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Identification of potential water harvesting sites using GIS & remote sensing technologies: a case study of Sadiyagad watershed, central Himalaya, India

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Abstract
The identification of water resources and its proper management practices are very essential with respect to the population growth and their increasing needs. Geographical Information Systems (GIS) and Remote Sensing (RS) are powerful tools to manage and analyze spatially distributed information. ArcView, a powerful desktop GIS to visualize, update, analyze geographic information, and create quality presentations that brings the power of interactive mapping and analysis, was used in the present study. An attempt was made for the identification of potential water harvesting sites which can fulfil both the drinking and irrigation needs of the population living in the Sadiyagad watershed.

The GIS and Remote Sensing techniques provided the base information on the land-cover and land use maps, the pattern and placement of villages, forest, agricultural land and road network. Using an elevation contour map prepared in ArcInfo (version 3.4); a Digital Elevation Model (DEM) was prepared in ArcView (version 3.0) on a desktop computer system. From the DEM model we have developed models for Flow Direction, Flow Accumulation, Stream Channels and finally Unique Basins to split the whole watershed into 9 basins. Spring criteria and stream criteria maps were developed using the land use and infrastructure maps to reach our final target of finding the suitable sites for the construction of storage tanks. In all 40 sites were identified which could be developed for harvesting runoff water for the purpose of irrigation and other domestic uses. Out of these, 21 sites are within 100m from the road and easily accessible; about 50Km^2 area can be irrigated within 1/2km distance from these potential sources in the Sadiyagad watershed.

INTRODUCTION

Geographical Information Systems (GIS) and Remote Sensing (RS) are powerful tools to manage and analyze spatially distributed information. Their ability to assimilate data from widely divergent sources, to analyze trends over time, and to spatially evaluate potential environmental impacts caused by development form the basis of information source in developing countries. RS and GIS techniques are being effectively used in recent times as tools in determining the quantitative description of basin geometry *i.e*., morphometric analysis including stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio and elongation ratio and prioritization of sub watershed (Biswas *et al*., 1999). Arc/Info and ArcView GIS tools along with remotely sensed data proved their ability in delineating the alluvial plain, flood plain, in filled valley and deeply buried pediplain which are the prospective zones of ground water exploration and development (Jain, 1998). These techniques are also useful in monitoring the crop acreage and irrigation water requirements vis-à-vis irrigation water supplies which is important to obtain a realistic view of the 'irrigation potential' and 'potential utilized'. Satellite data provides information on crop area and thereby net irrigation water requirements of crops (Hariprasad *et al*., 1996). GIS has been providing a valuable information on land use land cover changes analysis in relation to elevation, slope, aspect and bio-climatic classes and also the identification of suitable land for agriculture (Ghosh *et al*., 1996). Studies on applicability of GIS and RS techniques for watershed management was attempted in Sikkim (Krishna, 1996). Water resource is the most abundant yet ironically also most elusive commodity in Himalaya. Its sustained perennial supply is directly correlated to prosperity in hill economy. However, the population growth, changes in land use patterns and environmental degradation has raised serious concern regarding status of water resource in Himalaya. Population in Hindu Kush Himalaya (HKH) has doubled during last four decades and expected to follow similar trend in future too, raising newer demands. The depleting vegetation cover on mountain slopes can affect infiltration rate of precipitation and may adversely affect ground water recharge. Natural springs and other ground water reserves are the major source of drinking water in the villages, where about 87% population resides in the HKH region. Rivers and streams are useful sources for irrigation of agricultural land, but unfortunately very poorly tapped in the region despite a high degree of scope. More recently, various international assistance programs using modern tools and approaches have focussed attention on some of these potential sites to tap water at macro level. However, the traditional management of water based on diverse sources and diverse needs are highly significant in mountains. For instance, it provides over 90% irrigation in hills of Nepal. In the present study we made an attempt to identify the potential water harvesting sites using the GIS and Remote Sensing, in a representative watershed of central Himalaya with the following objectives:

Identification of water potential source in Sadiyagad watershed: The objective was selected because there is an acute shortage of water in the area. About 99% of the agriculture area depend on rainfall. The existing ground water sources and springs are barely sufficient to meet the drinking water needs and the requirement of livestock.

