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Technical Note

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING TECHNIQUES IN CATCHMENT LAND USE MANAGEMENT : A REVIEW

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ABSTRACT : GIS has significant potential as a tool to support catchment land use management. Remote sensing technique, on the other hand, with its cost-effective, repetitive and large area coverage in a digital format is becoming attractive for GIS data base development. The role of these techniques for catchment management are considered here with particular reference to the land use in catchment areas. A number of current applications in major fields namely hydrological modelling, environmental problems assessment, soil erosion assessment, land use modelling, and urban growth estimation are reviewed here. Each of the following research is briefly discussed and a number of general conclusions are drawn about the significance of GIS/RS in catchment land use management to enhance the future work.

INTRODUCTION

Catchment is a large area of diverse land use activities (such as agricultural, industrial and recreational). Many of the activities undertaken in catchment affect the land, forests of vegetation, rivers, water supply and other natural resources including wildlife. For instance, deforestation results from poor land management can lead to soil erosion, land degradation, salinity and the silting of water courses and estuaries etc.

The term land use refers to human activities associated with a specific parcel of land (Lindgren, 1985). According to Jackson (1981) land use includes everything land is used for by residents of the country, from farms to golf courses, houses to fast food establishment and hospital to graveyard.

Proper management of land resources is desirable for mandatory healthy economy and continuous development of living standard (Lindgren, 1985). Two important concepts should be taken into account

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for successful policies - one is highest and best use and the other is multiple use of land resources. Highest and best use refers to the tendency of landowners to allocate land in such a way that expected result can be achieved. Use of land for several purposes serves the second concept.

With the passage of time, demand for healthy, productive and stable environment has been a key issue to the community and an awareness of necessity and overall responsibility to act together has been raised so that the natural resources of the catchment are used wisely and remain for future generation. But, natural resources can not be managed in isolation. The impact of one land use over another and on the border environment should be considered. Therefore, integrated catchment management yields a more accurate means to natural resources planning and ecological sustainable development (Moore, 1990).

Earlier land use data have not been gathered in any uniform manner. The various agencies acquiring data have tended to work quite independently of one another. In turn, a series of collection methods is the result and data set can not be aggregated. Usually, maps for information on land use and land cover made by the interpretation of aerial photographs supported by ground surveys, were the primary source of input to management programs. Conventional survey and mapping method cannot deliver the necessary information in a timely and cost effective fashion (Wieslaw, 1993). Due to diversity and heterogeneity of the natural and human-altered landscape, it is obvious that this type of time-honoured and laborious method of ground inventory is not efficient for mapping land use and land cover over large areas (Civco, 1993). In regard to the need a new technique called GIS for spatial data processing and integration of remotely sensed information with other data sources can provide an invaluable approach in many different applications to decision maker (Trotter, 1991).

NATURE OF GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING

Of the many technological and conceptual approaches to spatial data analysis, GIS have been widely recognised and used as the most promising tool capable of providing reliable information both for planning and decision making tasks (Michalak, 1993). GIS can be described as a computer based integrated information systems, equipped with a set of capabilities, and designed to handle spatial data acquired at different scales and time, even different format (Raster & Vector) to assist decision making processes. The set of capabilities consists of data input (collection and storage), data management (retrieval, add, delete, transformation), manipulation and analysis, display or output generation (Aronoff 1989, Burrough 1986, Star and Estes 1990). A prime function of GIS is to provide the means whereby information from a number of themes can be merged to provide an appropriate product in response to a particular user-specified inquiry (Trotter, 1991). The inventory analysis and mapping capability of GIS have wide applications ranging from information retrieval, development control, mapping (Newton and Crawford, 1988; Zwart and Williamson, 1988), site selection (Dangermond, 1983; Smith and Robinson, 1983), land suitability analysis (Lyle and Stutz, 1987; McDonald and Brown, 1984) to project programming and monitoring (Marble and Amundson, 1988; Levine and Landis, 1989; Yeh, 1990). According to Aspinall much of the current discussion on GIS are from technical point of view rather than possible roles for GIS- based methodologies in science and society. An area in which GIS technology and associated methodologies have the potential to make an important impact is land use planning and more specifically in investigating the possible effects of implementation of policy (Worrall, 1989).

