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Decision Support System for Sustainable Development of a Watersheds Using Remote Sensing and GIS

Engineering

KEYWORDS :

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ABSTRACT

The global awareness regarding the over-exploitation of the limited resources, at the expense of causing severe damage to the ecological system and environmental degradation resulted in evolving methodologies for optimum land and water utilization. This necessitates an integrated approach for the optimal development of available resources minimizing hazards to environment. Uniqueness of a watershed in its characteristics as well as problems, the interrelated nature of land and water resources invariably call for the integrated development of the total resources available in a sustainable manner with watershed as a basic hydrological unit for development planning. This leads to the need for a decision support system, which would assist the land user/decision maker for optimum utilization of resources in the watershed. This research focuses on developing a Knowledge based decision support system for agricultural land use development of a small watershed. Essentially, the DSS consists of three main components viz., database, model base and knowledge base. The database contains all the data required for the model base and the physical features of the watershed, which has been compiled from various sources. The model base required for effective watershed development is composed of models for rainfall-runoff, crop-land suitability assessment, soil erosion assessment and crop-water requirement. The knowledge base is developed from the results of the model base by utilizing the database. GIS technology, which provides a powerful set of tools for handling spatial and non-spatial data, is employed for the above modeling approaches.

Review of Literature

In recent years, computer modelling has gained wide spread acceptance as a cost-effective tool in determining the probable impacts of alternative management strategies and farming systems on water quality. Numerous lumped and distributed parameter H/WQ models, including ***CREAMS (Knisel. 1980), ANSWERS (Beasley and Huggms, 1982), AGNPS (Young et al., 1987) and SWRRB-WQ (Arnold et al.,1990)*** have been developed to predict the impacts of agriculture practices on the quality of surface water. Recent studies ***(Rose et a!., 1990; Oliver and Solomonn, 1990; Tim and Jolly, 1994; Corwin and Wagenet, 1996)*** provide excellent overviews of the state of hydrology and water quality modelling.

The spatio-temporal variability in landscape characteristics including soil, land use, topography and climate affect the hydrologic response of the physical system and severely limit the applicability of models ***(Tim and Jolly, 1994; Corwin and Wagenet, 1996).*** Hence, for the assessment of non-point source pollution, multidisciplinary approach involving remote sensing, GIS and simulation model is required. A recent and emerging technology represented by geographic information systems (GIS) provide the tools to generate, manipulate and spatially organize disparate data for distributed modelling. Interfacing remote sensing derived digital thematic maps with other relevant maps through GIS thus provides a powerful mechanism for the analysis of remote sensing based information in conjunction with other environmental variables or thematic layers in the geographic database. It also allows for rapid updating of the geographic database, thus making the GIS a functional and flexible environmental assessment tool. For assessing the non point source pollution, quantitative assessment of hydrological parameters of watershed such as peak flow rate, sediment production rate and volume of runoff is necessary and these are basic information for soil and water conservation measures in a watershed. Satellite imagery has been widely used in the fields of agriculture, forestry, watershed management, hydrologic modelling ***(Wischmeier and Smith, 1978; Ragan and Jackson, 1980; Short. 1982; Marble ct til., 1983: Burrough, 1986; Jensen, 1986; Porwal and Pant, 1989; Terry, 1990; Tiwari et al, 1991; Baxter and Needham, 1993; Mitchell etal., 1993; Reusing et al., 2000).***

DESCRIPTION OF THE STUDY AREA

Location and Extent of the Study Area

The proposed study area is located between Bayad Taluka of Sabarkantha district and Kapadwanj Taluka of Kheda district ***(Fig.1).*** It is lying between 23° 23' 00" (23.23 in decimal degrees) and 23°02'00" (23.03) north latitude, and 73°14'00" (73.23) and 73°04'30" (73.075) east longitude, covering a total area of 57565 ha. The study area falls in Survey of India (SOI) Topographical map No. 46-E / 04, 46-E / 07 and 46-E / 08.

