Remote sensing application in geomorphology

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Abstract: India has made tremendous progress in the aerospace technology in the last two decades. We are one, among the worlds best in satellite and the remote sensing technology. We are also one of the developing countries facing the natural disasters and trying level best to mitigate their ill effects. At the best we can minimize their effect. To achieve this, we need to have a comprehensive management program dealing with mapping and monitoring. The remote sensing technology with the fieldwork provides an edge to characterize the geomorphic aspects. The present paper reviews the application of the remote sensing tools in the application of geomorphology. A few case studies from the different part of the country are presented in the context of geomorphology of the foothills of Siwaliks, Central India and the eastern coast and use of remote sensing.

Resumen: En las últimas dos décadas la India ha hecho un enorme progreso en la tecnología aeroespacial. Somos uno de los países en vías de desarrollo que enfrentan desastres naturales y que intentan amortiguar sus efectos negativos. En el mejor de los casos podemos minimizar su efecto. Para conseguirlo, necesitamos contar con un programa de manejo de gran alcance relacionado con la elaboración de mapas y el monitoreo. La tecnología de percepción remota, en combinación con el trabajo de campo, ofrece ventajas en la caracterización de los aspectos geomorfológicos. El presente artículo revisa la aplicación de las herramientas de percepción remota a la geomorfología. Se presentan algunos estudios de caso de diferentes partes del país en el contexto de la geomorfología de las estribaciones de sierra en Siwaliks, India Central y la costa oriental, y del uso de la percepción remota.

Resumo: A Índia fez um enorme progresso na tecnologia espacial nas últimas duas décadas. Ela situa-se entre os melhores na tecnologia de satélite e detecção remota. Ela é, também, um dos países em desenvolvimento que enfrentam desastres naturais e fazendo o seu melhor para mitigar as suas consequências negativas. No melhor dos casos ela pode minimizar os seus efeitos. Para atingir este nível, é necessário dispor-se de um programa integrado de gestão que integre o mapeamento e a monitorização. A tecnologia de detecção remota, associada ao trabalho de campo, proporciona um avanço na caracterização dos aspectos geomorfológicos. Este artigo revê a aplicação dos instrumentos de detecção remota na geomorfologia. Alguns estudos de casos do uso da detecção remota são apresentados em diferentes regiões do país no contexto da geomorfologia da base das colinas de Siwaliks, Índia Central e na Costa Oriental.

Key words: Geomorphic mapping and analysis, geomorphology, landform, remote sensing.

Introduction

As the title of the article indicates, the subject matter consists of two disciplines, remote sensing and geomorphology. Remote sensing which is, primarily based on principles of physics, is the sci-
ence and art of acquiring information about an object or phenomena without physically coming in contact with it. Geomorphology is the science of study of the landforms of the earth. Both the disciplines are exhaustively covered in literature (Fairbridge 1968; Lillesand & Kiefer 2000; Sabins 1997 & Verstappen 1977). Remote sensing observations from aerial and space platforms which are currently in operation provide a synoptic view of terrain features in images which are interpreted by thematic specialists to understand and extract information of specific interest from the images. Formal training is required for interpretation to understand the significance of image elements contained in the image in addition to formal education in the theme speciality. Geomorphological mapping from satellite and aerial images for example, needs a thorough knowledge of the subject geomorphology, i.e., how certain natural and man-made processes lead to landforms. Since the most satellites data are essentially recorded in digital form without a stereoscopic coverage, generated images are two-dimensional. Geomorphological analysis of surface forms of the earth is a direct form of interpretation from space images. Aerial photos with required forward overlap usually provide the third dimension of height, which adds to the precision of interpretation including morphometry.

