<td>Mahakalpada</td>
<td>162,591</td>
<td>35</td>
<td>0</td>
<td>4</td>
<td>4169</td>
<td>1.0</td>
</tr>
<tr>
<td>Marshaghai</td>
<td>105,099</td>
<td>175</td>
<td>2</td>
<td>28</td>
<td>513</td>
<td>7.0</td>
</tr>
<tr>
<td>Pattamundai</td>
<td>131,372</td>
<td>388</td>
<td>8</td>
<td>109</td>
<td>260</td>
<td>15.0</td>
</tr>
<tr>
<td>Rajkanika</td>
<td>116,139</td>
<td>235</td>
<td>2</td>
<td>46</td>
<td>410</td>
<td>9.0</td>
</tr>
<tr>
<td>Rajnagar</td>
<td>118,939</td>
<td>200</td>
<td>5</td>
<td>32</td>
<td>501</td>
<td>8.0</td>
</tr>
<tr>
<td>Total*</td>
<td>1,149,501</td>
<td>2619</td>
<td>38</td>
<td>702</td>
<td>342</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* The total population constitutes both rural and urban population of the district.

Source: Field Survey, 1998

ACCESSIBILITY ANALYSIS OF HIGHER ORDER CENTERS AND CENTERS WITH SPECIFIC FUNCTIONS

An accessibility analysis was done here primarily to identify areas and parts of the population that obtain services from different functional centers and also to focus on areas and parts of the population that remain unserved.

TABLE 4: Distribution of settlements by functional hierarchical order

<table>
<thead>
<tr>
<th>Hierarchical Order</th>
<th>Composite Index Value</th>
<th>No. of settlements</th>
<th>% distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Order (Lowest)</td>
<td>1.1727 - 1.7347</td>
<td>314</td>
<td>75.66</td>
</tr>
<tr>
<td>2nd Order</td>
<td>1.7347 - 2.2967</td>
<td>83</td>
<td>20.00</td>
</tr>
<tr>
<td>3rd Order</td>
<td>2.2967 - 2.8587</td>
<td>15</td>
<td>3.62</td>
</tr>
<tr>
<td>4th Order</td>
<td>2.8587 - 3.4207</td>
<td>1</td>
<td>0.24</td>
</tr>
<tr>
<td>5th Order</td>
<td>3.4207 - 3.9827</td>
<td>1</td>
<td>0.24</td>
</tr>
<tr>
<td>6th Order (Highest)</td>
<td>3.9827 - 4.5447</td>
<td>1</td>
<td>0.24</td>
</tr>
</tbody>
</table>
The accessibility analysis also accounts for the effects of travel on participation in different activities, as well as allowing travel to be treated as a derived demand. It recognizes that in general people travel in order to reach activities/functions to fulfill their needs. This analysis focused on centers that have selected functions such as education (higher secondary and above), health (primary health center and above), marketing (periodic and daily markets), banking, and multifunction centers. These functions are important to support and strengthen rural development of the district in general.

The concept of two circular buffer zones around these centers, one at a radial distance of 2.5 and the other at 5 km, is used to illustrate accessibility in a simple way. These two levels of distance are chosen based on the primary survey results discussed earlier. Accessibility analysis by time zones was not possible due to non-availability of a complete road transport map of the district. However, the results obtained through distance buffer zones (Table 6) are considered quite significant as people either walk or use bicycles for commuting.

Analysis reveals that the multifunction higher order centers within 2.5 km radius (22 in this case) provide service to 16.3 percent of the total population of the district, cover 14.5 percent of the total area and 22.2 percent of settlements of different sizes (Figure 2). The situation improves within a radius of 5 km to cover 64.5 percent of the population, an area of 32.7 percent of the district and 57.1 percent of settlements. Conversely, nearly two-thirds of the area and more than one-third of the population of the district living beyond 5 km radius do not have ready access to adequate services, suggesting the need for upgrading some selected centers with additional functions to fill the current gap.

As far as higher secondary and college education is concerned, 290 centers operate at present and almost 100 percent of the population and settlements are adequately served within a distance range of 5 km from centers (Figure 3). The need is to improve the quality of education by upgrading infrastructural facilities rather than adding any more units in future.

Compared to education, a great vacuum exists in the health sector (Figure 4). More than one-third of the total population and two-fifths of the area remain beyond 5 km from the existing health centers (49 centers at present). This warrants priority for additional new centers and upgrading of facilities to overcome the present situation.

### TABLE 6: Service area and service population of various types of functional centers

<table>
<thead>
<tr>
<th>Type of Function</th>
<th>No. of Centers</th>
<th>Within 2.5 km radial distance</th>
<th>Within 5 km radial distance</th>
<th>Beyond 5 km radial distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SA</td>
<td>SP</td>
<td>SC</td>
</tr>
<tr>
<td>Multifunction</td>
<td>22</td>
<td>14.5</td>
<td>16.3</td>
<td>22.2</td>
</tr>
<tr>
<td>Education</td>
<td>290</td>
<td>74.8</td>
<td>97.6</td>
<td>97.1</td>
</tr>
<tr>
<td>Health</td>
<td>49</td>
<td>27.7</td>
<td>44.4</td>
<td>43.4</td>
</tr>
<tr>
<td>Marketing</td>
<td>35</td>
<td>16.2</td>
<td>35.4</td>
<td>26.3</td>
</tr>
<tr>
<td>Bank</td>
<td>59</td>
<td>31.8</td>
<td>54.0</td>
<td>49.0</td>
</tr>
</tbody>
</table>

SA = % of Service Area, SP = % of Service Population, SC = % of Settlements Covered, UA = % of Unserved Area, UP = % of Unserved Population
The existing market centers, both periodic and daily (35 centers), serve only about half the settlements and population, and they cover little more than one-third of the total area of the district within a 5 km radius, thus leaving a large proportion of the area and population unserved (Figure 5). There is a need to organize a set of regulated markets through government efforts in the remaining unserved areas to bridge the existing gap and to initiate a competitive rural marketing system in order to protect the interests of small farmers and rural producers.

Compared to marketing, the existing banking centers (59 centers) provide services to nearly 85 percent of the population and settlements and cover almost three-quarters of the area within the same radial distance (Figure 6). This is quite satisfactory at present but efforts should be made by the bank units to cover the whole area either by creating sub-centers or mobile units. It is well known that the rural banking sector has a great role and responsibility to play in rural development activities in collaboration with other functional centers operating various extension and development activities.

CONCLUSION

The research findings have three important implications for decision-making processes and for planning facilities and services for rural development. Firstly, the study identifies unserved areas and thus indicates their need and priority for further investment and support aimed at filling the gaps. Secondly, under financial resource constraints with limited provision of facilities and services, it is common that the political push-pull factors play a key role in decision-making processes such that functions are not necessarily located at the places best benefiting the interests of the people. This analysis not only provides a rational basis for making decisions but also strongly advocates the correct location for a specific function to
serve maximum numbers of people, settlements and geographical areas. Thirdly, this type of analysis also supports indirectly the location and allocation of facilities and services.

From spatial analysis and the above considerations, centers such as Rajnagar, Mahakalpada, Pattamundai, and Patkura need in future to be supported with additional functions and services to enhance their status as multifunction centers. For education, Rajnagar deserves to be upgraded with higher-order educational functions. Similarly, Rajnagar, Patkura, and Mahakalpada are strongly recommended for strengthening health, marketing and banking functions in order to reduce the unserved area around these centers beyond 5 km radial distance.

Improving the quality of the road transport network in the district is strongly desirable to extend the service areas of the higher order centers having almost all functions (as selected in the beginning). The transport factor is not taken into account in this study due non-availability of a complete transport map with necessary road statistics and information about road quality. This is no doubt a serious limitation of this study but this problem can be overcome to some extent as we (the authors) know this area and have adequate knowledge about the local transport situation. The recommendations made in this paper implicitly make allowance for the limitations of the information on the transport network.

REFERENCES

RESUMEN
La metodología aplicada en este estudio se basa en un trabajo de campo, la colección de datos primarios y secundarios, y el análisis y despliegue de resultados. Se utilizó SIG de diversas maneras, incluyendo la preparación de la cobertura de imágenes para interpretación, la planificación y la toma de decisiones. Se usaron diferentes clases de distancia para determinar la delineación de áreas de servicios con funciones específicas. Los resultados muestran que, dentro de un radio de 5 km, la mayor parte del área de estudio se encuentra cubierta a excepción de unas pocas funciones como son mercados, centros de salud y centros multinodales. La brecha entre áreas servidas es pequeña. Sin embargo, hay algunos trechos de áreas no-servidas que necesitan inmediatamente facilidades de servicios. El SIG ha sido particularmente útil para crear la base de datos requerida para planificación espacial. El SIG se implementan cada vez más en países desarrollados como una herramienta primordial en el área de la planificación urbana y regional.

RESUME
La méthodologie dans cette étude est basée sur un travail de terrain, acquisition de données primaires et secondaires, analyse et présentation des résultats. Un SIG a été utilisé de différentes manières, telles que la préparation des couches pour l'interprétation, la planification et la prise de décision. Différentes catégories de distances ont été utilisées pour déterminer la délimitation de zones de service pour des fonctions sélectives. Le résultat montre que dans un rayon de 5 km la plus grande partie de la zone d'étude est couverte à l'exception de quelques fonctions telles que marché, centres de santé et centres multinodaux. Le fossé entre des zones desservies est petit. Cependant il y a quelques poches de zones qui ne sont pas desservies et qui demandent des services immédiats. Un SIG a été particulièrement utile en créant une base de données requise pour une planification spatiale. Il est appliqué de plus en plus dans des pays développés comme un outil dans la planification urbaine et régionale.
Call for Papers

JOINT INTERNATIONAL SYMPOSIUM on GeoSpatial Theory, Processing and Applications

DATES: July 9 to 12, 2002
LOCATION: Ottawa Congress Centre/Westin Hotel Complex, Ottawa, Canada

You are invited to participate in the 2002 Joint International Symposium and Exhibition on “GeoSpatial Theory, Processing and Applications”. This collaborative symposium has been planned to foster closer relations and provide opportunities for greater interaction among the geomatics communities especially among those involved in research, development, applications, or management of geo-spatial data and information. Tutorials and workshops are scheduled for the 8th July 2002.

SITE:
Ottawa Congress Centre/Westin Hotel Complex is located beside the Rideau Canal in the center of Ottawa, Canada’s national capital. It is within walking distance of hotels, restaurants, shopping centers, the Parliament Buildings, the National Arts Centre, the National Gallery of Canada, museums and numerous cultural attractions. There are various seasonal festivals and also natural destinations such as the Gatineau Park and the Ottawa river.

ORGANIZERS:
This International Joint Symposium is co-organized by:
- IGU Commission on Geographic Information Science (www.hku.hk/cupem/igugisc)
- Canadian Institute of Geomatics (www.cig-acsg.ca)

with the support of Natural Resources Canada, Geomatics Canada (www.geocan.nrcan.gc.ca)

GUIDELINES FOR PAPER SUBMISSION:
Guidelines and procedures for the submission of abstracts and papers will be posted as soon as they become available on the Symposium’s web-site: www.geomatics2002.org

INFORMATION AND REGISTRATION:
Tom Herbert, Executive Director, Canadian Institute of Geomatics, 1390 Prince of Wales, Suite 400, Ottawa, Ontario, Canada K2C 3N6
(phone: +1 613 224 9851; fax: +1 613 224 9577; e-mail: exdircig@netrover.com)
Guide to authors

JAG (formerly ITC Journal) publishes original articles, short notes and review articles in all fields of applied earth observation and geoinformation (see aims & scope). Manuscripts reporting results of studies on methods, theories, techniques or procedures are solicited, particularly those relevant to developing countries. JAG also publishes book reviews.

MANUSCRIPT SUBMISSION AND CORRESPONDENCE

Manuscripts - in English - should be submitted in quadruplicate (an original and three copies) and, if possible, with a corresponding digital version to:

Editor-in-Chief, JAG
PO Box 6
7500 AA Enschede
The Netherlands.

All four (4) copies should include all tables and figures. One copy should contain the originals of figures and plates, and its cover page should indicate this by being labelled as the original. Symbols and special characters should be clearly visible on the hard copies.

The name, postal address, email address, telephone and fax number of the author responsible for correspondence, reprints, etc., should be given on a separate page. Receipt of manuscripts will always be confirmed and a manuscript number will be advised. Contributors should retain a full copy of the manuscript and illustrations for reference. All correspondence concerning submitted manuscripts should refer to the manuscript number and should be sent to the Editor-in-Chief. If the corresponding author changes address, the Editor-in-Chief should be notified immediately.

A manuscript is reviewed independently by two members of the editorial board or other suitable specialists, who communicate their findings to the Editor-in-Chief. The decision to accept or reject a manuscript is made by the Editor-in-Chief and is final. A manuscript that is accepted subject to revision should be resubmitted after revision in duplicate and, if possible, in digital form on disk, within three (3) months. After this time the Editor-in-Chief reserves the right to send the manuscript again for review.

If a manuscript is accepted, authors are encouraged to submit the final text on 3.5" diskette. The main text, table & figure legends, and graphics should be stored in separate files, with clearly identifiable names. Texts made in Microsoft Word and WordPerfect formats can be readily processed. For graphics the preferred formats are EPS or TIFF (3.5" diskettes, CD-ROM or on Zip disk, 100MB). However, BMP files are also acceptable for our Macintosh equipment (main software: Illustrator, Photoshop and QuarkXPress). Further information regarding graphics can be supplied in response to specific requests.

Page proofs are sent to the author(s). The corrected proofs should be returned to the Editor-in-Chief without delay. Instructions for proof correction will be included with the proofs.

There are no page charges. Published papers are copyright of the publisher, the International Institute for Aerospace Survey and Earth Sciences. Twenty-five free off-prints of each paper will be provided. Additional reprints can be ordered from the publishers on the order form accompanying the proofs.

Materials submitted for publication (manuscript, diskette, line drawings, photographs, etc.) are not returned to authors unless their return is explicitly requested and a suitable self-addressed envelope is supplied.

MANUSCRIPT PREPARATION

1. Manuscripts must be printed double-spaced on one side of standard size paper (A4) with margins of at least 3cm. All pages including tables and figures should be numbered.

2. Manuscripts should be concise and precise. Always consult a recent issue of the journal for details on format, sequence of headings and arrangement of the manuscript.

3. If a digital copy of the manuscript is submitted on disk, the name of the file, operating system and word processor used to prepare the manuscript should be indicated on the title page.

TITLE AND AUTHOR(S)

The title should be informative and brief. Subtitles should be avoided. The title, and name(s), address(es) and affiliation(s) of the author(s) should be placed on the first page of the manuscript.

KEYWORDS

Up to ten key words should be provided which are not included in the title. (Some) keywords may be chosen from the list published in this journal. They should be placed in alphabetical order at the top of page 2.

ABSTRACT

An abstract must be included after the keywords. It should be factual and not exceed 200 words.

MAIN TEXT

This should start on a page 3. For research papers, the text should normally consist of five sections, entitled Introduction, Method, Results, Discussion, Conclusions (or equivalent). Primary headings are left justified and in bold and secondary headings are left justified and in italics. All paragraphs should be indented, except those immediately after a heading. Footnotes should be avoided. References to articles and books should be limited to published work, work in press, or theses and dissertations. Citations in the text, normally in parentheses, should use the following forms: Jones, 1990; Smith & Jones, 1991; Smith et al., 1992. In multiple citations the semi-colon should be used as a separator. When author name(s) are part of the text, the date only should be placed in parentheses.

NOMENCLATURE

The International System of Units (SI) should be used for all measurements. The basis for the nomenclature of taxa and syntaxa used should be indicated in the Method section as should the latitude and longitude of study site(s), if
Check the manuscript to make sure that all references are cited and that all citations in the text are included in the References. Also check to make sure that all citations have the correct format.

Appendices
Information too detailed to be included in the main text, for instance a list of areas sampled or technical details of a model, may be presented in appendices. Appendices should be numbered sequentially and placed after the References.

Figures
1. All figures, drawings, etc, must be numbered, labelled and cited in the text as Fig. 1 or Figs. 1 and 2.
2. Line drawings should be prepared in black so that they can be reduced to one column or full page width with text still readable.
3. Use a scale bar rather than scale ratio to avoid misrepresentation after reduction.
4. Author name(s) and figure number should be written in pencil on each figure.
5. Figures should be placed after the References (and Appendices, if any) in the manuscript. They should be preceded by the figure captions on a separate page. Indicate in the margins of the manuscript where figures should be placed.
6. Photographs should be supplied as matte prints.

Illustrations can be printed in colour if the author or his affiliate organization / institution will pay the set amount to meet the cost of colour print. Requests for colour print should be forwarded to the Journal Editorial Office latest upon approval of the manuscript for publication.

Tables
Tables must be on separate pages, double spaced and numbered sequentially. The tables should be prepared so that they can be printed in one column or full-page width. Tables should be submitted at the end of the manuscript. Indicate in the margins of the manuscript where tables should be placed.

Font Styles
Italics should be used for secondary headings, scientific names of taxa (genus and lower) and syntaxa, algebraic expressions and symbols in formulae. If italics can not be printed, text to be set in italics can be indicated by underlining it once. Bold text, i.e., primary headings, can be indicated by underlining it twice if it cannot be printed.

Address Change: Please send to Subscriptions and Advertising, International Journal of Applied Earth Observation and Geoinformation (JAG), PO Box 6, 7500 AA Enschede, The Netherlands, and allow three (3) months notice.

Surname ___________________________________________ Forenames ________________________________
(Mr/Mrs/Miss)

Alphanumeric code from bottom right corner of address label ________________________________________

Old address __________________________________________ New address ________________________________

...
Application of the "3S" technologies in sustainable agricultural development and land use planning in mountainous regions

Zhao Qiguo

Nanjing Institute of Soil Science, Chinese Academy of Sciences

KEYWORDS: remote sensing, GPS, GIS, sustainable agricultural development and mountain land use planning

ABSTRACT
"3S" technologies include remote sensing, global positioning systems and geographical information systems. The technologies are described and various applications in the fields of sustainable agricultural development and mountain land use planning are given. The paper concludes with recommendations for application of 3-S technologies in integrated mountain development plans.

INTRODUCTION
Sustainable agricultural development and land use planning in mountainous regions is one of the basic problems concerning the global sustainable development. The three technologies of Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS), as new and advanced technologies for observing the earth, are widely applicable both in the field of sustainable agriculture like cropland monitoring, crop yield evaluation and precision farming, and in the field of mountainous land use like land resources monitoring, soil erosion and degradation and their control and natural disaster mitigate in the mountainous areas. These technologies play a greater and greater role in these respects.

The Hindu Kush Himalayas (HKH) is the highest region in the world, extending up to 3500 km from west to east and sustaining around 140 millions of population in the whole or part of eight countries. Application of the "3S" technologies in agricultural development and land use planning would be important and has both theoretical and practical significance for sustainable economic development of the region.

This article discusses the "3S" technologies and their development, application of "3S" in sustainable mountain agricultural development and land use planning. Recommendations were also made that integrated "3S" research projects should be carried out in the HKH region.

"3S", TECHNOLOGIES AND THEIR DEVELOPMENT
The "3S" technologies are three advanced and new space technical systems with regard to the Earth observation and survey, namely Remote Sensing (RS), Global Positioning Systems (GPS) and Geographical Information Systems (GIS).

REMOTE SENSING
RS is the technical system that can distantly identify, measure and analyse nature of objects. Recent development of Remote Sensing is fast and is characterised by multiple spectral sensors, high resolutions and multiple temporality.

Multi-Spectral Sensors and Radar
Multi-spectral sensors can cover the spectral zones of solar irradiance and earth emittance. The optical remote sensing covers the visible, near-infrared and medium-infrared spectra from 0.4-2.5 μm, mainly detecting the reflection and absorption of objects. Thermal infrared remote sensing covers the far-infrared or thermo-infrared spectra (8.0-14.0 mm), mainly detecting the thermal radiation features of objects, like transmission rate and temperature. The microwave remote sensors, using the 1-1000 mm wavelength domain of the electromagnetic spectrum for detection, are either active or passive systems. The target properties that determine the reflection of radar waves from active radar sources are: surface roughness, slope and orientation, and dielectric properties. Passive systems detecting the microwave radiance of objects are found sensitive to soil moisture of the bare soil surface. Modern active radar systems, the synthetic aperture radar (SAR), use Doppler frequency shifts to improve the spatial resolution and different polarisations to enhance the analysing capability of object properties. These advances in technology are applied in EOS-AM1 and EOS-PM1 of the MTPE (Mission to Planet Earth) of NASA (USA).
**High Spatial, Spectral and Temperature Resolutions**

High resolutions of remote sensing are reflected in the spatial resolution, spectral resolution and temperature resolution. The advanced CCD imaging scanner has a high spatial resolution of 1-2 m. The imaging spectrometer has a resolution of 5-6 nm. For instance, the recent American Lewis satellite divided the spectral zone of 0.10-2.56 mm into 384 bands. The temperature resolution of the thermal infrared radiometer can be enhanced from 0.5° K to 0.3° K, and even up to 0.1° K. This high resolution can realize overall geometrical and physical precision of the remote sensing characteristics of the objects.

**High Temporal Resolution**

The operation of commercial satellite programs will make it possible that the sampling of the earth can be made every 2-3 days with high spatial resolution of 2-3 m with a number of satellites. Through the multi-spectral and multi-polarized radarsat, the all-weather and all day-and-night earth observation can be realized in cloudy, rainy and/or foggy conditions. Rational combination and coordination of the satellite-borne, the airborne and the vehicle-mounted remote sensing is a powerful guarantee for obtaining georeferenced multi-temporal remotely sensed data. Comprehensively speaking, it is firmly believed that the remotely sensed observation of the Earth will display an unprecedented development in the next century.

**GLOBAL POSITIONING SYSTEMS (GPS)**

Since 1980s, especially 1990s, the GPS technologies which can simultaneously measure three-dimensional coordinates have extended the measuring and positioning technologies from land and offshore areas to the whole sea basin and outer space, from static observation to dynamic monitoring, and from post priori treatment to real-time position and navigation. The application scope of these technologies has been greatly widened.

Applications in China and other countries indicated that GPS can meet different demands and achieve different precision by adopting different measures and operations. Using C/A coded broadcast star catalogue the static single point positioning accuracy of the false distance method may achieve accuracy of ± 2-5 m. In recent years wide area GPS was broadly developed in various countries. This technique highly raised the real-time difference precision, being within ±1.0 m. The difference distance can increase from 100 km up to 1000-1500 km. The carrier-phase difference GPS can offer even higher relative positioning precision. The satellite-borne GPS receiver measures the on-orbit position and the vertical direction position, reaching a precision of 10 m, and a height precision of ±15 m.

The Topex/poseidon sea-measure satellite, launched in 1992 by NASA and the French National Space Center, are using satellite-borne GPS receivers and microwave altimeters to survey the sea surface morphology, reaching high accuracies. Wuhan Technical University of Surveying and Mapping of China recently used a continuous and real-time devices composed of several GPS receivers to monitor the deformation of reservoir dams in a Yangtze River branch, reaching a precision of 0.5-1.0 m.

**GEOGRAPHIC INFORMATION SYSTEMS (GIS)**

GIS is a specific and very important space information system. Its function includes collecting, archiving, managing, analyzing and describing data and information about spatial and geographic distributions derived from the whole or partial Earth surface (including the atmospheric layers).

According to their scope and scale, GIS can be divided into global, regional and local ones. The wider is the scope, the lower is the resolution and vice versa. Ordinarily, GIS can be mainly used to study the space distribution of several elements of the Earth’s surface layers, falling into 2.0-2.5 dimensional GIS. The GIS based on and filled in three-dimensional space is real 3-dimensional system. The digit-position model (two dimensions) combined with the digital elevation model is generally called 2+1 or 3 dimensional model. If time is added, the 3-dimensional GIS is referred to as 4-dimensional or dynamical GIS.

Nowadays, one direction of GIS development is the client/server structure-based GIS, with which users can operate their terminals to call and use data and programs installed in the server. Another direction is development of the Internet GIS or Web GIS. Using this type of GIS, users can search and retrieve the needed geographical and spatial data from a far distance, including the graphics and images; users can also conduct various geographical or spatial analyses. This progress was realized by contemporary communication technologies, which combined the GIS with the information highway, and also integrated the GIS, RS and GPS. The integrated “3S” technologies have become important tools for sustainable agricultural development, mountain land use monitoring and for all research and management enterprises and organisations.

**APPLICATIONS OF THE “3S” TECHNOLOGIES IN SUSTAINABLE AGRICULTURAL DEVELOPMENT**

**AGRICULTURAL LAND RESOURCES MONITORING AND PROTECTION**

Quantitative and qualitative variation of the agricultural land can be monitored using “3S” technologies. The method is that through use of the large scale aerial photographs and TM images (medium scale), integrated with GIS and GPS agricultural land distribution maps for dif-
different time intervals can be compiled at various scales and with various accuracies. By measuring the agricultural lands at different times, the quantitative and qualitative change in different times can be estimated, which will facilitate "how to use and how to protect agricultural lands".

ESTIMATION AND MONITORING OF CROP YIELD
Estimation of crop yield consists of 1) estimation of crop planting areas, 2) crop growth vigor monitoring through remote sensing-derived leaf area estimates and per unit yield models. With the results of the above activities, estimation of the total crop yield can be made.

In the past, the common method available is the frame-area sampling method, developed by USDA and recommended by FAO. This is a synthesized method composed of the statistic yield estimation, meteorological yield estimation and remote sensing spectral yield estimation. Since 1982, TM images possessing multi-bands characteristics and high spatial resolution (30 m) were employed to improve interpretation accuracy of the crop planting areas. Simultaneously, the NOAA data were also used for crop area, per unit yield and growth vigor evaluation. Considering geometry, combination of RS and GPS offered much better results.

USE OF THE "3S" TECHNOLOGIES IN THE PRECISION FARMING
Precision farming is high technology-controlled, information-oriented, contemporary agriculture, which was supported by geographical, ecological and agronomic theories and "3S" technologies, communication and automation technologies. By these technologies we can timely obtain the dynamic information about crop growth and development and take management measures. The precision farming is expected to give impulse to a global agricultural technical revolution in the 21st century.

The motive or driving force for precision farming technology research and development is that the spatial differences of the crop growth environment and the actual harvested yield can be figured out and necessary management adjustments can be made accordingly. Using "3S" technologies, it is possible to timely adjust and control the differences within land parcels and among the land parcels, so that the resources potentials in the agricultural lands could be rationally and effectively utilized to produce the needed products.

As stated, the "3S" technologies can play an important role in the precision farming practices. The applications include the following:
- The high spatial, spectral and temporal resolution of aerial and aerospace remote sensing make it possible to timely (every 2-3 days) monitor the situation about crop growth vigour, being related to soil moisture and fertility, insect and pests. The resulting maps are called "symptom-maps" that are used for diagnosis, decision making and yield estimation. In order to obtain real-time data, the repeated aerial remote sensing or global data collecting network by satellites are required.
- GPS
Using established databases of soil background, irrigation, fertilizer application, seeds, and symptom maps, analyses could be conducted and diagnoses could be made, with which the diagnosis maps could be made. Input and output evaluation could be made and action plans could be worked out through synthesizing the results of above-mentioned activities, combining MIS and socio-economic information.
- GPS+GIS
This is an integrated system which can be installed on agricultural machinery in order to realize automatic command and control of farmland activities. Various site specific farm work and operations, namely, land preparation, sowing, fertilizer application, weeding, irrigation, harvesting, and so on, can be automatically directed and controlled by machinery. In order to ensure accuracy of this fieldwork, it is necessary to establish corresponding electronic thematic maps and regional or local GPS differentiating service network.

In the Western countries such as the United States, the United Kingdom, Canada, etc., the "3S" based precision farming has been tested and adopted. Some examples are given below.

Example 1: Agricultural remote sensing for "precision farming", organized by TASCIWSI Corporation.
This company consists of three units, namely information acquisition (20 persons), information manipulation (25 persons) and information analysis (75 persons). At present, small-sized Kodak DC460 CCD camera installed in airplane has been used with GPS and image displacement compensation devices to carry out panchromatic, color and color infrared photography. The specifications of CCD camera are; size 3K X 2K (K=1024), f = 28 mm, and pixel size 9 mm. The duration of each flight is 3.5 hours, covering an area of 300 hectares. Processing of data took 48 hours and the results were provided to farmers in CD-ROM (geometric accuracy 0.2-1.0 m). Agricultural and soil technicians would carry out field sampling and survey in order to compile symptom maps, which will be used for decision making and action taking. The cost is estimated as around $ 0.2/acre. These technologies have been applied in five agriculture-centered states in U.S.A.

Example 2: GEROS project of GER company, U.S.A.
This is a project of agricultural monitoring using satellites. The system consist of a series of six satellites, each
with scanning width of 120 km, and with a return cycle of about three days. Each satellite is equipped with both visible and short wave-infrared sensors. The 3rd-6th satellites of this series are additionally equipped with a thermo-infrared scanner for acquiring temperature and other information from the earth surface. The information can be used for monitoring crop growth vigour, insect and pest, floods, drought, and so on, mainly serving precision farming. The estimated serving fee is $1 per acre. This company is trying to raise more funds. The Hughes Cooperation and the Rockhid-Martin Cooperation have shown interests in this project.

APPLICATION OF THE «3S» TECHNOLOGIES IN MOUNTAIN LAND USE PLANNING

Mountains are characterized by high elevation, steep slope and dissected terrain. The «3S» technologies can provide important tools in monitoring and evaluation of mountain land use planning and management.

ESTABLISHMENT OF DYNAMIC INFORMATION SYSTEMS OF MOUNTAIN LAND USE AND LAND COVER

The land use situation in mountains has distinct temporary and spatial characteristics. Regional monitoring and adjustment of mountain land use could be realised only through dynamic research of temporary and spatial changes in land use. In the past, application of GIS for mapping of and searching for land use information could provide only the spatial and nature information of land use and could not reflect time dimension. This type of GIS is called SGIS (Static GIS). The GIS which can simultaneously manipulate the spatial, natural and temporal dimensions is known as TGIS (Temporal GIS). Such a system is needed for monitoring the temporal and spatial variation of the mountain land use/cover.

TGIS is the research pioneering of GIS and there are only few mature TGIS data models until now. In view of the importance and urgency of this information system, TGIS is applied in various regions to achieve the function to monitor land use/cover. It is an important research direction for the dynamic monitoring research of mountain land use in the future.

STUDY ON MONITORING AND CONTROL OF SOIL EROSION AND LAND DEGRADATION

Soil erosion and land degradation in mountains has exerted great influence upon the regional ecological environment. With use of «3S» technologies, effective synthesis could be carried out and accurate annual soil erosion and deposition could be obtained. The annual soil erosion rate is an important indicator of mountain soil erosion and land degradation. First of all, RS is used to obtain the latest land cover information about vegetation, crop, etc. GIS is used to determine soil erodibility based on soil, land use, geomorphology, elevation, precipitation, etc. Soil erodibility, geomorphology, slope gradient, slope length and rainfall erosivity are effectively synthesized. Through a monitoring model and related software, the annual river sediment yield from each pixel (30 m x 30 m) can be estimated. According to the experience from application in Shandong Province of China, such a method of integrating RS and GIS can give an accuracy of 83 per cent. However, according to the experiences from the mountaneous areas of Fujian Province of China, if GPS is also used to update the existing information of GIS (such as newly built highways and other constructions), the precision will be up to more than 90 per cent.

In addition, «3S» technologies can also be used to compile spatial and temporal degradation maps of soil fertility decline, soil acidification, soil pollution, soil stoniness, soil sandification, etc. These maps will serve as important bases for monitoring, regulating and controlling the ecological change in mountainous land. This application is particularly important for land use and sustainable mountain development in the HKH region.

APPLICATION OF «3S» TECHNOLOGIES IN MOUNTAIN HAZARD ENGINEERING

The current global application fields of GPS in natural hazard research include monitoring global plate movement, monitoring regional or within-plate crust movement, monitoring global sea level variation and monitoring landslide, surface subsidence and distortions of big engineering constructions. Thus it can be seen that it is significantly important to develop GPS technologies for monitoring landslide, surface subsidence and distortion of engineering constructions in the HKH region.

