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Development of Automated Watershed Prioritization Model Using Remote Sensing and GIS

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ABSTRACT

An automated model for watershed prioritization has been developed by the All India Soil and Land Use Survey. The model integrates ARC/INFO GIS software linked with INGRES Relational Data Base Management System (RDBMS) and ERDAS Digital Image Analysis System (DIAS). The application of the model in prioritization of Matatilla watershed of Lalitpur district, UP has been demonstrated.

Introduction

The rapid advancement of Remote Sensing Technology and Geographical Information System (GIS) has made it possible to automate the conventional approach of watershed prioritization. The remote sensing techniques have great potential because of wide synoptic view, multispectral and multitemporal capabilities, repetitiveness and computer compatibility (Das *et al.*, 1986; Saini *et al.*, 1987). Besides, remote sensing provides real time information that has enhanced the scope of automation in mapping the dynamic elements, such as land use and land cover, degradation profile and computing the priority categorization of subwatersheds on real time basis. This advancement in remote sensing technology and continuous inflow of satellite data have given necessary inputs and realization for periodic updating of the priority status of subwatersheds. After an in-depth system analysis of the conventional watershed prioritization approach the All India Soil and Land Use Survey (AISLUS) has successfully developed an automated model for watershed prioritization. An optimized revised watershed prioritization model has been developed with the help of ARC/INFO Geographical Information System (GIS) software linked with INGRES Relational Data Base Management System (RDBMS) and ERDAS Digital Image Analysis System (DIAS). The present paper describes the automated model and demonstrates its application in prioritization of the Matatilla catchment of Lalitpur District, U.P.

The Automated Watershed Prioritization Model

System environment

To deal with voluminous spatial and statistical data, a Remote Sensing Centre has been established at the Head Quarter of AISLUS with advanced computer system for development of Soil and Land Resource Information System (SLRIS). A SUN SPARC-10 workstation based computer system with ACR/INFO version 7.03, ERDAS IMAGINE version 8.2 and INGRES version 6.0 software packages has been installed for Geographic Information System (GIS, Digital Image Analysis System (DIAS) and Relational Data Base Management System (RDBMS), respectively. The SUNSPARC-10 workstation is the main server networked with four SUNSPARC-4 workstations and 4PC/ATs emulated for working in SUN Open Windows environment under SOLARIS 2.5 Operating System. Various peripherals viz., Electrostatic Plotter, Digitizer, Digital Scanner, Pen Plotter, Thermal Printer, Erasable Optical Disk Drive, Cipher and Cartridge Tape Drives are also networked with the system.

Soil and land resource information system

Soil and Land Resource Information System (SLRIS) has been developed by integrating Remote Sensing Techniques with ARC/INFO Geographical Information System (GIS), ERDAS/IMAGINE Digital Image Analysis System and INGRESS Relational Data Base Management System Software, on catchment basis. The computerized SLRIS allows soil and land resource data and related interpretative grouping to be edited, stored, analyzed, manipulated and presented in various formats quickly, accurately and in well defined exchangeable formats on electronic media amenable to computer processing and analysis unlike the conventional approach.

GIS data set development

The drainage network is taken from Survey of India (SOI) Toposheets on 1:50,000 scale for digitizing the drainage and for delineation of subwatershed boundaries. The digitized coverage were edited, edgematched, joined and attributed. Theoretically, it is possible to develop subwatershed boundaries from elevation data but the task is difficult to automate and is consequently more quickly and accurately performed by manual delineation of the boundary lines on mosaic drainage network.

The subwatershed boundary coverage is considered to be the master spatial data set. It is developed from topographic sheets by delineating hydrologic unit across the contours, the naturally occurring boundaries. The subwatershed boundary coverage is digitized and attributed using the ARC copycov command with the study area boundary coverage as a template, coverage PAT item names are copied into the new coverage. The subwatershed boundary coverage is used to "clip" the boundary of the other coverages so that significant silver polygons are not created in the overlay process.

The Erosion Intensity Mapping Unit (EIMU) is the foundation of the rapid reconnaissance survey methodology. It is landscape mapping unit consisting of slope, land use/land cover, soil texture, soil depth, soil erosion, surface condition land use and management practices. Based on estimation of combined contribution of different landscape observed in the field, each EIMU is assigned a weightage factor and delivery ratio to be used in the SYI model.