Geomorphology as a science developed much later than geology although several aspects of geomorphology are embedded in geological processes. Geomorphology deals with the genesis of relief forms of the surface of the earth’s crust. Certain natural processes are responsible for the forms of the surface of the earth. A thorough understanding of various processes leading to landforms is necessary to understand the environment in which we live. Remote sensing is an effective tool in this understanding, as aerospace images contain integrated information of all that is on the ground, the landform, the ecology, the resources contained in the area and the impact of human actions on the natural landscape. The dynamism with which changes occur in the landscape is brought out effectively by repeated coverage of images of the same area at different times. Images convey many things even to the untrained eye and for a professional it conveys much more including many features hitherto unknown or unseen on the ground.

**Geomorphology - basic concepts**

The earth’s surface forms are primarily due to hypogene or endogenous processes, which include diastrophism, leading to geologic structure, tectonic activity and volcanism leading to volcanic landforms. These forms are modified by epigene or exogenous processes, which include erosion and depositional activities of water, wind and ice. Other activities include weathering, mass wasting or movement of material by gravitational action, land-ocean interaction resulting in landforms due to waves, currents, tides and tsunamis. Climate is another important factor, which has relevance in shaping of the earth’s surface because the processes that act upon the surface material are different in different climatic zones (Van Westen 1994). For example, limestone forms hills in a dry climate whereas in wet climate, it forms Karst topography with sink holes, caves and caverns predominating

<table>
<thead>
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<th>Table 1. Landform processes.</th>
<th>Form (of varying scales)</th>
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<td><strong>Process</strong></td>
<td><strong>Local (Example)</strong></td>
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<tr>
<td>Tectonic/Structural</td>
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<td>Volcanic</td>
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<td>Fluvial (Riverine)</td>
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<td>Marine</td>
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<td>Glacial</td>
<td>Cirque, drumlin, esker, moraine ridge</td>
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<td>Aeolain</td>
<td>Sand dune, yardang</td>
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<tr>
<td>Solution</td>
<td>Sink hole</td>
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<td>Antheropogenic</td>
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because of its susceptibility to solution activity. Similarly, granite stands out as hard rock in non-tropical areas whereas in the tropics it undergoes deep chemical weathering and becomes a soft rock. It is also understood that climate has strong influence on vegetation which in turn has relationship with landforms. Landforms and plant ecology thus form a sound combination; a change in plant ecology may have significance in change in landform and vice-versa, although human influence on vegetation may disturb the relationship. Time is another important factor that may preserve or destroy the natural landform, because it controls the stage in the sequence of processes leading to forms. At any given time, the more recent processes and the resultant forms dominate the landscape. The Pleistocene to Holocene glacial cycles with intervening interglacial periods i.e. cold and warm cycles have modified the surface forms throughout the world and many of the forms of the present day are a result of these cycles. It is generally considered that most forms are not older than Tertiary and there are some relict forms of pre-Tertiary period.

**Classification of landforms**

In order to understand the landforms systematically in the context of the origin of landforms, a genetic classification is generally accepted as most appropriate. Table 1 shows the major natural processes, which result in various forms with a few typical examples at local and regional scale.

**Geomorphological mapping**

The first geomorphological map prepared in 1914 but the main demand for the maps came cover form planner and agronomists after World War II. However, a formal mapping system was designed only during 1950s. Many systems were developed by European countries like France, Poland and Russia. The International Geographical Union’s Sub-commission on geomorphological mapping was set up in 1960 to standardize legends for mapping. However, specific consensus was arrived at a modified legend. A geomorphological map must give information about morphology (appearance), morphometry (dimensions and slope values), morphogen (origin/genesis) and morphochronology (the age) of each form. Representation of these details is an involved and complicated matter on a single map.

The most comprehensive geomorphological survey method is the one evolved by ITC (Verstappen 1977) which resulted in three different kinds of maps: Analytical geomorphological map, synthetic geomorphological map and pragmatic (applied) geomorphological map. Analytical geomorphological maps are applicable for mapping at all scales and serve as a basis for applied geomorphological mapping. The informations contained in these maps include

(a) morphogenesis i.e. the terminology should indicate the process/ gneisses (e.g. alluvial fan, piedmont);

(b) morphostructure/lithology. Usually the underlying bedrock and structure will have a profound influence on the landform (e.g. structural hill, granitic residual hill etc.);

(c) morphometry i.e. quantitative information about relief e.g. height of terrace, slope angle etc;

(d) morphochronology i.e. different ages of landforms whenever such information is available.