Climate

The study area falls in the hot arid/semi arid regions of Western India and experiences hot summer during March to middle of June. The max dry temperature ranges from between 42° to 45°. The region encompassing three distinct seasons namely winter, summer and monsoon. The winter season starts in November and lasts till the end of February. The summer season begins in March and lasts till mid June The monsoon sets in by mid June and continues till mid November. The temperature increases from January onwards and reaches max in May and then starts falling. The wind direction is predominantly North East during November to March. During May and the first week of June, the winds have westerly component. With the onset of monsoon, South west winds are strong and are humid with relative humidity more than 60 %.

Physiography

The physiography of the study area is gently sloping pediments to gently sloping alluvial plains. The area has normal relief and the general slope of the area is Northeast to Southwest.

Agriculture and Cropping Pattern

The region is mostly dominated by tribal population. In this region, agriculture has remained backward for a long time. Tribal communities, who till a few decades ago, were mainly dependent on forests for their livelihood dominate the region also practiced subsistence agriculture. Their main crops were Bajra and Jowar in the rainy season and Maize, Grams and Tuwar in winter

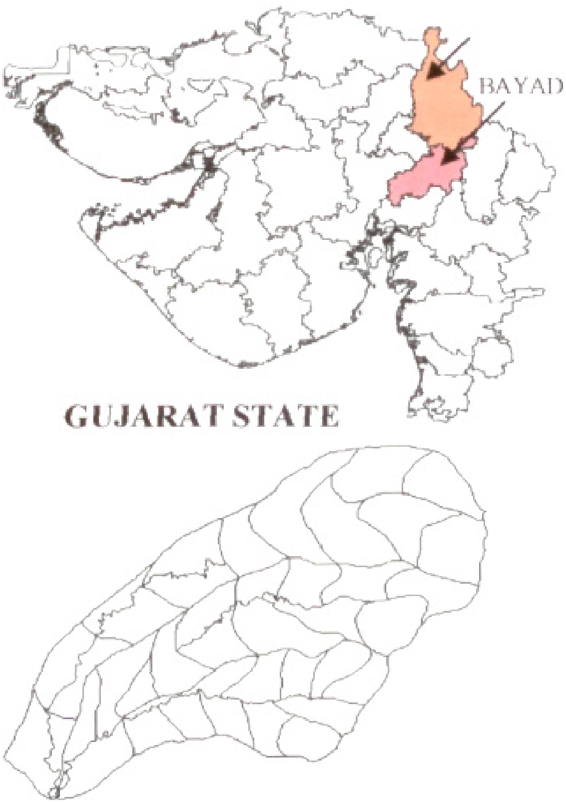

Fig. 1: Study Area

Irrigation Facilities
Though well irrigation has a long history in the region, the extent of irrigation was very low. Energisation of wells was at a very slow pace due to poor socio-economic conditions. Though energisation of wells had helped increase the intensity of cropping in the region, due to poor yield of wells, the dug wells go dry by the onset of summer and irrigation is limited to mainly winter. The farmers in the area grow irrigated crops such as castor and wheat and fodder crops

Geology
The region mainly consists of quartzite of Alwar series of Delhi System and Phyllite, slate, schists, quartzite etc. of Aravalli system. These rocks are foliated in nature except quartzite, which is blocky and hard due to the hard rocks, recharge from rainfall and groundwater storage potential in this area is very poor.

Soils
The soils of Gujarat show much diversity and can broadly be classified into the following five orders: Entisols; Inceptisols; Vertisols; Andisols; Alfisols. Out of these, Inceptisols are found in the study area.These have formed over basaltic, granitic, gneissic and alluvial parents occur on gentle to moderate and steep pediments, in sloping isolated plateaus, valley bottoms and moderately sloping interfluves. These are dark gray to light gray, reddish-brown, yellowish red, and dark reddish brown in colour and are products of weathering under tropical semi-arid to humid climates with annual precipitation of 500 to 2000 mm. Inceptisols are generally calcareous in nature and vary in depth from 30 cm. to 80 cm Texturally the soils are silty-loam to clay and are neutral to alkaline in reaction. Ustochrepts, Helaguepts and Haplaquepts are the main taxonomic soils of this order.