From the viewpoint of disaster monitoring and prevention, the main application fields of RS are twofold. One is monitoring and controlling earthquakes and evaluating earthquake damage and the other is predicting, monitoring and controlling of drought and flood hazards, both are important in the HKH region.

In hazard mitigate systems, GIS is used mainly in two fields, namely study of data structures of GIS and analysis of models. Among the great number of hazard analysis models, universal mathematical and geographic models probably can be formulated, which will improve the existing GIS software function. Application of multimedia technology and information in decision-making of hazard mitigation will have significant impact upon system design and implementation of RS and GIS. These constitute an important aspect of the land use research in mountains.
RECOMMENDATIONS

To sum up from the above, it is suggested that an integrated research of « 3S » technologies should be conducted to achieve sustainable agricultural development and integrated mountain development in the HKH region. The research contents may include new RS technologies for sustainable agriculture (precision farming) and mountain land use planning, methodologies for design and establishment of basic agriculture and land use information systems, study of GIS supported information extraction and diagnosis systems of crop and land use symptoms, RS-based dynamic monitoring systems and time sequences data base of mountain agriculture and land resources, mountain farmland and land information systems integrating RS, GIS and field rapid testing system, diagnosis systems of crop and land quality and expert countermeasure systems and development of intelligence agriculture and land facilities (including sowing, irrigation, soil improvement, harvesting, etc.), equipped with mountain farmland, land information systems and geodesy systems.

The basic problems, probably involved, are the study of remote sensing as indicator of environmental stress factors (water, fertility, hazard, pest), the integration of RS and GIS for diagnosis of mountain crop growth stress and land degradation and the relationship between the RS quantification and the spatial differentiation of crop growth and harvesting in mountains. To solve the above mentioned theoretical and practical problems, it is suggested that priorities must be given to the multi-spectral satellites with high spatial and temporal resolution, radar remote sensing and the key technologies of « 3S » integration. In brief, full utilization of « 3S » technologies to promote sustainable mountain agriculture and land resource use and exploitation would have important theoretical and practical significance for the ecological construction and sustainable development in the HKH region.

REFERENCES

Mineralogical analyses and remote sensing for comprehending the role of Himalayan Orogeny in the genesis of salinity in the Indian sub-continent

Raj-Kumar

Department of Soils, Punjab Agricultural University, Ludhiana-141 004, India

KEYWORDS: salinity, mineralogy, geology, remote sensing

ABSTRACT
A total of 8.58 M ha are salt affected in the Indian sub-continent. A majority of these soils occur in the plains of the Indus and Ganges rivers. The origin of salinity in these plains has been suggested to be the release of sodium by weathering of alumino-silicates and subsequent carbonation resulting in the formation of sodium carbonate. Sodium feldspars have also been proposed as a diffuse source of sodium. Thermodynamic investigations indicate increased stability of Na-feldspars in the high pH soil environment. Presence of appreciable amounts of chloride in these soils can not be explained on the basis of alumino-silicate weathering. The Na2O content of the sand fraction (representing mostly the Na-feldspars) was found to be poorly correlated with soil pH ($r=0.16$) thus indicating insignificance of Na-feldspars in the development of alkalinity. Identification of certain salt, smectite and silt rich geological formations of the Himalayas with the help of satellite imageries, provided vital clues to the solution of this problem. Correlation of remote sensing data with ground truth indicated the occurrence of salt affected soils along the river courses and in the palaeo-channels. LISS III data (IRS-1C) of Rakas and Mansarovar lakes in the Himalayas from where the Satluj (a tributary of the Indus) originates indicated the presence of highly saline water in these lakes. The Salt Range in the western Himalayas shows the accumulation of rock salt (NaCl) associated with other salts such as CaSO4, MgSO4, CaCl2 etc. In the north of the Himalayas, the Tibetan plateau contains saline lakes as well as soda plains, having marine sediments of Cambrian to Eocene periods. Retreat of Tethys from the Himalayan province during the Cretaceous period left saline basins in Tibet and Ladakh. These salt rich marine formations of the Tethyan sea which engulfed the extra-peninsula at one time, form the parent material of alluvium deposited by the ancient river system during the Pleistocene to Recent period.

INTRODUCTION
Soil salinity constitutes a global problem as it covers about 10 per cent of the total dry land [Szabolcs, 1989]. In the Indian sub-continent about 8.58 M ha are salt affected, of which 2.8 M ha have a soil alkalinity problem. A major chunk of 2.5 M ha of these alkali soils is present in the plains of Indus and Ganges rivers in northern India [Singh and Bandyopadhyay, 1996]. These alkali soils have been reported to occur in small patches in micro-depressions in a zone with rainfall of 500 to 1000 mm under ustic soil moisture regime only. Genesis of these salt affected soils has been suggested to be the release of sodium by weathering of alumino-silicates and subsequent carbonation resulting in the formation of sodium carbonate [Bhargava et al., 1981]. Sodium feldspars have also been advocated as a diffuse source of sodium [Gupta and Gupta, 1989].

In fact, this mechanism has been borrowed from Kovda [1964] who proposed it for the formation of alkaline soils from basaltic and volcanic parent materials. However, owing to the near absence of such parent materials in the catchment of alkaline soils of north India, the exact mechanism of their formation is still obscure. Accordingly, the present investigation was undertaken to understand the genesis of alkali soils through detailed morphological, physical, chemical and mineralogical analyses, by studying the weathering sequences of primary and secondary minerals in the alkaline environment, by understanding the make up of different geological formations in the catchment area and by interpretation of remote sensing data in the context of the Himalayan Orogeny.

STUDY AREAS
The area under investigation included the Salt Range in north-eastern Pakistan, the Siwalik Range in the Himalayas, and the Indus and Ganges Plains of north-west India, and the Tibet Plateau in China (Figure 1). These areas were subject to repeated tectonic movements and orogenic upheavals.

METHODOLOGY
Basic information to study genesis of salt affected soils in several parts of the Indian subcontinent comprised of: (1) literature study on salt impregnated geological formations of the Himalayas; (2) characterisation of soils in the hills and the plains; (3) determination of the mineralogical assemblage of soils and geological formations; (4)
thermodynamic studies to predict the stability of primary and secondary minerals; and (5) processing remote sensing data to obtain a synoptic view of the area and using its multi-spectral capability in identification of saline soils.

For remote sensing, LISS III data (IRS 1-C) with band combinations of 2 and 4 have been used. Saline soils were detected because of their negative effect on plant growth and/or due to their high reflectance when there was salt efflorescence at the soil surface.

Correlation of ground truth and remote sensing data of northern plains indicated the occurrence of salt affected soils along the river courses and in palaeochannels. These observations provided reasons for fresh thinking on the genesis of the alkali soils.

MINERAL ASSEMBLAGE

The fine fraction mineralogy of these soils was dominated by illite followed by smectite, mixed layer minerals, chlorite, kaolinite and vermiculite (Table 2) [Raj-Kumar et al., 1993a, 1993b]. The clay mineral assemblage of alkaline as well as adjoining normal pedons were similar. Transformation of illite to vermiculite appears to have occurred before transportation in the geological stage itself. The geological formations contributing to the alluvium contained as much as 43 per cent smectite. Smectite as well as kaolinite have been inherited as constituents of alluvium. The occurrence, weathering and transformation of clay minerals in these soils should be interpreted only in the light of mineralogical composition of the geological formations associated with the source of this alluvium. The coarse fraction of these pedons representing normal and alkali soils were dominated by quartz followed by plagioclase, mica, orthoclase chlorite, kaolinite, calcite amphiboles and mixed layer minerals [Raj-Kumar et al., 1995].

SMECTITE CONTROVERSY

There have been several reports regarding in-situ formation of smectite in the alkaline soils of north India [Kapoor et al., 1981]. It is opined that poor drainage, high Si:Al ratio and presence of alkaline earths and alkaline pH are the conditions most conducive and globally accepted for in-situ formation of smectite, but such occurrences in the alluvial soils of this area seem doubtful.

The mineralogical data on clays from the Subathu geological formation in the Siwalik Hills are not affected by pedogenesis. These formations have made major contributions to the alluvium of these flood plains thus explaining the smectite richness of the deposits. If the mechanism of smectite formation as mentioned above is to be believed, it would be impossible to justify the presence of 19-20 per cent smectite in the clays of Panchkula soils and 31-43 per cent in Ramgarh soils as these sites are located on the eroding hill slopes (Table 2). Both the sites are alkaline. Present geomorphology of these sites does not allow stag-
nation of water or existence of poorly drained conditions. In fact these clays are rich in smectite (along with salts, silt and carbonates) as they are marine/salt water lagoon sediments and contain large quantities of illite along with, kaolinite, chlorite and mixed layer minerals. Smeectite present in these clays is not the result of any pedogenic activity and instead belongs to much older formations in the geological history. These depositions might have occurred under the marine environment of the Tethyan basin in the Eocene period.

**ELEMENTAL COMPOSITION**

Detailsd elemental composition of sand, silt, clay, lime concretions, Fe-Mn concretions and soil is reported elsewhere [Raj-Kumar et al, 1995]. Discussion here is limited to Ca and Na content of different fractions. The CaO content of the coarse fraction is less than one per cent and, depending upon parent material, the Na₂O content of sand varies from 1.0 to 2.3 per cent. A major portion of CaO is attributed to Calcite. As such the considerable amounts of plagioclases in these soils are mainly alkali-calcic and/or alkalic plagioclases. Alkali plagioclases are known to be more stable than calcic and/or calcic-alkalic plagioclases [Rai and Kittrick, 1989]. The Na₂O content of the sand fraction (representing mostly alkali feldspars-albite) was not related to the pH of the saturation paste (pHₛ). Data indicated that the Na₂O content of both alkali and normal pedons was almost identical (2.0 to 2.1) and pHₛ varied from 7.5 to 9.8 (Figure 2). Further, the soluble Na content decreased from 4.50 to 0.79 g kg⁻¹, whereas insoluble Na content remained unchanged even after twenty years of reclamation (Table 3). These results clearly establish the uniformity of parent material of alkali and adjoining normal soils and do not establish any linkage between sodicity and alkali feldspars. Thus, the chances of alkali feldspars acting as a diffuse source of Na seem doubtful.

**STABILITY OF ALUMINO-SILICATES**

The pH and cation composition of the ambient soil solution control solubility/weathering or stability of alumi-no-silicates. Minerals that maintain lowest Al³⁺ activity are most stable. Al³⁺ activity at H₂SiO₄ activity level of 10⁻³ M was plotted against pH (Figure 3). The primary minerals (albite, microcline, muscovite) as well as secondary minerals (kaolinite, illite, montmorillonite, chlorite, vermiculite) have been found to be highly stable in these alkali soils. The reports of Bhargava et al [1981] and Kapoor et al [1981] indicating high weathering of aluminio-silicates in high pH environment and low stability of albite in alkaline soils [Gupta and Gupt, 1989] do not support our results as well as those of Lindsay [1979] and Rai and Kittrick [1989]. Had the hypothesis behind the above reports (feldspars are less stable in high pH environment) been true, the prevailing climate would not have permitted the presence of normal soils in Indo-Gangetic plains. Furthermore, the silicate mineral weathering as a source of sodium cannot explain the appreciable presence of Cl⁻ ions in these soils.
It is quite possible that certain highly water soluble minerals like halite (NaCl), trona [Na₃H(CO₃)₂·2H₂O], thenardite (Na₂SO₄), mirabilite etc, which are generally not detected by conventional X-ray diffraction procedure for clays, might have contributed salts to these alluvia. Some of these minerals have been detected in the Subathu geological formation in the Himachal Pradesh Himalayas.

**HIMALAYAN OROGENY AND FORMATION OF SALT AFFECTED SOILS**

As discussed earlier, alkali soils occur in almost every geomorphic location, in high as well as low rainfall areas, in udic as well as ustic moisture regimes, and presence of lithological discontinuities in the profiles do not support in-situ formation of these salt affected soils. Relatively similar insoluble sodium content of salt affected as well as normal, reclaimed as well as unreclaimed alkali soils, and increased stability of alkaline feldspars and other soil minerals, points towards a non-pedogenic origin of these soils. The presence of 21,000 km² of soda plains and salt lakes on the Tibet plateau, 300 km long Salt Range in Pakistan-Himalayas, brine springs, rock salt and saline marine deposits in Indian-Himalayas; smectite, salt, silt and carbonate rich geological formations in the Siwalik Hills; and the general presence of salt impregnated soils along the river courses and in the palaeochannels of rivers as evident from the satellite imageries, points towards a geological origin of the salts. LISS III data (IRS 1-C) of Rakas and Mansarovar lakes in the upper Himalayas from where Satluj river (a tributary of Indus river) originates, indicated the presence of highly saline water in these lakes. Salt deposits of the Pre-Cambrian Shali formation in the Mandi district of Himachal Pradesh Himalaya which suffered intense tectonic complications are correlated with saline series of the Salt Range in

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water soluble Na (%)</th>
<th>Na content in the soil separates (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreclaimed alkali - pHs 10.1</td>
<td>0.45</td>
<td>1.12  1.36  0.72  1.17</td>
</tr>
<tr>
<td>Reclaimed alkali (5yr) - pHs 9.0</td>
<td>0.11</td>
<td>1.12  1.44  0.56  1.20</td>
</tr>
<tr>
<td>Reclaimed alkali (10yr) - pHs 9.1</td>
<td>0.09</td>
<td>1.20  1.52  0.36  1.22</td>
</tr>
<tr>
<td>Reclaimed alkali (20yr) - pHs 8.2</td>
<td>0.071</td>
<td>1.20  1.28  0.64  1.16</td>
</tr>
</tbody>
</table>

**pHs**: pH of saturation paste

**FIGURE 2**: Effect of alkali feldspars on soil pH

**FIGURE 3**: Stability of primary and secondary alumino-silicates
Pakistan [Srikantia and Sharma, 1972]. These salt rich formations, which are an aftermath of the uplift of the Himalayas from within the Tethyan sea (Himalayan Orogeny), have contributed lavishly to these alluvia deposited by the ancient river system, resulting in the formation of vast salt impregnated alluvial plains in northern India. Further, the salt formation or transportation should not be correlated with present day river systems or the quality of water carried by them now or a few hundred years ago as this part of the sub-continent has suffered intense tectonic upheavals in the past.

CONCLUSIONS
In the Indian sub-continent 75 percent of the sodic soils occur in plains of the Indus and Ganges rivers. Alumino-silicates, including sodium feldspars are highly stable in high pH environment of these soils. As such these can not act as diffused source of sodium. Geological maps and remote sensing data indicated occurrence of salts, smectite, silt rich formations and saline lakes in the Himalayas and Tibet. Salt impregnated soils have been observed to occur along river courses and in paleo-channels. Such evidences suggest geological origin of salts in these areas. It seems probable that detritus of salt rich geological formations of Himalayas contributed lavishly to the alluvium, which was transported by the ancient river system and deposited in the Indus and Ganges river basins, resulting in the formation of vast salt impregnated plains.

REFERENCES


Assessment of resources in hilly areas from semi-detailed survey information applying GIS techniques

M M Rahman

Director Soil Resource Development Institute (SRDI), Dhaka, Bangladesh

KEYWORDS: GIS and soil survey

ABSTRACT
In development planning of mountainous areas, information on location of particular landforms, and specifically slope characteristics, is needed. This information is usually not shown on semi-detailed soil survey maps. The maps show only landforms and soils but not the specific location of landforms or land features. Under each landform, description of soils and slope classes is usually provided. In this study, available soil and landform maps (1:50,000) and topographical maps (1:25,000) are used as base materials which are digitized to produce contour based landform and slope class maps in the same scale. Boundaries that are delineated for each landform on the semi-detailed soil survey map and on a map prepared by applying GIS techniques reveal two completely different pictures. In contour based landform maps, high hills, medium high hills, low hills and valleys are clearly differentiated. Boundaries and areas of earlier mapping units and those estimated from the mapping units of the contour based landform map differ significantly. The slope class map shows the spatial pattern of slope steepness. It also shows the land features in greater detail. A comparison of the areas derived from the digitized slope class map and those estimated during semi-detailed soil survey is now possible. Correction of areas of different soil series occurring in different slope classes is also possible and this in turn facilitates correction of land uses. Other features such as areas susceptible to different degrees of soil erosion/land slides, land use, soil cover etc. can be shown more reliably in the contour-based digitized map. Overestimation of areas with gentle slopes can be avoided if the contour intervals are reduced. In countries where resources are a constraint, GIS could be used successfully to extract reconnaissance/semi-detailed soil survey data and to analyse and prepare digitized natural resource maps which are more useful to planners and policy makers.

INTRODUCTION
Information available from reconnaissance soil surveys and semi-detailed soil survey reports of plains and mountainous areas do not serve the purpose to identical extents. For development planning of plains, semi-detailed soil survey information is usually sufficient, whereas this is insufficient for mountainous areas. In development planning of mountainous areas, specific information about land slopes and location of landforms is needed. This information is usually not shown on semi-detailed soil survey maps because it is very costly to generate during conventional semi-detailed soil surveys. Moreover, it is rather difficult to show these features using classical cartographic techniques. However, the information can be derived rather cheap using Geographical Information Systems (GIS) and Remote Sensing. Reconnaissance and semi-detailed soil survey (Scale: 1:50,000) reports of mountainous areas are available. The main disadvantage of these reports is the lack of information on location of particular landforms and slope classes. Areas with different land use in each slope class and in each landform are not delineated. The objective of this study is: (1) to assess resources of semi-detailed information; and (2) analyse and use this information applying GIS techniques in a case study.

MATERIALS AND METHODS
The study area, Tankabati union, is situated in the southern part of Bandarban Thana (A Thana is a sub-division of a district) within the hilly region of Bangladesh. It is located between 22°05' and 21°55' North and between 92°10' and 92°19' East at elevation from 15 m to 1000 m above mean sea level. The rocks of the area are largely made up of consolidated sandstone and shales (Surma-Tipam rocks) of Tertiary age, which have been subjected to considerable folding, faulting, tilting and dissection. The ridge-crests are at heights of 300-1000 meters above mean sea level. The medium and low hills are at heights between 150 meters and 300 meters and lower than 150 meters above mean sea level, respectively. These are composed mainly of unconsolidated sandstone (Dupitila rocks) of late Tertiary age. The area has a humid tropical climate with a mean annual rainfall ranging from 2100 mm to 3000 mm, the major portion of which is received between May and October. The mean annual air temperature is 27.6° C with mean winter and summer temperature being 21.8° C and 31.3° C, respectively.

Reconnaissance and semi-detailed soil survey of Tankabati union were carried out in 1968 and 1988, respectively. Most of the soils, developed on very steep to steep slopes on Surma-Tipam rocks are shallow, excessively to moderately well drained and have sandy loam to silty clay loam/clay texture and light brown to dark brown colours. On the other hand, most of the soils
developed on very steep to steep slopes on unconsolidated, sandy Dupitila rocks are deep, excessively to moderately well drained and have sandy loam to silty clay loam texture and dark brown to red colours. Information on soils and land occurring on different slopes along with land use in high hills, medium high hills, low hills and valleys is available.

In this study, soil and landform maps (1:50,000) and topographic maps (1:25,000) are used as base materials. Soil and landform map of Tankabati union under Bandarban Thana is digitized and reproduced at 1:25,000 and 1:120,000 scale (Figure 1). From the toposheet information, contour lines above 30 m altitude and with 15 m vertical intervals are digitized. On the basis of altitude the boundaries of different types of hills and valleys are delineated on the map and the areas are calculated. After conversion of the scale from 1:50,000 to 1:25,000, the digitized soil and landform map is superimposed on the contour map and reproduced at 1:100,000 scale (Figure 2). The calculated areas of each landform from semi-detailed survey information and from the landform map (Figure 2) prepared from contour data are given in Table 1. The digitized contour map is used to calculate the slope making use of TIN (Triangular Irregular Network). The slope class map is prepared based on steepness making polygon coverage using TINARC command with percentage of slope option at 1:25,000 scale and is reproduced at 1:100,000 scale (Figure 3). The areas with different slope classes assessed from semi-detailed soil survey information and from the slope class map (Figure 3) are given in Table 2. A part of the map is reproduced to display the features in details at 1:10,000 scale (Figure 4).

RESULTS AND DISCUSSION

Digital landform maps based on contours (Figure 2) are more informative than the soil and landform map (Figure 1). Under each mapping unit, 2-3 landforms are mapped in association. The lack of location of a particular landform limits the practical uses of the map. In Figure 2, the position of particular landforms, eg, high hill or medium high hill and the distribution patterns are easily recognizable. Thus, the area of interest can be studied more reliably than would be possible with the soil and landform map alone (Figure 1). A comparison of areas estimated from semi-detailed soil survey information and those calculated from contour based digitized landform map (Figure 2) reveals that the latter are more accurate...
Assessment of resources in hilly areas

SYMPOSIUM PROCEEDINGS

SLOPE CLASS MAP OF TANKABATI UNION

FIGURE 3: Slope class map of Tankabati Union

and realistic than the former. The boundaries of mapping unit no. 1 (high hills) in the earlier map, and its estimated area, differ significantly from the boundaries and the calculated areas of unit no. 1 in the latter map (Table 1).

Figure 3 shows the areas with different slope classes based on steepness estimated from the contour map. The biggest advantage of this digitized map is that the location and the area of land within each slope class are delineated. Now it is possible to locate the area of hills with different slope percentages. From this map, it is also possible to correct the areas with identified soils and land uses, and areas with risk of soil erosion/land slides. It is also possible to suggest remedial measures necessary for sloping land agriculture. If it is desirable to assess the resources of the area under study in more details, the map scale can be enlarged according to the user requirement. The areas with different slope classes in this map (Figure 3) also differs considerably from those estimated from semi-detailed soil survey information (Table 2).

The area with slopes less than 5% may be overestimated by the GIS technique because contour lines less than 30 m above mean sea level are not shown on the slope class map (Figure 3). This can be overcome if contour intervals from mean sea level are reduced. Figure 4 in fact shows the land features in greater detail. Here, lands with different slope class are differentiated. The slope class map could be used as a base to show the areas of land with

TABLE 1: Areas of Soil and Landform in Tankabati Union

<table>
<thead>
<tr>
<th>Name of Landform</th>
<th>Semi-detailed soil survey estimate (hectares)</th>
<th>GIS estimate (hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Hill</td>
<td>3265.6</td>
<td>1869</td>
</tr>
<tr>
<td>Medium high hill</td>
<td>5462.7</td>
<td>5208</td>
</tr>
<tr>
<td>Low hill</td>
<td>5612.7</td>
<td>6966</td>
</tr>
<tr>
<td>Valley</td>
<td>928</td>
<td>1225</td>
</tr>
<tr>
<td>Total</td>
<td>15268</td>
<td>15268</td>
</tr>
</tbody>
</table>

TABLE 2: Areas with different slope classes in Tankabati Union

<table>
<thead>
<tr>
<th></th>
<th>Gently sloping &lt;5%</th>
<th>Moderately sloping 5%-15%</th>
<th>Strongly sloping 15%-30%</th>
<th>Very strongly sloping 30%-50%</th>
<th>Steep 30%-50%</th>
<th>Very steep &gt;70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semidetailed survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>estimate (hectares)</td>
<td>542</td>
<td>1469</td>
<td>852</td>
<td>5858</td>
<td>6162</td>
<td></td>
</tr>
<tr>
<td>GIS estimate</td>
<td>5681</td>
<td>2053</td>
<td>3370</td>
<td>1517</td>
<td>1189</td>
<td></td>
</tr>
</tbody>
</table>
erosion features eg, rills, gullies, landslides and areas of sedimentation.

For the purpose of planning crop production and other use of sloping land, slope class maps may also provide a better basis. The success of presentation of all features on the map and its perfection depends on the accuracy of the contour map and the quality of imagery. GIS and remote sensing may be used for improvement of semi-detailed soil survey information and make the map a more useful tool for future soil survey and land use planning of the hilly areas.

ACKNOWLEDGEMENTS
The author wishes to express thanks to the following Officer & Staff of data processing and statistical section and cartographic unit: Mr. A.H.M. Kamrul Hahib Khan, System Analyst (in charge) for overall supervision of maps digitizing, computing & data processing; Mr. Md. Shahidulla, Junior Programmer for preparation of digitized slope classes maps and necessary computing of the areas; Mr. Moqbul Hossain, SSO, & Mrs Dilara Hasan, SO for preparation of digitized soil & landform map of Tankabati Union; Mr. Mohammad Ullah, Ass. Cartographer for digitizing the contour map of Tankabati Thana.

REFERENCES
Soil resources mapping of lower Himalayas

L M Pande, Suresh Kumar and Jitendra Prasad

Indian Institute of Remote Sensing, Dehradun, India

KEYWORDS: soil survey, physiography, remote sensing and GIS

ABSTRACT

Mapping of landform and soils is described of the Himalayan areas of Mussoorie and Alaknanda. The application of remote sensing and GIS was found useful for this purpose, using IRS-1C, aerial photographs and topographic sheets as basic data. Part of one physiographic soil map and two legends, showing physiographic units, soil classes and area, are commented on.

INTRODUCTION

The vital need for wisely managing our valuable land resources is appreciated due to the realization that uncontrolled exploitation of lands will lead to disastrous results to economic welfare and environmental hazards. Thus increasing emphasis is now being laid on scientific management of land resources in a manner that ensures optimal utilization, keeping in view conservation and environmental protection needs. In other words, developmental planning itself needs to be oriented to both land resource conditions as at present and optimal land utilization practices.

Himalayan terrain consists of very high mountains with steep and precipitous slopes. Throughout the area, farmers have attempted to squeeze out a living from lands not suited for crop production. Improper landuse and management practices are ruining the entire landscape due to land slide, avalanche, severe soil erosion leading to hazards like floods and sedimentation in the areas down below. Resource inventories, particularly soils and their interpretation, are a prerequisite to planning in resource management for their sustainable use. The identification of biological and physical characteristics of land and environment provide the basis for determining their inherent capability for sustainable utilisation. For this purpose survey and mapping of soils is essential. Remote sensing techniques have proved to be very useful tools to prepare soil maps, in different types of landforms particularly in difficult terrain like the Himalayas [Pande 1987, Pande et al, 1992; Misra and Prasad, 1992; Suresh Kumar et al, 1998; Bhadra et al, 1998].

Today, we have very high resolution satellite data from Indian Remote Sensing Satellite (IRS) which can be used to prepare soil and landuse maps in the scale of 1:25,000 and 1:12,500 for effective soil management. Integrated use of digital image processing and GIS in mapping of soils in Himalayas can overcome the problems of difficult and inaccessible terrains.

An attempt has been made to identify and map the soils of part of lower and middle Himalayas using RS techniques. The study areas are Mussoorie hills and part of Mandakini, Alaknanda and Pinder river catchments. The major land forms are mountains, steep to very steep side slopes and river valleys. The area receives about 1850 mm average annual precipitation, and the temperature regime is ranging between thermic and hyperthermic.

The soils found on the mountain tops are generally loamy skeletal Typic Argiudolls and loamy skeletal Mollic Hapludalfs whereas on the side slopes, these are Loamy skeletal Typic Hapludolls and Loamy skeletal Typic Hapludalfs. The soils occurring on the river terraces are generally Loamy skeletal Typic Haplustalfs, Fine loamy Typic Haplustalfs, Fine loamy Typic Eutrochrepts. The soil composition of the river valleys is Coarse loamy Typic Udorthents, Loamy skeletal Typic Udorthents and Typic Udipsamments.

The thematic interpretation of landform and soil maps is helpful in evaluating the various land units for sustainable development. Most of the lands are highly to moderately susceptible to erosion and require varying management practices for soil conservation. Afforestation programmes have to be implemented on steep to very steep slopes to prevent soil loss. Geographic Information Systems, specifically ILWIS, have been used to analyse the quantum of thematic data for land evaluation and suggesting optimal land utilization for sustainable development. Socio-economic aspects, once incorporated, will enhance the utility for implementing management practices and conservation needs.

MATERIALS AND METHODS

IRS-1C data were used for mapping the soils in both areas. Aerial photographs of medium scale were also
used but in a limited manner. Ancillary data comprised Survey of India toposheets and other data of terrain features.

Automated physiographic analysis was done with the help of GIS applications. Spatial data viz. landforms, geomorphology, land use and topography were generated through GIS and were integrated to generate homogenous terrain units (physiographic units) which represent the natural division of the terrain system.

PC based ILWIS (Integrated Land & Water Information System), 2.2 windows version GIS software (developed by ITC, The Netherlands 1997) was used to prepare digital coverages and perform spatial analysis in the study. The physiographic soil map and contours were scanned and digitized. Contours were interpolated to create DEM (digital elevation model) and to construct a slope map. A 3-dimensional view (3-D view) was generated to study the soil-landscape of the area and assist the production of Land Utilization Type maps [Shrestha, 1997]. The soil map was reclassified to generate a pasture suitability map following FAO [1976] framework for land evaluation.

Remote sensing satellite data provide details of the land surface characteristics where soil can not be observed directly. A combination of image elements having direct relationship with the soil formation was used in the present study. The approach has a wide adaptability to different terrain conditions and varying scale of mapping.

Himalayan terrain comprises of many landforms such as steep to very steep slopes, ridges, river terraces, alluvial fans and valleys. Intricate spatial distribution with repetitive occurrence of these landforms makes it difficult to delineate landforms monoscopically on satellite images. The upper and middle part of the Himalayan terrain are covered by snow and scrub vegetation. Lower Himalayas and part of middle Himalayas are under cultivation or are covered by dense forest vegetation. These different elevated lands require different management practices. High lands topography in Himalayan region makes it difficult to access by road different areas during field checks. The level of mapping or intensity of observations recorded during field check, and their accuracy, depend on the terrain variability and on the requirements of soil conservation planning and environmental protection needs.

Himalayan lands have steep to very steep slopes and cast shadow effects on satellite images in north and northwest direction. The problem is solved by digital image analysis and performing GIS spatial operations. Image enhancements and ratio images are generated to reduce shadow effect and to extract land surface features to facilitate visual analysis. Enhanced images can be draped over 3-D view of landscape generated through GIS to improve delineation of landforms and land surface features. In the integrated method of GIS and remote sensing, used in this study, a number of interpretation elements were used for identification of the physiographic soil units. These were: relief, slope aspect, hill and drainage pattern, colour tone on remote sensing imagery (combinations of IRS-1C bands: 3, 2 and 1) and land use.

CASE STUDY 1: SOIL SURVEY AND MAPPING IN MUSSOORIE AREA

The survey area is located between 77° 45' to 78° 10' east longitude and 30° 15' to 30° 25' north latitudes. Between the mountainous terrain in the north and Siwalik in south, there is a sloping terrain essentially composed of piedmont material which has been subsequently reworked by orogenic, as well as fluvial processes forming terraces at different elevations and of different ages. Soil formation by and large, is governed by the processes of weathering and erosion. Depositional areas are not found. Forests have been noticed to have some effect on soil formation in providing mollic integrades of Haplustalfs at some sites. Among river terraces, the youngest ones are generally hydromorphic, having an aquic moisture regime. A brief description of various physiographic units is given below. The soil profiles were described as per FAO guidelines [1966] and the soils were classified according to the keys to Soil Taxonomy [USDA, 1996].

Almost the entire Himalayan area in the region is classified under mountains which have slopes that vary from 30% to 100%. They have a veneer of shallow soils with a limited capacity for plant growth though at most places the parent rock is weathered and broken, allowing plant roots to penetrate and support plant growth. The mountains are subjected to change in micro climate depending upon the typical aspect of slopes. It is very difficult to assign any range of bearing with respect to different aspects. Any area which is falling under hill shadows is having a good vegetal cover due to its orientation to solar radiation (northern slopes receive less radiation from the sun). Most characteristics features of the northern slopes are climatic differences with respect to temperature and moisture supply. The soils on the mountains are lithic and skeletal. At places, a mollic epipedon is noticed over rock. At some places, soil erosion is minimum due to poor erosivity and good vegetal cover.

