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A GIS-Based Approach for Identifying Potential Runoff Harvesting Sites in the Bhavani Watershed, Tamilnadu, India

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ABSTRACT

In this study, potential runoff generating sites, and thus priority areas for runoff harvesting, in a small rural community at Bhavani basin, Tamilnadu, India are identified with the use of Remote Sensing (RS) and Geographic Information Systems (GIS). Adopted criteria for selecting potential runoff generating sites, and thus priority areas are watershed characteristics, soil suitability, slope suitability, land use, and harvesting potential for the upstream catchment and socio-economic parameters such as distance from croplands and settlements. The potential runoff generating sites for a given rainfall event over the basin are identified using Soil Conservation Service Curve Number (SCS-CN). Output of this study, is presented using 'suitability maps'. The 'suitability maps' for locating priority sites for runoff harvesting, helps to reduce the extent of the area to be investigated for effective runoff harvesting, by identifying specific areas that are potential sites for runoff harvesting, and which can then be verified in the field.

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INTRODUCTION

In recent days Tamilnadu in general is facing water shortage for irrigation, domestic and industrial purposes. In this regard the ground water plays a vital role in overcoming this shortage. Since, the over exploitation of ground water without proper recharge mechanism and scanty rainfall, the water table of the open or dug wells in the region are being gone into deeper parts of the surface and many a times even some of them were dried up. This problem has been further compounded due to large-scale urbanization and growth of mega cities, which has drastically reduced open lands for natural recharge. In order to improve the ground water situation it is necessary to artificially recharge the depleted ground water resources.

The study identifies priority areas for runoff harvesting in the rural watershed with the use of Remote Sensing (RS) and Geographic Information Systems (GIS). For small watersheds, the Soil Conservation Service Curve Number (SCS-CN) (Mishra and Singh, 2003) method is the most widely used technique for estimating surface runoff for a given rainfall event. It considers the relationship between land cover and hydrologic soil group, which together make up the curve number. A curve number

is used to ascertain how much rainfall infiltrates into soil and how much rainfall becomes surface runoff.

In this study, potential runoff generating sites, and thus priority areas for runoff harvesting, in a small rural community at Bhavani basin, Tamilnadu, India are identified with the use of RS and GIS. Adopted criteria for selecting potential runoff generating sites, and thus priority areas are watershed characteristics, soil suitability, slope suitability, land use, and harvesting potential for the upstream catchment and socio-economic parameters such as distance from croplands and settlements. The potential runoff generating sites for a given rainfall event over the basin are identified using SCS Curve Number.

Output of this study, is presented using 'suitability maps'. The 'suitability maps' for locating priority sites for runoff harvesting, helps to reduce the extent of the area to be investigated for effective runoff harvesting, by identifying specific areas that are potential sites for runoff harvesting, and which can then be verified in the field. Providing an accurate spatial representation of the runoff generation potential within a watershed is an important factor in developing a strategic runoff harvesting plan for any water scarce rural watershed. The use of GIS approach to facilitate this process

improves the accuracy level for locating suitable areas for runoff harvesting in view of the GIS capability to utilize spatial information in an integrative manner and spatially displaying it through maps.

Study Area:

Bhavani drainage basin is important in terms of agriculture which covers cultivated area of 3246 km².

In this basin, river Bhavani, a tributary of River Cauvery, flows and forms the major source of irrigation. Bhavanisagar dam is located on the river Bhavani and the dam is used to divert water to the lower Bhavani Project. Location of the study area in Cauvery basin within Tamil Nadu is depicted in Fig 1.

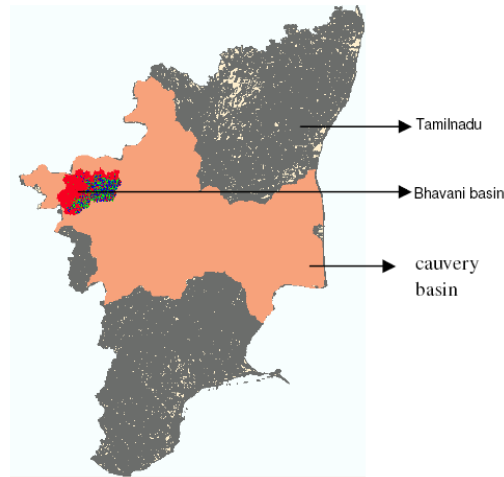


Fig. 1: Location of Bhavani Sub Basin in Cauvery River Basin, Tamil Nadu, India

The Bhavanisagar Dam and Reservoir, also called Lower Bhavani Dam, is located on the Bhavani River between Mettupalayam and Sathyamangalam in Erode District, Tamil Nadu, South India. The dam is considered to be among the biggest earthen dams in the country. Bhavani Sagar dam is constructed on Bhavani River, which is merely under the union of Moyar River.