Development of slope maps was a major work in this project. Although slope data is labour intensive, but, it is the most vital layer in any land based study. The contour and drainage maps were traced on mylar sheets for scanning and vectorisation. Drainage lines were used as breaklines with contour data and spot elevations to create slope and aspect layers. These layers were developed for a part of Matatilla catchment with the expectation that they will be used at a later stage for the development of priority delineation model. Software tools in ARC/INFO were developed to assist in the generation of GIS data sets. The land use/land cover legend was modified to provide consistent inputs to both the land degradation model and the watershed prioritization model.

Sediment yield index (SYI) model

The SYI model is a function of the assigned Weightage Factors (WFs) and Delivery Ratios (Drs) for the EIMUs within each subwatershed as shown in equation (1).

$$SYI = \frac{\sum_{i=1}^{i=n} (Ai \times Wfi \times Dri)}{Asw} \times 100 \qquad (1)$$

Where,

n = number of EIMUs within a particular subwatershed

Ai = Area of the ith EIMU

Wfi = Weightage Factor of the ith EIMU

Dri = Delivery Ratio of the ith EIMU

Asw = Total area of the subwatershed

In an effort to reduce the subjectivity involved in assigning the weightage, the Wfs and Dri have been distributed among a number of controlling factors for each EIMU i.e. slope, land use/ land cover, soil texture, soil depth, soil erosion, surface condition and management practices.

A data structure in INGRES for handling the soil information has been designed and developed based on the information contained in survey reports. After removing inconsistencies in table and field nomenclature, the database was populated with available soil information for the study area. The linkages were then created between ARC/INFO coverages and the appropriate tables in the INGRES database. Algorithms were created for running the SYI model using ARC/INFO coverages with INGRES tables.

Model run

For the system to be scientifically robust, model runs were performed adjusting the Wfs and Dri until the results were consistent with field observations. Thus, watershed prioritization maps and tabular reports were created.

RDBMS data set development

An exhaustive database has been designed in INGRES with proper validation and joins definitions, which can accommodate all the data, contained in soil survey reports. The field survey data are entered into the customized INGRES database. All the EIMU and their associated soil and land use properties are entered into "mapunits" table. The reference tables of each parameter of EIMU are populated with the appropriate WFs and Dri. The INGRES table '1oc_mast_hu' contains a superset of all HU_ID and their associated rainfall intensity and drainage density values. These attributes are used in the calculation of Sediment Yield Index in the SYI Model.

SYI model programming structure

The SYI model has been programmed using ARC/INFO Macro language which employs various GIS Analysis techniques. There are 8 main routines in the SYI model programme designed to be run from the ARC or ARCPLOT prompt. Cursor to ARC/INFO coverage are called cursors, while cursors to INGRES tables are called dbms cursors.

(i) Routine SET RELATES command connects ARC/INFO *coverages to INGRES database. This* procedure checks for the presence of HU_ID and MU_ID item names in the attribute tables of subwatershed and EIMU coverage respectively. Next, the relates are set between coverage PAT and four crucial INGRES tables viz., priority syiwf, syidr and loc_mast_hu.

(ii) Routine PRIME TABLES creates a temporary table in INGRS from the ARC/INFO of the overlay coverage pat. Then it clears the previous contents of INGRES table priority. Then it extracts unique MU_IDs from the coverage, places them into table priority, clears the previous contents of tables syiwf and syidr, extracts unique MU_IDs from coverage Pat and places them into tables syiwf and syidr.

(iii) Routine FILL_TABLES sets dbms cursors cur_mu_wf to syiwf, cur_mu_dr to syidr and cur_mu_ref to map units tables. Next, all the record in table map units containing map units equal to *MU_ID in table syiwf are selected. Program* GET_FACTOR is then called for calculating Wfs and Dri (Weightage factors and delivery ratios) for slope, land use, depth, texture, erosion, surf_cond and management for each EIMUs, by opening dbms cursors to appropriate EIMU factor reference table, performing the appropriate mathematical calculations, and placing the result in syiwf and syidr tables. The process is repeated for each MU_ID in table syiwf.

(iv) Routine CALC_AGGR calculates the aggregates WF and DR for each of the MU_ID *within each HU_ID.*

(v) Routine CALC_SYI calculates the enhanced SYI for each HU_ID. In the case of calculating DR-final for the SYI, drainage density and rainfall intensity are referenced from table locmast_hu. CALC_SYI also fills up the total area and syi columns of priority table.

(vi) Routine ANALYZE analyze the syi values statistically and transforms them into natural logarithmic domain to make the value distribution closer to "Normal distribution"

(vii) Routine CATEGORY categories the aggregate SYI values into five priority categories based on ranges of SYI values defined for each category.