The southern aspects of mountains are contrastingly different from the northern aspects with respect to not only soils, but climatic parameters, as well. A very large part of slopes with southern aspect is devoid of vegetation.
This either has a thin grass cover or scrubs. The soils in this area of southern aspects are mostly Entisols and Mollisols. The area having poor vegetation, mostly comprise Lithic Udorthents, but at places Loamy skeletal Typic Udorthents are also noticed. The cultivated areas on the southern hills comprise Loamy skeletal families of Dystric Eutrochrepts and Typic Udorthents with low soil depth.

Apart from the mountainous and hilly terrains the area comprises of two distinct landscapes i.e., piedmont plains and river terraces. It is difficult to draw a sharp line of distinction between these two landscapes apart form the fact that terraces are mostly flat and comprise finer sediments sorted out by local rivers and streams, whereas piedmont material is closer to hills and usually has gently to strongly sloping lands. They have appreciable amounts of coarse fragments as we go from lower reaches to upper reaches. Most dominant soils are Fine loamy Dystric Eutrochrepts and Fine loamy Typic Hapludalfs in the upper reaches. The lower reaches of the Piedmont can be presumed to be the best land of the area. They have deep fine loamy moderately developed soils mostly Typic/Mollic Hapludalfs and Dystric Eutrochrepts. The slopes are gentle, but the area is subjected to sheet erosion due to high erosivity of the rainfall in the area.

The other important landforms are uplifted terraces and river terraces in the area. The uplifted terraces have developed due to block faulting whereas river terraces are formed due to lateral shifting of the rivers. The dominant soils in the uplifted terraces are Fine loamy Mollic Hapludalfs and Typic Hapludalfs. There are various levels of terraces. The uplifted terraces comprise of low and high altitude (ranging 800 m to 980 m from sea level), the soils generally are Fine loamy Mollic Hapludalfs and Typic Ustochrepts. The soils of river terraces are widely varying (Table 1; notations: LS or Loamy skeletal, CL or Coarse loamy and FL or Fine loamy).

CASE STUDY 2: SOIL SURVEY AND MAPPING IN PART OF ALAKNANDA CATCHMENT

The soil mapping (at scale 1:50,000) has been done in the geographical area between 78° 55' to 79° 15' east longitudes and 30° 15' to 30° 30' north latitudes. Remote Sensing techniques were used for soil survey and mapping in part of Alaknanda catchment. Physiographic analysis was done in the same way as it was done in Case Study 1. Schematic cross sections, derived from DEM, were interpreted on physiography and soils. They are given in Figures 1 to 3 and show mountainous physiographic units (Figures 1 and 2) and river terraces (Figure 3).

The following land units were identified: (1) mountains; and (2) terraces. These main land units were further subdivided with the help of various image elements.

The mountains occupy the major part of the area. There is a very high relief variation ranging from 740 m to 3680 m above mean sea level. The main parameter responsible for development of soils is the slope aspect. Generally the slopes with northern aspect are occupied by dense vegetation whereas slopes with southern aspect are cultivated and inhabited.

MOUNTAINS

This landscape covers about 84% of the area. The area is characterized by very high relief variation. Steep to very steep slopes, escarpments and hanging valleys are quite common. The magnitude of the relief variation is significant. The lowest elevation is 240 m above mean sea level and highest elevation is 3680 m above mean sea level. Mountains have been further subdivided as follows: (1) very low mountains below 1000 m above mean sea level; (2) low mountains – having elevation 1000 to 2000 m; (3) high mountains – between 2000 to 3000 m; and (4) very high mountains – more than 3000 m.

Since the aspect has considerable effect on soils and landuse, these units have been further sub-divided based on northern and southern aspects. Beside aspect, the units were identified by relief, pattern, colour tone and land use. Physiographic units, area and percent of coverage and soils are given in Table 2 whereas other characteristics of these units are described below:

- **Very low mountains, northern aspect**
  - The slopes with ranges from 20 to 40% are generally cultivated. The soils are deep and gravelly.

- **Very low mountains, southern aspect**
  - These comprise moderately steep to very steep lands with the slopes varying from 30 to 60%. The soils are generally deep and gravelly.

- **Low mountains, northern aspect**
  - These comprise moderately steep to steep slopes ranging from 30 to 70%. These are moderately eroded soils. The soils are deep and gravelly.

- **Low mountains, southern aspect**
  - This unit comprises moderately steep to steep slopes. The variation in slope is from 25 to 40%. The soils are shallow to deep and are gravelly with slight to moderate soil erosion.

- **High mountains, northern aspect**
  - This unit comprises of moderately steep to steep lands. The slope varies from 20 to 40%. These lands are generally under cultivation. There is slight erosion in these units and the soils are generally deep and gravelly.

- **High mountains, southern aspect**
  - These comprise moderately steep to steep slopes. The slope varies from 20 to 45%. These soils are generally deep and gravelly and have slight erosion.

- **Very high mountains, northern aspect**
  - These are very steeply sloping lands of the northern
aspect where slope varies from 45 to 85%. 
Very high mountains, southern aspect
This unit comprises of very steep sloping lands. The slope varies from 45 to 85% in this unit. The soils are generally gravelly and shallow, at places exposed rocks are found.

RIVER TERRACES
These comprise depositional as well as erosional terraces made by Alaknanda and Mandakini Rivers and are encountered on the bank of the rivers. Occasionally they are flooded during monsoon. Two types of terraces are identified on the basis of the relative height difference (Table 2).
- Upper Terraces
  This includes the highest level with moderately to strongly sloping lands on both sides of the river. Upper terraces are most valuable for agriculture and have udic moisture regime.
- Lower Terraces
  These comprise gently sloping lands which are depositional as well as erosional terraces. Occasionally they are flooded during monsoon. They have young soils which are under cultivation.

### Table 1: Physiographic Units and Soils of Mussoorie Area

<table>
<thead>
<tr>
<th>Physiographic units</th>
<th>Soils</th>
<th>Area (ha)</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountains (M)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern aspect (M1)</td>
<td>L.S. Typic Udorthents</td>
<td>8288</td>
<td>4.31</td>
</tr>
<tr>
<td></td>
<td>L.S. Mollic Hapludalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.S. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern aspect (M2)</td>
<td>L.S. Typic Udorthents</td>
<td>13504</td>
<td>7.03</td>
</tr>
<tr>
<td></td>
<td>L.S. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C.L. Lithic Udorthents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hills (H)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top (H1)</td>
<td>C.L. Lithic Udorthents</td>
<td>3888</td>
<td>2.02</td>
</tr>
<tr>
<td></td>
<td>L.S. Typic Udorthents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side slopes (H2)</td>
<td>F.L. Mollic Hapludalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F.L. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C.L. Lithic Udorthents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uplifted terraces (UT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top (UT1)</td>
<td>F.L. Mollic Hapludalfs</td>
<td>4592</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>F.L. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side slopes (UT2)</td>
<td>L.S. Typic Hapludalfs</td>
<td>2016</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>F.L. Typical Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River terraces Asan and Song (AS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower (AS1)</td>
<td>C.L. Aquic Eutrochrepts</td>
<td>7312</td>
<td>3.81</td>
</tr>
<tr>
<td></td>
<td>L.S. Typical Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle (AS2)</td>
<td>F.L. Mollic Hapludalfs</td>
<td>9760</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>F.L. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper (AS3)</td>
<td>F.L. Typical Hapludalfs</td>
<td>4160</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td>L.S. Typical Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River terraces of Ganga (GT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower (GT1)</td>
<td>F.L. Typic Haplouquents</td>
<td>448</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Typic Udipsammets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle (GT2)</td>
<td>C.L. Mollic Hapludalfs</td>
<td>2048</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td>F.L. Typic Haplouquents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper (GT3)</td>
<td>C.L. Mollic Hapludalfs</td>
<td>1808</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>L.S. Typical Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Terraces of Yamuna (YT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower (YT1)</td>
<td>F.L. Aquic Eutrochrepts</td>
<td>896</td>
<td>0.47</td>
</tr>
<tr>
<td>Middle (YT2)</td>
<td>L.S. Typical Eutrochrepts</td>
<td>960</td>
<td>0.50</td>
</tr>
<tr>
<td>Upper (YT3)</td>
<td>F.L. Typical Hapludalfs</td>
<td>896</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>L.S. Dystric Hapludalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piedmont plains (P)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Piedmont plains (P1)</td>
<td>F.L. Dystric Eutrochrepts</td>
<td>25280</td>
<td>13.16</td>
</tr>
<tr>
<td></td>
<td>F.L. Typic Hapludalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F.L. Mollic Hapludalfs</td>
<td>26896</td>
<td>14.00</td>
</tr>
<tr>
<td>Lower Piedmont plains (P2)</td>
<td>F.L. Dystric Eutrochrepts</td>
<td>39792</td>
<td>20.72</td>
</tr>
<tr>
<td></td>
<td>L.S. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F.L. Mollic Hapludalfs</td>
<td>192080</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Miscellaneous

Total
The soil map of a part of the study area Alaknanda Catchment is depicted in Figure 4. This map shows the distribution of mountains and terraces. The mountains are subdivided according to their elevation and aspect. Two types of terraces are distinguished: lower and upper.

CONCLUSIONS
An integrated GIS and remote sensing method, using IRS-1C data, and aided by topographic data and aerial photo-interpretation, proved to be adequate to map physiography and soils of Himalayan areas at scale.
**TABLE 2: Physiographic Units and Soils in Part of Alaknanda Catchment**

<table>
<thead>
<tr>
<th>Physiographic units</th>
<th>Soils</th>
<th>Area (ha)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountains (M)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very low mountains</td>
<td>F.L. Typic Hapludalfs</td>
<td>3631.25</td>
<td>5.22</td>
</tr>
<tr>
<td>(M1) (&lt;1000 m above m.s.l.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern aspect (M11)</td>
<td>L.S. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.S. Typic Argiudolls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern aspect (M12)</td>
<td>L.S. Typic Haplustalfs</td>
<td>3962.5</td>
<td>5.70</td>
</tr>
<tr>
<td>Low mountains (M2)</td>
<td>F.L. Typic Haplustalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1000-2000 m above m.s.l.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern aspect (M21)</td>
<td>L.S. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.S. Typic Hapludolls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern aspect (M22)</td>
<td>L.S. Typic Ustochrepts</td>
<td>25781.25</td>
<td>37.05</td>
</tr>
<tr>
<td>High mountains (M3)</td>
<td>F.L. Typic Haplustalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2000-3000 m above m.s.l.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern aspect (M31)</td>
<td>L.S. Lithic Argiudolls</td>
<td>8981.25</td>
<td>12.90</td>
</tr>
<tr>
<td>Southern aspect (M32)</td>
<td>F.L. Typic Haplustalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.S. Typic Hapludolls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F.L. Lithic Ustochrepts</td>
<td>5593.75</td>
<td>8.04</td>
</tr>
<tr>
<td>Very high mountains (M4)</td>
<td>F.L. Typic Hapludolls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(&gt;3000 m above m.s.l.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern aspect (M41)</td>
<td>L.S. Lithic Argiudolls</td>
<td>343.75</td>
<td>0.50</td>
</tr>
<tr>
<td>Southern aspect (M42)</td>
<td>L.S. Typic Haplustalfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F.L. Lithic Ustochrepts</td>
<td>225.00</td>
<td>0.30</td>
</tr>
<tr>
<td>River terraces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower terraces (T1)</td>
<td>C.L. Lithic Ustochrepts</td>
<td>737.50</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>L.S. Dystric Eutrochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Typic Udipsamments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper terraces (T2)</td>
<td>L.S. Typic Hapludalfs</td>
<td>543.75</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>F.L. Dystric Eutrochrepts</td>
<td>812.50</td>
<td>1.16</td>
</tr>
<tr>
<td>Misc. (Rivers etc)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>69600.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

1:50,000. Furthermore, the ILWIS software enabled a preliminary land evaluation.

Most of the lands in the areas appear to inhabit degraded vegetation and are recommended for protected forest. In moderately steep to steep slopes with southern aspect of mountains, cultivation practices are recommended with suitable conservation measures. The lands should be provided with vegetal cover particularly before onset of the monsoon. Some of the areas are recommended for afforestation of adapted species of forest. Areas recommended for pasture development are very steep slopes which are not susceptible to severe erosion. Another promising land utilization type is wheat.

**REFERENCES**


Shrestha, D.P., 1997. Soil erosion modeling. ILWIS 2.1 Applications Guide. ILWIS Department, ITC, Enschede, the Netherlands.


Land use dynamics and land degradation in the Jhikhu Khola watershed

Bhuban Shrestha and Gopal Nakarmi

International Centre for Integrated Mountain Development (ICIMOD) Kathmandu, Nepal

KEYWORDS: land use dynamics, land degradation, air-photo-interpretation and GIS

ABSTRACT

Population growth and rapid land use transformation are affecting the sustainable use of biophysical resources. Active land degradation is evident in 6% of the Jhikhu Khola watershed mainly due to increasing demand for food, fuel wood, and fodder which first affects permanent vegetation cover, biodiversity, and soil fertility, and then leads to accelerated soil erosion (rills, gullies), and nutrient losses. GIS overlay techniques showed that historic deforestation in the late 1950's was largely responsible for initiating the degradation process. Despite large efforts of afforestation in the 1980's the degradation process continued due to the high demand for fodder from grazing land and forests. The sites with poor vegetation cover, and subject to rill and gully erosion and landslides were identified on aerial photos and field work and incorporated into the GIS database. Overlaying the degraded areas on the rock and surficial materials maps, the topographic and land use map, it was possible to identify the key factors where degradation is most widespread. The most frequent degradation occurred on mica-schist and residual soils, at elevations between 900-1200m, at 5-35% slopes and on south and east aspect classes and under forests and shrub use. By selectively displaying combinations of these factors in GIS it was possible to show where the highest risk exists for potential future degradation. All combinations of factors occur on approximately 10% of the watershed and these represent sites with the highest risk for degradation.

INTRODUCTION

Population growth and rapid land use transformation are affecting the sustainable use of biophysical resources. The demand for food, fuel wood, and fodder is increasing rapidly with as result land degradation in the form of erosion (rills, gullies), land slides, leading to a decline of permanent vegetation cover, biodiversity, and nutrient content. Aerial photographs along with intensive field verification and GIS overlaying techniques were used to quantify the land use dynamics along with other resources inventory in the Jhikhu Khola watershed.

The Jhikhu Khola Watershed is located 45 km east of Kathmandu (27° 33' 45" to 27° 42' 30" latitude to 85° 31' 15" to 85° 42' 30" longitude) and represents an 11141 ha Middle Mountain watershed. The high elevation range (800 to 2100 meters) and steep topography creates different micro-climatic conditions which together with the highly variable geology results in a complex land cover pattern.

There are few systematic studies examining the interactions between land use and land degradation process in mountain watersheds of Nepal and a detailed GIS based analysis can contribute significantly towards gaining a better understanding of the relationship between use of natural resources and land degradation. With detailed information on land use dynamics and inherited geological and topographic conditions, planners, resource managers and policy makers can make more informed decisions related to development.

OBJECTIVES

The overall goal of the paper is to link land use management with land degradation and examine geological and topographic factors that likely lead to accelerated degradation. The specific aims are to:

- Show how GIS can be used to document historic land use changes
- Develop a GIS database on degraded lands consisting of poorly vegetated landslides, and rilled and gullied areas
- Document the use of the GIS overlay technique to identify the key factors that are likely contributing to degradation
- Illustrate where the potential risk areas are for future degradation by producing a GIS factor map, which displays combinations of elevation, aspect, slope, geological materials and land use most subject to degradation.

METHODS

Topographic maps, aerial photographs, and field data were the primary source for the GIS based analyses. The stereoscopic capability of aerial photography allows us to obtain an overall view of the terrain as a three dimensional image, and reveals detailed qualitative and quantitative information of the geo-surface in terms of land use, landforms, topography, soils and the drainage network.
The historic land use information of 1947 and 1981 were derived from topographic maps at scale of 1:50,000. Land use changes over time are interpreted from aerial photographs of 1972, 1990 and 1996 (scale varied from 1:20,000 to 1:25:000). Likewise prominent geological features, surficial material, currently unstable areas were first interpreted on the aerial photographs (scale 1:25,000), followed by detailed field surveys. The information on the aerial photos was transferred to the 1:25,000 scale topographic map and incorporated into the GIS database using referenced control sites. GIS maps were produced for land use, geology, geomorphology, and currently degraded areas. The DTM data were used to create slope, aspect, and elevation slice maps.

A quantitative historic land evaluation was carried out using the GIS overlay method, and the same method was used to identify the key factors affecting degraded areas. By selectively displaying different combinations of factors in GIS it was possible to produce potential degradation maps having different degrees of risk.

### LAND USE CHANGES BETWEEN 1947 AND 1981

Land use comparisons were made between 1947 and 1981 based on 1:50,000 scale existing land use maps. The major land use changes over the 34-year period are shown in Table 1.

### LAND USE 1972 - 1990

A second set of land use data was generated using 1:20,000 scale aerial photographs. Detailed 1972 and 1990 land use maps were prepared using airphoto-interpretation and intensive field verification in consultation with local farmers. Six detailed land use classes were compared including khet (irrigated land), bar (rain-fed agriculture), forest, shrub, grassland and other (landslides, hills, gullies, water bodies, settlements, abandoned, orchard, sand and boulders). The land use changes over the period of 18 years were examined using GIS overlay techniques. During this period the forest cover increased by 10% and bari by 5% while khet land only increased by 1%, probably due to a lack of available water resources. In contrast, shrub land decreased by 9% and grassland 5% (Table 2).

The GIS results showed that forests had a net gain of 1178 ha over the 18-year period. The gains came from 861 ha that were previously under shrub and 317 ha which were previously under grass. Agricultural expansion was mainly at the expenses of shrub (250 ha) and grazing land (224 ha).

A significant change in forest species composition occurred during this period, with 63% of the increase in forest cover due to pine plantations [Shrestha and Brown, 1995]. Although pine trees are useful in stabilising soils and improving future timber production, they do little to address the large shortage of animal feed, fuel wood and organic litter used in agriculture. In addition, 65% of all pine plantations were established on slopes of less than 35% and 84% at elevation below 1200 m, rather than on steeper slopes and higher elevations, where the need for soil erosion protection is greatest [Shrestha and Brown, 1995]. This suggests that the forest expansion has not entirely occurred in the most critical upland portions of the watershed. During the 1972 - 1990 period, significant agricultural changes occurred in two directions: expansion onto marginal land and crop intensification. Bari land increased by 5%, and 66% of that expansion occurred on slopes greater than 20%.

### TABLE 1: Land use 1947 and 1981

<table>
<thead>
<tr>
<th>Land use Types</th>
<th>Area (ha)1947</th>
<th>Area (%)</th>
<th>Area (ha)1981</th>
<th>Area (%)</th>
<th>% Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>5567</td>
<td>49</td>
<td>6631</td>
<td>59 +</td>
<td>10</td>
</tr>
<tr>
<td>Forest</td>
<td>4908</td>
<td>43</td>
<td>2184</td>
<td>19</td>
<td>-24</td>
</tr>
<tr>
<td>Shrub</td>
<td>829</td>
<td>8</td>
<td>2481</td>
<td>22</td>
<td>+14</td>
</tr>
</tbody>
</table>

Source: Topographical map and LRMP at 1:50,000 scale

### TABLE 2: Land use 1972 and 1990

<table>
<thead>
<tr>
<th>Land use Types</th>
<th>Area (ha)1972</th>
<th>Area (%)</th>
<th>Area (ha)1990</th>
<th>Area (%)</th>
<th>% Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khet</td>
<td>1653</td>
<td>15</td>
<td>1719</td>
<td>16</td>
<td>+1</td>
</tr>
<tr>
<td>Bari</td>
<td>3844</td>
<td>34</td>
<td>4354</td>
<td>39</td>
<td>+5</td>
</tr>
<tr>
<td>Forest</td>
<td>2181</td>
<td>20</td>
<td>3359</td>
<td>30</td>
<td>+10</td>
</tr>
<tr>
<td>Grassland</td>
<td>1184</td>
<td>11</td>
<td>466</td>
<td>4</td>
<td>-7</td>
</tr>
<tr>
<td>Shrub</td>
<td>1857</td>
<td>16</td>
<td>937</td>
<td>8</td>
<td>-8</td>
</tr>
<tr>
<td>Other</td>
<td>422</td>
<td>4</td>
<td>306</td>
<td>3</td>
<td>-1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11141</strong></td>
<td><strong>100.0</strong></td>
<td><strong>11141</strong></td>
<td><strong>100.0</strong></td>
<td><strong>0.0</strong></td>
</tr>
</tbody>
</table>

Source: Land use maps of IIS, Topographical survey branch, Department of Survey scale at 1:20,000.
and the majority in the 36-49% slope class [Shrestha and Brown, 1995]. Dry land agriculture expanded onto steeper more marginal slopes and higher elevations create higher erosion risks, resulting in lower production potential [Schreier et al., 1995].

**LAND USE 1990 - 1996**

A third set of land use data was generated using the 1:20,000 scale aerial photographs flown in 1996. The six major land use categories were again compared after the land uses for 1990 and 1996 were superimposed in GIS. The GIS analysis shows that during this time period only minor changes in land use occurred (Table 3). While there was significant increases in forest cover during 1972 to 1990 period, no such expansion was evident during 1990’s.

**GEOLOGY**

The study area is characterised by two geological domains, with the upper area dominated by medium grade, crystalline rocks beginning with garnetiferous mica schist at the base through marble, quartzite, gneiss, sandstone and siltstone near the top. The underlying formations comprised of low grade, non-crystalline grey phyllite, limestone, dolomite, and some black slates. The formations are separated by a northeast-southwest trending thrust fault. Table 4 shows that mica schist and schistose quartzite together occupy nearly half (50%) of the watershed area, followed by sandstone and recent deposits.

**SURFACE MATERIAL**

The surficial materials were classified into alluvium, colluvium, and deeply weathered residual material. Table 5 shows that the residual material predominates (53%) over other materials. This group is characterised by deeply weathered and well-developed soil profile with thickness exceeding 1m [Saijo, 1991].

**TOPOGRAPHIC FACTORS**

Five elevation zones, five slope classes, and four aspect classes were created from the DTM data. The 900-1200 m elevation zone occupied nearly half (48%) of the watershed, while the slope and aspect classes were more evenly distributed.

**DEGRADED LAND**

Landslides (both active and old - more than 5 years), areas affected by rills, gullies, badlands, and areas with active bank cutting were identified as degraded and unstable. They represent surfaces with little or no surface vegetation cover. As shown by Carver and Nakarmi [1995] these areas are the biggest source of stream sed-

---

**TABLE 3:** Land use changes between 1990 and 1996

<table>
<thead>
<tr>
<th>Land use Types</th>
<th>Area (ha) 1990</th>
<th>Area (%)</th>
<th>Area (ha) 1996</th>
<th>Area (%)</th>
<th>% Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khet</td>
<td>1719</td>
<td>16</td>
<td>1838</td>
<td>17</td>
<td>+1</td>
</tr>
<tr>
<td>Bari</td>
<td>4354</td>
<td>39</td>
<td>4264</td>
<td>38</td>
<td>-1</td>
</tr>
<tr>
<td>Forest</td>
<td>3359</td>
<td>30</td>
<td>3319</td>
<td>30</td>
<td>-&lt;1</td>
</tr>
<tr>
<td>Grassland</td>
<td>466</td>
<td>4</td>
<td>613</td>
<td>5</td>
<td>+1</td>
</tr>
<tr>
<td>Shrub</td>
<td>937</td>
<td>8</td>
<td>781</td>
<td>7</td>
<td>-1</td>
</tr>
<tr>
<td>Other</td>
<td>306</td>
<td>3</td>
<td>326</td>
<td>3</td>
<td>+&lt;1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>11141</strong></td>
<td><strong>100</strong></td>
<td><strong>11141</strong></td>
<td><strong>100</strong></td>
<td><strong>0.0</strong></td>
</tr>
</tbody>
</table>

Source: Land use maps of PARDYP/ICIMOD, scale at 1:20,000

---

**TABLE 4:** Areal cover of different geological units

<table>
<thead>
<tr>
<th>Geological Material</th>
<th>Overall area (ha) (ha) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent deposits</td>
<td>1526 (14)</td>
</tr>
<tr>
<td>Sandstone/siltstone</td>
<td>2036 (18)</td>
</tr>
<tr>
<td>Schistose quartzite</td>
<td>2692 (24)</td>
</tr>
<tr>
<td>Mica schist</td>
<td>2943 (26)</td>
</tr>
<tr>
<td>Quartzite</td>
<td>413 (4)</td>
</tr>
<tr>
<td>Carbonate</td>
<td>475 (4)</td>
</tr>
<tr>
<td>Phyllite, slate</td>
<td>627 (6)</td>
</tr>
<tr>
<td>Gneiss</td>
<td>429 (4)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>11,141</strong> (100)</td>
</tr>
</tbody>
</table>

---

**TABLE 5:** Distribution of surficial material

<table>
<thead>
<tr>
<th>Geological Material</th>
<th>Overall area (ha) (ha) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>1948 (18)</td>
</tr>
<tr>
<td>Colluvium</td>
<td>447 (4)</td>
</tr>
<tr>
<td>Residual</td>
<td>5904 (53)</td>
</tr>
<tr>
<td>Rock</td>
<td>2842 (25)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11,141</strong> (100)</td>
</tr>
</tbody>
</table>
Land use dynamics and land degradation

Symposium proceedings

Unstable sites were dominantly found in the middle part of the study watershed. They are mostly dominated by deeply rilled and gullied badlands, while landslides were more scattered throughout the fringe area of the watershed. Based on the GIS analysis 520 ha or 6% of the watershed area was mapped as degraded.

RESULTS

The degraded areas were overlaid on the geological maps, the topographic maps and the land use maps to determine what the dominant factors are for degradation. The results of this analysis are provided in Table 6.

The results show that quartzite/mica schist, residual surficial materials, elevation between 900 and 1200 m, slopes between 5 and 34%, south and east facing aspect, under forest and shrub cover are the factors that dominate all degraded areas. Each individual factor ranged between 50-70% of all degraded sites. Slope angle as shown in Table 7 seems to be the least dominant while elevation was the most dominant factor.

We can now use the information gained from the analysis of the degraded areas and apply them to the watershed to produce a potential degradation risk map. If we assume that a single factor poses less risk for degradation than two factors, and two factors pose less risk than three factors, we can produce a three-category potential risk assessment for potential degradation in the watershed.

To simplify the analysis the following combinations of factors were used:
- Geological factor (schistose quartzite, mica schist and residual materials were combined)
- Topographic factor (elevation 900-1200 m, slopes 5-34%, and aspects South and East were combined)
- Land Use factor (forest and shrub, combined).

Using the GIS overlay technique we can selectively display where and how much of the watershed has single, double and triple factor combinations that are considered critical for degradation. Of the existing 620 ha of degraded sites, 139 ha (or 22% of the degraded sites) had all combination of factors (Table 7) and in the water-

### TABLE 6 Distribution of unstable areas on the major geological materials

<table>
<thead>
<tr>
<th>Factors</th>
<th>Overall watershed area (ha)</th>
<th>Degraded area in watershed (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>11,141 100</td>
<td>620 100</td>
</tr>
<tr>
<td>Geologic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schistose quartzite</td>
<td>5635 51</td>
<td>397 64</td>
</tr>
<tr>
<td>Mica schist</td>
<td>5506 49</td>
<td>223 36</td>
</tr>
<tr>
<td>Other rock materials</td>
<td>5904 53</td>
<td>387 62</td>
</tr>
<tr>
<td>Residual material</td>
<td>5237 47</td>
<td>233 38</td>
</tr>
<tr>
<td>Other surficial materials</td>
<td>5337 48</td>
<td>436 70</td>
</tr>
<tr>
<td>Topographic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation 900-1200 m</td>
<td>5237 47</td>
<td>233 38</td>
</tr>
<tr>
<td>other elevation classes</td>
<td>4573 41</td>
<td>309 50</td>
</tr>
<tr>
<td>Slope 5-34%</td>
<td>6568 59</td>
<td>311 50</td>
</tr>
<tr>
<td>Other slope classes</td>
<td>5058 45</td>
<td>400 65</td>
</tr>
<tr>
<td>Aspect: South and East</td>
<td>6083 55</td>
<td>220 35</td>
</tr>
<tr>
<td>Other Aspects</td>
<td>4296 39</td>
<td>421 68</td>
</tr>
<tr>
<td>Land Use</td>
<td>6845 31</td>
<td>199 32</td>
</tr>
</tbody>
</table>

### TABLE 7 Summary of individual factors most prone to degradation (in percent of total degraded area)

<table>
<thead>
<tr>
<th>Individual factors</th>
<th>Geology</th>
<th>Surficial material</th>
<th>Elevation</th>
<th>Slope</th>
<th>Aspect</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schistose quartzite &amp; Mica schist</td>
<td>64</td>
<td>62</td>
<td></td>
<td></td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>Residual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>900-1199 (m)</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-34 (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South &amp; East</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65</td>
</tr>
<tr>
<td>Forest &amp; Shrub</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (ha)</td>
<td>620</td>
<td>620</td>
<td>620</td>
<td>620</td>
<td>620</td>
<td>620</td>
</tr>
</tbody>
</table>
shed as a whole an estimated 10% of the area is considered to have the highest potential risk. A graded potential risk map can then be produced as outlined in Table 8.

From this analysis it is evident that GIS offers a unique possibility to predict where potential risk areas of degradation are in form of single, double and triple critical factors. These reflect key inherent conditions and land use that are the likely cause of degradation on existing sites but do not reflect external factors such as rainfall amount, duration and intensity, and landscape modification by other human activities. Nevertheless, the technique serves as a useful planning tool to initiate prevention and conservation measures in those areas that show the highest risk.

It is interesting to note that commonly assumed topographic factors such as steep slopes and high elevation, and land uses such as agriculture did not show up as being critical factors for degradation in the Jhikhu Khola watershed. It appears that the forest quality rather than the forest cover plays a much bigger role in degradation and this suggests that we need to find better forest indicators than forest cover in order to predict degradation processes under forest land use.

**SUMMARY AND CONCLUSIONS**

The historic GIS analysis of land use in the Jhikhu Khola watershed showed three stages of land resources dynamics:

- Massive deforestation and agricultural expansion between 1947 and 1981 dominated by expansion of subsistence agriculture and degradation of forests;
- Significant forest rehabilitation and agricultural expansion occurred at the expense of grazing and shrub lands between 1972 and 1990. Pine plantation becomes dominant forest cover;
- Minor changes in land use between 1990-1996, but decline in forest quality and biodiversity.

In terms of degraded areas it was found that the schistose quartzite, mica schist and residual materials were the dominant geological factor of degraded areas. The topographic factor was dominated by elevation between 900-1200 m, slopes 5-34% and aspects south and east. The dominant land use factor of the degraded areas was forest and shrub. Since shrub and forestry are the dominant land uses on the degraded sites this suggests that the massive deforestation in the late 1950’s had a significant effect on the degradation process, which is still evident today in spite of afforestation efforts in the 1980’s.

**REFERENCES**


**TABLE 8.** Potential risks associated with using critical single, double and triple factor combinations.

<table>
<thead>
<tr>
<th>Single Factor</th>
<th>Two Factors Combined</th>
<th>Three Factors Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology</td>
<td>Geology-Topography</td>
<td>Geology-Land use-Topography</td>
</tr>
<tr>
<td>Topography</td>
<td>Geology-Land use</td>
<td></td>
</tr>
<tr>
<td>Land Use</td>
<td>Topography-Land use</td>
<td></td>
</tr>
</tbody>
</table>

Concerns have to be expressed that if the rapid population growth is continuous, this will lead to higher pressure on the forest and shrub resources and will ultimately lead to more degradation in the near future, since 2/3 of the current degraded areas are under forest and shrub use.