Locating suitable sites for constructing water storage tanks: The villages in Sadiyagad watershed are scattered. Terrace farming is the traditional pattern of agriculture lands. The runoff water is lost along the drainage channels without much use. Identification of suitable sites along these channels can be useful for harvesting water for irrigation purposes.

STUDY AREA

Sadiyagad watershed lies between $29^0$20'22": $29^0$35'18" N and $79^0$50'33": $81^0$01'00' E in Almora district of Uttar Pradesh in Central Himalaya. It is situated about 50km on the north east of district headquarter Almora and spreading over 79.33km^2. The elevation gradients in the watershed ranges from 700 to 2100m above the mean sea level. The undulating topography, uneven slope, deep valleys, uplands and series of ridges makes it unique in its form. The watershed includes 47 revenue villages at different elevations having total population of 14,479 and the population density is 183 per square kilometer. The web of several small perennial and seasonal streams spread over the whole watershed where Sadiyagad the main perennial water source flows from west to east. It originates from the Dhauladevi and joins in the Panar River near Sindiyakhet.

The watershed falls within the sub-tropical climate in lower valley and sub-temperate climate in the higher elevations. The watershed vegetation represents sub-tropical zone and is characterized by mixed forests dominated by pine (*Pinus roxburghii*) and Oak (*Quercus leucotrichophora*), Deodar (*Cedrus deodara*) and Sal (*Shorea robusta*) as associated species at different altitudes (Singh and Singh, 1987). Agriculture is completely dependent on southwest monsoon rains from June-September. Apart form an additional short winter spell (Dec-Jan), the region experiences a rather long dry period. Sadiyagad is receiving an annual average rainfall of 114.26 cm and the mean monthly temperatures are varying between 9.65^0C - 25.16^0C during 1998. Since 1997 the highest and the lowest temperatures observed are 35.5^0C and -0.5^0C, respectively. Out of the watershed area of $79.33km^2$, agriculture (including settled) area constitutes 62.89% in 1996 and 46.44% during 1963. The agriculture extension is predominantly found between 1000 to 1700m elevations. Irrigation facilities do exist only in the lower elevations near the junction of the Sadiyagad with Panar River. Remaining agriculture terraces are dry, sloppy and scattered over the upper zones of the watershed. These areas need water harvesting through construction of check dams or storage tanks along the stream sources.

METHODOLOGY

Spatial Criteria used

Derivation of watershed model (Unique Basin) from the Digital Elevation Model (DEM). The area needed to be classified into smaller basins for better understanding of appropriate drainage pattern.

Identification of maximum water accumulation sites within each sub catchment. This is expected to provide water harvest sites for construction of storage dams from where adjoining agriculture areas in each basin can be irrigated.

A distance ranging between 500 to 1000 meter has been taken as criteria to select two successive water storage tanks.

Identification of existing spring sources and their separation from the road network: The information is further useful to asses water capabilities for drinking and livestock use, and provides information regarding deficit areas where drinking water sources are presently lacking.

Data used and generated

The following available data has been used in the present study:

Topographic sheet 53 O/14, 53 O/15, 62 C/2 with scale 1:50,000.
FCC-IRS1C LISS-III Band - 2,3,4 dated 17th November 1996.
Drainage map (perennial & seasonal).
Land use map.

The following maps were generated in the present GIS analysis to achieve the aforesaid objectives using ArcView (3.0) software:

An elevation contour point map was digitized from the topographic map.

Digital Elevation Model (DEM) was prepared using digitized elevation contour point map.

Using Map Calculator we calculated the Flow Direction and Flow Accumulation using the filled DEM.

Using Map Query, Flow Accumulation >10000 was calculated.

Stream order (Strahler) and Steam Ids. were calculated using Map Calculator.

Unique Basin model was prepared using flow direction and Stream Ids. In all 9 major sub catchments were identified in the study area.

Agriculture and settlement map was generated from the existing landuse map and the same was buffered with a distance of 500m.

Available spring sources were plotted using Infrastructure map, and half a kilometer buffer zone was created for the spring source map. The infrastructure features were identified within the half a kilometer (500m) range on the buffered spring source map.

After reclassifying the unique Basin map in to two classes *i.e.*, 0-No data and 1-1, separate maps were generated for each individual basin (Basin1-9).

Each basin map was multiplied with Accumulation > 10000 map to obtain the water source in that basin.