As an information system, GIS contains database. Data acquisition and integration is the most expensive and difficult component (Barker 1988, Trotter 1991). It has been estimated that upto 80% of time and costs involved in GIS are spent on database construction (Ehlers et al. 1991). Complex process of building databases called data conversion for GIS, generally consists of converting existing information (paper maps, records) to digital format that can be used directly by GIS. Figure 1 illustrates the data conversion process. GIS technology without a reliable database will not be a promising tool in decision making environment. In this regard, correct and appropriate data are the prerequisite for reliable data base.

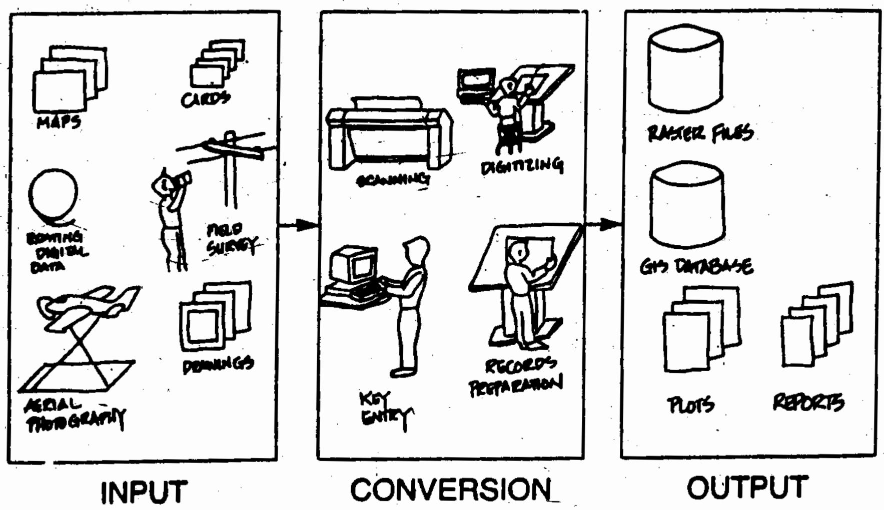

Fig 1. Major components of the data conversion process.

Data bases in GIS are arranged in different layers of data. Representative sample layers are shown in Fig. 2. Retrievals of different data layers can be executed easily and promptly. This capability enables different disciplines to share the data bases of GIS for various applications. Hence data base developed for a particular application should have wide range objective and ability to integrate other data bases and other GIS (Pathirana, 1992).

The data incorporated into a GIS can be in the form of historical, exiting maps and data bases and may occur in various form and format (raster and vector) (Star & Estes, 1990). As an integrated system, GIS is capable of multi-dimension data such as maps, report, aerial photo and satellite imagery.

It is impetrative in using GIS to know exactly the geographical location of a particular natural resource. In other words data incorporated into the GIS must have some characteristics namely geographic location, attribute, spatial relationship and time (Aronoff, 1989; Burrough 1987) For inaccessible locations, information of these locations can be acquired by remote sensing technology (air craft & satellite imagery). It serves as a spatial data source for GIS.

For any resource management, planning, or regional policy program, timely and accurate information on existing resources are inevitably necessary. To obtain current and reliable information conventional survey and mapping methods are not sufficient. Remote sensing with its systematic, repetitive coverage and capability to collect information in digital form over large areas at very high speed can mitigate the demand for current and accurate data (Michalak, 1993). Remotely sensed images are increasingly used as one of the major data sources specially land cover/land use change analysis.