Using the GIS overlay technique it was possible to produce degradation risk maps by identifying the geologic, topographic and land use conditions most prone to degradation but currently not degraded. By using single or combined factor maps it was possible to show higher risk factors. It is postulated that sites with a combination of all three factors represent the highest risk areas. Two factor combinations are somewhat less risky to degradation, while single factors have an even lower risk. This graded risk assessment will serve as a useful tool for resource managers and decision-makers.
The use of RS and GIS for monitoring land use in mountainous areas of Myanmar

Myo-Kywe

Senior Lecturer, Department of Agronomy, Yezin Agricultural University, Yezin, Myanmar

KEYWORDS: land use, remote sensing and GIS, Myanmar

ABSTRACT

The soils of Myanmar have been developed under differing climate, topography and location. Generally the soils are grouped into three types; namely, the alluvial soils covering 50%, the black clayey soils 30% and the red lateritic soils 20% of the surface. The earliest aerial photograph in Myanmar was taken in 1924 to estimate the forest area. Most of the soils in mountainous land are cultivable waste land. However, due to communication and transportation problems, mountainous lands in Myanmar are less exploited. During 1980 and 1989, aerial photographs of the forest cover of Myanmar were taken using 1:1,000,000 Landsat imagery. RS and GIS technology in Myanmar is still at an early stage. Although land use is known to be intensive and marginal in Myanmar, there is little information on land use and land degradation. The study of Land Use Changes and Land Degradation in Shan State (Myanmar) will be focused on the use of unique frequency distributions of spectral values by using Landsat TM image with RS/GIS technology.

INTRODUCTION

Myanmar has been an agricultural country for centuries due to its favorable agro-climatic conditions and rich natural and human resources. And it will remain so for years to come. It is basically related with other social and economic sectors and the more it progresses the more national economy would develop [DAP, 1999].

Myanmar is geographically located between 9 degrees 58’ and 28 degrees 31’ North and 92 degrees 9’ to 101 degrees 10’ East. Bounded by land on north-west, north and east, and the remaining sides by sea, it stretches as far as 2076 km from north to south and 931 km from east to west. The total area of the country is about 676,577 square km. Due to vast potential of natural resources which remain to be further exploited and favorable economic system of the country, the agriculture sector is rendering good opportunities for both national and foreign investors. It is mountainous in the Shall State, the Kachin State, the Kayin State, the Kayah State, the Chin State, the Mon State, the Rakhine State and the Tanintharyi Division. Agriculture is the main economic activity in those areas. The major crops growing in hilly areas are paddy, wheat, groundnut, potato, soybean, maize, pulses, tea, coffee, sugarcane and citrus.

Myanmar could also be taken as a forest-clad mountainous country, with plateaus, valleys and plain mountain ranges with varying altitude from about 1000 to 2300 m forming a natural boundary between Myanmar and her neighbour-countries. The general slope of the country is from north to south, and all rivers flow in the same direction. Most of the soils in the mountainous land are cultivable waste land. However, due to communication and transportation problems, mountainous lands in Myanmar are less exploited.

In Rakhine and Tanintharyi coastal regions, narrow strips of plains along the east coast gradually rise towards the inland on the east till these become high mountain ranges called Rakhine and Tanintharyi Yomas. There are short small rivers traversing the narrow plains in both regions. With an annual rainfall varying from 2500 to 5000 mm, coastal regions form the main area for plantation of crops such as rubber, cocoa, oil palm and coconut.

Bago Yoma is a low range of hills dividing the southern portion of this flat region into Ayeyarwady river basin on the west and Sittaung river basin on the east. Another low range of hills in the northern portion divides the Ayeyarwady river basin on the east and Chindwin river basin on the west. In the remaining hilly regions of Chin and Shan States, improper land use methods adopted during the colonial days have resulted in the formation of large expanses of land which are not well suitable for crop production.

High altitude has resulted in the formation of cooler belts in the southern tropical regions. Myanmar receives its annual rains mainly from the South West monsoon from mid-May to mid-October. The precipitation, however, varies depending on the locality, elevation and months.
SOILS
Consequent upon the wide range of climate and parent rocks for soil formation, the soils of Myanmar vary a great deal. But there are only three agriculturally important soil groups; namely, alluvial soils, black soils and red lateritic soils:

1. Alluvial soils occupy some 50 per cent of the total sown area and are generally deep and variable in structure, ranging from sticky clays to sandy loams. These soils are located along Ayeyarwady, Chindwin and Thanlwin river basins as a result of alluviation processes; in lower Myanmar, the old alluvial soils are acidic;

2. Black soils occur in about 30 per cent of the area and are generally found in regions with an annual rainfall ranging from 500 to 1000 mm. Agriculture has to be aided by irrigation on such soils while at the same time drainage and erosion are serious problems; these soils contain 40-60 per cent clay and are plastic and sticky when wet and very hard when dry;

3. About 20% of the total sown area are red lateritic soils which are generally associated with undulating topography and have an annual rainfall ranging from 1000-3000 mm; these soils are low in lime and magnesium and deficient in nitrogen; available phosphate and organic matter content are also relatively low.

LAND USE
Myanmar has abundant natural resources such as cultivable land and water which have only partially been exploited. Although Myanmar has a potential cultivable land area of 18 million hectares, only about one half of it or 9 million hectares are being utilised for crop production [MOAI, 1998]. The remaining 9 million hectares of cultivable land are uncropped and classified as fallow or 9 million hectares are being utilised for crop production. From this table, with the exception of areas under reserved forests, other forests and unclassified land which could not be used for crop land, it will be seen that the sum total of net sown and fallow areas constitutes current cultivated areas. “Fallow land” in some cases are left out of cultivation as part of a well defined rotation system for fertility conservation purposes. Partap [1997] reported that average crop yields in mountainous areas of HKH region declined within a range of 5 to 30 percent during the past few decades.

GIS AND REMOTE SENSING
Myanmar is densely forested in mountains that are remote and mostly inaccessible. Agriculture in mountainous areas is largely based on integrated crop-livestock-agroforestry farming systems, especially horticulture and pasture management, which are very important in mountainous areas, are not sufficiently studied in Myanmar. Today an increase in the spatial and radiometric resolution of remote sensing instrumentation, coupled with our environment, have enabled workers to use remotely sensed data to determine, for example, the amount of soil moisture in a field or to estimate green leaf area index [Curran, 1983]. Modern GIS and RS technology could be used to reduce environmental degradation, to a more friendly condition in environmental establishment and to develop sustainable agriculture in mountain areas.

The activities of the GIS section of the Forest Department under the Ministry of Forestry and the GIS section of the Settlement and Land Record Department (Ministry of Agriculture and Irrigation) were run from five years ago. The training course on ‘Application of GIS and RS in Mountain Natural Resources Management’, sponsored by ICIMOD (Nepal) was conducted at the Institute of Forestry (IOF), Yezin, Myanmar from 1st to 26th March, 1999. Sixteen trainees from various Departments attended this training. One GIS/RS laboratory was installed at IOF, Yezin in 1999. An attempt is being made to introduce GIS and RS technology as a part of the agriculture, forestry and animal husbandry curriculum at the university level in Myanmar. Teaching and research activities on GIS/RS will be carried out in the near future.

Myanmar is one of the early users of aerial surveys and aerial photo-interpretation [Saw-Win and Saw Eh-Dah, 1987]. The earliest aerial photograph in Myanmar was taken in February 1924, over 1,000 square miles of forest areas in the southern part [Aung-Myint, 1956]. Since then, subsequent aerial photographic missions were conducted, covering almost the entire region of the country [Aggrawal, 1980]. In 1980 under the FAO/UNDP project a quick appraisal of the forest cover of Myanmar was carried out using 1:1,000,000 scale Landsat imagery of the years 1972-75 [Saw-Win and Saw Eh-Dah, 1986]. It was based on the comparison of 1950 aerial photographs at a scale of 1:20,000 and 1:50,000 and enhanced by Landsat imagery of 1:1,000,000 scale taken between

<table>
<thead>
<tr>
<th>Type of Land</th>
<th>Percent (%)</th>
<th>1996-97 Area Hectare (000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Net sown acreage of crop land</td>
<td>13</td>
<td>8741</td>
</tr>
<tr>
<td>2. Current fallow land</td>
<td>2</td>
<td>1395</td>
</tr>
<tr>
<td>3. Culturable waste land</td>
<td>12</td>
<td>8075</td>
</tr>
<tr>
<td>4. Reserved forest</td>
<td>15</td>
<td>10398</td>
</tr>
<tr>
<td>5. Other forest</td>
<td>33</td>
<td>22032</td>
</tr>
<tr>
<td>6. Unclassified land not suitable for crop land</td>
<td>25</td>
<td>17045</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>67659</td>
</tr>
</tbody>
</table>
1973 and 1979. Flying was started in the dry season of the fiscal year 1981-82 [Ral-Lian-Sum et al, 1990]. Table 2 shows the total photographic coverage at the end of 1989.

<table>
<thead>
<tr>
<th>Period</th>
<th>Scale</th>
<th>Area in Km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981 to 1989</td>
<td>1:25,000</td>
<td>379,722</td>
</tr>
<tr>
<td></td>
<td>1:50,000</td>
<td>234,308</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>614,030</td>
</tr>
</tbody>
</table>

The total gross area covered to date amounted to 614,030 Km² that is about 90% of the total area of the country. Up to the end of the year 1989, a total of 207 forest type maps have been prepared. In 1984 a consultant appraisal indicated that closed forests affected by shifting cultivation, degraded forests and degraded forest affected by shifting cultivation covered 33.6%, 15%, 8.7% and 13.1% respectively, while the forests were depleting at the rate of 600,000 ha per annum. However, in 1989 a detailed study of change in forest cover showed only 0.4% of the total area to be depleted. At this rate the annual rate of forest depletion in the reserved forests all over the country could be about 40,000 ha only.

Forest cover of Myanmar was also analysed based on LANDSAT imagery of 1989, and HKH region of Myanmar constituted only four out of fourteen state/divisions of the country [Kyaw-Tint et al, 1991]. The results are presented in Table 3.

Even in a densely forested country like Myanmar it is evident that the Ayeyarwady mangrove forest areas and the Central Myanmar are suffering from high deforestation.

<table>
<thead>
<tr>
<th>State/Division</th>
<th>Closed Forests</th>
<th>Degraded Forest</th>
<th>Shifting Cultivation</th>
<th>Non-Forest</th>
<th>Water Bodies</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Kachin</td>
<td>73,618</td>
<td>3460</td>
<td>6,051</td>
<td>5,147</td>
<td>763</td>
<td>89,039</td>
</tr>
<tr>
<td>2. Kayah</td>
<td>4,345</td>
<td>2539</td>
<td>2,423</td>
<td>2,345</td>
<td>79</td>
<td>11,731</td>
</tr>
<tr>
<td>3. Kayin</td>
<td>14,289</td>
<td>3,218</td>
<td>6,796</td>
<td>5,897</td>
<td>182</td>
<td>30,382</td>
</tr>
<tr>
<td>4. Chin</td>
<td>22,884</td>
<td>1,303</td>
<td>11,397</td>
<td>419</td>
<td>14</td>
<td>36,017</td>
</tr>
<tr>
<td>5. Saliang</td>
<td>57,700</td>
<td>7,797</td>
<td>3,773</td>
<td>24,201</td>
<td>1,150</td>
<td>94,621</td>
</tr>
<tr>
<td>6. Ta-Sinlthary</td>
<td>34084</td>
<td>3,304</td>
<td>3,087</td>
<td>2,112</td>
<td>756</td>
<td>43,343</td>
</tr>
<tr>
<td>7. Bago</td>
<td>14,999</td>
<td>2,681</td>
<td>3,661</td>
<td>16,914</td>
<td>1,148</td>
<td>39,403</td>
</tr>
<tr>
<td>8. Magway</td>
<td>5,009</td>
<td>11,866</td>
<td>10,306</td>
<td>16,205</td>
<td>1,433</td>
<td>44,819</td>
</tr>
<tr>
<td>9. Mandalay</td>
<td>6,837</td>
<td>6,131</td>
<td>4,576</td>
<td>18,710</td>
<td>768</td>
<td>37,022</td>
</tr>
<tr>
<td>10. Mon</td>
<td>3,008</td>
<td>1,828</td>
<td>1,837</td>
<td>5,032</td>
<td>591</td>
<td>12,296</td>
</tr>
<tr>
<td>11. Rakhine</td>
<td>20,575</td>
<td>2,580</td>
<td>2,267</td>
<td>8,980</td>
<td>2,375</td>
<td>36,777</td>
</tr>
<tr>
<td>12. Yangon</td>
<td>1,164</td>
<td>331</td>
<td>292</td>
<td>7,998</td>
<td>386</td>
<td>10,171</td>
</tr>
<tr>
<td>13. Shan</td>
<td>52,089</td>
<td>30,681</td>
<td>44,140</td>
<td>27,991</td>
<td>895</td>
<td>155,596</td>
</tr>
<tr>
<td>Total</td>
<td>315,537</td>
<td>81,310</td>
<td>101,779</td>
<td>164,600</td>
<td>13,327</td>
<td>676,553</td>
</tr>
<tr>
<td>Percent of Total Area</td>
<td>46.6</td>
<td>12.0</td>
<td>15.0</td>
<td>24.3</td>
<td>2.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

RESEARCH PROPOSAL ON LAND USE OF MOUNTAINOUS AREAS IN MYANMAR

Tropical environment is typically characterised by the diversity of land cover and land use. Unlike North America and Europe, lands in the tropics are segmented into smaller and more heterogeneous units [Bandibas et al, 1995]. This study would be focused on the use of the unique frequency distribution of spectral values in land-use classification under tropical conditions by using Landsat TM image. The data on Satellite Image would be required in Soft Copy and Hard Copy. Frequent field visits and counter checking with Global Positioning System (GPS) would have to be conducted.

One of the areas in Shan State will be chosen as a training field. Data collection will be made through satellite images eg, JAFTA, LANDSAT, MOS, etc. The image processing will be conducted by the electromagnetic radiation (EMR) with seven radiation bands including PCA (Principle Component Analysis), NDVI (Normalized Difference Vegetation Index) and ISODATA (Interative
Self-Organizing Data Analysis Technique) classification methods. Field visits including data input, eg, Soil type, pH, slope, land degradation, social information and other attribute data, etc. will be conducted to obtain the GIS data to support the identification of land use pattern and land use changes in Myanmar.

REFERENCES


Saw-Win and Saw Eh-Dah (1986) Detection of Changes In Forest Cover of some Forest Reserves In Pegu Yoma Area using Sequential Aerial Photographs, Forest Department Leaflet No. 6: 85-86.


The use of the TM thermal band in the study of land cover/use and soil salinity in the mountains of the Iranian deserts

S K Alavi Panah

Iran Desert Research Centre, University of Tehran, Tehran, Iran

KEYWORDS: Iranian deserts, soil salinity, land use, desert mountains, TM thermal band

ABSTRACT

Mountains, with exposed weathered as well as solid rocks, scattered vegetation, complex slopes with different exposures, south- and north-looking faces, and various soil types (formed on alluvial, colluvial and/or residual material) with varying depth, show great variations in terms of reflectance. Such large heterogeneity in the mountains often confuses image analysis, as some parts may show reflectance similar to that of features in non-mountainous areas - low-lying surfaces. In this study, Landsat MSS and TM images of two different dates (September 14, 1975 and September 11, 1990) were used to study, among others, soil salinity in the Ardakan Deserts, Iran. Use of the TM thermal band was tested following several steps such as selection of band combinations using OIF, two-dimensional feature space analysis, digital image classification, and use of digital elevation model (DEM). To obtain the TM thermal-dependant soil ellipse, non-soil materials were masked. The results of the study support that the TM thermal band plays an important role in differentiating similar reflectance classes in mountainous and non-mountainous (the side-by-side low-lying) areas (plains). The TM thermal band provides a strong clue when combined with TM reflective bands for image classification in the deserts. It was also showed that some parts of the mountains, which were wrongly classified as 'vegetation' and 'saline soil' classes could be corrected by means of DEM, superimposed on the interpretation results.

INTRODUCTION

The diversity of environmental conditions in deserts causes complex landform patterns. The variability of climate in time and space has led not only to a large range of landform-producing processes, but also a complementary diversity of soils and vegetation [Cooke et al, 1993]. The basin-range deserts, which are most common in active tectonic areas, form the majority of Iranian deserts. This type of deserts corresponds to the closed drainage basins of Dresch [1982]. The relative proportion of mountain to plain in basin-range deserts may approach one, whereas it may approach infinity in the other types of desert. Poor accessibility for vehicles in deserts, especially in playas, hampers field observation during part of the year. Remotely sensed data allow to overcome or at least minimise this problem. Some factors such as landforms and soils play an important role in land degradation and must be analyzed to better understand the problem and propose recommendations [De Vliegher, 1993]. The study of land cover and soil salinity in desert areas and playas using Landsat satellite images needs: (1) a general understanding of the environmental settings and processes and (2) an understanding of the Landsat satellite images and their usefulness for delineating land units.

The main aim of this study is to prove that the TM thermal band, in a well defined band combination, can solve the problem of mapping salt-affected soils in the mountainous areas of the Iranian deserts, where the environmental settings complicate the use of digital image classification.

THE STUDY AREA

The Ardakan area under the present study is a part of the Yazd basin, in the central Iranian deserts, which extends from Ardistan to Kerman and occupies a linear depression between the Volcanic Belt and a discontinuous mountain chain composed of sedimentary rocks. The area represents severe desert conditions, with annual rainfall of about 60 mm and mean annual evaporation of more than 2500 mm. The Ardakan area lies between latitudes 32° 3'- 32° 34' N and longitudes 53° 45'- 54° 14' E, within the Ardakan-Yazd watershed, north of the city of Yazd and south of the Ardakan playa. Elevation ranges from 965m asl in the Ardakan playa to 1939m asl in the Harish mountain in the northeast.

MATERIALS AND METHODS

Landsat MSS images with four bands (CCT with path/row 174/38 dated September 14, 1975) and Landsat TM images with seven bands (with path/row 162/38 dated September 11, 1990) were used to study soils, soil salinity and land cover. Computer software included ILWIS,
two-dimensional FS between the most informative TM were mainly defined based on field observations, soil and TM thermal band for the study of land cover/use and soil salinity. This result shows that MSS and TM images in the same area. The result of the correlation matrices for MSS and TM data were obtained for the same area. The result of the correlation matrices of TM and MSS shows that the TM bands are more decorrelated than the MSS bands. This is more pronounced for TM infrared and TM thermal bands. The correlation coefficients between TM thermal and TM reflective bands vary from -0.132 to +0.265. This result shows that MSS and TM images in the Ardakan area with differences in spectral and spatial resolutions and number of bands may have different capabilities for separating land cover types [Alavi Panah, 1997].

From the OIF values we may conclude that the high information content of the TM thermal band is not only due to the contrast between shadow and sunshine areas in mountainous areas, but also to land cover types. Among the six TM reflective bands, TM 3, 4, 5 and 7 are the most informative bands for the classification of the total area.

**COMPARISON BETWEEN THE CONVENTIONAL AND TM THERMAL DEPENDENT SOIL LINES**

The author attempted to interpret the TM and MSS training classes and compared the conventional (soil line as a result of FS between red and infra red bands) and the TM thermal-dependent soil lines. In the FS between the TM thermal and TM reflective bands, there is no soil line but the soil units assemble in an ellipse-shaped cluster or an elongated cluster (non-soil material classes). In the FS between TM red and TM thermal bands, the mountain

**RESULTS AND DISCUSSION**

**INFORMATION CONTENT OF MSS AND TM BANDS**

Due to differences between TM and MSS on-board sensors, the TM and MSS data were not completely comparable. For a general comparison between the MSS and TM bands, the correlation matrices for MSS and TM data were obtained for the same area. The result of the correlation matrices of TM and MSS shows that the TM bands are more decorrelated than the MSS bands. This is more pronounced for TM infrared and TM thermal bands. The correlation coefficients between TM thermal and TM reflective bands vary from -0.132 to +0.265. This result shows that MSS and TM images in the Ardakan area with differences in spectral and spatial resolutions and number of bands may have different capabilities for separating land cover types [Alavi Panah, 1997].

**OPTIMUM BAND SELECTION**

The application of the OIF technique to seven TM bands resulted in 35 combinations. Because of low correlation between TM bands combination 4, 5 and 6 ranks first with an OIF value of 42.69 (Table 1). The first two band combinations provide maximum information on natural resources and may thus be used for digital analysis and classification. So the best band combination includes bands 3, 4, 5 and 6. The mountainous areas show an important contrast between sunshine and shadow areas, therefore elevation can have an important effect on cooling the land surface.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Total area</th>
<th>OIF value</th>
<th>Non-mountainous area</th>
<th>OIF value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 5 6</td>
<td>42.693</td>
<td>3 5 6</td>
<td>45.982</td>
</tr>
<tr>
<td>2</td>
<td>3 5 6</td>
<td>41.024</td>
<td>5 6 7</td>
<td>40.517</td>
</tr>
<tr>
<td>3</td>
<td>5 6 7</td>
<td>36.976</td>
<td>1 5 6</td>
<td>40.429</td>
</tr>
<tr>
<td>4</td>
<td>1 5 6</td>
<td>36.576</td>
<td>2 5 6</td>
<td>39.791</td>
</tr>
<tr>
<td>5</td>
<td>4 6 7</td>
<td>36.490</td>
<td>4 5 6</td>
<td>39.512</td>
</tr>
<tr>
<td>6</td>
<td>3 4 6</td>
<td>36.441</td>
<td>3 6 7</td>
<td>37.102</td>
</tr>
<tr>
<td>7</td>
<td>2 5 6</td>
<td>35.447</td>
<td>1 3 6</td>
<td>33.995</td>
</tr>
<tr>
<td>8</td>
<td>3 6 7</td>
<td>33.790</td>
<td>3 4 6</td>
<td>33.958</td>
</tr>
<tr>
<td>9</td>
<td>1 4 6</td>
<td>33.728</td>
<td>4 6 7</td>
<td>33.585</td>
</tr>
<tr>
<td>10</td>
<td>2 4 6</td>
<td>30.930</td>
<td>2 3 6</td>
<td>32.970</td>
</tr>
<tr>
<td>11</td>
<td>1 3 6</td>
<td>30.886</td>
<td>1 6 7</td>
<td>31.950</td>
</tr>
<tr>
<td>12</td>
<td>1 6 7</td>
<td>29.534</td>
<td>1 4 6</td>
<td>31.394</td>
</tr>
<tr>
<td>13</td>
<td>2 3 6</td>
<td>29.529</td>
<td>2 6 7</td>
<td>31.294</td>
</tr>
<tr>
<td>14</td>
<td>2 6 7</td>
<td>28.488</td>
<td>2 4 6</td>
<td>28.836</td>
</tr>
<tr>
<td>15</td>
<td>1 2 6</td>
<td>25.482</td>
<td>1 2 6</td>
<td>27.973</td>
</tr>
<tr>
<td>16</td>
<td>3 4 5</td>
<td>21.942</td>
<td>4 5 6</td>
<td>21.453</td>
</tr>
<tr>
<td>17</td>
<td>4 5 7</td>
<td>21.938</td>
<td>3 4 5</td>
<td>21.396</td>
</tr>
<tr>
<td>18</td>
<td>1 4 5</td>
<td>21.851</td>
<td>1 4 5</td>
<td>21.377</td>
</tr>
<tr>
<td>19</td>
<td>3 5 7</td>
<td>21.205</td>
<td>3 5 7</td>
<td>20.633</td>
</tr>
<tr>
<td>20</td>
<td>1 3 5</td>
<td>20.919</td>
<td>1 3 5</td>
<td>20.337</td>
</tr>
<tr>
<td>21</td>
<td>1 5 7</td>
<td>20.464</td>
<td>1 5 7</td>
<td>19.915</td>
</tr>
<tr>
<td>22</td>
<td>3 4 7</td>
<td>20.224</td>
<td>3 4 7</td>
<td>19.848</td>
</tr>
<tr>
<td>23</td>
<td>1 4 7</td>
<td>19.879</td>
<td>1 4 7</td>
<td>19.564</td>
</tr>
<tr>
<td>24</td>
<td>2 4 5</td>
<td>19.703</td>
<td>2 4 5</td>
<td>19.220</td>
</tr>
<tr>
<td>25</td>
<td>1 3 4</td>
<td>19.325</td>
<td>1 3 4</td>
<td>19.002</td>
</tr>
<tr>
<td>26</td>
<td>2 3 5</td>
<td>19.312</td>
<td>2 3 5</td>
<td>18.762</td>
</tr>
<tr>
<td>27</td>
<td>2 5 7</td>
<td>18.979</td>
<td>2 5 7</td>
<td>18.464</td>
</tr>
<tr>
<td>28</td>
<td>1 3 7</td>
<td>18.695</td>
<td>1 3 7</td>
<td>18.254</td>
</tr>
<tr>
<td>29</td>
<td>1 2 5</td>
<td>18.523</td>
<td>1 2 5</td>
<td>17.996</td>
</tr>
<tr>
<td>30</td>
<td>2 4 7</td>
<td>17.870</td>
<td>2 4 7</td>
<td>17.548</td>
</tr>
<tr>
<td>31</td>
<td>2 3 4</td>
<td>17.318</td>
<td>2 3 4</td>
<td>16.985</td>
</tr>
<tr>
<td>32</td>
<td>2 3 7</td>
<td>17.220</td>
<td>2 3 7</td>
<td>16.816</td>
</tr>
<tr>
<td>33</td>
<td>1 2 4</td>
<td>16.855</td>
<td>1 2 4</td>
<td>16.572</td>
</tr>
<tr>
<td>34</td>
<td>1 2 7</td>
<td>16.277</td>
<td>1 2 7</td>
<td>15.886</td>
</tr>
<tr>
<td>35</td>
<td>1 2 3</td>
<td>16.163</td>
<td>1 2 3</td>
<td>15.788</td>
</tr>
</tbody>
</table>
and urban classes are not included in the ellipse and are defined as non-soil materials. Gravelly surfaces are located in the upper part of the FS because they warm up faster than surfaces with no or little gravel. The comparison between the conventional and TM thermal dependent soil lines shows that (1) the TM thermal and TM infrared bands are highly dependent on each other in the conventional soil line, while the red and thermal bands are almost independent of each other in the TM thermal-dependent soil line; (2) the TM thermal soil line delineates an ellipse-shaped cluster which comprises the soil materials. Thus the urban and mountainous clusters are mostly separated from the soil clusters. The position of the training areas in a conventional soil line and TM thermal dependent soil line shows that the vegetation classes, with the exception of the salt affected vegetation, are mostly separated from the soil classes along the conventional soil line. The position of the mountain class in the FS 3&6 or FS 4&6 allows to distinguish between soils developed in mountain areas and soils developed on alluvial fans [Alavi Panah, 1997]. Thus, in general, the comparison between the position of the training samples in the conventional and TM thermal-dependent soil lines provides a better understanding of soil and non-soil features.

**IMAGE CLASSIFICATION**

Both the TM and MSS images were dependently classified and registered and the accuracy of the classified images was determined. For supervised image classification, a-priori knowledge about land cover types was obtained from fieldwork and our local knowledge of previous years. Because of differences in spectral, spatial and radiometric resolutions of TM and MSS images, a new sampling file was created for the MSS image classification. In this study, 26 and 18 training samples were initially used for TM and MSS classification, respectively. In fact, it was not possible to obtain the same number of spectral classes for both the MSS and TM scenes because of the (1) resolution differences; (2) the fact that the spectral range covered by the TM band 6 is not included in the MSS sensor; and (3) the fact that some new classes were found in the TM images (most recent images) which are not found in the MSS imagery. Therefore, the classes of the classified MSS image are not completely comparable with the TM image classes.

Regarding spectral signature evaluation and assessment of classification images, two possibilities to improve the classification accuracy were examined: (1) merging some training samples before assessing the classification performance, and (2) regrouping some classes after assessing the classification performance. After merging existing classes, the separability of the new classes was again evaluated to assess the enhancement of the separability of the new 11 spectral classes resulting from the 18 original spectral classes. From the above result we conclude that merging some training classes is necessary to improve the accuracy of the MSS classification. In this study, two maximum likelihood classifications were applied using four MSS bands: (1) the classification based on the 18 training samples (before merging), and (2) the classification based on the 11 training samples (after merging). The purpose of the classification of the 18 training samples was to assess the separability of the training samples by using classification accuracy and compare its result with the result of the classification based on 11 training classes. This classified image also shows that some pixels in mountainous areas (sun facing slopes) were wrongly classified as vegetation and soil salinity classes in the MSS classification image.

From the above results we conclude that the MSS images have a lower capability than the TM images in separating some land cover types. This is mainly because of: (1) the effect of the TM thermal band on the classification accuracy; (2) the fact that the TM data are more recent and thus closer to the information obtained from fieldwork; and (3) higher efficiency of the TM reflective bands in comparison to the MSS bands. Joshi and Sahai [1993] studied the reflectance from saline areas on Landsat TM and MSS images and compared them with ground observations. They obtained the best map of saline soils when using Landsat TM data, because the latter had better resolution and were more recent. Jensen [1983] found that the lower accuracy of the MSS classification was due to the four broad MSS bands which were optimised for general terrain analysis and not for a specific purpose. In the Ardakan area, the information content of the MSS bands is highly redundant, which lowers its capability to separate some of the land cover types. Jensen [1986] gave examples where the four-dimensional vector of the MSS data provided sufficient information to do a correct classification for change detection. It is also important to note that the TM image classes have to be regrouped to be comparable with the MSS image classes. The MSS image classification showed that some pixels in sun-exposed areas of the Harish mountains were wrongly classified as vegetation and soil salinity classes because of reflectance similarity. This problem was solved by using a digital elevation model (DEM). The mountains in the Ardakan area are totally bare; therefore, non-correctly classified pixels at elevation higher than 1100 m were corrected using the DEM.

**PROPOSED APPROACH FOR EVALUATION OF THE TM THERMAL BAND**

It is essential to evaluate the information content of the TM thermal band for computer aided digital classification. This may be achieved by the information content as measured by the OIF. To evaluate the effect of the TM
TM thermal band for the study of land cover/use and soil salinity

Behavior of TM thermal band on land cover types

Relationship between TM thermal and TM reflective bands on land cover types

Relationship between TM thermal and TM reflective bands with soil salinity on different soil salinity types

TM thermal band

Relationship between TM thermal and TM reflective bands on land cover types

Non-mountainous area

Mountainous area

Selection of two TM band combinations

TM thermal-based band combination

TM reflective-based band combination

Image classification

Classification accuracy

Visual comparison

Interpretation

Selecting or neglecting TM thermal band

CONCLUSION

Problems of spectral similarities and confusion, especially in mountain areas, may be solved by integrating data sources, to compare the accuracy of classified Landsat images. This study shows that some problems in the multi-temporal analysis can be solved or minimised by regrouping the classified Landsat TM image in a meaningful way to be comparable with the classified Landsat MSS image. Landsat satellite data, especially the TM thermal band, and GIS techniques can be applied for the mapping of land cover types and saline areas. More research is necessary to evaluate the advantage of using the TM thermal band in image classification and its disadvantage in relation to its low spatial resolution.

REFERENCES


Monitoring land use changes in the Sundi Khola micro-watershed, Kavre district, for the sustainable development of agriculture by using geographic information systems

Kamal Sah

Soil Science Division, Khumaltar, Nepal

KEYWORDS: GIS, aerial photographs, topo and LRMP maps, land use, natural resources

ABSTRACT

Assessment of natural resources is always a challenging and crucial task to the agricultural researcher since a variety of recent tools and techniques are used in the assessment. The use of GIS and remote sensing in resource assessment, the latest development in this field, has been accepted world-wide. Aerial photographs, Topo map, and maps of the Land resource Mapping Project (LRMP) are used for natural resource assessment in the study area from August 1998 to June 1999. The special focus of this study is to detect the changes on the use of natural resources over the years. Overall results show that forest encroachment for agricultural land is at 10.4 percent from 1978 to 1992. This change has contributed to soil erosion, landslides and flooding resulting in the reduction of agricultural production and productivity. Likewise, with the extension of new farming technologies in the study area, the culture of planting horticultural trees especially Citrus species has increased by 0.1 per cent in the study site.

RATIONALE OF THE STUDY

Natural resources play a vital role in the development of the nation. In Nepal, natural resources are being depleted rapidly. The problems like decline soil fertility, deforestation, soil erosion, flooding and degradation of forest are being magnified day by day. The population growth of man and livestock would further increase this problem if not appropriately managed. Due to food deficiency, the people and livestock are malnourished. To solve these problems, it is necessary to know our natural resource base like soils of agricultural land, forestland, grazing land, vegetation resources, water resources and climate. For the management of these natural resources, a reliable and relevant database is required. For database and information generation, geographic information systems techniques are being used in many parts of the world. Therefore, this study also envisages applying some of the techniques in order to monitor land use changes and develop a database.

