Identification of Potential Rainwater Harvesting Sites in Semi-Arid, Achaean Terrain, Using SCS-CN Method

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Abstract:

In this paper, to discuss the Bhīma River Basin is a drought prone area located in the Survey of India (SOI) top sheets 57 O/2 & 57 O/6 and the extent of the area is 146.90 sq.km was done to find possible locations for building rainwater gathering structures. Thematic maps of land use/land cover, slope, drainage, and runoff were created with the aid of remote sensing and geographic information systems. Satellite image merged (Linear Image Self Scanner and Panchromatic) and SOI toposheetswere used to prepare thematic maps. Runoff is derived from Soil Conservation Service Curve Number method. Runoff potential is observed from water body, wastelands (scrub land and Stony waste) is high and low runoff is observed from agriculture and forest land. Forest area and agriculture area are two major categories among all in the study area. Hydro geomorphology and geological considerations are integrated in the identification of harvesting structures. Field verification is carried to check the suitability of derived sites. Check dams and percolation tanks are the harvesting structures present in the study area.

Keywords: SCS-CN method, Runoff, Rainwater harvesting, Remote Sensing, Geographical Information System, Archean terrain.

Introduction:

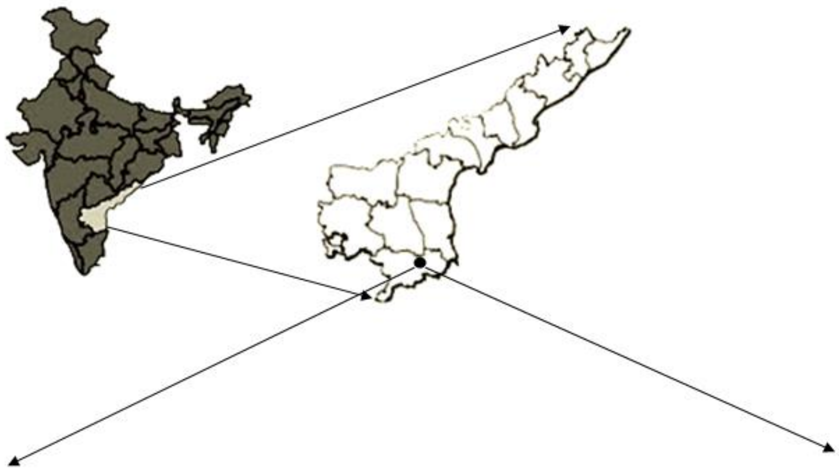
Water is the most valuable resource and the foundation of all life. It is also a crucial resource for all economic activity, from agriculture to industry. Due to population explosion, rapid industrialization, rapid urbanization and agriculture activities resulted in over exploitation of fresh water. On the other hand the groundwater recharge potential has reduced. In hard rock terrains, groundwater availability is of limited extent. In such rocks, groundwater occurrence and migration are primarily restricted to cracks and weathered regions. The lineament intersection zones offer the possibility of groundwater recharging and deposit.