The total Bhavani drainage basin length is about 3500 km long perennial river fed mostly by the

southwest monsoon and supplemented by the northeast monsoon. Its watershed drains (Fig 2) an area of 6,840 km² spread over Tamil Nadu (87%), Kerala (9%) and Karnataka (4%). The main river courses through entire of the North-Western Erode district of Tamil Nadu. About 90 per cent of the river's water is used for agriculture irrigation. 6 million people live along its banks.

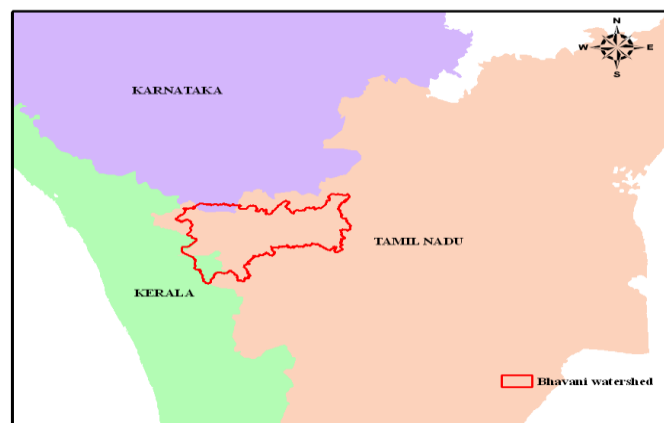


Fig. 2: Location of Bhavani Watershed

The study identifies priority areas for runoff harvesting in the rural watershed with the use of RS and GIS. For small watersheds, the Soil Conservation Service Curve Number (SCS-CN)

method is the most widely used technique for estimating surface runoff for a given rainfall event.

- With the help of RS and GIS to produce curve number and runoff maps with the help of

ArcCN-Runoff tool (Zhan and Huang, 2004) available in ArcGIS (ESRI, 2001; Gangodagamage and Clarke, 2001).

- Slope map of the basin were derived from the Digital Elevation Model (DEM), along with the SCS curve number are used to determine the runoff potential.

- Locating priority areas for runoff harvesting is based on the physically derived potential runoff map as well as the socio-economic factors such as distance to croplands and land use and land cover pattern.

- Thus, through GIS analysis, potential runoff harvesting sites are identified in relation to the areas that concentrate runoff and where the stored water will be appropriately distributed.

There are many studies and that have been carried out to estimate groundwater recharge locally and worldwide. Sharma and Kujur (2012) applied RS and GIS for potential recharge zone over Gola Block, Ramgarh district, Jharkhand, India. This paper aims to establish basic information for site selection of artificial recharge structures to the aquifer systems by preparing various thematic maps which have been prepared on visual interpretation techniques using the RS data with the help of GIS techniques and topographic information. Nag and Lahiri (2011) adopted coupled R S and GIS technique to come out as an efficient tool in delineating drainage pattern and water resource management and its planning. Winnaar *et al.* (2007) identified potential runoff harvesting sites in the Thukela River basin, South Africa. In this paper the representation of spatial variations in landscape characteristics such as soil, land use, rainfall and slope information is shown to be an important step in identifying potential runoff harvesting sites. Sreedev *et al.* (2005) studied the drainage characteristics of Pageru River basin is a chronically drought prone area of the Rayalaseema region, Cuddapah district, Andhra Pradesh, India. In this paper an attempt has been made to study the drainage characteristics of the basin by analysing the topographical maps and land-sat imageries. Waikar and Nilawar (2014) applied RS and GIS technique for locating potential groundwater recharge zone over Penganga river basin, Parbhani district, Maharashtra. Their study reveals that integration of six thematic maps such as drainage density, slope, geology, geomorphology, lineament density and land use/land cover gives first hand information to local authorities and planners about the areas suitable for groundwater exploration.