Livestock Resources
The livestock population in the region comprises cows, bullocks, buffaloes, sheep, goats and camels. Cows, buffaloes and camels are treated as large livestock and the rest are small the livestock owner normally provides water to large animals either in the home or the animals are taken to the farm wells. It is normally the livestock rearing community, namely “Rabari”, which maintain large herds of sheep and goat growing deterioration of water availability situation, is also found to be affecting livestock population.

DATA COLLECTION
Satellite Data
Satellite images of the proposed study area are required to be collected in an effort to select the best data for the purpose of LU/LC classification. It is proposed to use the False Colour Composites (FCC) of IRS-IC PAN + LISS-ffl merged geocoded products on 1:25,000 scale for classification of various themes.

Non-Spatial Data (Rainfall Data)
Daily rainfall data of the Kapadwanj and Bayad rain gauge stations for 20 years in mm would be collected from State Water Data Center (SWDC), Gandhinagar.

RAINFALL ANALYSIS
The statistical analysis of rainfall for the available data of 20 years would be performed to compute the weekly distribution of rainfall, determination of crop growth period, probabilities for consecutive dry spells for assessing drought severities etc.

METHODOLOGY
Database Development for the model
The GIS database would be created for the watershed focusing on attributes and data necessary to run the model. The major elements of the watershed database include topography, hydrography, soil, land cover, land management and climate. The best site specific resolution would be chosen to facilitate the subdivision of watershed into grid cells, which are basic operational units for model. This decision would result in the creation of grid cells for the watershed. The model would specific that only those cells that have 50% or more of the area in the watershed should be used. All encoded digital data, coverage, and model variables in the GIS would be spatially organized with the same resolution and coordinate system. Activities would be undertaken to acquire data and establish the watershed GIS to assist in are described below.

Topography
The topography affects the runoff characteristics and transport processes of sediment and nutrients, which are to be simulated for each cell. The model would take care of topography, by considering aspect and slope in percentage for each cell. Land slope coverage, aspect coverage and curvature (slope/shape factor) coverage of the study area are planned to be generated using ARC-INFO GIS.

Soils
The soil coverage collected from the Soil Conservation Department of Government of Gujarat would be digitized. Soil erodibility index (K) of USLE and hydrologic soil groups are the model parameters, which are associated with GIS Polygons of the soil coverage. The hydrologic soil group is necessary for calculating SCS runoff curve number. Reclassification of soil coverage with values for these parameters would result in input parameter layers for the model.

Land Use
Several of the proposed model inputs such as SCS curve number, Manning’s roughness coefficient, USLE cover (C) factor, USLE support practice (P) factor, surface condition constant, fertilization level, and fertilization availability factor would be derived from the grided land cover and land management data. Remote sensing data would be used for digital classification of land and water resources of the study area. Digital interpretation of the satellite imagery would be carried out using ERDAS-IMAGINE digital image processing software.

Field investigation
Some factors such as gully erosion amount, impoundment factor, channel slope and channel side slope are best determined in the field. These factors are point source indicators, which allow the addition of known point sources to a cell and can only be found

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through field investigation. However, channel side slope and slope shape would be assigned global default values based on general field observations. Sensitivity analysis has shown that these parameters have little influence on model output.

Management

The USLE cropping factor (C), USLE practice factor (P), the fertilizer amount and incorporation per cent are related to agricultural management practices, and hence are available only through interviews with farmers in the watershed. However reasonable factors can be assigned representing baseline conditions or a planning scenario. The other model parameters are obtained either from published data or available watershed records. Some of the standard variables for the required parameters would be obtained from model's user guide.