Less than 500m buffer zone was identified from the water source of the basin to estimate the water source and command area of the individual basin.

Water deficit area in each basin was obtained from the product of water source and command area and the spring distance maps using Map Calculator.

Irrigation potential of each basin was calculated by multiplying Water Source and Command Area and Agriculture & Settlement maps.

The flow chart illustrates the aforesaid methodology to achieve the objectives (Figure 1).

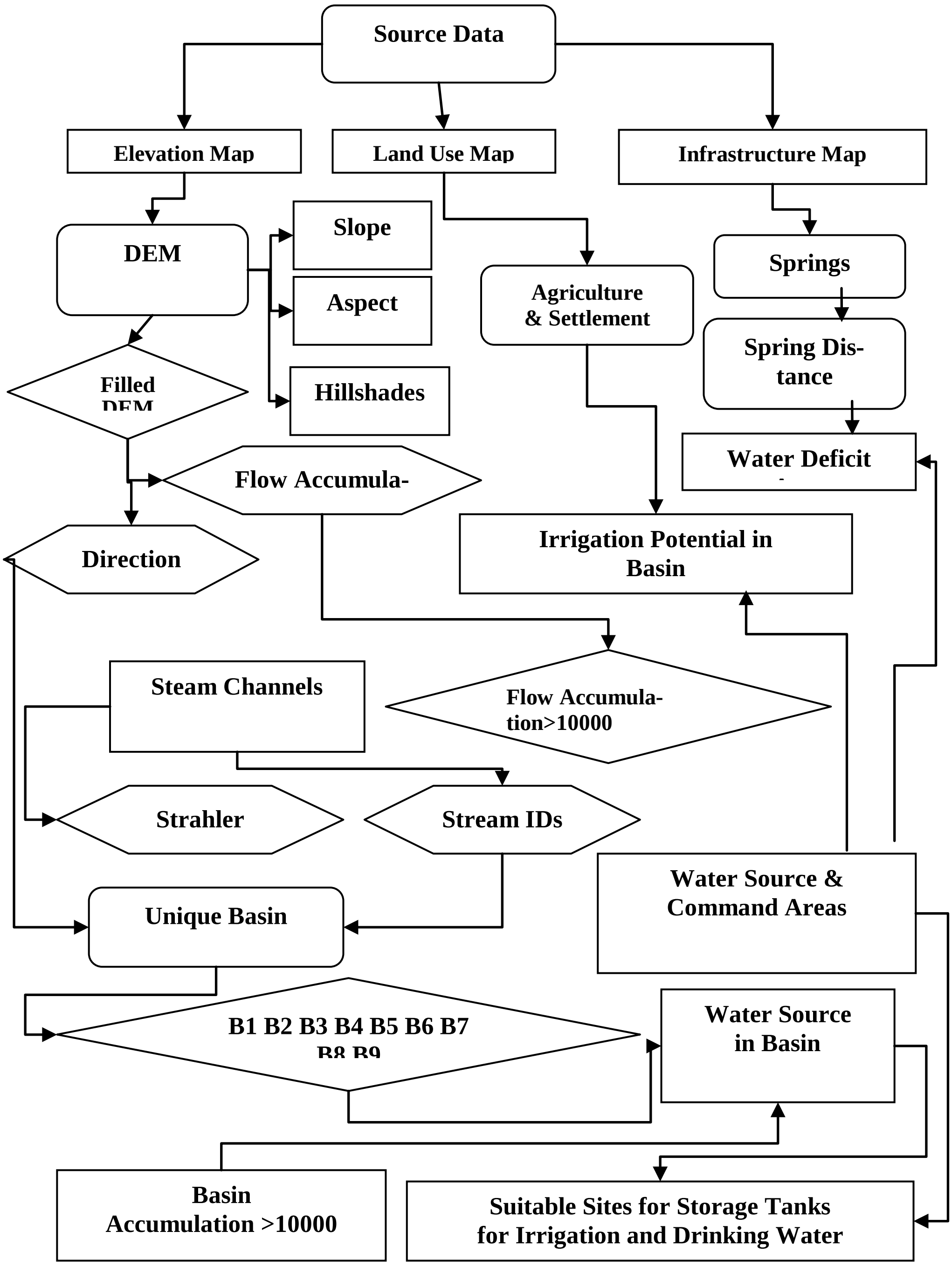

Figure 1. Flowchart illustrating the methodology.