Methodology:

The representation of spatial variations in land surface characteristics such as soil, land use, land cover aerial images, soil survey using aerial images and the Advanced Space borne Thermal Emission

and Reflection Radiometer (ASTER) and slope information is shown to be an important step in identifying potential runoff harvesting sites. With the help of drainage map obtained from Public Works Department (PWD) the digitization of drainage network is done. The drainage basin parameters are categorized to find the stream order. Stream Order is the first step in drainage basin analysis and expresses the hierarchical relationship between stream segments, their connectivity and the discharge arising from contributing catchments. The numbers of stream segments present in each order are counted and it is observed that the number of stream segments decreases as the stream order increases.

The aerial images are obtained from the LANDSAT programs. The Land sat Program is a series of Earth-observing satellite missions jointly managed by NASA. LANDSAT satellites have collected information about Earth from space. LANDSAT satellites have taken specialized digital images of Earth's continents and surrounding coastal regions for over four decades, enabling people to study many aspects of our planet and to evaluate the dynamic changes caused by both natural processes and human practices. From the aerial images the Land Use Land Cover (LULC) classifications are obtained to identify the type of usages of lands in that area, so that we can identify Distance to crop and Distance to home can be determined.

From the aerial images the soil surveys are done and by using these various surveys the information about the soils in these areas are collected. The soils are grouped according to its hydrological properties, The Soil Conservation Services (SCS) method is the most widely used technique for estimating surface runoff for a given rainfall event from small catchments. The SCS method considers the relationship of land cover and hydrologic soil group, which together make up the curve number

Slope map is created from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), a Digital Elevation Model (DEM) of 30 m accuracy. ASTER is one of the sensor systems on-board Terra a satellite. ASTER monitors cloud cover, glaciers, land temperature, land use, natural disasters, sea ice, snow cover and vegetation patterns at a spatial resolution of 90 to 15 meters. The multispectral images obtained from this sensor have 14 different colors, which allow scientists to interpret wavelengths that cannot be seen by the human eye, such as near infrared, short wave infrared and thermal infrared. The term digital elevation model or DEM is frequently used to refer to any digital representation of a topographic surface however; most often it is used to refer specifically to a raster or regular grid of spot heights. A slope map is created from the

DEM. From the SCS number calculated and from the slope map the run off potential map is obtained. Figure 3 shows the major steps taken to process the collected datasets and generate useful output in the

form of runoff potential and suitable runoff harvesting areas using GIS platform.

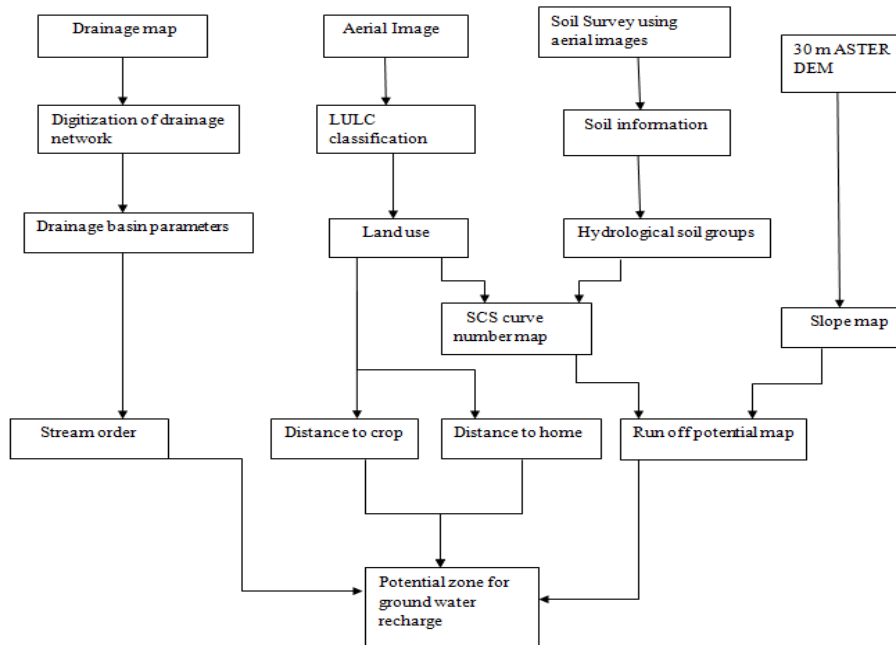


Fig. 3: Flow chart of methodology for deriving suitable runoff harvesting sites

Drainage network:

This study is undertaken to determine the morphometric characteristics of Bhavani River basin using drainage maps on a scale of 1:50,000. The total area of the Bhavani River basin is 6840 km². It is divided into III sub-basins for analysis. The quantitative analysis of various aspects of river basin drainage network characteristics reveals complex morphometric attributes.