Continuous failure of rainfall, over exploitation of groundwater cause to depletion of groundwater and also natural recharge cannot keep up with demand for water since the balance is disrupted, thus available rainfall runoff must be collected in the appropriate structures. Chowdary, et al., (2003) developed a generalized integrated framework for assessment of groundwater resources in large canal irrigation project areas with varying soil, weather, crop and water use conditions. Pawar (1996) carried out study on investigation of groundwater potential to find out the future prospects of groundwater development in two blocks of Jalpaiguri District and feasible alternatives to utilize available groundwater economically. He showed that recharge to groundwater from rainfall is about19.5% to 24.6%. In Jalpaiguri district, less than 20% of the cropped area is provided with irrigation through minor irrigation projects. In order to increase groundwater resources in the West Medinipur district of West Bengal, India, Chowdhury et al. (2010) suggested a method to delineate artificial recharge zones and to recognize beneficial artificial recharge sites utilizing integrated RS, GIS, and multi-criteria decision-making (MCDM) methods. Geomorphology, geology, drainage density, slope, and aquifer transmissivity were among the thematic layers taken into account in their analysis. These layers were created using IRS-1D images and traditional data. Based on their relative contribution to groundwater recharge in the area, various themes and the accompanying features were given appropriate weights, and normalized weights were determined using Saaty's analytic hierarchy technique (AHP). According to their suitability for artificial recharging, the study region was classified into three zones on the artificial recharge map: "suitable," "moderately suitable," and "unsuitable." Based on modeling of rainfall runoff and land use, soil, topography, and groundwater recharge, Sargaonkar et al. (2011) identified potential locations for groundwater recharge structures. A methodology for mapping potential infiltration zones was described by Soares et al. (2012), taking into account thematic maps (geology, pedology, geomorphology, and land use/land cover) and the spatial distribution of precipitation. Only about 7% of the watershed's surface, which comprised of gentle slopes, fluvial tertiary sediments, and yellow oxisols, was found to be highly suited for infiltration, according to the study. The contributing elements were identified as lithology, land cover/use, drainage, slope, and lineaments in a study by Huang et al. (2013) to evaluate groundwater recharge and possible exploitation zones in the central division of the mountain ranges of Taiwan.

Many people throughout the world advise the use of potential rainwater harvesting techniques to increase the production of water in a region. (Handiaet al.2003; Vohland and Barry 2009).In order to reduce the time spatial information technology is used to spot the rainwater harvesting sites. (Winnaar et al. 2007;Jasrotia et al. 2009).One of the key important factor in predicting rainwater harvesting sites is runoff which in turn depends on moisture condition of the area, soil type and land use/Landover. (Winnaar et al. 2007).Different methods like Theissen polygon and Soil Conservation Service Curve Number (SCS-CN) method(Kim et al. 2003), agricultural non-point source (Mohammed et al. 2004), as water balance approach (Jasrotia et al. 2009); are used to study rainfall runoff of water sheds. SCN-CN method results in “Curve Number” which is the combination of climatic factors and watershed parameters.

In the field of research, building rainwater collection structures is important for improving aquifer recharge rates and lowering soil and runoff rates. The aim of the current study is to (1) evaluate a region's runoff potential using the SCS-CN approach and (2) locate potential locations for rainwater collection.

Study Area: The study region is the Andhra Pradesh state of India's Bhima Micro Watershed of Swarnamukhi River Basin (part of Chittoor district). It falls in the Survey of India map numbers 57 O/2 & 57 O/6and is entangling from 13^0 30' to 13^0 40' North latitudes and 79^0 5' to 79^0 20' Eastern longitudes having geographical area of 146.90sq.km. From July through October, the watershed averages 755.5mm of rain per year. The region experiences low to moderate runoff and significant evapotranspiration due to its semi-arid climate. Both alluvial soils and red soils are present in the study area. The alluvial soils occur predominantly in and adjacent to the Bhīma river only. The region's topography is depicted by the mountainous landscape that represents the peninsular gneissic complex. The research area's maximum and minimum elevations are 970m and 220m, respectively. These rocks are intercepting by innumerable dyke rocks of considerable width and linear extent. Dykesare continuous and discontinuous in nature and traverse through the gneissic rocks, which extends from few meters to a few kilometers. Apart from the dyke rocks, veins of quartz traverse the granitic terrain along the predominant joint directions. Their width ranges from few centimeters to a few meters.



