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Delineation of Watersheds in Plain Areas

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Abstract: Watershed is the basic planning unit for rural development in India. In this paper an Analytical Hierarchy Process (AHP) and multi-objective programming are integrated with Geographical Information System (GIS) to develop a decision support system for the delineation of watersheds in plain areas/zone of internal drainage frequently encountered in the Indian arid zone. The resultant technique settles the conflicts arising out of areas related to more than one drainage or more than one watersheds for the same outlet. This allows decision-maker's involvement and has application for similar scenario having many objectives and alternatives to be handled simultaneously.

Key words: Analytical hierarchy process, multi-objective programming, conjunctive use, decision support system, GIS.

About 148,000 km^2 area in the states of Rajasthan and Gujarat, within the Indian arid zone, have no integrated stream network in the conventional sense, i.e., a zone of internal drainage (Sharma, 1999). Rather, there is a system of repetitive micro-hydrology. A large-scale surface hydrology is active only during extreme events. A multidisciplinary approach is required for sustainability of such systems, which calls for the use of Geographical Information System (GIS). A GIS is suited for continual updating and rapid re-computation of alternatives as is typically required for water resource projects (Waranic and Haness, 1994).

Multi-objective Decision Support Systems (DSS) in water resources management include implicit preference functions by decision-makers with interactive multi-objective analysis (Duckstein and Opricovic, 1980). Integrating technologies to support the multi-objective analysis in the form of a rule-based expert system to facilitate and improve the choice of multi-objective programming, weights are assigned (Simonovic *et al.*, 1995). To make this operation as objective as possible, an Analytical Hierarchy Process (AHP) is being used as a tool for addressing the complex technical issues such as conflicts arising out of areas related to more than one watershed for the same outlet. Further, interpolation of elevation information and delineation of watersheds using Digital Elevation Model (DEM) has much significance in flat terrain as small deviation, on relative scale, may have larger effect on flat slope compared to the steeper slopes. This study aims at delineation of watersheds

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in plain areas. For this purpose the plain area between the Mithri and the Luni River (Sharma, 1997) has been selected. The objective of study is to develop a framework for general application and to test its functionality using the selected case study.

Methodology

In the delineation of watershed, it is necessary to assign some areas, which have relationships with more than one river, to only one of them. Application of each of the physical criterion, such as surface drainage, flooding areas, village boundary, etc., leads to a different solution. The best criterion to use in delineation of watersheds in plain areas was found through:

- Generation of DEM for the study area and delineation of the part of a river basin.
- Defining the outlets.
- Preparation of thematic maps.
- Scheme finalized for weights to be assigned for the defined areas.
- Modified AHP applied.
- Overlaying thematic maps and decision-maker's preferences under GIS environment.
- Delineation of watersheds having outlet defined by user.

The complex physical problem of delineation of watersheds in plain areas was studied through the use of physical criterion. For each of them a thematic map, describing the relationship between each part of the territory and the river they could belong to, was developed. Afterwards, weighting coefficients were applied to the different areas in order to quantify these relations. For example, if an area is flooded by the Mithri River during ordinary floods, but damaged by the Luni River only in case of extraordinary floods, it is clear that this area has a closer relationship with the Mithri than with the Luni. Therefore, the weight of the former must be higher than that assigned to the latter. Weighting coefficients depend on the physical criterion applied. For the case study the following alternatives were used:

- Alternative 1 = possible assignment to the Mithri watershed; and
- Alternative 2 = possible assignment to the Luni watershed.

The physical criteria are shown in Table 1. For each of these criterion a thematic map was prepared and weights were applied. Overlying the thematic maps, with the use of a GIS, it was possible to obtain 'elementary areas' with homogenous weights.

Selection of Weights

Criterion for the strongest area-outlet relationship was searched for. Weights were assigned according to the importance of the criterion decided by the decision-makers. The AHP was used as a tool for such assignment. The AHP is based on representing a decision-making problem as hierarchical structure of activities and objectives. Each objective is compared with all possible alternatives and preference is given on AHP scale, as shown in Table 2. The combination of different weighting processes for each physical criterion provides relationship between polygons having same weights or small units having relationship with that of the outlet. Thereafter,

Table 1. Application of physical criteria to case study

Criteria	Description	
Technical	Surface Drainage	Natural Artificial
	Flooding areas	With embankments Without embankments
	Water utilization	Irrigation Water supply
Administrative	'Weak'	Regional limits State limits Land reclamation Irrigation district
	'Strong'	Village boundary

multi-objective analysis for technical and administrative criteria was performed using different ranking methods.

Ranking Method for Technical Criterion

Ranking method, applied for the technical criterion, is based on a multi-objective analysis technique called compromise programming. This technique uses the measure of distance, Ls (j), from the ideal solution. The best compromising solution corresponds to the minimum distance from the ideal point, i.e.,

$$L^*s = \min [Ls (j)]$$

Degree of belonging to particular outlet, I_p, is determined by:

$$I_p = 1 - \frac{L^*max - L' s}{L^*max - L^*s}$$

where,
L^*s= the minimum of Ls; L′s = the second best Ls; and L*max = the maximum value of Ls (j).

Derived index viz., degrees of belonging to outlet are then grouped into graduations by defining the interval in GIS for display. Thus, the resulting map showing the division among areas associated with different outlets are called watersheds.

Ranking Method for Administrative Criterion

The intervening criterion is the aggregation of watershed within one administrative unit. The average value replaces the calculated measure of distance from the ideal solution, i.e., the Ls belonging to the same unit. Ranking method applied for such criterion is:

$$L''s\ (j) = \sum \frac{L's \times A(j)}{A_{tot}}$$

where,
A(j) = surface of each single 'elementary area'; A_{tot} = summation of A (j) within administrative unit; L′s = input value for measure of distance from ideal solution; and L″s (j)= output value for the measure of distance from the ideal solution. The administrative criterion forces the 'elementary areas' within territorial units to be reunified.