Stream Order:

In the drainage basin analysis the first step is to determine the stream orders and is based on a

hierarchic ranking of streams. In the present study, the stream segments of the drainage basin have been ranked according to Strahler's stream ordering system. According to Strahler, 1964, the smallest fingertip tributaries are designated as order 1, where two first-order streams join, a channel segment of order 2 is formed; where two segments of order 2 join, a segment of order 3 is formed; and so on. The trunk stream through which all discharged of water and sediment passes is therefore the stream segment of the highest order. The study area belongs to the 6th order drainage basin (Fig 5).

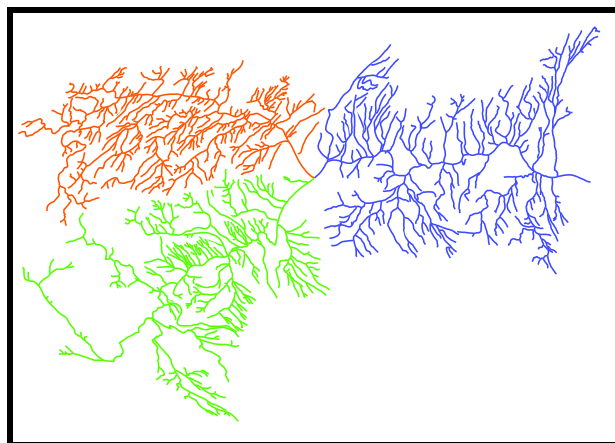


Fig. 4: Bhavani Drainage Network

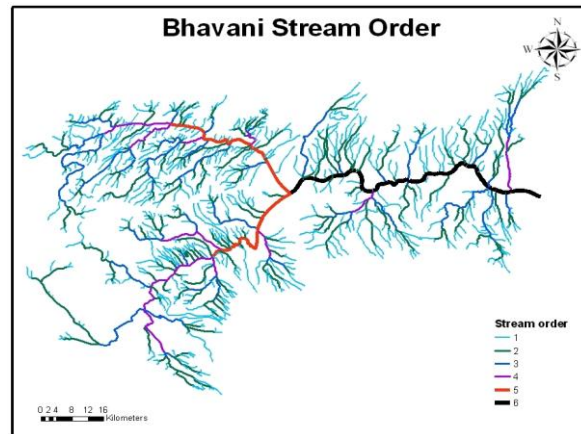


Fig. 5: Bhavani Stream order

Relief:

Basin relief is an important factor in understanding the denudation characteristics (the denudation landforms are formed as a result of active processes of weathering, mass wasting and erosion caused by different exogenesis geomorphic agents such as water, glaciers, wind etc., the landforms formed by the agents of denudation are identified as pediments, Pedi plains etc.) of the basin. Relief is the difference between the maximum and minimum elevations in the basin. The maximum height of the Bhavani River basin is 2633 m and the lowest is 154 m (Fig. 6).

Land use map:

Land use is one of the important parameter for deciding the suitability of the land for recharging. A barren land is more suitable for recharging, when the other parameters are similar. The land use map was obtained from LISS III satellite imagery corresponding to the year 2002 and updated with Google Earth. Using the GIS software ArcGIS, the satellite image was processed and classified using supervised classification method. From the classified image, the land use map was extracted. The land use map of the basin is shown in Fig.7.