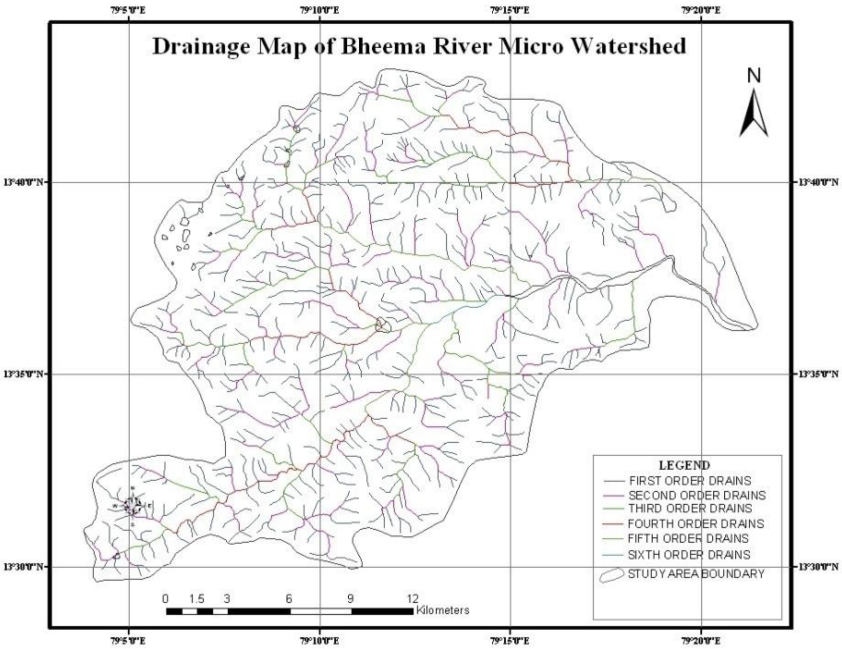


Fig.1. Location map of the Bhīma River basin along with Drainage

Materials and Methods: Watershed boundary of the study area is delineated based on the Survey of India toposheetswere (SOI). Soil map is procured from agriculture department and used for integrated analysis. Geological map of Geological Survey of India (scale 1:250,000) was also used.

These SOI toposheets of 1:50000 scales were used to derive base, drainage and contour map. The drainage map was prepared using SOI toposheets (scale 1:50,000) and updated with satellite data. Horton (1945) method of stream ordering was adopted for giving order to drainage. Slope map is prepared in Arc Map 9.3 using spatial analyst tools. Land use/ land cover map of 1:50000 scale was derived from LISS and PAN merged data using supervised classification.

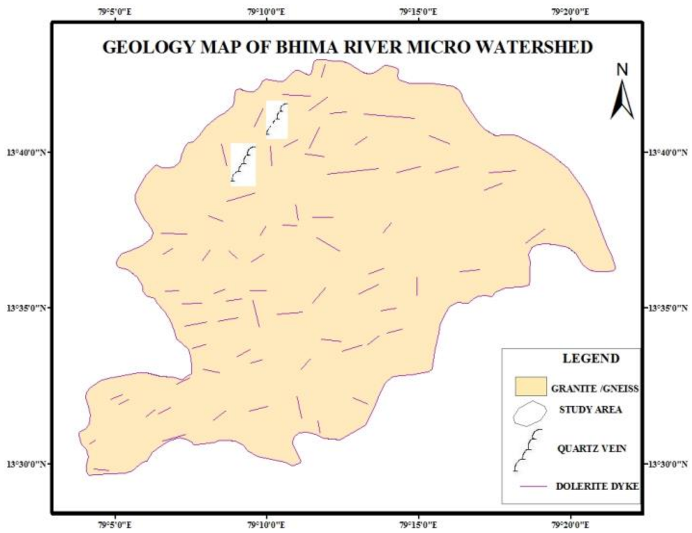


Fig.2 Geology map of Bhīma River basin

To estimate the runoff in the study area, rainfall data from the years 1995 to 2013 were examined. Curve Number, a watershed coefficient in the SCS-CN approach, is dependent on the hydrological soil group, land use, and preexisting moisture conditions. Due to the fact that the sole source of rainfall data used in this study was one meteorological station, curve numbers were only analyzed for the antecedent moisture conditions II condition for the study area (Geetha et al.2007). The structure's location for its runoff potential is determined by the soil's penetration rate and texture (Jasrotia et al. 2009)