RESULTS

The entire watershed area is segregated into nine sub-units, termed as basins or catchments, based on the criteria of elevation, slope, aspect, stream channels, flow direction, *etc*. Potential water sources along the perennial stream sources in each basin were identified (Figure 2) on the basis of water accumulation (accumulation no.>10000). A total of 40 suitable potential water accumulation sites were identified in the 9 basins (Table 1). Basin 6 and 7 having the highest number of potential water accumulation sites of 12 and 11 respectively; are largest in area as well. Basin 3 and 8 having the lowest number of potential water accumulation sites (one each). The basin no.9, which is at S-W direction, doesn't have any suitable site for water harvesting.

Table 1. Sub basins, their area (km^2) and the number of potential water harvesting sites in Sadiyagad watershed.

Basin No.	Basin Area in km^2	Number of potential water harvesting sites
01	9.46	03
02	7.79	04
03	4.11	01
04	2.87	06
05	1.68	02
06	25.17	12
07	21.54	11
08	0.02	01
09	4.04	00

All the identified potential water accumulation sites are not found within a close proximity to road for easier accessibility (Figure 3). Therefore we have generated a map which depicted potential water accumulation sources located within 100m distance from the road. It is envisaged that such locations are convenient for routine fetching of water for domestic and livestock use. Basin 6, despite having largest number of potential water accumulation sites, has only three potential sources within the stipulated distance criteria in comparison to the 4 with 9 potential sites, and basin 1 with 7 sites. Further, some of the potential water accumulation sites at the peripheral margin of a basin can serve as source to the adjoining basins. Depending on the existing spring sources as well as the identified potential water accumulation along the stream source we presumed they will be able to cater only up to 1/2km from the source and assessed the alternate areas within this region (Figure 4). The over lay of existing and proposed water harvest sites are used to calculate the total feeding capacity in terms of area; some of these represented common intersection areas (Figure 5). These sources are expected to cater to the need of about 50.06km^2 area out of 79.33km^2 of total watershed area.

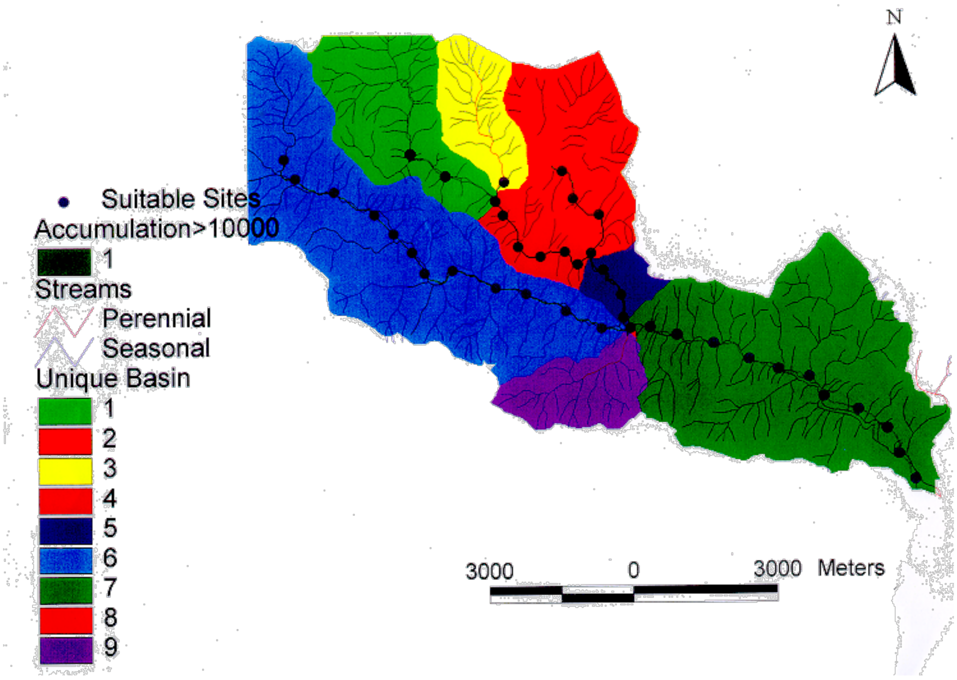

Figure 2. Suitable sites for the construction of storage tanks/check dams for irrigation along the perennial water sources in Sadiyagad watershed.