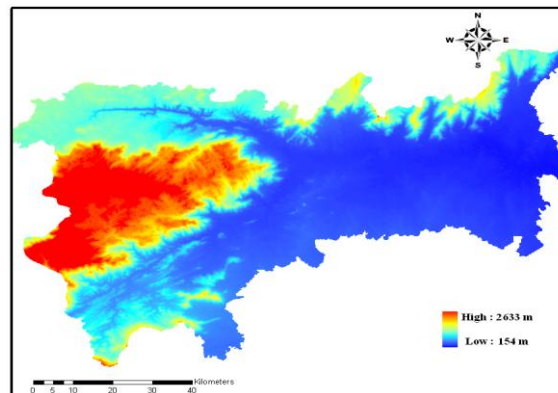


Fig. 6: Relief of the Basin

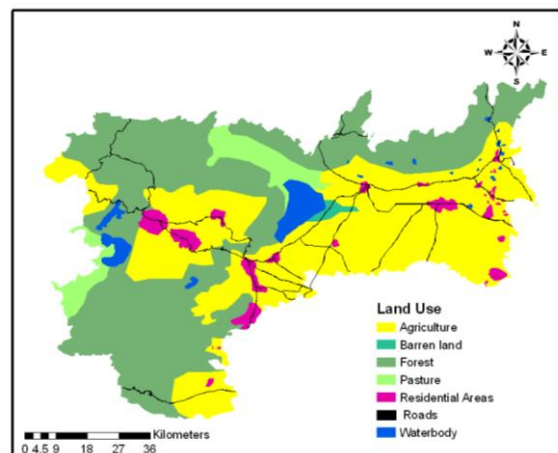


Fig. 7: Land Use Map

Above Fig. 7 shows the land use land cover map of Bhavani basin. This map shows that the Bhavani basin is covered with agriculture and forest. Land use is a description of how people utilize the land and socio-economic activity - urban and agricultural land uses are two of the most commonly known land use classes. At any one point or place, there may be multiple and alternate land uses, the specification of which may have a political dimension.

Hydrologic soil group:

Hydrological soil groups (HSG) of the basin is determined on the basis of information from NBSSLUP map. It is evident from the Fig. 8 that the region predominantly comprises of HSG B (about 40%) and C (about 60%).

SCS Curve Number:

In this study takes help from GIS to produce curve number and runoff maps with the help of ArcCN-Runoff (Zhan and Huang, 2004), a runoff tool available in ArcGIS. In ArcCN-Runoff tool, soil and land data are processed through the following three steps: (1) Soil and land use data for the

watershed are clipped using a polygon feature such as the watershed boundary layer (2) Processing time is reduced by dissolving the soil and land use layers before intersection, based on the attributes 'hydrogroup' in soil and 'covername' in land use, (3) Soil and land use layers are intersected to generate new and smaller polygons associated with soil 'hydrogroup' and land use 'covername'. This step keeps all the details of the spatial variation of soil and land use, and can be taken to be more exact than using any average method to determine curve number (6). Employing the ArcCN-Runoff tool, the curve number for each polygon was determined from the soil and land use data for the Bhavani Basin.

The curve number is an index expressing a basin runoff potential zone to a rainfall event (Schulze *et al.*, 1992) and therefore indicates the proportion of rainwater that contributes to surface runoff. For Bhavani watershed curve numbers vary from 0 to 98 where greater curve numbers represent a greater proportion of surface runoff (Stuebe and Johnston, 1990; Schulze *et al.*, 1992). A map giving spatial variation of the curve number was generated as shown in Fig. 9.

