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Mapping Land Use Patterns in a River Catchment using Geographical Information Systems

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The paper describes a methodology developed to compile land use maps using multiple data sources integrated using geographical information systems (GIS). A river basin is the base unit for the study, being a complete hydrological and topographical unit. The methodology developed has real applications in river basin modelling. Multi-temporal satellite imagery, from different agricultural seasons, was used to produce land-cover maps for the catchment, using knowledge-based re-classification. The drainage network, elevation and other topographic and thematic data were digitized from maps. The GIS was used to integrate these data sources and provide tools for manipulation of the data. This procedure enabled spectrally inseparable classes to be delineated and land use maps to be prepared. Various land use classes, including wastelands, and appropriate preventive measures, have been developed. The paper also envisages some future studies for catchment management policies.

Keywords: land use, catchment, remote sensing, geographical information systems (GIS).

1. Introduction

Information on the existing land use pattern and its spatial distribution is a prerequisite, among the various parameters, for the planning, utilization and formulation

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of policies and programmes in making any developmental plans. Such information is sometimes supported by spatial information from departmental maps and other conventional sources. With the advent of remote-sensing techniques, with its opportunities for repeated observations and multi-spectral capabilities, it has been possible to prepare land use maps at various levels of detail. However, the application of multispectral classification techniques in extracting land-cover classes has been a subject of discussion for many years. No single technique has proved completely successful, with many techniques being dependent on particular seasonal and regional differences. This inconsistency occurs because of similarities in spectral responses: different information classes may have the same or similar spectral responses in all spectral bands (Bocco and Valenzuela, 1991). In most cases, visual classification by trained interpreters, making use of texture, shape, context and local knowledge, provides the most cost-effective form of classification.

The technology of geographical information systems provides a means of introducing information and knowledge from other data sources into the decision-making process, and provides tools for handling and manipulating remotely-sensed data.

"The effective utilization of the large amounts of spatial data produced by remote sensing systems is dependent upon the existence of an efficient, geographic data handling and processing system that will transform the data into usable information" (Marble and Peuquet, 1983).

"A GIS represents the most effective mechanism for making use of the data captured by remote sensing systems and also enhances the effectiveness of this data capture operation through correlation of remotely sensed data with data already stored in a GIS" (Marble, 1984).

"Remotely sensing classification systems could, in many instances, benefit from access to highly accurate, ancillary ground data which could significantly improve spectral classification procedures" (Marble and Peuquet, 1983).

This paper describes a methodology for GIS-assisted mapping of land use and natural resources in a river basin. The river basin is chosen as the fundamental unit in both the modelling and monitoring of the effect of catchment management policies. This application is related to the optimization of land and water resources whilst minimizing the impact on the environment.

2. The study area

The river basin chosen for this study was the Malhar Sagar catchment, also known as the Nazre medium irrigation project. It covers about 400 km^2, is 30 km long, 73° 53′E to 74° 12′E, by 16 km wide, 18° 15′ N to 18° 25′N (see Figure 1).

The catchment is bounded by hills on the north, south and west and by plains in the east. The area is a basaltic landscape with physiographic units of plateau lands, escarpments, hills, dykes, piedmont plains and colluvio–alluvio plains. Local relief ranges from 500 m to 1500 m.

The perennial Karha River drains most of the area flowing from north-west to the south-east. The drainage density across the catchment is moderate to high. Drainage is mainly dendritic, with a sub-parallel system adjacent to stream courses particularly in the alluvial belt.

The climate of the area is sub-tropical monsoonic, characterized by mild winters, hot summers and a short monsoon. The rainfall is generally low, highly erratic in