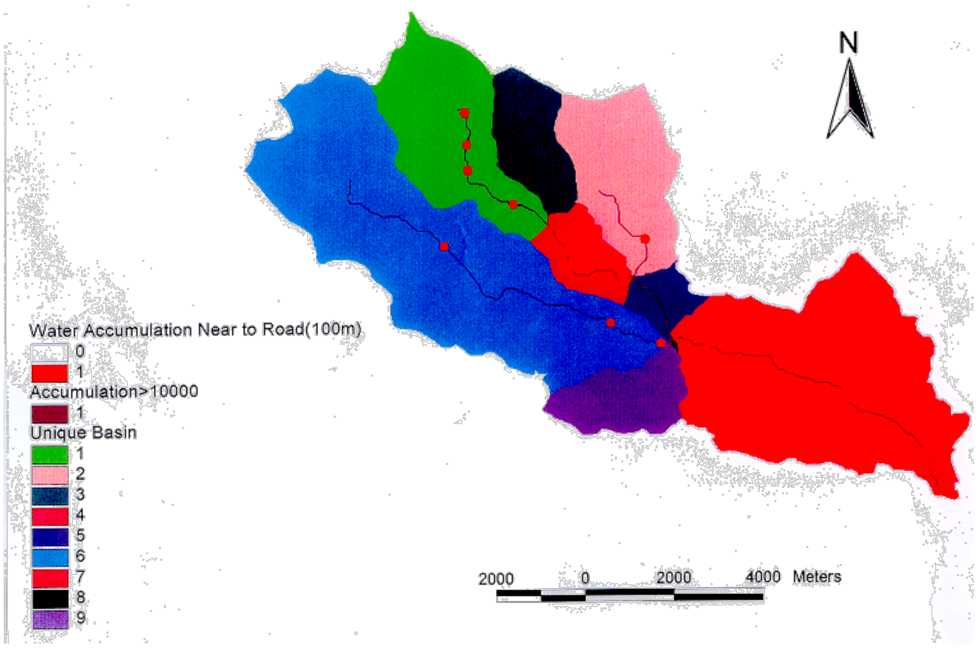

Figure 3. Water source accumulation and suitable storage sites (100m away from road) in sub-catchment of Sadiyagad watershed.

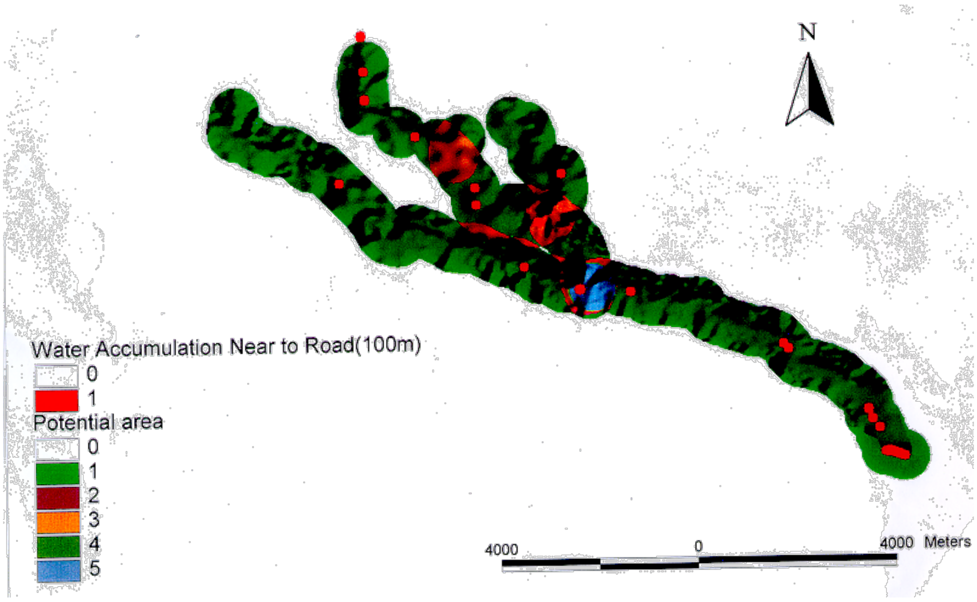

Figure 4. Landuse in 500m buffer zone along the streams in Sadiyagad watershed where irrgation could be used in agriculture fields.