METHODOLOGY

Assessment of land use/land-cover, and changes in their use, are determined by using aerial photographs as the primary sources of information. However, this study is based on the Topo Maps and land use maps produced by the Department of Survey. The interpreted aerial photographs were verified in the field. Then the interpreted maps were geo-referenced with the Topo map. The LRMP of 1978 and Topo Map of 1992 of Batase area were digitized at 1:50,000 and 1:25,000 scale in order to prepare land use maps by using ARC/INFO program. The information captured from the Topo map of 1992 was used as the base map to detect the changes in land use. The area under each land use found in the respective maps were tabbed and compared to determine the land use change. Likewise, the digital forms of each land use of 1978 and 1992 were rasterized and overlaid to detect changes in land use over time.

DESCRIPTION OF THE STUDY AREA

The study was conducted in Sharada Batase Village Development Committee (VDC) of Kavre District which is located between 85° 32' 30" to 85° 35' 00" eastern longitude and 27° 37' 30" to 27° 35' 00" northern latitude. The altitude of the study area varies from 1400 to 1900 meter above mean sea level. The landscape of the study area consists of upland terraces, flat valley bottoms with red silty loam soil. The climate is warm-temperate and annual rainfall was found to be 1540 mm.

The study area is densely populated with various ethnic groups. They are Brahmin, Chhetri, Thakuri, Newar and Tamang. There are 725 households of which 687 belong...
to the farming community. The major sources of income to the farming communities are growing potato, citrus, rice, goats and milk. For landless farm households farm and non-farm wage labour provide major items of the household income. Some households also earn significant income from service, especially in Army and domestic jobs in foreign countries. The majority of the population lacks enough food for the year. The villages are scattered throughout the hill slopes and houses are built on the terraces and flat lands. Men and women have different roles to be performed in farming and their roles are differentiated by historical, ideological, economic and cultural developments.

RESULTS

SITUATION OF AGRICULTURAL LAND

Agriculture in Nepal is the integration of forest, livestock and cropland linkages. Land is an important asset for the inhabitants because it is a source of livelihood, farm income and social status. About 90 percent of the farm households have fragmented land holdings with less than one hectare of land. Farming is performed in a wide range of land. The dominant land types are lowland (Khet), upland (Bari) and Pakho (marginal land nearby the forest and cultivated land). On an average, the ratio of lowland and upland is almost equal, occupying 50 percent of the total land by upland.

Rice, wheat and potato are the major crops grown on lowland whereas growing maize, millet and fruit on the upland. The low-productive uplands are used for growing maize and millet due to shortage of arable land to the growing population. However, the recent trend of commercialization of potato cultivation is gradually replacing the traditional cropping system.

SITUATION OF FOREST LAND

Forest is an integral part of farming in all parts of the country. Forest products are used for fuel-wood, fodder and timber. The leaves and small branches of the forest trees are used for animal litters, which, then ultimately are applied on farmlands to increase soil fertility. Therefore, majority of the farming communities fully depend on forest in order to run their livelihood and farm properly. The dependence on the forest generally increases with the altitude because forestlands are mostly found on the higher slopes rather than on the flat-

lands. The inhabitants of the low land use less farmyard manure in their crop fields but add more nutrients through chemical fertilizer. The villagers residing near to the forest incorporate more biomass to their crop field.

A variety of forest species plants are grown on the edges of farmlands since mixing forest plants, agricultural crops and fodder plant on the farmlands is a tradition. The forest and agro-forestry systems protect cultivated land from landslides and erosion and improved natural resources of water (springs) for irrigating crop fields. Over-exploitation of forest resources decreases soil fertility and increases soil erosion, thus leading to less crop productivity from cultivated areas. The forest directly affects the micro-climatic conditions of the area such as rainfall pattern, floods, drought, landslides, etc. The forest type is mainly mixed hardwood (Chilane: Schima wallichii, Utis: Alnus nepalensis, Banjhi: Anogeissus latifolia) and Chir-pine (Pinus roxburgii). The forest area in the year 1992 is 137.16 hectare.

CHANGES IN LAND USE

The land resource is used for various purposes. The main land uses are agriculture, forest, and orchard. Table 1 gives the detail account of land use pattern of 1978 and 1992. The spatial changes of land use are shown in Figure 1 (Map-1).

CONCLUSIONS

The detection of changes on natural resources over time has been a matter of great concern for all development experts. Most households depend on agriculture for
their livelihood; agriculture is at subsistence level. Both men and women play important roles in the farming and the socio-economic systems of the mountain agriculture. About more than half of the total land is under agriculture, of which 10 percent of the land is fully irrigated from natural streams.

The forest is located at higher altitudes and steep slopes; forest resources are used for livestock and farming; the forest area has decreased over time with 10.4 percent due to expansion of the agricultural area; the area of agricultural land has increased over the years by 10.3 percent; people have started planting orchard trees at their homestead; and food shortage is a prominent problem for the majority of the population. The natural resources have depleted due to over-population so they need control; forests need protection for sustainable yield; and alternative sources of income generation, other than agriculture, need to be promoted.

REFERENCES
Landscape planning for Mexican mountains: a geo-ecological approach

Alejandro D’Luna Fuentes

National University of Mexico, Asturias 243-101, Colonia Alamos, 03400, Mexico

KEYWORDS: geo-ecology, policies, mountainous land

ABSTRACT

More than as a simple landform or a body, being the result of certain tectonic processes, a mountain can be considered as a vertical system which is characterised by strong biophysical contrasts and a high geomorphological instability. Due to these elements the mountains have a great biodiversity and, as a result, a huge use potential, that’s why it is better to name them “mountain biotopes”. Almost 60% of Mexico’s surface are integrated by mountain biotopes, which support a great deal of resource. In spite of this, their inhabitants generally have a low standard of life. From a geoecology point of view, that is, of relationships among structures and functions with biological, socio-cultural and physical characteristics into a given spatial and temporal frame, mountain’s biotopes can be analysed upon the following basis:

1. Mountain conceived as a physical-geographic landscape, which includes the analysis and the dynamics of mountain’s geomorphological and geographic structure and its relationship with the neighbouring landscapes.
2. Biodiversity and mountain’s resources, which studies the biological contrasts, as well as current and potential uses for natural resources.
3. Mountain’s hazards and risks, which analyse the natural influence of the natural processes (volcanism, landslides, and erosion) over the human activity.
4. Mountains from a human point of view, which studies the spatial occupation and the economic productivity of this biotope, and finally
5. Mountain’s management, which emphasises political aspects and decisions in a national or international frame.

The use of databases, GIS and remote sensing is very important to obtain results, with more precision and speed of processes. The basic covers (relief, climate, soils, population, etc.) can overlap in one map with one database, and then manipulate the information through a decision-table. With these processes, we can obtain maps of resilience, fragility, risks, stability, social pressure and ecological quality. Incorporating these techniques and the geoecological elements into the scientific research about mountain’s biotopes and into the political decisions in management or land planning programs, might contribute to obtain a better conservation and exploitation potential of these very fragile lands.

INTRODUCTION

Mountains are usually considered as a landform which is the result of endogenic processes, like volcanism and tectonics, and arise as a positive relief over the neighbouring area. From the point of view of landscape ecology, a mountain can be considered as a vertical system, which is characterized by strong biophysical contrasts and a high geomorphological instability. Due to this elements, the mountains have a great geo-diversity (landscapes contrasts) and bio-diversity (biological contrasts). Therefore, and with this considerations, it is better to name them as “mountain landscapes” or “mountain biomass”.

Almost 60% of Mexico’s surface is integrated by mountain landscapes, which support a great deal of resources (forest, mining, water, wildlife). In spite of this, their inhabitants generally have a low level of life. From a bioclimatic point of view, Mexican mountains can be classified in temperate mountains (coniferous and deciduous forest), high-mountains (alpine grassland, above 3,800 m asl), tropical and subtropical mountains (tropical forest) and xerofile mountains. However, most of the mountain’s surface has a temperate climate.

Usually, mountains are elevated more than 500 meters or 1600 feet above the adjacent surface, this difference of altimetry allows the presence of bioclimatic belts in most of the Mexican territory. In other latitudes, the difference can decrease until 200 meters. For example, in the Scandinavian Mountains, the snowline is at 700 meters above sea-level, and all the belts (upper and low timberline, crop belt, grazing belt) are in this space. Other important characteristics of mountains are the consolidated or semi-consolidate substratum, strong slopes, high climatic and geomorphological dynamics, and evidences of tectonic processes, like faulting, folding, volcanism, terraces, drainage patterns and asymmetric valleys.
From a geo-ecological point of view, that is, of relationships among structures and functions with biological, socio-cultural and physical characteristics into a given spatial and temporal framework, mountain's landscapes can be analysed upon the following basis:

- landscape structure and mountain dynamics, which analyse the form, condition and function of the mountain's components and the shape of regions;
- human settlements and activities, which studies the spatial occupation of people and the economic use of these lands;
- natural hazards and risks, which analyse the natural influence of the natural processes over human activity;
- policies and management on mountains, which emphasises political aspects and decisions into a national or international framework.

Inhabitants of mountains located in developing countries are characterised by high levels of tradition and ethnic patterns, furthermore, their marginality is high. Economic activities are concentrated in grazing, self-consumption farming, hunting and forestry, although in many cases natural fragility in association with intensive land-use causes intensification of natural processes, such as erosion and landslides.

**NATURAL HAZARDS AND RISKS**

The recent theories about risks and natural hazards consider a global equation as the basis for these studies: 

\[ \text{Risks} = \text{Natural hazards (origin of the phenomenon)} + \text{Vulnerability of human settlements and activities, and the global environment)} + \text{Value (potential loss of human lives and infra-structure).} \]

The natural hazards consist in the natural potentiality of an event to cause a phenomenon of disaster, in ecological or human terms. Mountains present a wide spectrum of phenomena, classified in geological hazards, geomorphological hazards, meteorological hazards, edaphic and biotic hazards and human hazards. Vulnerability and value depend for specific human conditions, like distance to the origin of the phenomenon, people capability to assimilate the event, and resistance of the infra-structure. The most important events in mountains are volcanism (lahars, pyroclastic and lava flow), debris flows, landslides, active faulting, and forest fires.

**HUMAN SETTLEMENTS AND ACTIVITIES**

There are important contrasts of the human condition in developed and in developing countries. In the first case, people have a high standard of living, which depends mainly from trade, industry, tourism and activities derived from protected areas management; and in the last case, there is a lot of poverty and marginality caused by low accessibility of means of communication and services.

**POLICIES AND MANAGEMENT OF MOUNTAINS**

In a contemporary international context, the most important frame for mountains is the Agenda XXI derived from the "Cumbre de Río" in 1992. Chapter 13, title "Managing fragile ecosystems: sustainable mountain development", involves some of the main principles and objectives for the participant countries concerning to mountain management. Derived from this Agenda, some specific projects have been realized under the coordination of FAO (Food and Agriculture Organization), mainly in developing countries.

National policies on mountains mainly depend from the Constitution, the National Plan of Development and the Mexican environmental law: General Law of the Ecological Balance and Environmental Protection. This law includes some instruments like protected areas and their management programs, programs for flora and fauna protection, environmental impact assessment, and land-use planning. Nevertheless these instruments, a reduced area of Mexican mountains is regulated by some kind of program.

The use of databases, GIS and remote sensing is very
important to obtain results for prospecting and model the mountainous environment with more precision. We can divide the basic inputs in two groups: physical-ecological and socio-economic dynamics. The first group includes relief, lithology, tectonics and relief-molding, climate (mainly temperature and rainfall precipitation) edaphology, hydrology (surface and groundwater), and land-use cover. The second group contains socio-economic dynamics, such as demography, ethnology, migration, and land-occupation for economic purposes. All these elements must be represented in a cartographic expression, digitised and incorporated in a Geographic Information System (GIS).

There is an important problem in spatial representation. Whilst physical-ecological information can be processed by polygons which represent the exact accuracy of the information, socio-economic dynamics must be represented by an administrative area, such as a state, a municipality, a county, etc., creating over-representation of the information, mainly in large territories. The use of punctual data can reduce this problem and allow overlap.

CONCLUSIONS
The different structures of mountainous land can be estimated and processes can be identified with the aid of remote sensing and GIS. Human pressure on the land in developing countries and policies should be considered in inventory and evaluation because of their high impact. Incorporating these techniques and the geocological elements into the scientific research about mountain’s biotopes and into the political decisions on management or land planning programs, might contribute to obtain a better conservation and exploitation potential of these very fragile lands.
An integrated land evaluation approach of crop planning for lower Himalayan mountainous lands of UP State, India - a case study

D Martin and S K Saha

National Bureau of Soil Survey and Land Use Planning, Regional Center, IARI campus, New Delhi 110 012, India and Indian Institute of Remote Sensing, Dehradun, 248 001, UP, India

KEYWORDS: land evaluation, remote sensing, GIS, land utilisation type, cropping pattern

ABSTRACT

Different quantitative land evaluation procedures, like the land capability classification, land productivity index, soil site suitability analysis for land utilization types, were performed to obtain cropping plans for the kharif (summer) and rabi (winter) seasons. In this approach the data related to soil, land, climate were derived from the remote sensing satellite data (Landsat TM, bands 1 to 7) and the analysis was performed in GIS environment (ILWIS version 2.1). The analysis was performed to estimate the soil erosion loss by using USLE model for the watershed area to identify the priority areas for soil conservation measures. Integrating the maps in GIS, generated all the attribute factor maps (R, K, L, S, C and P). Using the soil loss map as one of the input attributes for land capability classification (USDA, Soil Conservation Department) the area was classified into different land capability units. The mapping units, found not suitable for agriculture production, were delineated and mapped as non-agricultural land. The area suitable for agricultural production was carved out for imparting the productivity analysis; the land suitable for raising agricultural crops was delineated into different mapping units as productivity ratings good, fair, moderate and poor. Further, land evaluation by FAO framework for different land utilisation types (paddy, wheat, maize, mustard, sugarcane) using different land qualities (based on soil texture, soil depth, erosion, slope, flooding, coarse fragments) was carried out. Integrating the individual crop suitability maps generated Kharif and rabi season crop suitability maps. Finally the cropping sequence map for the agricultural crop calendar was obtained.

INTRODUCTION

Land evaluation using scientific procedures is essential to assess the potentials and constraints of a given piece of land for agricultural needs [Rossiter, 1996; FAO, 1976]. Presently, the effects of land use on quality of the environment and environmental sustainability in agricultural production systems have become major issues [Fresco, 1990]. The problems associated with intensive agriculture in some industrialised countries leading to declining soil fertility and erosion have to be regarded in association with low input farming against a background of over exploitation of natural resource bases and scarcity of external inputs in the least endowed countries [Lanen Van, et al, 1991]. Land evaluation may address some of these problems by presenting favorable land use that meets the objectives of crop planners and farmers. The potential of the integrated approach in using Geographical Information Systems (GIS) and Remote Sensing (RS) technology for qualitative and quantitative physical land evaluation was demonstrated widely by several researchers [Beek et al, 1997, Merolla et al, 1994, Rao et al, 1996]. Therefore, the objective was taken to accomplish the land evaluation by using Remote Sensing (RS) and Geographical Information Systems (GIS) environment for suggesting suitable cropping pattern for a watershed area.

GEOGRAPHY OF THE AREA

The study area, called Suarna river watershed, is a part of the Doon valley (77° 45' 22" to 78° 0' 20" and 30° 20' to 30° 28' 21") of the Dehradun district, UP state, India, with a subtropical and semi arid to semi humid climate. The mean annual temperature ranges from 30.85° C in summer to 15.22° C in winter. The mean annual rainfall is 1700 mm. The physiography of the watershed comprises the lower Himalayan Mountains in the North and a luvial plains in the South and sloping terrain with piedmont material. The soils are dominantly Entisols and Mollisols in different physiographic units. The natural vegetation of the area mainly comprises of dense forest of Shorea robusta, mixed, moderately dense and some areas of degraded forests with the common tree species of Pinus roxburghii, Sisham (Delbergia sissoo), Babul (Acacia arabica). Apart from forest trees, Shrubs (Lantana camara, Agave sisillia) and grasses (Saccharum spontaneum, Cynodon dactylon) also occupy considerable areas. The main river in the study area is the Suarna river. The Himalayan snowmelt keeps some of the drains as perennial and irrigation canals are constructed for agriculture in the upper and middle piedmont areas. The major agricultural crops are paddy, wheat, mustard, maize, sugarcane, apart from vegetable and fruit crops. Horticulture plantations also occupy considerable areas.
MATERIALS AND METHODS

DATA SET
The digital data of Landsat TM (146-39, March 1, 1998) bands 1-7 were used to generate the false colour composite from the 5-3-2, bands by Optimum Index factor method. The Survey of India (SOI) toposheet (53 F/13) at 1:50,000 scale was used for generating the base map and contour map and to derive some geomorphic features of the study area. PC based raster GIS software, Integrated Land and Water Information System (ILWIS) Windows version 2.1 was used for GIS aided integrated analysis.

PHYSIOGRAPHIC SOIL MAP
To generate the physiographic soil map, a collective approach of combining satellite data, topographic information, supplemented with the field data on soil survey information on the morphogenesis of the soil in the sampled areas, was adopted. The physiographic soil map at 1:50,000 scale of the Doon valley, prepared by the Indian Institute of Remote Sensing (IIRS), Dehradun, was taken as a source map to delineate the physiographic soil map of the study area. Based on the variations in the FCC image, characteristics with respect to terrain variability (hills, piedmont, valleys, slopes and alluvial plains), vegetation, land use/land cover, the physiographic units were delineated. The soil association of each physiographic unit was established by studying soil profiles and mini pits in the sampled areas.

LAND USE/LAND COVER MAP
The land use and land cover map was generated by supervised classification of the Landsat TM bands FCC 5-3-2 digital data, by applying maximum likelihood classifier. Suitable filters were also applied for smoothening. In this process suitable training sets were taken from the sample strips during fieldwork and amended with the ancillary data on land use/land cover of the study area to generate the final map. Out of the study area, the land under agriculture and non-agricultural practices (forest cover, settlement and river) were marked by crossing the physiographic soil map with land use/land cover map using “Cross” operation. A new attribute table was also created with the land units under agriculture and used subsequently for land productivity evaluation and cropping system analysis.

SOIL EROSION
For prioritization of micro-watersheds, actual(A) and potential(p) soil loss were quantitatively estimated by the empirical Universal Soil Loss Equation (USLE) model [Wischmeir and Smith, 1978]. The methodology is presented in flow chart 1 (Figure 1).

1. R Factor: The rainfall map was generated by using the empirical equation developed for Doon Valley with DEM as below:
Rainfall = 1384.2 + 0.329 * DEM
R Factor = (0.1059 * a * b * c) + 52
where
a: Average annual rainfall (cm)
b: 24 hours maximum rainfall of 2 years recurrence interval (cm)
c: 1 hour maximum rainfall of 24 recurrence interval (cm)

2. K-Factor: Soil characteristics of permeability, texture, structure and organic matter content for each soil unit was used to derive the soil erodibility factor by using the nomograms and placed in the soil attribute table and map was generation by K-Factor = Soil map . Soil Table . K-factor column

3. LS Factor: Polygons containing small drainage units were digitised and average slope length value was attributed for each polygon. LS factor for the slope percentage less than 21 per cent and more than 21 percent was generated separately by using the relationship given by and integrated using “map calc” operator.

LS factor-1: (U/72.6) * (65.41 * Sin(S) + 4.56 * Sin(S) + 0.065)
LS factor-2: (U/22.1)°7 * (6.432 * Sin(6)° + 0.79 * Cos(6))
LS factor = iff (Slope <21, LS factor-1, LS factor-2)
Where LS factor = Slope factor
L : Slope length (m)
S : Slope steepness (%)

4. C and P factors: Different land cover (C) and management practices (P) obtained for the experimental values were used to take C and P factor values in the landuse/landcover attribute table and attribute raster

FIGURE 1: Flow chart 1, USLE model and prioritization of micro-watershed
An integrated land evaluation approach

LAND CAPABILITY CLASSIFICATION

The methodology given by Soil Conservation Service, USDA, was adopted for land capability classification. The four levels of classification, order, class, sub-class and unit are analysed for each soil mapping unit with the land qualities Surface soil texture, Slope, Drainage, Soil depth, Erosion hazard, Flooding hazard. Attribute maps of the land qualities were evaluated and rated using “Logical operator” in “Map Calc” to classify into capability class I to VIII and limitations in each mapping unit are noted. All the maps were integrated to incorporate the land qualities for capability class by using Max operator in “Map Calc” modules, which gave rise to the classified land capability map of the study area. The complete methodology is presented in flow chart 2 (Figure 2). Out of the study area, the land under agriculture and non-agricultural (forest cover, settlement and river) were marked by crossing the physiographic soil map with landuse/landcover map using “Cross” operation. A new attribute table was also created with the land units under agriculture and used subsequently for land productivity evaluation and cropping system analysis.

LAND PRODUCTIVITY EVALUATION

The Storie index (revised) ratings method [Storie, 1978] was applied to quantitatively estimate the productivity indices to classify the area under interest. The ratings were selected in percentage values and converted into decimal equivalents for use in formula and the final values were converted into percentages (flow chart 3, Figure 3).

Land Productivity Index (LPI): \[ A \times B \times C \times X \times Y \]

Where:
- \( A \): Percentage rating for the general soil profile characteristics.
- \( B \): Percentage rating for the texture of the surface horizon.
- \( C \): Percentage rating for the slope of the land.
- \( X \): Percentage rating for the site conditions (salinity, soil reaction etc.)
- \( Y \): Percentage rating for the annual rainfall.

Percentage rating for each above said parameters were enumerated and attribute maps for land productivity index were generated. The final LPI map was generated by integrating all the attribute maps.

LAND EVALUATION AND SUITABILITY ANALYSIS

Five land utilization types (LUTs) were chosen for land evaluation. Each soil scape/physiographic unit was evaluated for the LUT suitability. The selected LUTs, LUT-I (paddy), LUT-II (wheat), LUT-III (maize), LUT-IV (mustard) and LUT-V (sugarcane) were evaluated by using FAO framework of land evaluation [1976]. The deterministic land characteristics and qualities soil texture, soil depth, drainage, erosion, coarse fragments and flooding were taken for suitability analysis (Table 1). The methodology adopted is presented in the flow diagram 4 (Figure 4).

By incorporating the land utilisation criteria in the map calculation module of ILWIS, the suitability ratings for each land quality map were generated. By further integration and reclassification of each land quality with each LUT, the suitability maps were generated in the Max operation module. Kharif and rabi season suitability maps were generated separately by further integrating the respective season crops in Cross operation. By integrating
TABLE 1 Criteria and ratings of soil and land qualities for five LUTs

<table>
<thead>
<tr>
<th>Soil and land Quality</th>
<th>Suitability class</th>
<th>LUT-I (paddy)</th>
<th>LUT-II (wheat)</th>
<th>LUT-III (maize)</th>
<th>LUT-IV (mustard)</th>
<th>LUT-V (sugarcane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>$S_1$</td>
<td>CL</td>
<td>L</td>
<td>SL</td>
<td>SL</td>
<td>CL</td>
</tr>
<tr>
<td></td>
<td>$S_2$</td>
<td>SL</td>
<td>SL</td>
<td>L</td>
<td>CL</td>
<td>$S_1$</td>
</tr>
<tr>
<td></td>
<td>$S_3$</td>
<td>coarse SL</td>
<td>LS</td>
<td>CL</td>
<td>SC</td>
<td>$S_2$</td>
</tr>
<tr>
<td></td>
<td>$N$</td>
<td>$S$ fragmental</td>
<td>$S$ fragmental</td>
<td>$S$ fragmental</td>
<td>$S$ fragmental</td>
<td>$S$ fragmental</td>
</tr>
<tr>
<td>Soil depth</td>
<td>$S_1$</td>
<td>deep</td>
<td>very deep</td>
<td>deep</td>
<td>deep</td>
<td>very deep</td>
</tr>
<tr>
<td></td>
<td>$S_2$</td>
<td>moderate</td>
<td>deep</td>
<td>mod deep</td>
<td>mod deep</td>
<td>deep</td>
</tr>
<tr>
<td></td>
<td>$S_3$</td>
<td>shallow</td>
<td>mod deep</td>
<td>shallow</td>
<td>shallow</td>
<td>mod deep</td>
</tr>
<tr>
<td></td>
<td>$N$</td>
<td>very shallow</td>
<td>shallow</td>
<td>very shallow</td>
<td>v shallow</td>
<td>v shallow</td>
</tr>
<tr>
<td>Drainage</td>
<td>$S_1$</td>
<td>imperfectly to</td>
<td>well</td>
<td>well</td>
<td>well</td>
<td>well</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poor</td>
<td>drained</td>
<td>drained</td>
<td>drained</td>
<td>drained</td>
</tr>
<tr>
<td></td>
<td>$S_2$</td>
<td>moderate to</td>
<td>mod well</td>
<td>mod well</td>
<td>mod well</td>
<td>mod well</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Well</td>
<td>drained</td>
<td>drained</td>
<td>drained</td>
<td>mod well</td>
</tr>
<tr>
<td></td>
<td>$S_3$</td>
<td>imperfectly</td>
<td>imperfectly</td>
<td>imperfectly</td>
<td>imperfectly</td>
<td>well</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drained</td>
<td>drained</td>
<td>drained</td>
<td>drained</td>
<td>poorly</td>
</tr>
<tr>
<td></td>
<td>$N$</td>
<td>excessively</td>
<td>poorly</td>
<td>poorly</td>
<td>poorly</td>
<td>poorly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drained</td>
<td>drained</td>
<td>drained</td>
<td>drained</td>
<td>drained</td>
</tr>
<tr>
<td>Slope</td>
<td>$S_1$</td>
<td>level</td>
<td>flat to level</td>
<td>nearly level</td>
<td>nearly level</td>
<td>level</td>
</tr>
<tr>
<td></td>
<td>$S_2$</td>
<td>very gentle</td>
<td>gentle slope</td>
<td>mod sloping</td>
<td>very gentle</td>
<td>v gentle</td>
</tr>
<tr>
<td></td>
<td>$S_3$</td>
<td>gentle slope</td>
<td>mod slope</td>
<td>mod slope</td>
<td>mod to strong</td>
<td>gentle sloping</td>
</tr>
<tr>
<td></td>
<td>$N$</td>
<td>moderate to</td>
<td>step to</td>
<td>step to</td>
<td>steep</td>
<td>steep sloping</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steep</td>
<td>very steep</td>
<td>very steep</td>
<td>slope</td>
<td>sloping</td>
</tr>
<tr>
<td>Erosion</td>
<td>$S_1$</td>
<td>none</td>
<td>slight</td>
<td>none</td>
<td>very low</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>$S_2$</td>
<td>slight</td>
<td>moderate</td>
<td>slight</td>
<td>low</td>
<td>slight</td>
</tr>
<tr>
<td></td>
<td>$S_3$</td>
<td>moderate</td>
<td>high</td>
<td>moderate</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td></td>
<td>$N$</td>
<td>severe</td>
<td>severe</td>
<td>severe</td>
<td>severe</td>
<td>severe</td>
</tr>
<tr>
<td>Coarse fragments</td>
<td>$S_1$</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>$S_2$</td>
<td>slight</td>
<td>slight</td>
<td>slight</td>
<td>slight</td>
<td>slight</td>
</tr>
<tr>
<td></td>
<td>$S_3$</td>
<td>moderate</td>
<td>moderate</td>
<td>moderate</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td></td>
<td>$N$</td>
<td>severe</td>
<td>severe</td>
<td>severe</td>
<td>severe</td>
<td>severe</td>
</tr>
<tr>
<td>Flooding fragments</td>
<td>$S_1$</td>
<td>very low</td>
<td>very low</td>
<td>none</td>
<td>very low</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>$S_2$</td>
<td>medium</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>$S_3$</td>
<td>high</td>
<td>moderate</td>
<td>moderate</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td></td>
<td>$N$</td>
<td>very high</td>
<td>severe</td>
<td>high</td>
<td>severe</td>
<td>high</td>
</tr>
</tbody>
</table>

SL = sandy loam, CL = clay loam, L = loam, LS = loamy sand, S = sand, $S_1$ = Highly suitable, $S_2$ = Moderately suitable, $S_3$ = Marginally suitable, N = Not suitable

RESULTS AND DISCUSSION

The watershed area with diverse terrain characteristics like low Himalayan Mountains in the north to alluvial plains in the south and with sloping terrain was essentially composed of piedmont material (Table 2). From Table 3 the soils were found to be dominantly Entisols and Mollisols in different physiographic soil units. The results on land use/land cover analysis by supervised classification of the digital data (Table 4) showed that the maximum area (4541.31 ha) was predominantly under wheat crop. Moderately dense forest occupies 19.5 percent of the area. It is interesting to note that the area

kharif and rabi season suitability maps with the newly created attribute table for kharif and rabi season suitability maps, the cropping pattern map for the agricultural crop calendar was generated.

![Flow diagram for soil and land suitabilities for each LUTs based on FAO Land Evaluation Model](image)

FIGURE 4: Flow chart 4, soil and land suitabilities for each LUT (based on FAO Land Evaluation Model)
under degraded forest (1835.46 ha) is also larger than the area under dense forest (1619.19 ha), which indicates the deforestation activities in the area. The river course occupies 9 percent of the total area apart from scrub lands and settlement.