Synthetic geomorphological maps contain, in addition to four levels of terrain mapping units, also contain additional environmental information required of every terrain mapping unit gathered subsequently on the basis of number of site observations in every unit. These observations include, for example, soils, hydrology, vegetation/ land use/ landcover and topography. These data are presented in tables or use of GIS can be made to indicate each theme as a spatial layer.

Pragmatic or applied geomorphological maps can be derived from analytical and synthetic maps. Maps related to natural hazard assessment and developed for mitigation programs are increasingly becoming useful, as hazard zoning which has a direct bearing on geomorphology is possible in all cases. Maps on flood hazard zoning, mountain hazard zoning, drought hazard zoning, earthquake hazard zoning, volcanic hazard zoning, cyclone hazard zoning are some typical examples of pragmatic geomorphological maps (Verstappen 1977). Other applied geomorphological mapping examples include maps for mineral and hydrocarbon exploration, which contains geomorphic anomalies indicative of suitable subsurface structures. For example, incipient radial drainage or compressed meanders may indicate active buried structures suitable for mineral/ hydrocarbons. Similarly high recharge zones (piedmont), disappearing drainage
lines and discharge zones indicated by sudden appearance of vegetation throw light on ground water exploration. Anomalously displaced terraces and alluvial fans (Rao 1977, 1978), indicative of neotectonic activity changing river courses leading to anomalous lakes (Rao 1975) and study of Paleodrainages, indicative of climatic and tectonic activities all have immensely benefited in understanding the phenomena through the knowledge of geomorphology.

Traditionally geomorphological mapping has been in practice ever since aerial photos became available. Landforms have been the direct object of interpretation of aerial photos and these are interpreted in terms of other themes like geology, soils etc. Inductive and deductive reasoning is resorted to for interpretation of soils, for example, as pedological information is not directly seen and it has to be extracted from terrain feature like landforms, geology, vegetation, drainage etc.

Remote sensing application

Remote sensing as described earlier is sensing from a distance. The electromagnetic energy after interacting with matter can be recorded by a sensor and the recorded data can be seen as an image or photo depending upon the sensor. The electromagnetic spectrum is a continuum of energy that ranges from meter to nanometers in wavelength and travels at the speed of light. The spectrum has several windows through which reflected or emitted radiation is recorded in sensors (Sabins 1997). Among the sensors are aerial cameras, which employ a film for recording in visible (B&W and color) and near infrared band. Data from visible, near infrared and other optical windows are recorded by multispectral scanners. Thermal scanner records thermal (emitted) radiation. Active microwave sensors (SLAR or SAR) record data from microwave region of spectrum and have the advantage of recording day and night as well as through clouds. Thus technologically it is possible to record terrain information by various sensors.

Advantages of remote sensing

Remote sensing satellites by virtue of their orbiting in a sun synchronous orbit and crossing the equator at the same local time, capture the images of the terrain with the same illumination and provide repetitive coverages i.e. satellite revisit the same site at regular intervals of time which varies depending upon the orbit height, inclination etc. The following are specific advantages of satellite images for deriving information on ground features, some of which are dynamically changing, like land use.

Multi temporal capability

Indian Remote Sensing satellite (IRS) at a height of about 800 km, revisits every 22 days the same site; any change occurring between two successive visits becomes evident in the image. While no change occurs in major landforms in the short period, the changes brought about by disasters like floods, cyclones, landslides change in river courses, erosion of the river banks etc., can be automatically detected. Additionally, landuse/land cover changes, which are dynamic, highlight certain landforms during some seasons of the year.