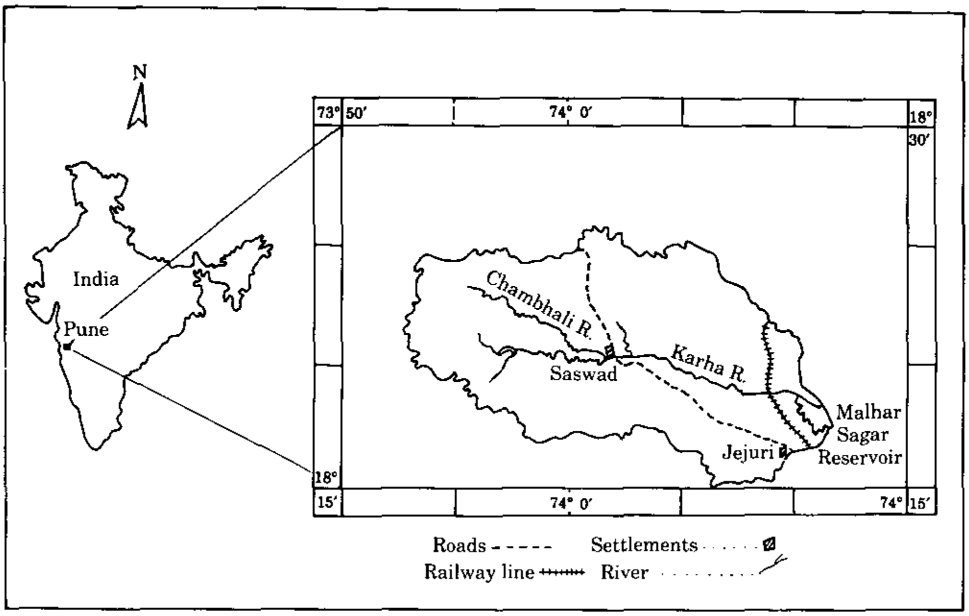

Figure 1. Location map of Malhar Sagar catchment.

intensity and quantity, and concentrated within a short time period, making rain-fed farming very difficult.

There are two types of forest commonly found in the area, tropical dry deciduous and tropical thorn forests (Forest Atlas of India, 1976). The area has mainly black soils, with alluvial soils adjacent to streams. The soils fall into three major categories, vertisols, inceptisols and entisols (Soil Taxonomy, 1975).

The area generally has sparse vegetation cover, steep slopes and dry overall climate with erratic monsoon rainfall, resulting in a high susceptibility to erosion in the upper reaches. The generation of accurate land-cover maps is therefore of primary importance in categorizing erosion risk in the catchment. Soil erosion, deforestation and cropping patterns were the bases for selection of this catchment for the study.

3. Data sources

Two dates of IRS LISS-II satellite imagery were acquired. The October/November (kharif season) image shows general overall vegetation cover, the March/April (rabi season) image shows sparse vegetation in the upland areas. IRS LISS-II imagery has a ground resolution of 36·25 m and four spectral bands similar in response to the first four bands of Landsat TM.

Ancillary data were compiled from the following sources:

1. Survey of India Topographic Maps, 1:250 000 and 1:50000.
2. Irrigation Atlas of India.
3. Forest Atlas of India.
4. Landsat TM derived land use/cover map (visual interpretation).

Ground-truth data were also available from sample sites, providing information on land use patterns, drainage, soils (moisture, erosion, colour, texture, etc.), slope and other surface features.

4. Creation of information databases

The data sources were integrated in the GIS in grid-cell format. The GIS used was the PC-based ICONOCLAST Image Processing and Spatial Analysis System developed in-house at the Remote Sensing Unit, Aston University. This GIS is a raster-based system enabling rapid integration of data from image and map sources.

4.1. CO-ORDINATE SYSTEM

For a raster-based GIS it is necessary to define a cell (pixel) that is the limit of the resolution of the system. Each cell has an exact location in space, related to the grid's orientation and cell size, and a list of assigned attributes.

Given the extent of the catchment and the required resolution, a grid cell of 1 minute of a degree was chosen. The origin of the grid was taken as 73° 50′E, 18° 15′N. A grid size of 1500 × 900 cells covers the catchment. A vector co-ordinate system was also defined, at 1/10′ of a minute of a degree, for the extraction of vector information.

4.2. LAND USE/LAND COVER

Each date of image was separately classified using a supervised classification technique. Ground-truth data were used to derive training sets for all the significant classes. A maximum-likelihood classification was then performed.

The results of these classifications highlighted some of the problems in discriminating between some land use classes. Most notable was the confusion between agricultural land in the low-lying areas and upland vegetation in the kharif season. During the rabi season, the upland vegetation is generally sparse, and a simple logical operation combining the two classifications could therefore be used.

Both classifications were corrected to the co-ordinate system, thus enabling per-pixel/cell logical combination operations within the GIS. This combination was achieved by identifying a number of ground-control points (GCPs) on both the satellite imagery in pixel co-ordinates, and the 1:50 000 topographic maps in grid co-ordinates. A standard warp to GCPs transform was then applied to correct the image classification.

4.3. MAP DIGITIZATION

The GIS used can make use of a process known as video digitization (or frame grabbing) to digitize map data. The process involves setting up a map area under a video camera on a copy stand. A specialist computer graphics card enables the video camera's output to be digitized, producing a raster representation of the map on the image display.

A number of control points are defined to enable the co-ordinate axes to be aligned and any geometric distortion to be corrected. At this state, a relationship between pixel co-ordinate and map co-ordinate is precisely defined. Any features on the image can then be manually or semi-automatically traced on-screen, producing a vector list in co-ordinate system units.