### TABLE 2 Soil and land characteristics of the mapping units of the Suarna river watershed

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Soil physiographic unit</th>
<th>Texture</th>
<th>Soil Depth</th>
<th>Slope (%)</th>
<th>Erosion</th>
<th>Drainage</th>
<th>Flooding hazard</th>
<th>Coarse fragments</th>
<th>Moisture availability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>M11</td>
<td>Loamy Skeletal</td>
<td>Very deep</td>
<td>25-50</td>
<td>Moderate</td>
<td>Well</td>
<td>Very low</td>
<td>&gt;35%</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>M12</td>
<td>Loamy Skeletal</td>
<td>Very deep</td>
<td>25-50</td>
<td>Low to Moderate</td>
<td>Well</td>
<td>Very low</td>
<td>35%</td>
<td>Low to Moderate</td>
</tr>
<tr>
<td>3</td>
<td>M21</td>
<td>Loamy Skeletal</td>
<td>Very deep</td>
<td>25-50</td>
<td>Moderate</td>
<td>Well</td>
<td>Very low</td>
<td>35%</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>M22</td>
<td>Loamy Skeletal</td>
<td>Very deep</td>
<td>25-50</td>
<td>Low</td>
<td>Well</td>
<td>Very low</td>
<td>35%</td>
<td>Low</td>
</tr>
<tr>
<td>5</td>
<td>P11</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>1-5</td>
<td>High</td>
<td>Well</td>
<td>Very low</td>
<td>&lt;35%</td>
<td>Low</td>
</tr>
<tr>
<td>6</td>
<td>P12</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>1-5</td>
<td>Moderate</td>
<td>Well</td>
<td>Low</td>
<td>&lt;35%</td>
<td>Low</td>
</tr>
<tr>
<td>7</td>
<td>P21</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>1-5</td>
<td>Low</td>
<td>Well</td>
<td>Low</td>
<td>&lt;35%</td>
<td>Moderate</td>
</tr>
<tr>
<td>8</td>
<td>P22</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>1-5</td>
<td>Moderate</td>
<td>Well</td>
<td>Low</td>
<td>&lt;35%</td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>T1</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>&lt;3</td>
<td>Slight to Moderate</td>
<td>Well</td>
<td>Very low</td>
<td>&lt;35%</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>10</td>
<td>T2</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>15-25</td>
<td>Moderate</td>
<td>Excessively well drained</td>
<td>Very low</td>
<td>&lt;35%</td>
<td>Low</td>
</tr>
<tr>
<td>11</td>
<td>AT1</td>
<td>Clay loamy</td>
<td>Very deep</td>
<td>&lt;3</td>
<td>Slight</td>
<td>Moderately well drained</td>
<td>Moderate</td>
<td>&lt;35%</td>
<td>Moderate</td>
</tr>
<tr>
<td>12</td>
<td>AT2</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>&lt;3</td>
<td>Slight</td>
<td>Well drained moderate</td>
<td>Low to</td>
<td>&lt;35%</td>
<td>Moderate</td>
</tr>
<tr>
<td>13</td>
<td>AT3</td>
<td>Fine loamy</td>
<td>Very deep</td>
<td>&lt;3</td>
<td>Slight</td>
<td>Well drained</td>
<td>Low</td>
<td>&lt;35%</td>
<td>Low to moderate</td>
</tr>
</tbody>
</table>

### TABLE 3 Brief description of the Physiographic Soilscape Units of the Suarna watershed

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Physiography</th>
<th>Soil Association</th>
<th>Area (ha) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mountains (North aspect) open : M11</td>
<td>Loamy skeletal, Dystric Eutrochrepts</td>
<td>624</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loamy skeletal, Typic Udorthents</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.1)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Mountains (South aspect) cultivated : M12</td>
<td>Loamy skeletal, Dystric Eutrochrepts</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine loamy, Dystric Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.3)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mountains (South aspect) forest : M21</td>
<td>Loamy skeletal, Mollic Hapludalfs</td>
<td>586</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coarse loamy, Lithic Udorthents</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.8)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Mountains (South aspect) open : M22</td>
<td>Loamy skeletal, Dystric Eutrochrepts</td>
<td>633</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coarse loamy, Lithic Udorthents</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.1)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Upper piedmont (more eroded) : P11</td>
<td>Loamy, Dystric Eutrochrepts</td>
<td>2611</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loamy skeletal, Dystric Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(17.1)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Upper piedmont (less eroded) : P12</td>
<td>Fine loamy, Typic Hapludalfs</td>
<td>539</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coarse loamy, Typic Udifluvents</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.5)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Lower piedmont (more eroded) : P21</td>
<td>Fine loamy, Dystric Eutrochrepts</td>
<td>640</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loamy skeletal, Dystric Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.2)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Lower piedmont (less eroded) : P22</td>
<td>Fine loamy, Mollic Hapludalfs</td>
<td>955</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine loamy, Dystric Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6.3)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Top uplifted terraces : T1</td>
<td>Fine loamy, Typic Hapludalfs</td>
<td>2229</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine loamy, Mollic Hapludalfs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.9)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Slide sloping uplifted terraces : T2</td>
<td>Fine loamy, Dystric Eutrochrepts</td>
<td>1685</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loamy skeletal, Typic Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(11.1)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>River terraces (Lower) : AT1</td>
<td>Coarse loamy, Aquic Eutrochrepts</td>
<td>364</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loamy skeletal, Typic Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.4)</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>River terraces (Middle) : AT2</td>
<td>Fine loamy, Mollic Hapludalfs</td>
<td>1905</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine loamy, Dystric Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(12.5)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>River terraces (Upper) : AT3</td>
<td>Fine loamy Typic, Hapludolls</td>
<td>1253</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loamy skeletal, Typic Eutrochrepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8.2)</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 4 Spatial extent of different land use/land cover of the study area by supervised S.No. classification of Landsat digital data Land use/cover Area (ha) 1. Dense forest (Shorea robusta) 1619.19 2. Dense forest (mixed) 143.73 3. Moderately dense forest 2881.17 4. Degraded forest 1835.46 5. Cultivation (dominantly wheat) 4541.31 6. Cultivation (dominantly sugarcane, maize) 1429.11 7. Horticulture plantations (mango) 33.66 8. Scrub lands 512.73 9. Settlements 478.89 10. Rivercourse 1321.56

SOIL LOSS ESTIMATION AND MICRO-WATERSHED PRIORITIZATION
The soil loss estimated by the USLE model gave the soil loss in the area ranging from 1 to 34 ton ha⁻¹ yr⁻¹ in different micro-watershed areas (Table 5). As per the priority criteria (Table 6) the results showed that although the potential soil loss in the micro-watersheds S6 and J1 are alarmingly high, the land cover/use in the respective watersheds with proper management practices significantly reduced the soil loss. Out of 12 micro-watersheds only one micro-watershed (D) gave the maximum (34 tons ha⁻¹ yr⁻¹) soil loss for which the prioritization is very high. Three micro-watersheds (S6, I, J) need high prioritization followed by two (S5, S2), medium priority levels (S1, S). The remaining five micro-watersheds the land use and management practices are found to be stabilized. The actual soil loss for each micro-watershed was calculated using the “column-aggregation” and Area weighted average functions. Potential and actual soil loss in each micro-watershed area were also compared.

LAND CAPABILITY CLASSIFICATION
Based on the Soil Conservation Service, USDA methodology, the study area resulted in four major classes as given in the Table 7. In all the classes, erosion resulted as a major limitation apart from the other soil characteristics. In capability classes III and IV, which occupied 4083.1 and 4967.1 ha of land area, surface soil texture and slope were the second limitation. Although the study area was found to have forest and non-agricultural area of nearly 9500 hectares, the land capability analysis showed that about 10,700 hectares of the area is found presently suitable for agriculture (Figure 5b). Therefore, more area in the micro-watersheds can be brought under cultivation with minor conservation practises.

TABLE 5 Actual (A) and Potential (P) loss (ton ha⁻¹ yr⁻¹) in different micro-watersheds and their prioritization

<table>
<thead>
<tr>
<th>S.NO.</th>
<th>Microwatersheds</th>
<th>Land use/cover</th>
<th>Area (ha)</th>
<th>Actual loss (A)</th>
<th>Potential loss (P)</th>
<th>Prioritization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Dense forest</td>
<td>3186.0</td>
<td>4</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Under intensive cultivation</td>
<td>2453.0</td>
<td>23</td>
<td>49</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Degraded and moderately dense forest</td>
<td>1761</td>
<td>18</td>
<td>280</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Settlements</td>
<td>327</td>
<td>1.0</td>
<td>1.0</td>
<td>Medium</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Dense forest</td>
<td>857</td>
<td>1.0</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>-do-</td>
<td>442</td>
<td>1.0</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>-do-</td>
<td>581</td>
<td>1.0</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Under intensive cultivation</td>
<td>1239</td>
<td>12.0</td>
<td>12.0</td>
<td>Medium</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>Degraded forest</td>
<td>152</td>
<td>23.0</td>
<td>24.0</td>
<td>High</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>-do-</td>
<td>659</td>
<td>11.0</td>
<td>80.0</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>Open, moderate dense forest, under low intensive cultivation</td>
<td>1645</td>
<td>34.0</td>
<td>28.0</td>
<td>Very high</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>Scrub (open)</td>
<td>958</td>
<td>34.0</td>
<td>28.0</td>
<td>High</td>
</tr>
</tbody>
</table>

TABLE 6 The priority criteria classes for soil conservation measures.

<table>
<thead>
<tr>
<th>Soil Loss(Tons ha⁻¹ yr⁻¹)</th>
<th>Priority Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>Least</td>
</tr>
<tr>
<td>5-10</td>
<td>Low</td>
</tr>
<tr>
<td>10-15</td>
<td>Moderate</td>
</tr>
<tr>
<td>15-25</td>
<td>High</td>
</tr>
<tr>
<td>25-50</td>
<td>Very High</td>
</tr>
<tr>
<td>&gt;50</td>
<td>Very Very High</td>
</tr>
</tbody>
</table>

TABLE 7 Land capability classes in the study area

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Class</th>
<th>Sub class</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>II</td>
<td>lle</td>
<td>3571.83</td>
</tr>
<tr>
<td>2</td>
<td>III</td>
<td>llies</td>
<td>4083.10</td>
</tr>
<tr>
<td>3</td>
<td>IV</td>
<td>llves</td>
<td>4967.10</td>
</tr>
<tr>
<td>4</td>
<td>V</td>
<td>lvew</td>
<td>1462.50</td>
</tr>
</tbody>
</table>
LAND PRODUCTIVITY INDEX

By integrating the productivity ratings of different attribute factors in GIS the results obtained are presented in Table 8. The productivity of the watershed area in different mapping units was rated as good (70 LPI) to poor (22 LPI). The maximum area (3153.8 ha) of the watershed in upper and lower piedmont areas, which contributes to nearly 55 percent of the area under cultivation was rated as fair. A considerable extent of area (2374 ha) in the uplifted terraces and river terraces were also classified into good (>60 LPI) land productivity index ratings (Figure 5c). The physiographic soil units M11 and M12 gave poor (22) productivity index ratings.

LAND EVALUATION AND CROP SUITABILITY

It was clear from the suitability analysis (Table 9) that the low mountains with northern and southern aspects were not found suitable for paddy cultivation (Figure 6a). The upper piedmont (P11) area also showed limitation of erosion. The remaining soil units were found to be suitable with some minor limitations in texture, drainage, and slope for paddy cultivation. For wheat the uplifted terraces (side slopes, T2) were not found suitable (Figure 6b). The upper piedmont (P11 and P12) showed major limitations for wheat cultivation (Figure 6c & 6b). Maize and mustard were found suitable in majority of the mapping units with minor limitations. Sugarcane showed severe limitations in the upper piedmont (P11) and was

TABLE 8 Rating of different attribute factors for land units and land Productivity index (LPI)

<table>
<thead>
<tr>
<th>Land Unit</th>
<th>Attribute factor</th>
<th>LPI</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>M11</td>
<td>0.75</td>
<td>0.85</td>
<td>0.50</td>
</tr>
<tr>
<td>M12</td>
<td>0.75</td>
<td>0.85</td>
<td>0.50</td>
</tr>
<tr>
<td>P11</td>
<td>0.85</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>P12</td>
<td>0.85</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>P21</td>
<td>0.85</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>P22</td>
<td>0.85</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>T1</td>
<td>0.90</td>
<td>0.95</td>
<td>0.90</td>
</tr>
<tr>
<td>T2</td>
<td>0.90</td>
<td>0.95</td>
<td>0.90</td>
</tr>
<tr>
<td>AT1</td>
<td>0.75</td>
<td>0.95</td>
<td>1.00</td>
</tr>
<tr>
<td>AT2</td>
<td>0.90</td>
<td>0.95</td>
<td>1.00</td>
</tr>
<tr>
<td>AT3</td>
<td>0.90</td>
<td>0.95</td>
<td>1.00</td>
</tr>
</tbody>
</table>

FIGURE 5: Maps of part of the Ason River watershed: (a) land capability classes, (b) land productivity index, (c) prioritization of micro-watersheds and (d) suggested cropping pattern
TABLE 9 Soil suitability of mapping units of different land utilization type (LUTs)

<table>
<thead>
<tr>
<th>Mapping unit</th>
<th>Wheat</th>
<th>Mustard</th>
<th>Sugar cane</th>
<th>Suitability</th>
<th>Paddy</th>
<th>Maize</th>
<th>Sugar cane</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>M11</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>M12</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>P11</td>
<td>S3e</td>
<td>S3e</td>
<td>N</td>
<td>Wheat, Mustard</td>
<td>S3e</td>
<td>S3e</td>
<td>N</td>
<td>Paddy, Maize</td>
</tr>
<tr>
<td>P12</td>
<td>S2tse</td>
<td>S3e</td>
<td>S3et</td>
<td>Wheat, Mustard, Sugarcane</td>
<td>S3e</td>
<td>S2ts</td>
<td>S3et</td>
<td>Paddy, Maize Sugarcane</td>
</tr>
<tr>
<td>P21</td>
<td>S3t</td>
<td>S2se</td>
<td>S3e</td>
<td>Mustard, Wheat</td>
<td>S2tse</td>
<td>S2ts</td>
<td>S3e</td>
<td>-do-</td>
</tr>
<tr>
<td>P22</td>
<td>S2te</td>
<td>S2te</td>
<td>S2e</td>
<td>-do-</td>
<td>S2ts</td>
<td>S2te</td>
<td>S3e</td>
<td>-do-</td>
</tr>
<tr>
<td>T1</td>
<td>S3e</td>
<td>S2se</td>
<td>S2e</td>
<td>-do-</td>
<td>S2ts</td>
<td>S2te</td>
<td>S2e</td>
<td>-do-</td>
</tr>
<tr>
<td>T2</td>
<td>N</td>
<td>S3dse</td>
<td>N</td>
<td>Mustard</td>
<td>S3d</td>
<td>S3ds</td>
<td>N</td>
<td>Paddy, Maize</td>
</tr>
<tr>
<td>AT1</td>
<td>S2d</td>
<td>S2ef</td>
<td>S2ed</td>
<td>Wheat, Mustard, Sugarcane</td>
<td>S2ds</td>
<td>S2de</td>
<td>N</td>
<td>Paddy, Maize Sugarcane</td>
</tr>
<tr>
<td>AT2</td>
<td>S2t</td>
<td>S2ef</td>
<td>S2e</td>
<td>-do-</td>
<td>S2tse</td>
<td>S2tds</td>
<td>S2e</td>
<td>Paddy, Maize Sugarcane</td>
</tr>
<tr>
<td>AT3</td>
<td>S2t</td>
<td>S2ef</td>
<td>S2e</td>
<td>-do-</td>
<td>S2tse</td>
<td>S2tds</td>
<td>S2e</td>
<td>Paddy, Maize Sugarcane</td>
</tr>
</tbody>
</table>

e = erosion, cf = coarse fragments, t = texture, d = drainage, s = slope, f = flooding, N = not suitable

FIGURE 6: Maps of part Ason river watershed: suitability for (a) wheat, (b) mustard, (c) paddy and (d) maize
also found not suitable in the side slopes of the uplifted terraces. The physiographic soil units M11 and M12 were found not suitable for any of the LUTs that are evaluated for suitability.

CROPPING PATTERN
As observed in the suitability analysis in the upper, lower piedmont and alluvial plains, a wheat-paddy sequence was suggested. In some parts of lower piedmont mustard-maize sequence was found suitable. In the uplifted terraces where, flooding is a limitation for wheat, mustard-paddy was suggested. In the rest of the uplifted terraces and alluvial plains sugarcane-paddy was found as appropriate sequence. By overall examination of the suitability combination wheat, mustard along with sugarcane as ratoon cultivation was found to be a wise suggestion for rabi season. Similarly, for the kharif season, paddy, maize with sugarcane as ratoon resulted as suitable. Wheat - sugarcane in the rabi season and sugarcane - paddy in the kharif season is expected to occupy a net sown area of 2359.5 ha of watershed area in the respective seasons. Wheat - mustard and paddy - maize reported to occupy 1776.3 ha area in rabi and kharif seasons, respectively. Integration of land productivity index for the suggested cropping pattern areas reflected the inherent soil productivity potential to support the sustainable growth of the suggested cropping sequences (Figure 5c).

CONCLUSION
The results demonstrated how the available remote sensing satellite data in collaboration with soil survey data can be utilised best. In mountainous areas acquiring the soils and land use/land cover data always remains a difficult task. The multiple integration options offered by GIS technology helped to know the ways to understand and obtain the remote sensing data and analysing them for getting better results in a shorter duration of time for sustainable utilisation of natural resources for longer periods.

ACKNOWLEDGMENTS
The senior author is thankful to Dr. M. Velaythum, Director, National Bureau of Soil Survey and Landuse Planning (NBBS&LUP), Nagpur for deputing to IRS, Dehradun, and also thankful for Dr. P.S. Roy, Dean and Prof. L.M. Pande, Head Agriculture and Soils, and the faculty of Indian Institute of Remote Sensing (IIRS), Dehradun for providing the necessary facilities to undertake this project.

REFERENCES
GIS application for land use planning in Bhutan

Dungkar Drukpa

Ministry of Agriculture, Policy and Planning Division, Thimpu, Bhutan

KEYWORDS: GIS, land use planning, Bhutan

ABSTRACT

In the small, Himalayan kingdom of Bhutan, land use planning and resource management are now being done with the help of Geographical Information Systems (GIS). This has gained impetus after an agreement between the government and the Danish International Development Agency (DANIDA) was signed to embark on a land use planning project. From first knowing about the existence of such tools as GIS, when the project began, to learning GIS with eagerness, the Land Use Planning Section (LUPS) in the Ministry of Agriculture is equipped today with a satisfactorily operational trained manpower to deal with most of the GIS related works. All important information related to land use planning are now in digital format, all of which has been digitised initially, then updated and now usable for query and analysis. The database developed thus forms the basis for many of the related organisations involved in the planning and management of natural resources. A number of analyses, based on requests from outside has been carried out. Quite recently, Landsat TM satellite data of 1998-99 covering the whole country have been acquired. The images will be used mainly for updating the existing land use data.

BACKGROUND

Bhutan has a total land area of approximately 40077 square km. Out of this, 72 percent is forest, 4 percent pasture, 16 percent includes snow covered and rocky areas, orchards and settlements and only 8 percent is agriculture [LUPP, PPD, MoA, 1995b]. According to a preliminary desk study conducted by LUPP (Land Use Planning Project) with the help of GIS, only 13 percent of the total land area are considered having potential for expansion of agricultural land use. The rest of the land, either due to rocky and permanent snow covers or due to steep slopes cannot be used for any form of agricultural practice. Potential agricultural land, therefore, is very limited, and it has become imperative that farsighted policy and planning on this limited resource is in place.

There was therefore, a general felt-need for reliable information and national capability for land use planning. In 1992, a Land Use Planning Project (LUPP) was conceived in order to generate the required information and to develop the national capability for the planning and management of the Renewable Natural Resources (RNR) Sector.

The DANIDA funded LUPP ran from May 1992 to July 1997 and coincided with the 7th Five Year Plan of the government. Project management, baseline information development, policies and projects on sustainable land use, and training and capacity building were the major components of this project. The ultimate objective of this project was to contribute to the sustainable development of the RNR sector by establishing capability and procedures at central and district level to promote sustainable land use. This was to be done through: (1) the preparation of land use maps of the whole country at 1:50,000, 1:100,000 and 1:250,000; (2) the preparation of land use plans for four sub-districts – one in the east, two in the southwest, and one in central Bhutan; and (3) undertaking concerted training elements to ensure that the fundamentals and skills involved in the A-Z of planning were passed on to the national staff.

LAND USE PLANNING IN BHUTAN

The overall definition of land use planning in Bhutan is: Land use planning defines the means of support to farmers and rural communities who make their living from utilisation of natural resources, so that their standard of living increases sustainably, ie, without creating conflicts between the different types of land uses and land users, and without diminishing the resource base in future.

One of the most important prerequisites for the preservation and sustainable management of the natural resources in Bhutan is a sound distribution of land for various appropriate purposes, viz, arable production, forestry, grazing, urban and industrial areas, infrastructure, and nature parks. However, the distribution in itself is not sufficient to ensure sustainability. The land husbandry, ie, the way the land is managed by the land users, is of equal importance. If, for example, it has been decided that a certain area should be used for arable production, the conditions for the decision must be known: for example that terracing is mandatory, that contour ploughing is necessary, that crop rotation has to be practised, etc.

Land use planning therefore involves a systematic registration and evaluation of the present land use and land
users and of the capability of the natural environment to sustain these different types of land uses. These land uses are often interchangeable, so land use planning must by nature be integrated planning [LUPP, PPD, MoA, 1995b]. In other words, land use planning includes a systematic assessment of physical, social, cultural and economic factors and a certain level of empowerment in such a way as to encourage and assist the land users in selecting management options that increase their productivity, their general standards of living, are sustainable and meet the needs of the local society as well as the nation as a whole.

Land use planning in Bhutan is planning at the national, the district, the block [Case study: Dungkar Drukpa et al, 1996], the watershed, the village and the farm level. It involves the farmers as well as the policy and decision-makers. Planning at the national level deals with policy and legislative issues rather than master planning [LUPP, PPD, MoA, 1995a]. At the district and block levels, planning does not differ significantly in terms of the planning process and techniques but the government’s endeavour to decentralise and involve the people in the planning and decision-making entails that, in the future, the focus mostly will be on block level land use planning.

Planning at lower levels include management recommendations, in line with farmer-perceived needs and aspirations, together with decisions taken on where to place the school, the basic health units, the community forestry area, or whether to take in more land for farming. However, farm and field management will form an important part of most of the block plans.

In general the key aspects of land use planning in Bhutan are:
- to find a balance between the needs of the people and the overall aim at conserving the environment;
- to build on existing structure, utilise them, and if justified to assist the policy makers in formulating and implementing new reforms;
- to establish a policy and legislative framework in order to facilitate the implementation of land use plans and recommendations;
- to raise the awareness among the decision makers and the farmers that soil erosion is a problem and that it will escalate in the near future if nothing is done today;
- to make sure that the land is utilised in the most cost-effective way keeping in view that the total arable land resource is very limited;
- to ensure that the people’s needs are the driving force in the planning process at the district, block and village level, and
- to suggest alternatives, which can relieve the pressure on the most, affected areas.

THE PROCESS OF GIS APPLICATION
GIS has been applied by ICIMOD et al  [1997] in a watershed study in the Garhwal Himalayas (India). It has generally been of use to land use planners in the following three major capacities:
- the maintenance of general purpose data,
- the generation of specific purpose information from such data; and
- the utilisation of such information in decision-making context.

The process of GIS application for land use planning in Bhutan encompasses all these three steps. When the project began, there were no data available in digital form. People had to be trained in the use of GIS. All input data such as contour lines, drainage system, settlements, roads, and land use (after field verification) were digitised manually. All these layers were sent through a process of rigorous quality check beginning from the operator to the district planners. They were then combined to produce the land use working maps at a scale of 1:50,000, which was taken for presentation of the districts. Based on the corrections and suggestions received, they were later combined to produce the land cover maps for the districts and then finally for the whole country. The land cover maps of the districts were compiled to produce land cover and area statistics in: “Atlas of Bhutan”, published in 1996. The process of GIS application has been explained logically in Figure 1.

The need for and the use of GIS became quite clear when the project embarked on local planning as exercise
and selecting four sub-districts. A variety of maps showing land use and land cover, geology, slope, aspect, infrastructure, and land capability, involving the local people were prepared and presented to both planners and local people. Specific maps based on the requirement of a particular planning site such as migration route, network of hydroelectric power plant, were also produced. Some sample maps with exercises are for example the Pilot Study in Bongo and the Gengu blocks in the Chhukha district. Important findings of such studies were finally incorporated into the national development plans.

At the national level GIS was used to explore potential agricultural development areas on the basis of slope, land use and elevation. A potential user of this analysis result was the soil surveyor for identifying their areas of interest. Also, given the rugged terrain with steep slopes in the country, a lot of areas, even those where risks of soil erosion is great, are cultivated. In order to have a better understanding of this situation with the help of GIS, a study was done to look for areas presently used for any form of permanent cultivation that is above 50 per cent slope.

Presently, the land use database and maps are being updated with the combined application of GIS and remote sensing. The project has recently acquired Landsat TM data of 1998 and 1999. The update process as such is also being carried out on the basis of feedback received from districts, agencies and individuals and also in co-ordination with relevant divisions. Various types of maps on farming systems, showing crop and livestock distribution, were also produced. Further, maps showing the Renewable Natural Resources (RNR) facilities are prepared for all the twenty districts. On the analysis part, PC ARC/INFO and IDRISI were used to divide the country into different agro-climatological zones. Outputs from this exercise include maps showing rainfall, temperature, and radiation distribution, based on which potential evapotranspiration and the length of growing periods were to be estimated. Such information was not much used before, mainly due to lack of data but they are definitely going to be important criteria for planning agricultural development in the future.

SOFTWARE
The main software systems used were PC ARC/INFO, SEM, and IDRISI. PC ARC/INFO was the major software and was used for digitising, database maintenance, and vector overlay and plotting. SEM and IDRISI were used mainly for terrain modelling and for processing raster data. Presently four ArcView licenses are available and it is already being used side by side with PC ARC/INFO.

CONCLUSION
The Bhutan-Danida Land Use Planning Project has been able to successfully achieve all the objectives outlined in the project document. The four units of the project, viz, Management, Land Resources, Farming Systems, and GIS were all equally active, busy and contributing. Being relatively a new technology, GIS caught more enthusiasm and as one proceeded on, it was also realised that GIS is a really useful tool. First, analogue topographic maps were purchased from the Division of Survey and all the major coverage layers were digitized that took well over a year for two staff members. Using the SPOT Pan hard copies, the Land Resources staff went to the field and brought back an immense amount of field data. These were also entered into GIS one by one. Once these exercises were completed, the data generated by GIS formed the basis for the Farming Systems Unit and at times for the whole Ministry, all for planning purposes.

The earlier enthusiasm of the staff in the GIS Unit has not declined. Within the limits of data availability, any forms of maps required by the land resources and/or natural resources planners and managers are being prepared. Similarly the analysis capability of GIS is also being used increasingly.

All in all, GIS has played an important role, in all its capacities, in land use planning in Bhutan. There were, however, certain factors that inhibited the full application of this exciting tool. Often, important thematic data such as soil and meteorology, both very important parameters in land resource analysis, were not available at all. There were also other types of data, equally important, which were not made available because of the policy implications. Outside the GIS Unit’s office, there are quite few people who understand the capability of GIS and this therefore has limited their demand for GIS application and assistance in their planning and management aspects. With changing times, these situations will also undergo a change and GIS will definitely find its right place in the minds of policy and decision-makers.

ACKNOWLEDGEMENTS
The author is grateful to the Royal Government of Bhutan for granting approval to attend this very important Symposium. Thanks are also due to ICIMOD for supporting with financial assistance to attend this symposium. DANIDA and ICIMOD also owe our utmost gratitude for the support we are continuing to get, particularly in the field of geo-information technology.

DISCLAIMERS
All maps and any figures included herewith are meant only to serve the purpose of this symposium. In other
words, they are used to make the paper more technical and scientific. Information contained in these maps, especially the boundaries, should not, under any circumstances, be taken as authentic and authoritative. Some of them may not even be accurate. The author respects and is bound by the sensitivity of such issues for his nation.

REFERENCES
Linking pixels with people for sustainable sloping lands management in Asia

Mohammad Rais
National Institute of Science, Technology and Development Studies, Dr K S Krishnan Road, New Delhi-1 10012, India

ABSTRACT

The advances in remote sensing (RS) technology, with the finer resolution of pixels obtained in recent years, have made natural resource mapping and evaluation more easy. The RS data and geographic information system (GIS) is being used in monitoring the natural resource profile and infrastructure facilities in a given region. The identification of socio-economic variables in RS data is a major limitation. Although changing land use, roads, forests and the like are regarded as manifestation of more important variables, such as government policies, land tenure rules, market mechanism etc., none of which are directly reflected in the bands of the electromagnetic spectrum. The sloping lands management in hills which have fragile environment and complex socio-economic profiles, pose a special challenge. In this paper the experiences of the author during 1995-98 in sloping lands issues in Southeast and South Asia have been analysed. The degraded and denuded forest in the hills of Aravalli ranges in Northern India have drawn National and International attention. In order to accelerate the development of this region, waste land identification and land capability analysis was carried out by using remote sensing data (IPS-ISSS H) of part of Aravalli hills. The correct identification of wastelands and land suitability analysis was able to influence government policies in allocating funds. Further, while working for the International Board for Soil Research and Management (IBSRAM), Bangkok, the author carried out sustainability assessment studies in the middle hills of Indonesia, Nepal, Thailand, and Vietnam. The sustainability assessment has been carried out under the International Framework for Evaluating Sustainable Land Management (FESLM). The essence of this paper is to highlight that linking the GIS/R S analysis with people and its policies, particularly in hills, is very important. A comparative analysis of the remote sensing study in North India, and the field survey of middle hills in Indonesia, Nepal, Thailand, and Vietnam for sustainable land management in hills is presented. The integration of socio-economic issues with remote sensing analysis is difficult. But in order to achieve sustainable sloping land management the socio-economic integration of RS analysis is necessary.

INTRODUCTION

Sustainable land management (SLM) combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously: maintain or enhance production services (productivity), reduce the level of production risk services (security), protect the potential of natural resources and prevent degradation of soil and water quality (protection), be economically viable (viability) and be socially acceptable (acceptability) [Smyth and Dumanski, 1993]. Sustainable land management is complex and hard to assess in practice, requiring the understanding and integration of information from diverse sources. Sustainability is a normative concept based on the values and perceptions of the user of the term but a powerful one, which redefines agricultural development itself. Mountain researchers and practitioners have responded to many challenges surrounding this concept and have made substantial contributions [Rhoades, 1997]. The sloping lands management in hills which have fragile environment and complex socio-economic profile, pose a special challenge. The integrated mountain land development is emerging as new paradigm. However, the implication of an integrated assessment approach at the household and community levels, as linked to external conditions, are that it reveals and highlights available local resources for the development process as well as the needs that exist in rural mountain communities. Through such critical analysis, we can determine that households and communities may be well endowed in one set of local resources but lacking in others. The planning question then becomes what resources and in which amount do farmers bring them to project activity and what remains missing. It is essential to have the answers to this question in order to make the minimum investments in the resource improvement required to maintain or improve upon the quantity and quality of the resource base [Rhoades, 1997]. The remote sensing technology can help in quick assessment of land resources. It can also detect the change in resources, in terms of land degradation and related environmental consequences. But remote sensing can not explain the process and reasons that lead to degradation and change in resource base. It requires deeper understanding of socio-economic characteristics of the region under study. Liverman, D. et al [1998] has reported the complimentary essential link between remote sensing and social science through several case studies. A challenge in merging social science and remote sensing approaches is identifying congruent units of observation and developing appropriate linkages. Indicators from remote sensing can complement indicators from ground based sources. For example, agricultural intensification can be measured.
by using data from surveys of farmers' behaviour, sales
figures on agricultural chemicals and farm equipment, or
remotely sensed data on crop density and color.
Combinations of social and remote data can yield a
deeper understanding of type of intensification possible

EXPERIENCES FROM CASE STUDIES

This paper reports experiences of two approaches for
assessing land resources, namely remote sensing
(RS)/geographic information system (GIS) and field based
studies and surveys. Two case studies in North India
were conducted by using remote sensing/GIS methodology to assess land suitability analysis and wasteland
identification. The two blocks, Firozpur Jhirka and Tauru
are situated in the foothills of Aravalli ranges in North India.
The Firozpur Jhirka block was studied for wasteland identification [Khan and Rais, 1997] and the Tauru block
was studied for land suitability analysis [Rais, 1995]. The
attempt was made to integrate natural resource information with the socio-economic profiles of blocks. The pur-
pose behind the land suitability analysis of the Tauru
block was to determine the capability of the land - a
measure of what the land can be best used for - and
based on the capability, to recommend the development-
mental measures for the wasteland patches. To assess the
land potentials, limitations, degradation problem, etc.
the whole study area was divided into homogenous land
parcels.

The final map obtained, based on integrated analysis,
shows various village clusters for Firozpur Jhirka and
Tauru. The Firozpur Jhirka map, of wasteland identification,
was produced showing the wasteland types and
portion of wasteland in various villages. The wastel-
land classification was based on natural resource profiles
and can not explain the reasons and process of land
degradation. In Firozpur Jhirka, wasteland in the form of
degraded forest constitutes the highest percentage of
wasteland, followed by wasteland due to gully erosion,
waterlogged land, salt affected land, degraded pastures,
sandy and undulating types, and salt affected areas.
Except for the salt affected land, other types of waste-
land can be improved upon or utilized as pastures or can
be reclaimed by afforestation and other suitable tech-
niques. The Tauru map, of land suitability classification,
shows five village clusters (C I-V: Figure 1) representing
the most favorable to least favorable village for agricul-
ture development. Each village cluster represents more
or less homogenous natural resources and socio-econo-
mic characteristics. The village cluster map has been
obtained by integrated natural resource and socio-econo-
mic profile analysis. These village clusters could then
be used for initiating development action plans for
improving agricultural land use plans in the block.

Contrary to remote sensing data sources, sustainability
assessment studies were conducted by integrating long
term experimental research data, farmers survey and sub-
ject matter experts knowledge. These case studies, in
parts of Indonesia, Thailand, Nepal, and Vietnam, were
conducted at the International Board for Soil Research
and Management (IBSRAM), Bangkok, under the
Framework for Evaluating Sustainable Land Management
(FESLM) [Rais et al, 1998 a, b]. The main aim in these
case studies was to assess the impact of land manage-
ment practices of farmers with respect to farm
Productivity, Security, Protection, Economic Viability, and
Social Acceptability. In order to assess these impacts,
FESLM based sustainable land management indicators
were developed representing diverse knowledge sources
and primarily intended for farm level use. Some of the
SLM indicators are given in Table 1.