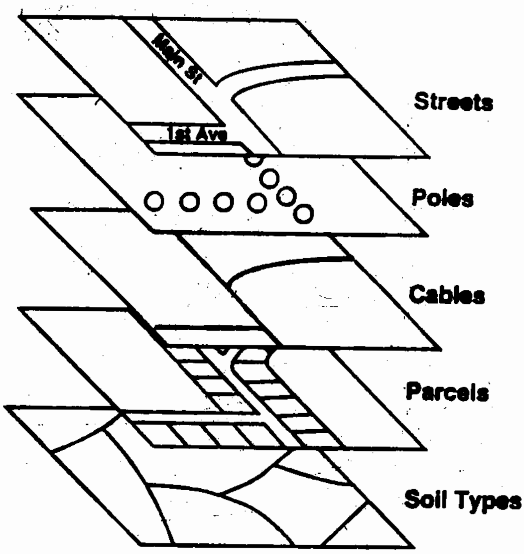

Fig 2. GIS data layers.

The integration of remote sensing information into a GIS occurs naturally in a raster GIS because both data structures are approximately same. Integration into a vector system requires somewhat more efforts, but several GIS and remote sensing vendors has achieved at least to the extent of updating vector information by using an image as a back drop for vector editing (ERDAS, 1989). Geometric correction and pattern recognition are the basic image processing and analysis tools. To preprocess remote sensing information into a form in which attributes are assigned to raster data instead of raw data values from spectral band of multi spectral imagery, these tools are expected to be available (Faust et al., 1991)

Once the remote sensing information is in a form that can be analysed as a part of GIS, system with both data representations apply a number of the same functions, even though they are implemented in a significantly different manner (Davis, 1991).

APPLICATION OF GIS AND RS IN CATCHMENT LAND USE STUDIES

Hydrological Model Development and Improvement

Hydrological modelling is a valuable tool for land and water resources planning. Application of GIS and RS in hydrological modelling provides more accurate and precious estimation of their responses for complex nature of the catchment. The following applications show how GIS and RS can be used to improve the hydrological models and hence their results.

Wolfe and Neale (1989) used GIS to assemble the data input system for a distributed parameter hydrologic model for a small watershed near Riesel, Texas. The particular system described here is Geographic Resources Analysis Support System (GRASS) applied to a distributed parameter model called Finite Element Storm Hydrograph Model (FESHM). The distributed parameter watershed models have great potential for application in land and water resources management and can help for further study of the effects of the land use changes at certain areas of the watershed. Preparation of data for distributed model requires large amount of time and this study exposes the fact that involvement of time in this regard can be reduced dramatically using GIS. Authors recommended that future additions will include programs to extract the information directly from GRASS files as well as the use of remotely sensed data to update watershed parameters. Planned updates of GRASS will offer features that will enhance integration of GRASS with distributed parameter watershed models. Recognising the potential of automating procedures and developing commands within the GIS environment which are tailored to watershed modelling, future research will enable to develop new models with improved accuracy and sophistication.

Berry and Sailor (1987) addressed the potential of GIS in predicting storm runoff for small urban watersheds in Connecticut, USA using US Soil Conservation Service (SCS) method under varying spatial conditions. Two cartographic models developed in this method were used to produce hydrographs and a comparison was done with actual storm data. GIS was employed in this research to examine the behaviour of the SCS method to determine runoff for different spatial conditions. The derived outcomes using GIS simulate the effects on runoff for several scenarios which would otherwise be more time consuming with conventional techniques. In addition to this advantage GIS yields more precise and accurate values of curve numbers for sub-catchments. Curve number is a SCS assigned factor for each of the various combinations of soil type and land use which typifies the runoff producing characteristics of soil-land use pair.

The study exhibits that the curve number estimated for entire area by manual technique was very similar to that calculated by the automated procedure. For sub-areas calculated curve numbers by hand showed quite different (17.1% maximum and average 9.6% from automated procedure but this deviation tend to compensate (4.6%) when the whole area was taken into consideration. It was found that SCS predicted peak discharge was always less than the observed discharge obtained by manual technique. On the contrary, application of GIS estimates more accurate and reasonable value in comparison with hand calculation.

The GIS application for the storm runoff prediction illustrates several advantages. This automated procedure facilitated to calculate more timely and accurate determination of curve numbers and showed more potential application to evaluate the proposed land use change effects under different conditions for exploratory analyses. It is evident that in addition to gain in speed and accuracy, GIS provides planners a powerful tool for expressing more complex spatial relationships of the earth surface.