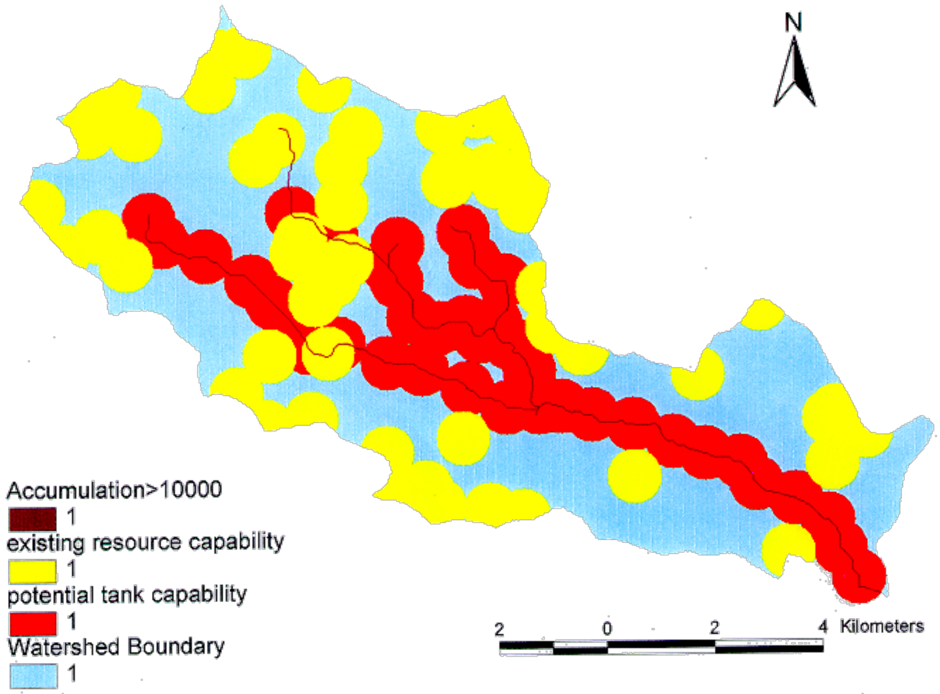

Figure 5. Estimated potential area (500 m around the sources) where drinking water facilities and irrigation potential could be developed in Sadiyagad Watershed.

DISCUSSION AND CONCLUSIONS

In Himalayas, steep slope causes high runoff of the rainwater which is eventually lost down the stream. It could be useful to tap this water at some higher elevation for either irrigating the terraces or meet other domestic needs. The GIS and Remote Sensing techniques provided the base information on the land-cover and land use maps, the pattern and placement of villages, forest, agricultural land and road network. The elicitation of drainage map and water accumulation capacity at different locations laid emphasis on identifying suitable sites for water harvest. Information on spatial criteria was useful to locate the two successive sites, and to further identify closer proximity of some of these sites from road for convenient routine harvesting. This information is required to be strengthened by adequate field studies and on site observation.

The 40 sites identified in the present study could be developed for harvesting runoff water for the purpose of irrigation and other uses. Out of these 21 sites lie within 100m from the road head and easily accessible. About 50.06km^2 area that can irrigate half a kilometer distance from potential water harvesting source inside the Sadiyagad watershed is identified.

Application of GIS technology for hydrological modelling is still restricted to research labs and projects of academic value only (Meijerink *et al*., 1994). Their application in development plans and projects is almost unheard in developing countries such as India. Another major problem is lack of data, inaccessibility of data when available as it is not available in digital form or official regulations. Under such extreme irregularity of data availability, putting the technology to practical uses are difficult. Though the area was part of world bank sponsored Integrated Watershed Development programme the digital data availability and its use during this programme was observed to be negligible. Even the usefulness of present model and prospective sites short listed for water harvesting could not be verified for their authenticity for want of relevant information on water requirements, existing irrigation structures, actual volume of water accumulations *etc*. However, potentials of water harvesting are already well documented for the region (Kothyari *et al*., 1991; Dhruva Narayana *et al*., 1990) interms increasing agricultural and plantation productivity.

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