A generalized Output Module DOMAP has been developed which can prepare a map composition with proper scale, legend, map and annotations with input from any user-selected ARC, POLYGON *or* POINT *coverage. Arcs,* Arclines, polygon-lines, polygon-shades and markers etc. are plotted depending on type of coverage with color symbols defined with user selected INFO items. Proper legend with user defined keys are also included.

Use of Automated Model in Prioritization of Matatilla Watershed in U.P.

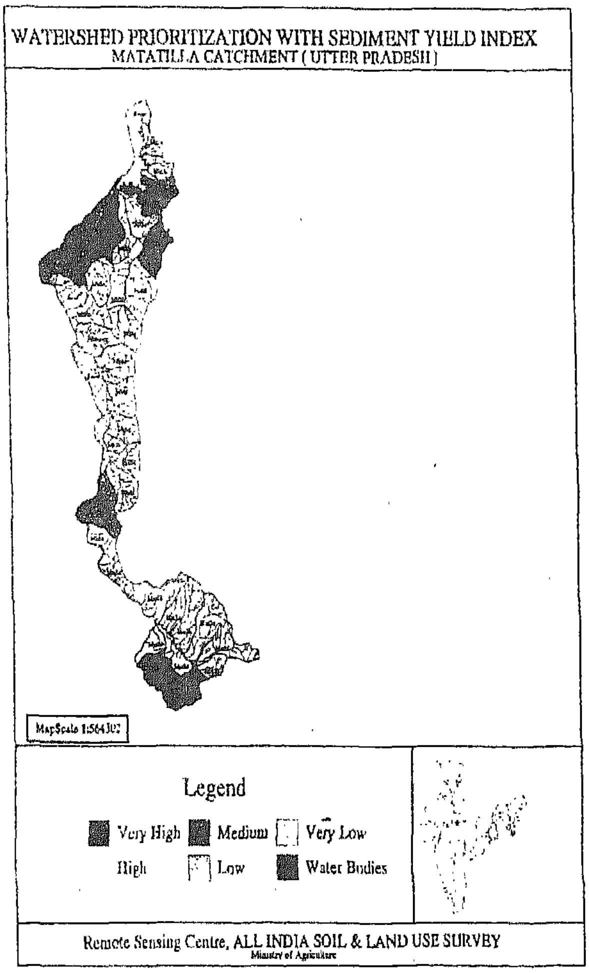
Study area

Matatilla catchment drained by river Betwa has a total area of 20.48 lakh ha of which about 1.0 lakh ha falls in U.P, which was taken in the present study. The study area lies between 24-15' - 25-16' North latitude and 78-10-78-30' East longitude forming a part of Lalitpur District, U.P. The area is characterized by hills, subdued hillocks, valleys and undulating pedeplain. Sandstone, granite and granite gneiss are major geological formations of the area. The climate of the area is semi arid to sub-humid with an average precipitation of 1000 mm (AISLUS, 1977).

Materials and Methods

The false color composites (FCC) on 1: 50,000 pertaining to the area were used for visual interpretation. Multidate IRS-IB, LISS-II FCC were interpreted visually with the aid of Survey of India toposheets for extracting information on physiography, soils land use/land cover, land degradation and slope-class. On the basis of image interpretation key and limited ground checks, a legend was framed to delineate Erosion Intensity Mapping Units (EIMU). The methodology developed by AISLUS (1991) was followed.

The drainage, subwatershed and EIMU maps were digitized. The data sets were processed for error correction and composite map was generated. The drainage network and subwatersheds of Matatilla RVP catchment and the union of EIMU were put together. The SYI model was applied to individual subwatershed to obtain the sediment yield indices. Results of 36 subwatersheds were worked out. Thus, the results, obtained are shown in fig.-1.



Updating of priority status

Subwatershed is the lowest hydrological unit ranging from 2,000 to 5,000 hactares in size in the prioritization model, which is viable for management purposes. Greater speed and less subjectivity in the watershed prioritization system are possible using 'automated' inputs derived form digital image analysis. Since few parameters related to soil can be derived from digital image analysis, field survey and laboratory analysis of field data will continue to be needed as inputs to GIS data sets for soil erosion modeling in the subsequent watershed prioritization and updating the priority status.

Conclusion

The results achieved with the completion of a part of the project are very significant as this technology can now be applied in other survey areas effectively and efficiently, with few more refinements. The results can be gainfully utilised for resource allocation for effective planning and development. This technology will also generate more accurate and comprehensive basic data on soil and resource management and will assist in more efficient and effective identification and monitoring of the status of degraded lands and erosion prone subwatersheds for their reclamation and management.

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