Environmental Problems Assessment

Environment is dynamic by human and natural activities, hence requires a periodic monitoring. Problems associated with these activities are land degradation, land sliding, salinity, non-point pollution, urbanisation effects, flooding etc. According to Peirce (1980) storm run-off and combined sewer system are the most significant non-point pollution sources in urban areas. Proper identification and analysis of these sources can help decision makers to plan and manage development activities within the catchment area. Combined use of GIS and RS play a major role in the management of these resources.

Land use planners are often facing problems in assessing the existing extent and the future susceptibility of a region to land degradation. The effectiveness and usefulness of remote sensing in conjunction with GIS can solve this problems. Jayawardhana (1992) used this promising technology to assess the land degradation in a mountainous region of northern Thailand.

For this study, a land degradation susceptibility map was developed with the help of the integration of slope classes derived from Arc/Info digital terrain model to the land use/cover classes obtained from satellite imagery. Author also discovers that to overcome the problems associated with shadow areas and areas with spectral similarities, remote sensing approach was found not satisfactory. But use of GIS with RS exhibited effective and quick resolution of these problems associated with the assessment of land degradation susceptibility. The potential of remote sensing and GIS can enable to inform land managers about the susceptibility of land to future degradation. Detailed methodology for remote sensing/GIS integration, a demonstration of use of spatial models for spatial analysis that have been developed and documented in this study would help the researchers to explore new areas that need to be addressed.

In another study, in view of periodic monitoring of coastal environment in a lower catchment, a methodology based on using remote sensing and GIS was developed for coastal area of Red River plain by Remote Sensing Application Division, National Centre for Scientific Research, Vietnam (Luong, 1992). The main objectives of this study were to map and monitor various components that largely influence any coastal environment namely coastal land use, coastal processes and water quality.

The assessment of land use change accuracy exhibited that use of remote sensing and GIS for land use change detection gave satisfactory results (Maximum accuracy 94.5%, minimum accuracy 76.2%). The results for shore line study illustrated that shoreline change was a symbolic phenomenon from north to south. Historical maps were used to establish a shoreline change map of the area with some land marks using GIS and remote sensing that should be accepted for solving some practical and scientific problems related to coastal environment of Red River plain.

The monitoring of coastal environment is found to be practical and flexible and it can be applied suitably for various studies such as assessment of the coastal environment, its resources and their dynamics. The results obtained from this study could be used as a basis of application of new technology for the management of the lower coastal areas.

Potential use of Remote Sensing and GIS to monitor a saline discharge zone was evaluated by establishing a temporal spatially referenced data base for the area on a wheat/sheep property in south

Australia for the period 1966-1990 by Kirkby *et al.* (1992). Remotely sensed data (SPOT and aerial photography) were analysed within a Geographic Information System database to identify the dynamic relationship between changing vegetation cover and increasing salt levels on a saline ground water discharge area.

The study exhibits, conjugal action of remote sensing and GIS may be recongnised as a viable tool for future monitoring of dry land saline areas. A general indication of quantitative and directional change in the saline discharge area will benefit land managers at the regional scale by quantifying salinisation trends. The methodology used in this research is not site-specific and could be applied to other catchment areas. Future research with additional data layers such as digital elevation models (slope/aspect), soil, geology, ground water elevation maps to the GIS data base may help to identify the existence of ground water recharge zones.

For mapping of ground water recharge areas in a catchment a study was undertaken in the Victoria Highlands, Australia utilising an integrated GIS/Remote sensing approach (Hill, 1992). The main objectives of mapping were production of accurate classification (>80%) of recharge areas over sedimentary bedrock areas and application of this information for use in the implementation of the Avoca and Loddon salinity management plans. The study found that for both stratified and unstratified data, the forest areas were identified with 100% accuracy. However, for unstratified data sets the accuracy was 75% while for stratified data set it was 80.5%.

Soil Erosion Assessment : Soil erosion is a common natural problem of any catchment management which causes severe flooding, navigation problem and water quality degradation. Proper identification, quantification and rectification of this problem are a great concern for all groups associated with catchment management. GIS in connection with remote sensing can boost a dramatic improvement in this field.