Multi spectral capability

Most remote sensing satellites have sensors, which record, not only in visible band but also in NIR, SWIR and MIR bands apart from thermal band in selected satellites. Microwave recording requires special effort and usually such satellite are exclusive. The advantage in multispectral capability is that certain bands or a combination of bands provide better contrast for image interpretation than other bands. The interpreter has to be knowledgeable to choose a particular sensor data depending upon the specific application. Unlike in aerial photos where visual interpretation is common, satellite multispectral data have an advantage in that the image data in various bands can be subjected to digital enhancement techniques for highlighting contrasts in objects for improving image interpretability (Sabins 1996). Also, because of large volume of digital data, digital techniques are the only means to handle data for selecting and analysing to extract required information quickly. While digital analysis is faster and appropriate in identification and delineation of crops and land use where each land use/land cover may have unique signature, landforms can be best interpreted on the basis of analysis of basic elements of interpretation outlined earlier namely tone, texture, size, shape, relief, drainage, slope, land use and association of features. Verstappen (1977) describes four phases of image interpretation namely:
(i) detection, (ii) recognition and identification, (iii) analysis and (iv) classification of observable features in terms of landform and genesis.

A good reference level in the subject plus a formal training in interpretation are essential to derive maximum information from image.

Multispatial capability

Satellite sensors, over the years have progressed, in terms of spatial resolution in addition to many other sensor improvements. Today 1-m resolution data are available along with other resolutions ranging from 2 m to 1000 m or more by satellites launched by space faring nations. While this range provides opportunity of multispatial capability, the need for selecting appropriate resolution data is imperative. Broadly, for regional mapping, low resolution data may be adequate whereas for understanding landscape ecology of a small area high-resolution data may be appropriate. Time, economy and objective of study have to be integrated to decide the optimum spatial resolution data.

Microwave remote sensing in geomorphic analysis

In contrast to optical remote sensing, radar being an active sensor provides all weather capability including day and night observation. Radar backscatter is sensitive to a different set of properties like surface roughness, slope and dielectric property of surface material. Radar image has unique characteristics of its own. The shadow effect, for example, is useful for terrain analysis. The subtle elevation differences, which are not directly perceived in optical remote-sensing image, are highlighted in radar image. Such subtle relief changes may have significance in neotectonics or may represent a boundary condition. The interpretation of radar image is based on form, topographic texture and pattern, topographic position, pseudo-3D presentation of form (slope) and regional geomorphic context.

Fig.1. Satellite data showing Doon Valley and surroundings.
One of the most commonly using applications of radar imagery in the Indian context is mapping of flood and cyclone affected areas. The change brought about by devastating floods in Brahmaputra river and changes in coastal configuration of Orissa coast in the after math of supercyclone Orissa coast in October 1998 are good examples.

**Geomorphology and landscape ecology**

According to Verstappen (1977, pp.138) "..... Natural and cultural landscapes are composed of a number of elements or components which are mutually interrelated through a frame work of landscape ecology". Many authors (Verstappen 1977) have described segmentation of terrain into distinct but unique character. The land system concept of CSIRO in Australia is a good example. The land systems are units having unique characters of landform, soil type, vegetation and land use. This can be extended to other characters like groundwater condition, slope etc. The close linkage between the landform and other ecological factors as exist in the terrain are reflected in the aerospace imagery through various degrees of correlation in the distribution pattern. For example, the point bar/natural levee/backswamp pattern of a typical fluvial landscape evidently has a strong correlation between land use and landform. The levees are invariably occupied by settlements, being higher in elevation whereas the backswamps have agriculture/aquatic vegetation. Indo-Gangetic plain is a typical example. Association of features, an important element of image interpretation, contributes also to a proper understanding of the landform. Vegetation, land use, drainage, mode of clustering of settlements together help in proper interpretation of geomorphology.