Estimation of Runoff

The volume of runoff for different rainfall events would be computed for each cell using the GIS modelled SCS curve number technique. Composite curve number would be generated cell wise for land use delineation definable from satellite data. For the other years of study, composite curve number would be derived from land use/cover map collected from the Soil Conservation Department of the Gujarat state. The improvements in the model results in case of remote sensing based approach may be because of modifications in the curve number and other parameters related with land use/ cover which are derived from remote sensing data, where much of spatial variability is considered.

Estimation of Sediment Load

Similarly, sediment loading would be modelled for different rainfall events data sets, which are used for runoff estimation, would be adopted. The output of the simulations would be effectively used to pinpoint critical areas within the watershed where control measures could be used best to reduce the input of potential pollutants to the trout stream. As the measured values are available for runoff and sediment yield and not for nutrient (pollutant) concentrations, only the runoff and sediment yield would be validated.

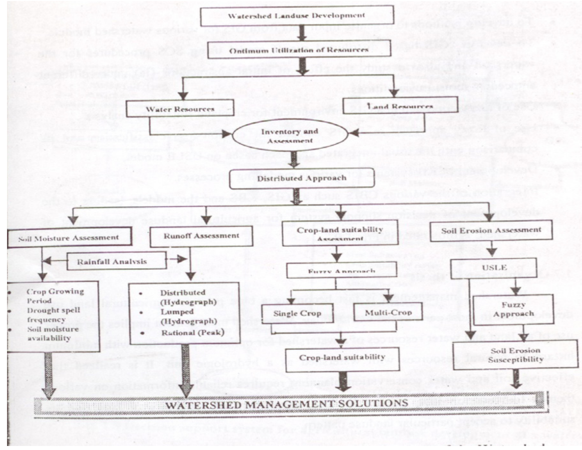
Estimation of Nitrogen and Phosphorus Load

Further analysis is planned to carry out for transport of pollutants such as N and P for the study area. The estimates on N and P loads would be discussed with respect to their expected temporal and spatial terms following their application in the watershed. The methods used to predict N and P yield from watershed would be adopted as reported by Frere *et al.,* (1980).

Development of Knowledge Based System

The structure of a knowledge based Decision Support System for Agricultural Landuse development of a small watershed in a dry climatic region of Gujarat with erratic rainfall distribution is presented in Fig. 2. This essentially incorporates the information from various models such as runoff, erosion, cropland suitability etc. Integration of GIS, KBS and the models, leading to the development of decision support system for agricultural land use development of the watershed is presented in Fig. 3.

Fig 2. <u>The Proposed Approach for Agricultural land use</u>



<u>Development of a Watershed</u>

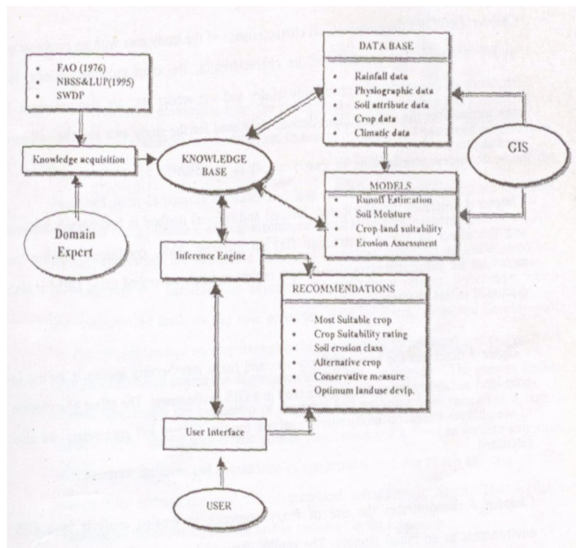


Fig 3. Decision Support System for Agricultural Land use Development of a Watershed

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