5. Manipulation of the information databases

Given that all the data sources are now in a common co-ordinate system, several useful combinations can be tried. Each satellite classification, on its own, was insufficient to

TABLE 1. Land use/land cover classification system

Level I	Level II
Agriculture	Cropped land (kharif and rabi) Upland agriculture Harvested high-water land Harvested medium-water land Harvested low-water land
Forest	Medium Poor
Water bodies	Reservoir Stream
Urban settlement	
Wasteland	Degraded pasture Land with/without scrub

discriminate between all the necessary classes. Natural vegetation in the upland areas is spectrally inseparable from agricultural land in the kharif season.

Simple logical combination of both satellite classifications, pixel by pixel, enables discrimination of these classes to be made, i.e.:

IF KharifClass = Vegetation AND RabiClass = Scrubland
THEN Class = Scrubland
IF KharifClass = Vegetation AND RabiClass = Vegetation
THEN Class = Agriculture

New information classes can be created by combining these and other data sources, using complex combinations, for example:

IF SpectralClass = Vegetation AND DrainageDensity < 10% AND Height > 600 m
THEN Class = Forest

Using these procedures, and a set of rules derived from knowledge of local land use patterns, a new classification was produced from the data sources. The final land-cover classes are shown in Table 1. Five major categories have been defined.

5.1. AGRICULTURE

The kharif season imagery, when most of the crop has matured and been harvested, highlights cropped areas predominantly in the central black soil region and alluvial zone. Almost the entire area is devoted bajra (pearl millet), groundnut, vegetables and sugarcane.

The rabi season imagery highlights cropland confined to irrigated tracts and alluvial plains adjacent to the river. The cropped lands are mainly wheat and dry crops (pulses) and vegetables. Particular crops cannot generally be discriminated due to the spectral characteristics of the crops, parcel sizes and resolution of the sensor.

Upland agriculture is confined mainly to plateau regions, gentle to moderate slopes, and is generally rain-fed.

5.2. FOREST

The forests are generally in a very poor, deteriorated condition. They are confined to the hills and some parts of the foot slopes. Forest plantations are to be found in the west of the catchment, on the Surya Hill Range.

Because of the soil conditions, the rugged terrain and climatic factors, only dry deciduous and thorn forests are found in the catchment. The forest area is considered to be very productive and cultivable for different forest species; however, most of the area is open forest. Effective plantation and afforestation measures, which would be economically beneficial, have not been undertaken.

5.3. WATER BODIES

The Karha River (perennial) is the only easily delineated river on the image. Other rivers and streams could only be identified as general location, by related relief and land use patterns.

The Malhar Sagar and Garode reservoirs can be seen easily. Throughout the catchment, numerous small reservoirs, part of many small irrigation projects, can be identified, but not named. The catchment has the capability to increase agricultural production through introduction of well, tank, filter and lift irrigation schemes.

5.4. URBAN SETTLEMENTS

Large towns such as Saswad and Jejuri were identifiable on the IRS imagery. Small villages and towns could not be mapped because of the limits of sensor resolution.

5.5. WASTELANDS

Land with/without scrub is defined as land that is prone to degradation, which may or may not have scrub cover (Manual of Wastelands, 1986). These areas have very thin soil cover, especially in the hilly regions, and are not capable of supporting much vegetation.

Degraded pasture lands are grazing lands that have become degraded due to overgrazing, or improperly managed soil conservation and drainage measures. These lands are generally confined to the hillocks, foot slopes and undulating uplands, and are mainly privately owned. Many areas suffer from severe soil erosion as a result of unsuitable farming methods.

The improvement of wastelands depends mainly on the reduction of crop farming on steep slopes and the extension of grassland cultivation, tree and forest crops. Suitable soil conservation, afforestation and cropping practices should be adopted. Contour or graded bunding, and other measures to reduce surface runoff, should be applied. Management practices such as grassland seeding, cultivation of fodder crops, bush control and rotational grazing are necessary in the pasture lands.

6. Conclusions

The raster-based GIS provides an easy method of integrating multi-temporal remotely-sensed data with thematic and topographic map data. Vector data are simply transformed to a grid cell by interpolation or polygon conversion. The resolution is limited only by satellite image sensor used. Once in raster form, per pixel logical operations are simple, and could almost be handled in a standard database.

This study has been limited to production of land-cover maps. Further work envisaged in this study is the introduction of rainfall estimates, soils and geology, transporation networks, and irrigability. Proposed applications include erosion risk mapping, land suitability and monitoring of the effects of catchment management policies.

This paper has demonstrated the applicability of GIS techniques in introducing local knowledge to the classification process. This introduction provides an extension to traditional methods of satellite-derived classification which should enable more relevant, and accurate, land use maps to be prepared.

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