Aerial photos have been historically used to capture ground features. Largely used in the beginning after World War II for geological mapping, it was soon realized that geomorphological understanding of terrain features is so direct from aerial photos. Several techniques of interpretation of aerial photos were developed. The basic elements which help in image interpretation are shape, size, tone, texture, slope/relief, drainage and association of features. These are related to the scale of aerial photos. The scales of commonly used aerial photos vary from 1:10,000 to 1:50,000 although for very large scale mapping, scales larger than 1:10,000 are used and for a quick reconnaissance surveys scales smaller than 1:50,000 are used. The advantage of aerial photo is that they provide stereoscopic view, enabling the interpreter to understand the genesis of landform in addition to amenability to measurement of slopes, heights etc. Although black & white

![Fig. 2. Horizontal profile along the points X and Y as shown in Fig. 1.](image_url)
aerial photos are used in majority of cases, infrared, color, thermal and radar images from aerial platform are also used for specific purposes. However, the mechanism of acquisition, storage, retrieval of images and their interpretation, is different for each type of image (Verstappen 1977). The ITC system of geomorphological survey is ideally suited for aerial photo interpretation, although the principles of survey remain valid for space imagery.

Interpretation of remotely sensed images from space platforms for geomorphological understanding is rather direct as the main object of interpretation is landform itself, which manifests itself in its form. Deduction is required unlike in other themes although for understanding the processes it may be employed usefully. The synoptic view of a large area in a single view enables understanding of interrelationship of various terrain features.

Case studies

Three case studies are presented here to illustrate the efficacy of remote sensing in environmental geomorphological interpretation including landform ecological correlation.

Doon valley

The Doon valley and surroundings (Figs. 1 & 2), in the foothills of western Himalayas, is geologically very young, representing upper Tertiary sediments, namely the Siwalik group of rocks and younger gravel beds. It is a high rainfall area receiving 2300 mm year$^{-1}$. A profile from south (X) to North (Y) in Fig. 2 describes the relationship of geomorphology, structure, geology and land use/vegetation. Along the section X to Y, wide alluvial plains partly under agriculture and partly under forest cover followed by abruptly rising Siwalik hills with sharp ridge separating drainage flowing

Fig. 3. Satellite data showing Mahanadi Brahmani delta system and surrounding coastal landforms.
north and south arisen. North of the ridge low Siwalik hills have a prominent but short upper and lower piedmont slopes abutting against long piedmont fan slopes of northern part of Doon valley on which the township of Dehradun is located.

South Siwalik ridge

Before the Siwaliks rise abruptly from the plains, two different piedmont slopes arisen. The lower piedmont is a gentle slope consisting of gravels and sand covered by rich alluvial soils. The upper piedmont consisting coarse gravels with steeper footslopes is conducive for high recharge and enable for artesian conditions at the junction with lower piedmont, thus making the lower piedmont a rich area for agriculture. Before agriculture was introduced this area also had Sal mixed forest. The upper piedmont has two components, namely a foothill zone where due to coalescence of fan deposits from several streams contains coarse boulders, gravels and sand admixed with silt and clay. This zone is a high recharge zone. The lower half of the upper piedmont has medium coarse material and relatively gentler slope. The entire upper piedmont is covered by deciduous mixed Sal forest, Sal dominating. The structural hills of middle Siwalik rocks rise abruptly over the upper piedmont because of a foothill fault. These structural hills are controlled morphologically by the lithology, the southern part consisting of alternating sandstone and shale overlain by massive sandstone, which have grassy slope facing south and open mixed Sal forest on northern aspects. These are overlain by upper Siwalik gravel and boulder beds with intermittent clay layers. The transition between middle Siwalik and upper Siwalik is seen with beautiful flat iron dip slopes, the north facing dip slopes having typical Sal forest and south facing ones having grasses. As the size of boulder increases, towards the crest of the ridge we see an area of intense dissection with high drainage density. There is a natural disturbance for the growth of dense forest because of scarp recession due to headward erosion of streams which is more rampant in the south side as compared to the north side.