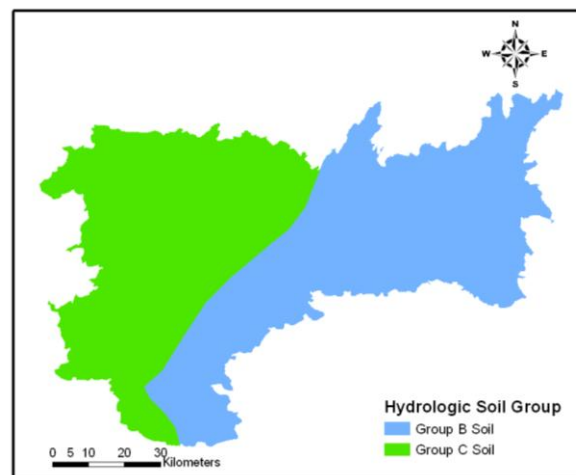


Fig. 8: Hydrologic Soil Group Map

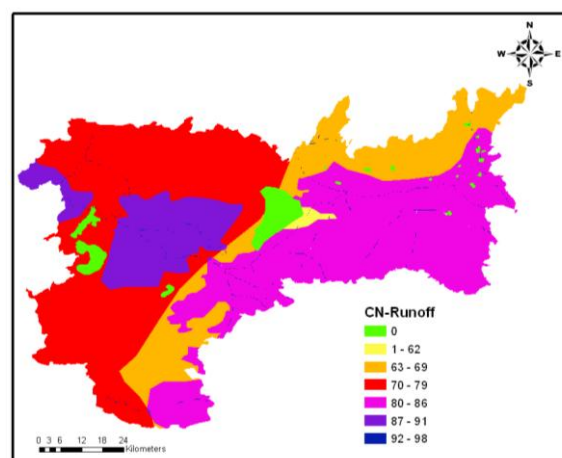


Fig. 9: CN-Runoff Number

Distances from homesteads and crop fields:

The homesteads and crop grids were classified into five categories of varying distance intervals taken as a straight-line distance. Depending on the criteria each interval class for the homestead and cropland map were allocated a suitability rank to facilitate the suitability analysis. Higher rankings represent areas of higher suitability for runoff harvesting. Generally there is a decrease in suitability with increasing distance from homesteads and croplands with the exception of croplands (0 m

interval class) having a low suitability. The areas utilised for cropping were given a low suitability, as this land is valued more for producing crop rather than developing runoff harvesting systems. Additionally, high interception rates during the maize growing season, which corresponds with the rainy season when most runoff is generated, is most likely to hinder the potential surface runoff. The Fig 10 and 11 shows the Homestead suitability ranking map and Crop suitability ranking map in the Bhavani Basin.

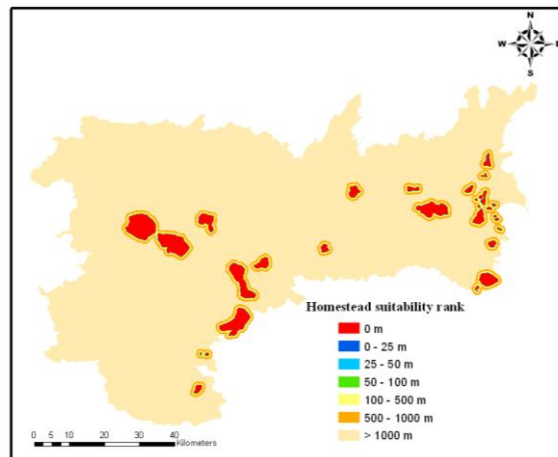


Fig. 10: Homestead suitability ranking map

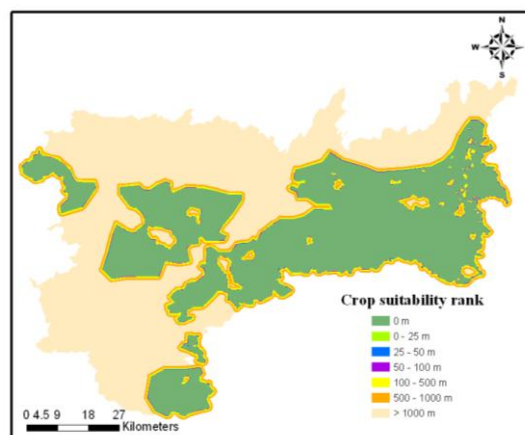


Fig. 11: Crop stead suitability ranking map

Conclusion:

In a water scarce rural watershed where the local community is dependent on rainfed agriculture, the ability to efficiently harvest the rainfall runoff is of vital importance to sustain agricultural production and reduce the community's vulnerability to water shortage. In this study, a RS and GIS approach has been utilized for identification of suitable runoff harvesting sites in the Bhavani basin located in the semi-arid Cauvery basin Erode district, Tamilnadu. Based on integrated GIS modelling, 'suitability maps' have been developed for potential runoff harvesting sites. The GIS approach for locating

suitable sites for runoff harvesting helps to reduce the extent of the area to be investigated for effective runoff harvesting, by identifying specific areas that are potential sites for runoff harvesting, and which can then be verified in the field. Providing an accurate spatial representation of the runoff generation potential within a watershed is an important factor in developing a strategic runoff harvesting plan for any water scarce rural watershed. The use of GIS approach to facilitate this process improves the accuracy level for locating suitable areas for runoff harvesting in view of the GIS capability to utilize spatial information in an

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