To facilitate watershed management for the White Rock Creek Watershed in Dallas and plano, Texas a basin and soil erosion model was developed using Computer Aided Drafting and Design (CADD), Remote Sensing and GIS techniques (Joslin *et al.*, 1989). The vector based CADD and raster based image processing (IP) were combindly used in developing this resource assessments and environmental model. In connection with that, a software program STREAMS (Soil, Transport, Rainfall, Erosion and Mapping System) was developed by Halff Associates, Inc., Dallas, Texas to facilitate the transfer of data between computer system for the purpose of flood plain watershed management.

This study reveals the incorporation of remote sensing, image processing and GIS can perform a comprehensive watershed basin analysis with more accuracy and efficiency than in the past. The results of STREAMS research plan was successful to develop a marketable package for different agencies for soil conservation, stream and flood control management, and also proper design of reverine structures and reservoirs.

Land Use Modelling : For a wide variety of earth science and land use applications, GIS are becoming basic tools.

This article presents successful integration of GIS with Linear Programming (LP) for land-use modelling on the Mediterranean coast of Spain (Chuvieco, 1983). LP is not a spatial technique but can be used as a guide for integration of variables or for optimisation of spatial distribution. In land use planning, LP is used with an objective of minimising the unemployment rate in the area. To obtain the objective of the study, three sets of constraints were considered. These were ecological constrain to conserve at least 75% of the natural vegetation; technical constrain to locate the new land uses to the most suitable areas; and financial constrain to increase the public investment. In this study, the application of GIS in LP was found a fruitful and valuable tool for modelling land use. The developed model can be applied for different new scenarios by changing coefficients of the decision variables, either in objective functions or in the constraints.

Hence, modelling of land use applying LP and GIS technology may be a flexible tool for the generation of different planning scenarios and evaluation of the multiple relationships between the decision variables and the constraints.

Urban Growth Estimation : Rapid population growth within a catchment may experience strong competition for agricultural land and urban uses. Consequently improper conservation of natural resources is the result. Hence forth it is essential to estimate regional urban growth and its associated problems for better catchment management.

An attempt was made to estimate urban growth with time (from 1975 to 2025) in the south east of France. Here GIS and satellite imagery were used to calibrate and to constrain the numerical model describing the urban growth (Meaille and Wald, 1990). The predicted maps for the year 2000 and 2025 together with the initial map showed the changes in urbanised areas. It was emphasised that since these predicted maps were not analysed in terms of accuracy, they must not be considered for planning but their spatial patterns in growth were remarkable. The results of this work exhibited that increase of the urbanised area was greater between years 1985 and 2000 than between 2000 and 2025. It indicated that available space in coastal areas being decreased and that density of population being increased.

The scope of the study is mainly methodological and subsequent studies must be needed to evaluate the applicability and improvement of this model. Here social and economical parameters have not been considered. From a methodological point of view, more accurate simulation of regional urban growth would be possible by introducing these parameters. Also, high resolution sensor Landsat TM or SPOT data can be used as more appropriate data over MSS sensor for the evaluation of urban land use.

CONCLUSIONS

Estimation of runoff, prediction of changes in the vegetation pattern, linkage of Geographic Information System with various watershed models, monitoring of ecological changes, flood protection management etc. imply a wide variety of applications of integrated Geographic Information Systems and Remote Sensing to catchment management. All of these applications justify these technologies have a greater potential over traditional methods to analyse the complex environment of the nature. Several studies exhibit that use of Geographic Information Systems reduce time and increases efficiency. On the other hand remote sensing technique provides more accurate and upto date data which helps the system to cope with the real world conditions and also to examine more in depth analysis for the catchment management.

Several scopes exist for future work on catchment management by automating the system to collect data directly from remote sensing and analysing the complex environment by introducing more factors to derive accurate results using Geographic Information System. There is also a potential scope available for future problem prediction and accordingly helps the decision makers to take proper judgement in any development works in the catchment area.

Hence it is essential to explore the new ways in using Geographic Information System and remote sensing techniques which would enable the users for more critical analysis of proper planning and management.

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