Table 1 shows some examples of SLM indicators, their
quantitative ranges and corresponding qualitative values.
It also shows threshold values for judging sustainability
status of farms. These indicators were validated in the
villages of Indonesia, Thailand, and Vietnam. During the
validation of Indicators for sustainability assessment in
one of the case studies of sloping lands in Thailand some
very interesting facts were revealed. In one village we
compared productivity of two farms during the last 7-10
years. We observed that farm X productivity in the initial
2-3 years was very high but from year 4 onwards, it start-
ed declining significantly. In case of farm Y the produc-
tivity in the beginning (1-3 years) was not as high as that
of farm X, but in subsequent years: 4-7, the productivity
was not only stable but much higher than farm X. We
probed the differences, and discovered that Farm X had
deeply ploughed his farm by using small tractor, and it
made topsoil of the farm very loose. It gave good yield
in the initial 2-3 years, but all topsoil got eroded in sub-
sequent years and farm productivity declined signifi-
cantly. In case of Farm Y, the ploughing was done by ani-

FIGURE 1: Land suitability of the Tauru region for agricultural
development of five village clusters: I - V most to least favorable
TABLE 1 Example of SLM Indicators: Thresholds, Qualitative and Quantitative Ranges.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Threshold</th>
<th>Qualitative Ranges</th>
<th>Quantitative Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield</strong></td>
<td>&gt; 25% or more Yield Reduction of the average of community</td>
<td>Yield Reduction: &gt; 25%</td>
<td>10 - 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>10 - 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>&gt; 25%</td>
</tr>
<tr>
<td><strong>Soil Colour:</strong></td>
<td></td>
<td>High: Dark soil</td>
<td>&lt; 1.2%</td>
</tr>
<tr>
<td>(Organic C)</td>
<td>&gt; 1.2 %</td>
<td>Medium: Brown soil</td>
<td>1-1.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low: Yellowish</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td><strong>Biomass: (% of crop residue)</strong></td>
<td>&lt; 50 % of crop residue</td>
<td>High amount for long time</td>
<td>&gt; 50% for &gt; 3 years</td>
</tr>
<tr>
<td><strong>Ploughed back to land</strong></td>
<td>&gt;= 3 years continuously</td>
<td>High amount for short time</td>
<td>&gt; 50% for &lt; 3 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low amount for long time</td>
<td>&gt; 50% for &gt; 3 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low amount for short time</td>
<td>&lt; 50% for &lt; 3 years</td>
</tr>
<tr>
<td><strong>Erosion</strong></td>
<td>4.5 cm or more during last 7 years</td>
<td>Low: Yd. Red. 0-10%</td>
<td>&lt; 0.7 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium: Yd. Red. 10-25%</td>
<td>0.7 - 4.5 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High: Yd red. &gt; 25%</td>
<td>&gt; 4.5 cm</td>
</tr>
<tr>
<td><strong>Difference between farm gate price and nearest main market price</strong></td>
<td>&gt; 50%</td>
<td>High</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>25 - 50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>&lt; 25%</td>
</tr>
<tr>
<td><strong>Size of farm holding</strong></td>
<td>1 ha</td>
<td>Big</td>
<td>&gt; 2 ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>1-2 ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small</td>
<td>&lt; 1 ha</td>
</tr>
<tr>
<td><strong>Land tenure</strong></td>
<td>Full ownership of land</td>
<td>1. Full ownership</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Long term user rights</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. No official land title</td>
<td></td>
</tr>
</tbody>
</table>

mals, and deep ploughing was avoided and this preserved topsoil. Hence, the difference in farm productivity in the same village was due to difference in farm management practices. Remote sensing can never capture this fact and only field based participatory analysis can reveal these important aspects.

CONCLUDING REMARKS
The comparative study of various case studies reported in this paper reveals that RS can help in the resource evaluation. However, this is not sufficient to understand the resource use, degradation, and improvement process. We may be able to identify the land capability and wasteland proportion in villages but without socio-economic information the development plan can not be implemented. On the other hand purely land based information processing, as revealed in SLM indicators analyses, without use of RS data, provides a very limited view of the region. Its analysis is very location specific and can not be used for wider regions. Therefore, integration of remote sensing information with field based participatory analysis involving local people of the region is essential so that the potential of RS data is exploited to the highest level.

REFERENCES
A short refresher course on the analysis and cartographic presentation of soil data

Jeroen van den Worm and Dhruba Pikha Shrestha

International Institute for Aerospace Survey and Earth Sciences (ITC), Hengelosestraat 99, PO Box 6, 7500 AA Enschede, The Netherlands

ABSTRACT

Spatial data analysis in GIS environment is being widely used lately, due to decrease in cost of computer hardware’s and the availability of GIS software’s in affordable price in developing countries. In addition to this, improvement and user friendliness of GIS spatial analysis functions make it popular in organisations dealing with development activities in many countries. However, not always, their staff is equipped with the theoretical and practical knowledge to use the available tools and to achieve the most effective result, as well in terms of the data analysis as well as communicative efficiency. Since 1994, the Dutch government is supporting the so-called refresher course program with a duration between one to three weeks to enable the Dutch international educational institutes to upgrade the knowledge and practical experience of their alumni. The course on the analysis and cartographic presentation of soil data is one of the third refresher courses executed in Nepal.

INTRODUCTION

Digital technology has been advancing lately because of improvement of computer hardware’s. On the other hand, development of software’s makes their application very attractive in many fields. Digital mapping is not an exception. Analysis of natural resources in a GIS environment is being widely used and representation of the analysis results has improved substantially. Considering this, many organisations in developed countries implement continuous staff-development programs to upgrade and maintain the knowledge. In developing countries, this is lacking because of limited resources. On the other hand, most of training institutes offer only long-term courses, which may create organisational constraints in terms of time, financial resource and manpower management. To encompass these constraints, the Dutch government is supporting since 1994 a so-called “refresher course program” with a duration between one to three weeks to enable the Dutch international educational institutes to upgrade the knowledge and practical experience of their alumni. Within the scope of this program, ITC organises 4 to 5 refresher courses on a variety of subjects, on a yearly basis, in various developing countries.

COURSE OBJECTIVES

The course aims at covering the following aspects:
- provide participants with knowledge of up-to-date functionalities and practical experience with GIS to analyse soil data, with special reference to soil erosion assessment;
- provide participants with a basis for a structural and sustainable approach in the presentation of soil data;
- provide participants with the principles of the cartographic communication process and design principles for the representation of soil erosion analysis results by means of 2D and semi 3D maps.
IMPLEMENTATION OF THE COURSE
The course content exists of three modules, each of one-week duration.

- Module 1: It includes principles of remote sensing and GIS, data base design, structure and management, and spatial analysis functionalities. All subjects are accompanied by a number of short practical exercises using ILWIS software.

- Module 2: Soil data analysis focussing upon soil erosion modelling.

- Module 3: Cartographic data visualisation for communicative purpose. Theoretical subjects include cartographic symbol design related to semi 3-dimensional maps, map-use and map output. Exercises include RGB and CMYK based colour selection and a comprehensive 3D-map production using a digital terrain model.

Modules 1 and 2 are based upon a soil erosion case study from an area in the western part of Doon Valley, Dehradun district, Uttar Pradesh, India. Participants become familiar with GIS functionalities and gain practical experience, starting from data collection up to spatial analysis. To practise GIS operations, the ITC-ILWIS software is applied. The presentation aspects are practised by hands-on training using ILWIS to generate a DEM based hill shading and Macromedia Freehand graphic software for the final cartographic presentation. The latter software is extended with a GIS plug-in filter (MaPublisher) developed by Avenza, a Canadian company. This filter enables the import and export of a number of well-known GIS file formats and enables the construction of maps within a graphic software program based on data attributes. Other functionality includes map projection and scale changes and semi-automatic text labelling. Both programs are characterised by their user-friendliness and a low learning curve. Free-Hand is used by many cartographers all over the world and can be used to produce almost any type of map.

Approximately 75 percent of the course duration is dedicated to hands-on training activities. Participants are guided by at least one ITC staff member and two of the local trainers. To complete the participants view on the subject, a field excursion in a suitable area, which shows the effects of and measures against soil erosion, becomes very effective.

ITC promotes the transfer of knowledge and experience by supplying the participants with learning materials such as lecture notes, exercise materials and in some cases necessary software’s. Participants are free to use these materials for the training of their fellow colleagues at their organisations. Its modular character enables further customisation of the course content.

CONCLUSION
About 120 ITC alumni applied for participation in the 1999 course, of which only 20 could be selected due to the number of available fellowships. The participants evaluated the course positively and the course was highly appreciated especially the GIS spatial analysis functionalities and map visualisation techniques which could be used in their home organisations.
High spatial resolution for detecting evidences of slope instability: SPOT 5 simulated stereoscopic data

O Rouzeau, F Girault, C King and S Chevrel

BRGM, Geomorphology and Remote Sensing Laboratory, Research Division, BP 6009 Orléans, France

Forecasting slope instabilities in mountainous areas is a major concern for population security and environment preservation. The detection of morphological evidences of instability, and their evolution along time, takes part in the assessment process of susceptibility to landslides at a regional scale. Previous studies have highlighted the efficiency of satellite imagery in landslide susceptibility mapping, but inappropriate ground resolution hampered the detection of morphological evidences of terrain disturbances. Indeed, the detection of evidences of slope instabilities lies on the reconnaissance of spectral and morphological criteria that requires high spatial resolution and high quality stereoscopic pairs, not disturbed by radiometric variations along the period of acquisition.

Simulated SPOT 5 satellite stereoscopic imagery have been acquired over the mountainous area of La Vanoise in the French Alps, with a ground resolution of 1.7 meter and back-forward stereoscopic acquisition mode. The study area is particularly exposed to instability hazards, threatening high-value economic interests. Data have been further processed at 5 meters ground resolution in panchromatic mode and 10 meters in multispectral mode (nominal SPOT 5 resolution). For comparison purposes with existing satellite facilities, the same data have been processed at 20 meters ground resolution.

The presented study aimed at defining the improvement of high spatial resolution imagery and derived Digital Elevation Models in the detection and inventory of morphological evidences of instabilities. Computer-aided image interpretation shows that the detection of linear features (faults, talus and debris, gullies) is highly facilitated with a ground resolution of 5 meters and becomes very close to the detection capabilities of aerial photographs. The recognition of typical small morphological forms, such as dissolution hollows, is significantly improved, while dynamic units (types of scree, mass movements, ...) are better differentiated.

A quantitative approach, based on morphological exploitation of DEMS, enables the mapping of parameters characterising the context, hence favouring susceptibility assessment.
Remote sensing and GIS for mapping erosion susceptibility evolution, coastal Cordillera, Chile

G Delpont, J F Desprats and S Chevrel

BRGM, Geomorphology and Remote Sensing Laboratory, Research Division, Orléans 45060 cedex 2, France

A Mediterranean climatic context and unsuitable agricultural practices are responsible for soil degradation in the Coastal Cordillera of Chile. Methodological developments proposed by BRGM for assessing erosion susceptibility, using satellite imagery, have been embraced by the Chilean Ministry of Agriculture in the frame of a project funded by the World Bank.

With a ground resolution suiting well to the parcel size, SPOT images give access to three essential parameters intervening in the erosion process, which allow assessment of erosion susceptibility:
- vegetation cover, which plays its part in soil protection and stability, is obtained through digital image classification;
- slope angle, which conditions water speed and aggressiveness, is derived from a digital elevation model obtained through SPOT stereo pair;
- drainage density, which stands for incision potential, is computerised from DEM.

Thresholds of these parameters allow the definition and computation of protection, aggressiveness and incision indexes, in the form of maps. This step requires a good knowledge of the local context.

GIS combination of these layers of information enables the processing of an erosion susceptibility map, following rules adapted to the climatic and morphological contexts. Obtained through analysis of satellite imagery only, this mapping is representative of local erosion phenomena; where available, taking into account additional data, such as geological maps, soil maps, ... would obviously increase the accuracy of the results, once introduced into the geographic database.

Analyses performed with sets of images at 3 to 5 year intervals enable the periodic updating of vegetal cover, and thus to monitor and map changes in erosion susceptibility. Follow up of these changes can be used in verifying the effectiveness of remedial measures or in controlling their implementation.

The methodology presented in this study provides land use planners and regional authorities with very simple, but efficient management tools, including:
- maps of erosion susceptibility at various scales, from 1:50,000 to 1:25,000;
- maps of susceptibility evolution along time, either natural (forest recovery after fires) or artificial (remedial or conservators measures).

It leads to the production of management documents useful in a sustainable development decision-aiding process. As an example, combining erosion susceptibility maps and population density maps enables prioritisation.
Mapping of vegetation structure as a means of describing chorological variation in land degradation and erosion

J Slurink

Wageningen, The Netherlands

LANDSCAPE STUDY ON LAND DEGRADATION
Between 1985 and 1990 an analysis of the landscape and the ecology of an area of about 1600 square kilometers north of Kathmandu was made. Man-induced land degradation formed a central issue. By using vegetation, man creates all kind of vegetation structure types, this process being dependent on climate and landform. The relation between soil surface erosion and other slope processes on the one hand and vegetation structure and degradation of vegetation on the other hand was studied. Spatial differences in the severity of vegetation degradation and the resulting increase of erosion were studied by mapping vegetation structure.

BACKGROUND
In the Himalayas erosion and other slope processes are natural phenomena, which also take place where vegetation is not disturbed by man. The rise of the mountains causes enormous amounts of rocks to erode away gently or to slip away faster. This happened already long before man became a factor of importance. Under natural conditions most slopes below about 4000 meter altitude would be forested with dense forest in the present climatic conditions. The species within these forests differ with climatic grading factors like altitude and aspect. Within ecosystems, soils develop in dependence on litter production and activity of soil organisms. Before man started changing everything there may have existed a sort of equilibrium between soil formation and soil surface erosion. Where landslides occurred, soil formation had to start again. These natural slope processes are part of the natural ecosystem and are not called land degradation in this study.

Man started exploiting vegetation already long ago. Structure of vegetation differs completely as a result of exploitation. On relatively gentle slopes, all forest was taken away to perform agriculture. On steeper slopes, forests remained but were exploited heavily for fodder, firewood and timber. Around new settlements, forests degraded to low open forests, shrub forests or even further to open shrublands, where only shrubs, grasses, ferns and herbs remained. Grazing caused much favoured species to diminish and less palatable species to overgrow extensive areas. In Nepal huge surface areas are covered with open degraded vegetation which doesn't produce enough to satisfy the needs of the increasing population. In those areas erosion is much stronger in comparison with erosion under natural conditions. This man-caused change within the ecosystem is called land degradation, because the ecosystem is less stable than it would be under natural conditions.

METHODS OF STUDY
To study the spatial variability of land degradation vegetation structure was mapped. Between the eroding soil and the satellite, which measures radiance, there is vegetation, except in sites where no vegetation remains, like on bare agricultural terraces. On most slopes within the study area there is vegetation, which may differ enormously in structure over short distances.

About 400 sites, representing different altitude zones, exposition and structure types were described in detail to study the process of degradation. All kind of data, like altitude, exposition, layering and coverage of vegetation, relevant soil features, indications of erosion and exploitation, were assessed. Correlations between different aspects of sites were studied with SPSS.

RESULTS
Results are qualitative. Natural vegetation structure changes with altitude and aspect. Within the study area, climatic conditions are the major factor causing changes within vegetation. Exploitation depends on landform and climate, being strongest on south facing slopes and below about 2000 meter. Vegetation structure is strongly related to vegetation exploitation and erosion is increasing with increasing degradation of vegetation. On an average, soils on south facing slopes have a lighter colour and a more stony surface as a result of stronger...
erosion. On north facing slopes and at higher altitude the A-horizon is better developed and soils are better covered with litter. Under forested conditions slopes are quite steep. Due to vegetation degradation, slopes become de-stabilised and will become less steep, causing strong erosion and increase of landslides.

The vegetation structure map gives an indirect representation of soil features and erosion. Maps like this one can be used for locating and planning land management activities.
Monitoring changes in arid mountainous rangeland of Morocco with remote sensing data

R Escadafal¹, J Mégier², S Bouziri³ and M Zouhri⁴

¹ Institut de Recherche pour le Développement, Paris, France
² EGEO unit, Space Applications Institute, Joint Research Center, Italy
³ CUST, Clermont Ferrand, France
⁴ ORMVAO, Ouarzazate, Morocco

On the southern foothills of the Atlas mountains of Morocco a wide area of pediments sustains a steppic vegetation. Elevation varies from more than 3000 m to 1200 m with a succession of plant communities distributed according to the climatic gradient. Along this gradient annual precipitation varies from 300 mm with a vegetation cover from 30 to 20%, to less than 100 mm where the vegetation cover becomes very low. The main use of these landscapes is rangeland for sheep and goats in the upper part and for camels in the lower part. With the shift from a full nomad to a more semi-nomad land use with recent settlements, and the associated evidences of local degradation phenomena, the need for a monitoring tool covering the whole has emerged.

In previous experiences in other arid regions and more specifically in this area, high resolution satellite data have already been tested for rangeland monitoring. In this study, part of a EC funded project (CAMELEO), the approach developed starts from the ground. The characteristics of the main soil and plant associations have been described in the field and their optical properties have been measured with portable spectro-radiometers. The resulting reflectance spectra have been put in a database with the information on position, soil and vegetation type and status.

To overcome the lack of a DTM on the area and the difficulty to take into account the bi-directional properties of the land surface, a series of satellite images has been selected with similar illumination and viewing angles. Data from the Landsat Thematic Mapper have been preferred to benefit from measurements into the SWIR spectral range, allowing a better discrimination of land surface materials (soils and rocks). Atmospheric corrections have been applied using natural targets as references and simplified models. Geometric corrections have been performed based on the topographic maps of the area and GPS data collected on the ground. Then several algorithms have been applied to detect changes: from simple band ratio differences between dates to linear unmixing and change vector computation. Results show important differences in distinguishing vegetation changes from soil surface changes, both giving information on land degradation status.

In conclusion the performances of the different change detection techniques are discussed, and recommendations are made for simple and robust methods applicable to the test area and to monitor the environment of other similar mountainous zones.
Mapping of Sri Lankan soils for land use planning using geographic information systems

R B Mapa¹, A R Dassanayake² and A Senarath³

¹ Faculty of Agriculture, University of Peradeniya, Sri Lanka
² Land Use Division, Department of Irrigation, Sri Lanka
³ Dept of Soil Science, University of Massey, New Zealand

Sri Lanka consist of 6.5 million hectares of land where about 65% is not available for agricultural purpose due to unsuitable terrain, rockiness, inland water bodies and protected areas. This land is divided into 24 agro-ecological regions depending on the rainfall pattern, elevation, landform, temperature and soil types. The lands occurring in the mid country (300-900 m above msl) and up country (>900 m above msl) show sloping to hilly terrain, while the lands in the low country (0-300 m above msl) show undulating terrain. On all these lands soil erosion is shown to be the major cause of soil degradation which has become a major environmental problem related to land. Scarcity of databases, which leads to inadequate land use planning, is the major reason for this land degradation. Therefore, the objective of this study was to generate a database for the wet zone of Sri Lanka and to generate maps using GIS for appropriate land use planning.

A total of 28 locations in the wet zone were studied including the landscape, slope, drainage, texture and detailed soil profile description. Slope was measured using a slope meter, texture using sieves and pipette method and soil profile descriptions according to the FAO guidelines. Georeference techniques were illustrated and map information including soil boundaries, hydrology and agro-ecological regions were digitized. After linking the supporting database to the digital map, maps were generated for different aspects.

The results show the derived maps for slope classes, drainage classes, textural classes and soils according to the local classification and Soil Taxonomy. The slope classes are used in land capability classification to show the areas susceptible for erosion and the need for soil conservation measures. The drainage map is used to separate the well-drained soils that could be used effectively for plantation and crop production in the wet zone. The surface texture map also helped in estimation of soil erodibility values. In addition, the classification of soils according to the Soil Taxonomy facilitate agro-technology transfer and other advantages that could be obtained from soil classification.

This work was possible due to funds provided by the Canadian International Development Agency (CIDA) through the Agriculture Institute of Canada (AIC) partnership program for the twinning project between the Soil Science Society of Sri Lanka and Canadian Society of Soil Science.
A 3-D Trekking map of the Langtang valley: the application of RS/GIS techniques for tourist mapping

Anu Rajbhandari Shrestha¹, Jeroen van den Worm² and Dhruba Pikha Shrestha²

¹ Dept. of Forest Research and Survey, Kathmandu, Nepal
² International Institute for Aerospace Survey and Earth Sciences, Enschede, The Netherlands

ABSTRACT
Tourism is one of the main sources of earning foreign currency in Nepal, which is emerging as a new industry in the country. To promote tourism, Visit-Nepal-1998 year was celebrated. Among various possibilities, trekking is one of the favourable options tourists visiting Nepal do not like to miss. As a result of this, various trekking organisations are offering services for undertaking trips in the mountainous areas. But, not every tourist is aware of the physical consequences of trekking in the mountains. In order to facilitate providing information on topography and physical conditions in the mountainous terrain, a case study is undertaken to prepare a semi-three-dimensional (3-D) trekking map. For this purpose, the Langtang National Park is chosen which is one of the most popular trekking areas in Nepal. The trekking map is designed on a DEM-based perspective view of the area on which a geo-referenced satellite image was draped. Trekking route and the location of villages were drawn on the 3-D satellite image. This gives realistic impression of the terrain and the conditions of the trekking route since three-dimensional representation is more effective as compared to two-dimensional map.

INTRODUCTION
The project started by an analysis of the mapping-needs of trekking agencies in perspective of their clients. Discussion with one of the leading Dutch travel agencies dealing with organising trips for trekking in Nepal led to the conclusion that realistic map viewing possibility will be better to inform their customers on trekking circumstances and conditions. By preference, emphasis should be put upon the visualisation of slope and accessibility aspects of the trek.

APPLIED METHODS AND TECHNIQUES
Topographic map sheets at scale 1: 50,000, covering part of the Langtang area were scanned and geo-referenced. Contour lines and other topographic objects, including the trekking route, were digitised using the software ILWIS ver. 2.2. As no topographic data were available for the whole area, data for the northern part of the valley was derived from maps at the scale 1: 125,000. To create a digital elevation model (DEM), linear contour interpolation was carried out. The raster based DEM is used to create a 2-dimensional grey scale hill-shaded image, by the application of a shadow filter, which simulates sun illumination from a north-west direction. DEM is also used to create several perspective three dimensional images with different viewpoints to achieve the most appropriate view of the Langtang valley. Landsat TM data of the area, acquired on 21 December 1990, were available. The satellite image was geo-referenced using topographic maps. Spatial enhancement technique was followed. A pseudo natural colour composite was created by using a band combination of TM3, TM4 and TM5. Image enhancement technique includes edge enhancement and histogram equalisation. The pseudo natural colour composite was then draped on the three dimensional perspective view of the area, created by using DEM. Layer tinting, visualising the height classification, was created by first generating a elevation zone map, based on the DEM. For each zone an individual colour is assigned. Colour intensity was generated by multiplying the primary colours with the hill-shaded image. (see Figure 1)

Both colour composites were exported as 300 dpi TIFF images and imported into Adobe Photoshop 5.0 for further graphic enhancement. Graphic enhancement included “blur and sharpen” techniques to reduce the visible pixel effect. To increase shadow effects, Photoshop’s airbrush option was selectively applied. After enhancement, both files were imported into FreeHand and combined with the vector based information. A vector based three dimensional perspective view of the area and topographic linear details such as rivers, streams, trekking routes and other topographic details such as villages, etc. was converted by ILWIS into format (.shp) suitable to be used in Macromedia Freehand, a popular graphic software program that is widely applied by cartographers, using the GIS plug-in filter, Avenza MAPublisher (ver. 3.0). (see Figure 2)

Using the software Macromedia Freehand, cartographic colour, line, fill and text styles were applied to finalise the map (figure 3). Freehand was also used to finalise the
CONCLUSIONS/RECOMMENDATIONS

Spatial modelling technique in GIS can be very useful in creating 3D tourist maps. Use of satellite image gives information on land cover, land use and other topographic/geomorphic features, which could be useful information for planning trekking routes. Improvement would be to classify slope classes along the trekking routes to classify portions of the routes into classes such as light, moderate and heavy. Slope gradient, trek condition and accessibility could lead to three classes: class 1 suitable for beginners, class 2 suitable for tourist with some mountain trekking experience and class 3 for experienced trekkers. As the time available for the execution of the project was only 6 weeks, these aspects could not be taken into account.

Combination with graphic software and landscape rendering software can be useful to assist map makers to create low budget 3-D tourist maps which have natural looking impression. DEM can be also applied as base for 3-D “fly through” models of the area, or as a dynamic, map interface for Web applications.
Remote Sensing and GIS for monitoring soils and geomorphic processes to assist development of Mountainous land

Summary of sessions

SESSION 1.1: RS AND GIS FOR INVENTORY OF THE MOUNTAINOUS ENVIRONMENT: BASIC ASPECTS
Four papers were presented as follows:
Zhao Qiguo: Application of the “3S” technologies in sustainable agricultural development and land use planning in mountainous regions.
Michel Mulders: Advances in application of remote sensing and GIS to survey mountainous land
Olav Slaymaker: Developments in terrain analysis and application in Canadian Cordillera.
F. Giannetti: Integrated use of satellite images, DEM and soil data in studying mountainous lands and in supporting their sustainable development.

SUMMARY BY THE SESSION CHAIRMAN, MR. PETER BITTER:
Prof. Zhao Qiguo from the Nanjing Institute of Soil Science gave an overview on the application of the “3S technologies” (GIS, RS, GPS) in sustainable agricultural development and land use planning in mountainous regions. He highlighted the promises of these new technologies in cropland monitoring, crop yield forecasting, and precision farming, but also in land degradation monitoring and disaster mitigation. He gave some examples from China and the USA. He also made some specific recommendations to ICIMOD to carry out integrated 3S technology research projects and compile a mountain farmland and land information system in the Hindu Kush Himalayan region. Questions were asked from the audience regarding the use of RS in soil moisture detection, earthquake prediction, and the relevance of multimedia technology in soil science.
Dr. Michel A. Mulders from the Wageningen Agricultural University outlined the recent advances in RS and GIS which are relevant to soil surveys in mountainous lands. He emphasised the promises made by new sensors which will deliver data of higher spatial, spectral and temporal resolution and will have improved stereo capabilities, thus facilitating the automatic generation of DEMs. He also highlighted new methods to extract landform information from DEM and to unmix RS pixels spectrally. Questions have been asked regarding the parameters that have been used to prepare mass movement hazard maps.
Prof. Olav Slaymaker from the University of British Columbia explained the change of emphasis from low frequency – high magnitude events to high frequency – low magnitude events in British Columbia’s natural hazard policy. This was due to the fact that low magnitude events are frequently induced by human activities, thus their occurrence can be influenced by proper land use planning and management, whereas high magnitude events are mostly caused by natural causes and are thus beyond human control. He also stressed the importance of the societal context of disaster mitigation. Questions were asked with regard to the mapping of terrain stability and the effect of land use changes on landslide vulnerability.
Dr. Fabio Giannetti from the Institute for Wood Planting and the Environment in Torino, Italy, presented a methodology to create ‘Eco-Pedological Maps’ from satellite images, DEMs, and geologic maps. The maps show units which are homogenous in terms of soil and ecology and are suitable for the planning of sustainable land use and for monitoring soil degradation. The methodology has been implemented at 1:250,000 scale in northern Italy; a variant of it has also been tested at 1:50,000 scale for the management of alpine pastures. A question has been asked regarding the relevance of the 1:250,000 scale, given the fact that many geomorphic events likely occur at spatial scales of 10-100 m. Dr. Giannetti pointed out that his work was in line with a general drive of the EU to create a soil database of 1:250,000 scale, and was meant for general hazard zonation rather than monitoring of individual events.

SESSION 1.2 : RS AND GIS FOR INVENTORY OF THE MOUNTAINOUS ENVIRONMENT: BASIC ASPECTS
Two papers were presented as follows:
Godert van Lynden: The role of GIS and remote sensing in land degradation assessment and conservation planning: some experiences and expectations
Thierry Negre: The development of an Alpine soil information system.

SUMMARY BY THE SESSION CHAIRMAN, MR. FABIO GIANNETTI:
In the first presentation Mr. Godert van Lynden, project officer of the International Soil Reference and Information Centre (ISRIC) of the Netherlands, gave us an overview of a number of RS and GIS applications aiming at land degradation assessment and conservation. He
focused on very large area coverage, soil and related issues databases, such as SOTER, which is replacing the FAO Soil Map of the World, and some ISRIC developed databases. Then potential applications of RS and GIS were highlighted, using 2 case studies: a soil degradation and conservation assessment in South and Southeast Asia (Fujian, China) using a common physiographic template and a soil erosion risk assessment and corresponding crop yield loss in a study area of Kenya. The first question regarded the potential users of small scale maps and Mr. van Lynden pointed out that the main users of this kind of maps should be planners at national-international level. Then he was asked if ground-truthing was done in the two exposed case studies. Mr. van Lynden answered that in Fujian this was hopefully realised by the data providers and in Kenya field work was done to some extent. During the discussion was also emphasized the importance of using standardized and scale-independent methodology such as SOTER, WOCAT etc. to link databases of different origin and to exchange experiences.

The second presentation, held by Mr. Thierry Negre of the Joint Research Centre (JRC) of the European Communities, was about the development of an alpine soil information system. Mr. Negre revised the various activities of the European Soil Bureau of JRC and highlighted the importance of developing a soil information database suitable for the regional scale applications, as required by the Alpine Convention. This soil protocol, signed in 1998 by the alpine countries, aimed at a sustainable use of soil resources in mountainous areas and specifically requiring tools for soil protection. In this frame the Article 11 calls for the establishment of a soil erosion risk database at a more detailed scale than the presently available 1:1 million scale soil database of Europe. The chosen scale is 1:250,000 scale in order to harmonise this erosion risk assessment instrument on the Alps with the future Georeferenced Soil Database of Europe that will be developed at this scale.

The future construction of the Alpine Soil Information System (ASIS), following the structure of the Georeferenced Soil Database of Europe, will use RS and GIS techniques.

Questions included the use of the 1:250,000 scale that wouldn’t allow to follow some relevant geomorphological processes in mountainous areas. Mr. Negre highlighted that this scale was useful for European planning purposes and more detailed scale researches must be developed at national and regional level.

SESSION 2.1: RS AND GIS FOR THE STUDY OF SOIL AND GEOMORPHIC PROCESSES IN MOUNTAINOUS ENVIRONMENTS.

Four papers were presented as follows:

Chevrel, S.: High spatial resolution for detecting evidences of slope instability: SPOT simulated stereoscopic data.

Raj Kumar: Use of RS for comprehending the role of Himalayan orogeny in the genesis of salinity in the Indian sub-continent.

Zinck, Alfred: Identification and modelling of mass movements in mountainous areas, using RS and GIS techniques.

Mool, P. K.: Use of Multi-temporal data for the study of glacier lakes and glacier lake outburst floods in Nepal Himalaya, Tsho Rolpa glacier lake as a case study.

SUMMARY BY SESSION CHAIRMAN, PROF. SLAYMAKER: Mr. Chevrel emphasized the use of high spatial resolution imagery and derived Digital Elevation Models to generate landslide susceptibility maps. Questions included what was the reaction of the Colombian government (positive); whether there had been any validation of the maps (negative) and what was the relationship between the potential drainage density and conventional drainage density (that was length measured form the DEM over basin area).

Mr. Kumar explained the puzzle of the source of widespread soil salinity in India by the use of remotely sensed data. Chemical analysis failed to support conventional views of origin of the salinity from weathering and/or evaporation. Salt rich formations of the Tethyan area are demonstrated to be connected via lakes in Tibet and groundwater movement.

Prof. Zinck provided a comprehensive summary of the use of aerial photographs, multispectral images, SAR imagery and GIS modelling as alternative approaches to exploratory and predictive modelling of mass movements and gullies. Questions included strategies of deterministic and probabilistic modelling and whether potential implications of climatic changes had been considered.