North of Siwalik ridge

The north side morphology is different with a short length of the upper Siwalik gently dipping north and merging with upper piedmont. The area has high drainage density and is covered by dense mixed Sal forest. In contrast, the lower piedmont slopes are covered by pure Sal forest as the brick red color indicates. Streams draining the slope join axial streams flowing west and east to the north of which the northern part of Doon Valley is predominantly covered by Doon fans which have long slopes having urban and agriculture land use. Dehradun is situated on one such big alluvial fan. To the east of Dehradun the water drains to the river Ganges and to the west into the Yamuna river. These Doon fans are having relict hills consisting of older boulder bed (Lamgha boulder bed of Rao 1977). These hills are once again covered by Sal forest. The Doon fans have (not along section line) patches of Sal forest particularly in the western part indicating the original ecological conditions, modified by human settlements. The high relief of Lesser Himalayas consists of denudational hills with steep slopes, which are sparsely covered by vegetation, which is totally different from Siwalik hills. The case study demonstrates how landform and ecological relationship exists and perceived holistically through satellite image interpretation.

Fig. 4. Horizontal profile along the points X and Y shown in Fig. 3.
Mahanadi Brahmani delta system

This area, in the east coast depicts landform resulting due to interaction of sea and land (Figs. 3 & 4). The area is largely covered by Mahanadi and Brahmani river Delta in the northeast and Chilka lake in the south. Mahanadi and Brahmani river delta is associated with estuarine bays, spits and bars, beach ridges and swamps. A profile from X to Y Fig. 4 describes the landform-land cover relationship. Towards south is Chilka lake, a former arm of the sea, now undergoing filling with sediments from hinterland. The typical delta of Mahanadi with multiple branches emanating from one single channel, one of which also debouches into Chilka lake. The lake has weeds in the northern part; the cross profile of the delta is convex up. While agriculture predominates most of the delta area, the area adjacent to coast is swampy having degraded mangrove vegetation. Formation of spits and bars is due to long shore drifting is evident and these spits are mostly covered by *Casuarina* as the spite consist of sands. In the bays, a healthy mangrove vegetation is seen (Porwal & Roy 1991; Roy et al. 1991). North of Brahmani river estuary NW-SE trending beach ridges occur, the ridges having *Casuarina* vegetation and swamps having mangrove vegetation. The current activity indicates the coast is prograding with abundant sediment covering from hinterland as seen by sediment plumes near Y in the section.

Kanha national park area

Geomorphologically this area in Central India (Figs. 5 & 6) comprises of structural and denudation hills with attendant valleys and remnants of plantation surfaces, which are locally known as ‘Dadars’. Lateritic caps, which add to the interpretation that the area has undergone plantation

![Figure 5](image-url)
usually, underlie these flattop Dadar. A profile across the park from X to Y Fig. 6 is described here. The streams are seen to be meandering in the area. The fact that remnants remarks of old plantation surfaces (Dadar) occur gives a possibility of river entrenchment which is indicative of the area having undergone uplift after undergoing regional plantation. The river also shows structural control. The complex structure of old geologic formation consisting of gneisses and schists is showing effects of denudation as well as structural imprints with the result that from the alluvial plain to high points in relief we can see gradual transition from undulating plain to denudational hills to plateau above which structural forms persist. The vegetation pattern has adjusted to topography, slope, moisture and climate. The profiles of vegetation cover change thus indicate that the morphology including micromorphology has strong control on ecology.

The unplanned and indiscriminate use of land has caused tremendous loss in natural resources. The technology development scenario and user requirements during the last decade have necessitated the launch of second generation remote sensing satellites. The use of this tool with the GPS and GIS provides unlimited applications for geomorphological studies.

References


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Fig. 6. Horizontal profile along the points X and Y as shown in Fig. 5.