Mr. Mool used satellite images to inventory of glacier lake outburst floods. Satellite images, aerial photographs and field investigations have formed a multi-stage approach with visual and digital image analysis techniques as well as GIS. Questions included the implication of climate change and whether there have been any studies of increasing frequency of such floods.

A general comment would be that all authors recommended use of as full a range of RS and GIS as possible.

SESSION 2.2: RS AND GIS FOR THE STUDY OF SOILS AND GEOMORPHIC PROCESSES IN MOUNTAINOUS ENVIRONMENTS.

Three papers were presented as follows:

M. M. Rahman (Bangladesh): Assessment of resources in a hilly area from semi-detailed survey information applying GIS techniques

G. J. F. Delpont and S. Chevrel: Remote sensing and GIS for mapping erosion susceptibility evolution, Coastal Cordillera-Chile.

SUMMARY BY THE SESSION CHAIRMAN, DR. DHRUBA P. SHRESTHA:
Prof. Schreier shows the application of GIS to examine the impact of human interference on soil and geomorphic processes. At micro and meso watersheds, human activities play a major role whereas nature seems to control the geomorphic processes at macro level. There are interactions between terrain stability and soil fertility. Indigenous management techniques seem to be very useful to prevent instability of low to moderate severe events. Studies show decrease of soil fertility, especially in the upland forests and grazing lands. The red soils have a similar problem. However, native plants and trees can be very useful to reclaim the badlands if managed carefully, which shows that there is still hope.

Mr. Rahman used landform and slope class maps generated from DTM as well as a soil map as overlays in a GIS. After map overlay procedures, there seem to be discrepancies in areal coverages between the conventional area calculation made on a semi-detailed soil map and the landform and the slope class maps. This addresses the error propagation issue in GIS, including the error in entering the data. A question raised was whether orthophoto was used in delineating the soil and landform units.

Mr. Chevrel used SPOT stereo-pairs to generate DTM on which auto-correlation was performed. From the DTM, slope index and drainage network were computed. Incision index was derived from the drainage network map and the land cover map was generated from image classification. Combination of these resulted in an erosion susceptibility map. Such maps can be generated using multi-temporal data which serves to monitor the erosion susceptibility of the area. A question raised was on the use of the soil erodibility factor in generating such maps.

SESSION 2.3: THE APPLICATION OF RS AND GIS TECHNOLOGY ON SOIL MAPPING AND ASSESSMENT

Five papers were presented, as follows:

Dobos Endre: Mapping soils of Italy with the use of integrated AVHRR and DEM data.
A.K. Maji et al.: Soil information system of Arunachal Pradesh in GIS environment for land use planning.
L.M. Pande: Soil resources mapping of Lower Himalayas.

Jeroen van der Worm and Dhruba Pika Shrestha: A short refresher course on the analysis and cartographic presentation of soil data.

SUMMARY BY SESSION CHAIRMAN, PROF. ZHAO QIGUO: The main viewpoints of the session are as follows: Multi-temporal and multi-spectral AVHRR data were used for extracting soil information. However, the purely AVHRR based model is still not satisfactory to detect soil differences caused by topographic position. Digital elevation and landscape descriptor data were essential to model for achieving acceptable results (Mr. Dobos Endre).

The soil resource inventory was carried out following a three tier approach viz. Image interpretation, soil survey and chemical analysis; GIS application for thematic mapping; the interpretation of database for developing a land use plan. The soil association maps on 1:250,000 scale were digitized topo-sheet-wise (14 topo-sheets) using polyconic projection to bring on the state soil map of India. (Mr. A. K. Maji)

GIS technology can be used to analyze the quantum of thematic data for land evaluation and suggesting optimal land utilization for sustainable development in the lower Himalayas. (Prof. L.M. Pande)

GIS technology has been useful in creating databases required for spatial planning. It is applied in developed countries as main tool in the field of urban and regional planning. The identification and accessibility analysis of service centers by GIS related methods is an important step in regional planning in developing countries (Mr. R.K. Mallick).

Each year ITC organizes four to five refresher courses in various countries. The course on the analysis and cartographic presentation of soil data is the third refresher course, which is executed within the framework of this programme in Nepal. (Mr. Jeroen van der Worm)

To sum up from the above, it is firmly believed that application of the RS and GIS technologies will be important and has both theoretical and practical significance for soil mapping and for the study of mountainous regions in the future.

SESSION 3.1: THE APPLICATION OF REMOTE SENSING & GIS FOR THE STUDY OF LAND USE AND LAND DEGRADATION IN MOUNTAINOUS AREAS.

Three papers were presented, as follows:

Jaap Slurink: Mapping of vegetation structure as a means of describing chorological variation in land degradation and erosion.
Shrestha, Dhruba Pikha: Land use classification in a mountainous area of Nepal - integration of image processing, digital elevation data and field knowledge.

SUMMARY BY SESSION CHAIRMAN, PROF. L.M. PANDE:
The first presentation was done by Mr. Jaap Slurin (Wageningen, the Netherlands) on Vegetation Survey. Mapping of vegetation structure was considered as a means of describing chorological variation in land degradation and erosion. The study was undertaken in the Nepal Mountains. He highlighted that natural vegetation structure changes with climate, altitude and aspect. Exploitation depends on the landforms existing in south facing slopes less than 2000-meter altitude, which are under cultivation. This includes soil erosion and landslides in the area. A question raised was: “What kind of image processing was carried out?” (answer: visual interpretation).

The second presentation was held by Dr. S. Folving Sr. Scientific Officer & Project Manager European commission. The paper was presented on behalf of Mr. R. Escadafal. The presentation was divided in two parts for two different areas. First was for monitoring changes in arid mountainous range of Morocco using remote sensing. He related the climatic gradient with the vegetation and finally with the land degradation. The rangeland monitoring has been successfully carried out using remote sensing data. By applying different image processing techniques, various vegetation changes could be distinguished from soil surface change, and was ultimately helpful in mapping the land degradation status.

In the second part of the presentation, he highlighted the use of remote sensing data for monitoring river basins in the European union. The monitoring is based on analysis of land surface parameters (viz. soil, vegetation), using satellite data. Various levels of mapping are done using different data products.

The third presentation was presented by Dr. Dhruba P. Shrestha from ITC (the Netherlands) on land use classification in Mountainous area of Nepal. He highlighted the problems in interpretation of satellite images due to illumination differences in various shaded aspects of mountains. The difficulty in classifying the land use could be overcome by normalizing the spectral bands by the total intensity. The results are further improved by image processing and spectral analysis using GIS. The classification accuracy was increased by 27%.

Chairman’s remarks: Remote Sensing & GIS is very helpful in Land Use Mapping. It can improve the accuracy, if soil information is characterised and stratified.

SESSION 3.2: REMOTE SENSING AND GIS FOR THE STUDY OF LAND USE AND LAND DEGRADATION IN MOUNTAINOUS AREAS
Five papers were presented, as follows:

Shrestha, B. & Nakarni, G.: Land use dynamics and land degradation in the Jhiku Khola watershed
Myo, K.: The use of RS & GIS for monitoring land use in mountainous areas of Myanmar
Alavi Panah, S.K. & Farshad, A.: Use of Landsat TM thermal band in the study of land use and soil salinity in the mountains of Iranian deserts
Sah, Kamal.: Monitoring land use changes in the Sundi Khola micro watershed.
Pradhan, Sushil.: Integration of GIS and RS for crop acreage estimation: an information system development approach - a prototype implementation in Razon Township, Hamadan Province, Iran.

SUMMARY BY THE SESSION CHAIRMAN, MR. MOHAMMAD RAIS:
Mr. Shrestha B. presented changes in land use pattern of Jhiku khola watershed which is 45 km east of Kathmandu. Time series mapping during 1947 and 1981 was done at 1:50,000 scale using topographic data. Another set of mapping was done during 1972, 1990, and 1996 at 1:20,000 scale by using historical data and aerial photographs. It was reported during the discussion that there has been a massive decline in forest area during 1947 and 1996 and in the denuded forest, pine plantation has been done in about 63% of the area. Further, in Bari Land, steep slope cultivation expanded at a very fast rate. During this period 90% of degradation has been in soils, which are below 1200 m elevation. It was reported that 70% of unstable soils are red soils. Since Bari land is under stress, 50% of these soils are degraded. During presentation, more detailed data was provided on soil classification and extent of damage it has undergone during the period. The period of 1947-81 has shown massive damages to land, however, during 1996-99, there have been minor changes in the land use systems.

Mr. Myo-Kywe presented the Myanmar case study of monitoring mountainous land using RS & GIS. The use of RS & GIS in Myanmar is relatively new. In 1980, FAO/UNDP supported a project to map 80% of the land at 1:1M scale, using landsat imagery. This activity was supplemented by aerial survey. Subsequently, ICIMOD and ITC supported their training for manpower development. The landsat based study during 1989 and 1999 revealed the land use changes during the decade. A new proposal from Myanmar to carry out comprehensive study of land use changes and manpower up-gradation is under development.

Mr. Alavi studied salinity in the mountains of the Iran desert by using Landsat TM thermal bands. The main purpose of study was to explore the capacity of Landsat...
TM bands and MSS images in combination with GIS for studying land use land cover analysis of Iranian deserts. The study also showed the application of statistical techniques such as principal component (PC) analysis, variance, covariance, and matrix analysis in evaluating TM reflective bands.

Mr. Sah demonstrated the use of GIS in monitoring changes in the Sundi Khola micro-watershed, of Kavre district, 35 km east of Kathmandu. The study uses data from the land resources mapping project (LRMP) during 1978 and 1998-99 at 1:50,000 in combination with aerial photographs of 1992 and field verification. The change detection analysis by GIS overlay revealed that during 1978 and 1992, the agricultural land area increased from 60 % to 76 %, resulting in forest area reduction by 10 %.

Mr. Pradhan presented a prototype for estimating crop acreage in Iran by integrating GIS and RS. The study demonstrated two methods for a crop acreage estimation information system (CAEIS). In CAEIS-I, area frame sampling (AFS), RS and their combination in Unix based ArcInfo software by using Arc Macro Language (AML). In CAEIS-II, MS Access '97 has been used. The studies mainly succeeded in demonstrating the integration of data from diverse sources. CAEIS have shown very good results.

SESSION 4: REMOTE SENSING AND GIS FOR EVALUATION OF SUITABILITY FOR SUSTAINABLE LAND-USE AND THE DEVELOPMENT OF MOUNTAINOUS LAND

Five papers were presented, as follows:

**Alejandro D. Luna Fuentes.** Landscape planning for Mexican mountains: a geoeological approach.


**Dungkar Drukpa.** GIS application for Land Use Planning in Bhutan.

**Mohammad Rais.** Linking Pixels with People for Sustainable Sloping Lands Management in Asia.

**SUMMARY BY SESSION CHAIRMAN, MR. STEN FOLVING:**

The session covered the range from application of GIS at the national and regional level to the necessity of analysing the needs and practices of the single farming unit.

A mountain landscape-ecological concept for suitability assessment and land use planning has been developed for Central America (Mr. Luna Fuentes). The main pillars of this concept consists of:

- Landscape structure assessment.
- Human settlement assessment.
- Natural risk and hazard assessment.
- Assessment of landscape management and mountain policy.

This concept supports a total (bio-) diversity approach in regional management. It, first of all, builds a strong analytical tool for describing and quantifying the energy and matter transfer from high areas to low areas (emission - transit - receiver functions). It facilitates the implementation and the impact assessment of international conventions, national policy and actual local development plans.

The benefit of using agro-ecological regions as operating units for environmental impact assessment in Asia was described. This approach, combined with careful selection of sites for detailed soil analysis builds the basis for the development of many types of indicator maps. These are important tools in environments where cash-crops often leads to erosion and degraded land. The maps might prevent future mistakes in the land-use planning, such as for example when afforestation forces farmers to move into marginal up-lands (Mr. R.B. Mapa).

The integration of soil-survey data into a total land evaluation assists the general sustainable development, both locally and regionally. Such soil-survey data are indeed needed for integrated crop-capability assessment and effective land use planning. When carefully planned, structured and integrated, soil and geomorphological data can be used in a GIS framework for deriving single crop suitability maps, but also for analysing whole crop-systems suitability. This assists the local authorities in setting up priorities at the local scale (Mr. D. Martin).

A National GIS of Bhutan has been established (Mr. Dungkar Drukpa), which provides both statistics and geo-referenced data on land cover, land use and landscape physiography: When carefully defined, such a tool is indispensable in optimising the data collection for specific purposes, such as for example soil data for crop-potential estimates.

The items described above logically leads to a need for careful analysis of the link between RS and what is actually going on at the very local scale. A “bottom-up” approach has to be considered if RS shall play any application oriented role at the local scale (Mr. Mohammad Rais). A pure RS based map does rarely assist the farmers in securing a production surplus – not even in subsistence. Therefore no actions should be taken, at the local level, from RS derived results without carefully analysing the situation at the farming level.
Remote Sensing and GIS for monitoring soils and geomorphic processes to assist integrated development of mountainous land

Results Round Table Discussions

A. SOIL AND TERRAIN DATABASES: ROLE OF REMOTE SENSING, APPLICATIONS AND USERS

PARTICIPANTS: GODERT W.J. VAN LYNDEN, THIERRY NEGRE, PETER BITTER AND RANJAN KUMAR MALLICK

Summary by Godert W.J. van Lynden

A.1. BACKGROUND:
Various approaches have been developed and implemented to create soil and terrain databases of the whole world or parts thereof: SOTER, European Soils Bureau, GLASOD, etc.

GIS offers a tremendous potential in creating information which is badly needed for integrated mountain development. However, the compilation of the necessary data base is expensive and time-consuming. In order to reduce the cost (money, time) of GIS applications in/on the HKH region and thus improve the availability and accessibility of geographic information on the HKH region, ICI-MOD/MENRIS is trying to establish a Regional Geographic Information Infrastructure, consisting of multi-purpose base datasets (preferably at 1:250,000), Metadata, standardized applications, trained manpower, and networked institutions. One of the basic datasets could be a soils and terrain database of the region. Therefore the discussion has been focussed on the potential applications and users of a future soil and terrain database of the HKH region, and the role of RS in this regard.

A.2. ROLE OF RS
RS is seen basically as a complimentary tool to fill gaps, where other (field) data is not available because of inaccessibility etc. It can also be useful to generate certain base data for the soil and terrain database, e.g. DEMs, land-/soilscape delineations, etc. An example has been given in the symposium by Giannetti. It has been mentioned that the planned Shuttle Radar Topography Mission which shall produce a worldwide DEM at 90 m resolution and the new Vegetation Instrument on SPOT-4 have a tremendous potential in this regard. Another example given by Endre, using RS data (and DEM) to classify soils directly is still more in a research stage. Finally, RS is ideally suited for monitoring dynamic processes. However, it has been pointed out that RS does not provide much information on processes and causes of problems. Also, RS is not a stand-alone solution, but a complimentary tool to other methods of data collection.

A.3. ROLE OF GIS
GIS is as an essential tool to integrate existing data from various sources (viz. Paper by van Lynden), and aids very much to present the information.

Applications of a Soil and Terrain Database in the HKH region
- Soil fertility assessment;
- Crop suitability evaluation (in connection with farming systems databases);
- Land degradation / soil conservation assessments;
- Crop yield modeling and monitoring;
- Linking field-based data, e.g. on soil fertility, to soil type maps (this, however, raises some issues of scale).

There is probably a need for a two-level approach: an inventory-type database of 1:1 million scale could provide an overview of the situation in the HKH region and can be used to identify specific areas of interest. Those areas should then be mapped at larger scales. Other datasets that will be useful in connection with a soil database:
- Climatic data;
- Socio-economic data;
- Land use / land cover;
- Agro-ecological zonations.

Users of the soil database: is there a need for it?
In the absence of a regional authority in the HKH region, the users would be mainly the scientific institutions and the countries themselves (in the form of consolidated scientific advice, e.g. from ICIMOD). They could use products from the soil database, e.g. degradation assessments, to direct the allocation of resources.

A.4. RECOMMENDATIONS:
A comprehensive infrastructure of multipurpose geospatial datasets (soils, terrain, AEZ, climate, socio-economic, land use) and corresponding applications (soil fertility and land suitability assessment, land degradation assessment, conservation inventories, crop modeling & monitoring) is a basic requirement for integrated development of mountainous lands. The georeferencing of field data should be encouraged. This raises issues of training of foresters, agriculturalists,
extension workers etc. in basic map usage. The potential of GPS in this regard has been highlighted. Small scale maps and databases (e.g. 1:1 million) are useful for planning at regional and sometimes national levels and for identifying areas of interest (hot spots) for more detailed investigations.

ICIMOD should, as a first step towards a regional soil database, assess the existing methods (SOTER, EUSIS, etc.) with regard to their suitability in mountainous areas.

There should be a stronger integration between RS/GIS specialists and other subject specialists in interdisciplinary teams. Or: RS should be incorporated by the thematic sciences and “RS specialists should disappear”.

B. PRESENT OBSTACLES FOR RS IN DEVELOPING COUNTRIES AND HOW TO ADOPT NEW TECHNOLOGIC DEVELOPMENTS AND IMPROVE DATA PRODUCTS AND COMMUNICATION WITH DECISION-MAKERS.

PARTICIPANTS: MYO-KYWE, MICHEL A. MULDERS, MD. MUSTAFIZUR RAHMAN, DHRUBA P SHRESTHA AND J. ALFRED ZINCK

Summary by By Dhruba P. Shrestha

Four questions were discussed. The questions are listed as follows:

How to prepare for coming accelerated development of RS in mountainous areas?

How to integrate RS & GIS for improving the quality of products?

What are the restrictions for the use of RS & GIS in developing countries?

How do we better communicate with planners, policy- and decision-makers: role of RS & GIS in this connection.

Question 1: how to prepare for coming accelerated development of RS in mountainous areas. It was clear that the quality of RS data will be improved in terms of spatial (1-3 m) and spectral resolution (hyper spectral data), which addresses the following points:

Need for more storage capacity;

Need for fast processors;

Need for improved classification/transformation methods;

Need for developing short courses on the use of new techniques and tools.

Question 2: how to integrate RS & GIS for improving the quality of products. The following recommendations were proposed:

Since RS data is in raster format, it is more useful to have all the data in raster format so that integration and analysis can be easily performed; A raster-based GIS will be in advantage for simplified integration of RS data and for spatial analysis;

Emphasis should be given to geo-referencing of all the thematic spatial information, including RS data to one common cartographic projection system;

Improvement of readability of map by removing unnecessary details;

Intensive use of expert knowledge;

Make metadata for quality control;

Improve communications among experts;

Proper cartographic representation.

Question 3: on the restrictions for the use of RS & GIS in developing countries, the following constrains were identified:

Enough computers and software’s but lack of skilled personnel in the organisation;

Separation of RS and GIS specialists; it addresses the need for improved communication among the specialists, also from other disciplines;

Availability and accessibility of data and restriction of data use; the need for awareness making to the governmental organisations on the availability of RS data and its derived products such as DTM from production organisations;

Financial restrictions.

Question 4: ‘how do we better communicate with planners, policy- and decision-makers: role of RS & GIS’.

The following recommendations were suggested:

During project implementation, interactions should be maintained among above-mentioned stakeholders;

At the end of the project, effective representation of the results should be made which should be easily understandable;

Level of reliability should be mentioned for the products;

Regular meetings should take place between various land resource institutions, managers, policy makers and planners to discuss research plans and the requirement/cost/expected benefits of new information technology.

C. FOR THE SUSTAINABLE DEVELOPMENT OF MOUNTAINOUS REGIONS A CONCEPT FOR A LANDSCAPE ECOLOGICAL, AGRO-ENVIRONMENTAL & SOCIO-ECONOMIC SUITABILITY ASSESSMENT IS NEEDED.

PARTICIPANTS: STEN FOLVING, ALEJANDRO D. LUNA FUENTES, JAAP SLURINK AND MOHAMMAD RAIS.

Summary by Mohammad Rais

For the sustainable development of Mountainous land, a concept for a Landscape ecological, Agro-environmental & Socio-economic assessment is needed. The main pillars of the Sustainable Land Management (SLM) concept consist of:

Landscape structure analysis;

Human settlement and farming practice assessment;
A comprehensive people oriented approach for mountain very open shrubland or grassland. Field data to be collected for each of these units separately could be:

- lifeforms and coverage per lifeform,
- leaf types and coverage per leaf type,
- dominant (tree) species.

Methods should be simple and quick.

A method to do so could be as follows:

The serious destabilising of Hindu Kush Mountainous region is a central issue to Global Change (see chapter 13, Agenda 21, 1992). With the present state of art of the remote sensing and GIS technology, the solutions to the problems of HKH region can be solved.

In the Symposium, all the papers presented addressed to the development of RS & GIS. Out of this a number of papers presented are related to Global Change, scaling and monitoring. These papers have been taken into consideration in developing these recommendations.

D. GLOBAL CHANGE AND LOCAL CHANGE; UP & DOWN SCALING

PARTICIPANTS: OLAV SLAYMAKER, LALIT MOHAN PANDE, KAMAL SAH

Summary by Olav Slaymaker

D.1. INTRODUCTION

The participants highlighted the land productivity, security, protection, economic viability and social acceptability should be taken up. One such approach could be to initiate projects at farm and micro-watershed level studies by using the International framework for Evaluating Sustainable Land Management (FESLM) (FAO 1993: World Soil Resources Services No. 73).

On different levels of responsibility for land, limited conception about ecological processes causes non-adapted mis-management of non-agricultural land, leading to land-degradation. For this reason in curricula for people responsible for land on different levels of education, the ecology of vegetation / soil / hydrology etc. of non-agricultural land should get an integrated place.

D.2. SCALING UP AND DOWN

Thematic maps produced globally are having different level of information as well as different scales which are not compatible in GIS environment. Hence there is necessity for scaling up and down. In general, scaling up is more desirable as it permits the utilisation of all available information. Where scaling down is necessary we normally rely on statistical procedures e.g. a hierarchical sampling design makes the assumption that closer links can be made between different levels of hierarchy. So we prefer an approach which starts from an individual farm or micro-watershed in a mountainous environment, this can be made between different levels of hierarchy. So we prefer an approach which starts from an individual farm or micro-watershed in a mountainous environment, this implies a necessity for scales at 1: 12,500 or better (Pande, this sym). We are not convinced that mapping at the scale of 1:250,000 as recommended by Montanarella and Negre (this Symposium) will provide information adequate for planning and decision making.

For HKH we recommend stratification of physiography at small scales. In case of Nepal, for example, we recommend High Mountains, Middle Mountains, foothills and
piedmont. It is our perception that the survey of Middle Mountains have a higher priority over other physiographic regions.

D.3. MONITORING

3a. Why monitoring?
Because mountains are dynamic fragile systems in which the study on changes in geomorphology and soil, and land use monitoring are essential.

3b. How to monitor?
- High mountains require monitoring at small scale and at longer time intervals.
- Middle mountains require monitoring with greatest intensity because of the degree of activity of natural processes combined with human activity.

D.4. RECOMMENDATIONS

Soil Scientists and geomorphologists make their main contributions to the understanding of global change by emphasizing cumulative change i.e. local changes in soil-geomorphic processes and land use that add up to progressive destabilising of mountainous regions. A reconnaissance level of mapping at 1:50,000 is recommended for planning and policy making.

In the HKH region we recommend identification of physiographic strata in which different scales of mapping are required because of different scale of variability in terrain parameters and different degrees of land use change.

On the question of scaling up and scaling down compromise solutions have to be found. Scaling up which is the desired goal is frequently too expansive for regional assessment. Scaling down on the other hand even when carried out by statistical experiments with hierarchical designs results in some potentially misleading assumptions.

Geomorphic processes, soils and landuse are changing so rapidly in mountainous environment that monitoring is essential. Most intensive monitoring is recommend for Middle Mountains in Nepal for example (1500 – 3500 meters) because of the intensiveness of the geomorphic processes and intensive land use.

We wish to direct the final recommendations to Planner and Policy Makers, Farmers, Foresters, NGO’s and the Public.
Participants list

Adhikari, Keshav  
GIS Unit  
Water Management and Study Program  
Institute of Agricultural & Animal Sciences  
Rampur  
Chitwan  
Nepal  
E-mail: iaas@imssg.wlink.com.np

Alavi Panah, S.K  
Desert Research Center  
University of Tehran  
Iran  
E-mail: salavipa@chamran.ut.ac.ir  
Fax: +98-21-6704144

Bitter, Peter  
RS specialist  
ICIMOD*  
E-mail: peter@icimod.org.np

Chevrel, Stéphane  
BRGM-DR/LGT  
BP 6009  
Orléans  
45060 cedex 2  
France  
E-mail: s.chevrel@brgm.fr  
Tel:+33 23864 3495  
Fax: +33 238 64 33 99

Dobos, Endre  
University of Miskolc  
Miskolc-Egyetemvaros 3515  
Hungary  
E-mail: ecodobos@silver.uni-miskolc.hu  
Tel: +36 46 565 111  
Fax: +36 46 362 972

Drukpa, Dungkar  
Land Use and Statistics Section  
Policy and Planning Division  
Ministry of Agriculture  
Thimpu  
Bhutan  
E-mail: ppd-moa@druknet.net.bt  
Tel. + 975 2 3223745  
Fax + 975 2 23 23748

Folving, Sten  
Space Application Institute  
Joint Research Centre  
21020 Ispra, Italy  
e-mail: Sten-Folving@jrc.it  
Tel. +39 0332 755009  
Fax. +39 0332 789469

Garcin, Manuel  
Geologist  
BRGM  
3 Av. Cte. Guillemin  
Orléans  
France  
E-mail: m.garcin@brgm.fr

Giannetti, Fabio  
Geologist  
IPLA SpA  
C.so Casale 476  
Torino 10132  
Italy  
E-mail: ipla@alpcom.it  
Tel: +39 011 89 98 933  
Fax: +39 011 89 89 333

Luna Fuentes, Alejandro D.  
Department of Geography  
UNAM  
Asturias 243-101  
Colonia Alamos  
C.P. 03400  
Mexico D.F.  
E-mail: delunaf@servidor.unam.mx  
Fax: + 525 624 35 87

Lynden, Godert W.J. van  
Researcher/project officer  
ISRIC  
POB 353  
Wageningen 6700AJ  
The Netherlands  
vanlynden@isric.nl  
Tel: +31 317 47 1735  
Fax:+31 317 47 1700

Maji, Amal Kumar  
Sr. scientist  
NBSS&LUP  
Amravati road  
Nagpur 440 010  
India  
E-mail: akmajii@nbsslup.mah..nic.in  
Tel:+91 712 532 386  
Fax: +91 712 522 534
Mallick, Ranjan Kumar  
Research Associate  
Human Settlements Development  
School of Environment Resources and Development  
Asian Institute of technology  
P.O.B. 04  
Pathumthani-12120  
Klong Luang, Thailand  
E-mail: ranjan_m@hotmail.com  

Mapa, R.B. 
Faculty of Agriculture  
University of Peradeniya  
Peradeniya  
Sri Lanka  
E-mail: mapa@agri.pdn.ac.lk  
Tel.: + 94 8 388 354  
Fax: + 94 8 388 041  

Martin, D.  
Scientist  
NBSS&LUP  
IARI Campus  
Regional Centre PUSA  
N. Delhi 110012, India  
E-mail: mrt_eve@yahoo.com  
Tel: +91 11 575 46 24  
Fax: +91 11 571 01 66  

Micheli, Erica  
Associate Professor  
University of Agriculture  
Godollo  
Zip Code 2100  
Hungary  
Email: micheli@RKT.GAU.HU  
Tel.: 36 28 410200  
Fax: 36 28 410200  

Mool, Pradeep  
RS Analyst  
ICIMOD*  
E-mail: mool@icimod.org.np  

Myo-Kywe  
Lecturer  
Yezin Agricultural University  
Yezin  
Myanmar  
E-mail:dap.moa@mtpt400.stems.com  
Fax: 095 1 663984  

Mulders, Michel A.  
Dept of Soil Science & Geology  
Wageningen University & Research centre  
POB 37, Wageningen 6700 AA  
The Netherlands  
E-mail: Michel.Mulders@BodLan.BenG.WAU.NL  

Nakarmi, Gopal  
PARDYP  
ICIMOD*  
E-mail : gopal@icimod.org.np  

Negre, Thierry  
European Commission  
Joint Research Centre SAVARIS  
TP 262 Ispra (VA)  
21020 Italy  
E-mail: thierry.negre@jrc.it  
Tel: +39 0332 78 61 02  
Fax: + 39 0332 789930  

Pande, Lalit Mohan  
Scientist (Prof.)  
IIARS  
Kalidas road  
Dheradun 284001  
India  
E-mail: lmpande@nde.vsnl.net.in  
Tel: +91 135 74 55 26  
Fax:+91 135 74 80 41  

Pelinck, Egbert  
Director General  
ICIMOD*  
E-mail: pelinck@icimod.org.np Pradhan, Pramod  
Head MENRIS  
ICIMOD*  
E-mail: pramod@icimod.org.np  

Pradhan, Sushil  
GIS Analyst  
ICIMOD*  
E-mail: sushil@icimod.org.np  

Rahman, Md. Mustafizur  
Director  
SRDI  
Krishi Khamar Sarak,  
Dhaka – 1215, Bangladesh  
E-mail: kampsrdi@citechco.net  
Fax: 880 2 811 884  

Rais, Mohammad  
Scientist  
NISTADS  
Dr. K.S. Krishnan road-PUSA  
New Delhi 110012 , India  
E-mail: rais@nistas.res.in  
E-mail: mohammad_rais@hotmail.com  
Tel: +91 11 572 64 06; +91 11 57 65 380  
Fax: +91 11 575 46 40
Participants list

Raj Kumar
Pedologist
Dept. of Soils
Punjab Agric. University
Ludhiana 141004
India
Tel: +91 161 4019 60 317
Fax: +91 161 400 945

Sah, Kamal
Scientist
Nepal Agricultural Research Council
Khumaltar, Lalitpur, Nepal
E-Mail: gisnarc@mos.com.np
Tel.: 523162

Schreier, Hanspeter
Professor
Institute for Resources and Environment
University of British Columbia
Vancouver, Canada
E-mail: star@interchange.ubc.ca

Shrestha, Anu Rajbhandari
Cartographer
Department of Forest Research and Survey
Ministry of Forest and Soil Conservation
Kathmandu, Nepal
Email : Maphouse@wlink.com.np
Tel. : 222601,223546 (Off.) ; 492134 (Res.)

Shrestha, Dhruba Pikha
Asst. Professor
Soil Science Div.
ITC **
E-mail: dhruba@itc.nl
Tel: +31 53 487 42 64
Fax: +31 53 487 43 79

Slaymaker, Olav
Professor of Geography
Department of Geography
The University of British Columbia
#217-1984 West Mall,
Vancouver, B.C. Canada, V6T 1Z2
E-mail: olav@geog.ubc.ca
Tel: +604 822 2663
Fax: +604 822 6150

Slurink, Jaap
Vegetation Survey
Thorbeckestraat 384
6702 CG Wageningen
The Netherlands
Tel: +31 317 42 43 84

Thapa, Rajesh
MENRIS
ICIMOD*
e-mail: menris@icimod.org.np

Worm, Jeroen van den
Lecturer
ITC **
E-mail: worm@itc.nl

Zhao Qiguo
Professor
East Road 3 71, Nanzing, P. R. China
E-mail: qgzhao@isas.as.cn
Tel: + 86 25 3611830
Fax: + 86 25 3353590

Zinck, J. Alfred
Professor & Head Soil Science Div.
ITC **
E-mail: zincka@itc.nl
Tel: +31 53 48 74 322
Fax: +31 53 48 74 399 *

* ICIMOD
International Centre for Integrated Mountain Development
MENRIS (Mountain Environment & Natural resources Information Systems)
Mail: P. O. Box 3226
Kathmandu
Nepal
Office: Jawalakhel
Tel: + 977 1 525 313
Fax: + 977 1 524 509 or +977 1 524 317 **

** ITC
International Institute for Aerospace Surveys and Earth Sciences
Mail: P. O. Box 6
7500 AA Enschede
The Netherlands
Office: Hengelosestraat 99
Tel: +31 53 48 74 444
Fax: +31 53 48 74 400