Table1. Classification of Antecedent moisture conditions

Sl.No	**AMC class**	**5 Day total antecedent rainfall (mm)**		**Condition**
		Dormant Season	Growing Season	
1	I	<12.5	<35	Dry
2	II	12.5-27.5	35-52.5	Normal
3	III	>27.5	>52.5	Wet

Knowing the value of curve number, runoff from study area was computed from Eqs. 1 and 2.

$$Q= [(P-0.3S)^2] / [(P+0.7S)] \text{ ------------------------------------ } 1$$

$$Q= [(P-0.1S)^2] / [(P+0.9S)] \text{ ------------------------------------ } 2$$

Equation 1 is applicable to all soil regions of India except black soil areas (CGWB, 2007).

For Indian condition

S = (1000/CN) – 10 in inch and S = (25400/CN) -254 in mm, SI units

Based on the properties of "Soil type" in the soil data and "category" in the land use/land cover data, soil data and land use/land cover data were intersected. In order to create new, smaller polygons associated with soil type and land use category name, soil and land use/land cover data were intersected. The curve number for the combined land-soil layer is displayed in table 3. The best locations for rainwater collection are found by combining different theme maps and checking them with drainage maps, for which the presence of water for these structures is proven through field research. Infiltration investigations were conducted as part of a ground truth assessment to evaluate the appropriateness of chosen sites for rainwater gathering. Infiltration studies authenticate the potential sites based on the rate of infiltration. At twelve locations infiltration studies were conducted in the basin of land use and land cover type (agriculture land , Waste land) and soil types (Red soil, Black soils) for infiltration studies with double ring infiltrometer.

Results: The study region includes hard rocks from the Archean group that display ten different forms of land use and land cover. The watershed's land use pattern affects the runoff and evapotranspiration of the study area and is crucial for choosing optimal locations for rainwater collection.

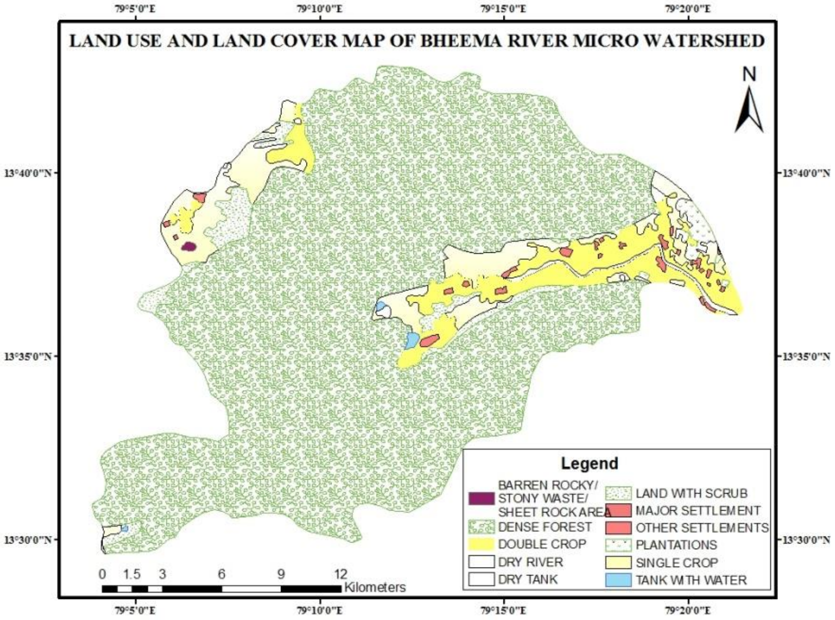


Fig.3 Land Use and Land Cover map of Bhīma River basin

It is observed that majority of area comprises of forest land and the other categories like agriculture land and scrub lands are occupied next to forest land. Open and scrub lands are suitable for possible rainwater harvesting structures in the study area because of availability of space and less public hindrance.

Table2. Statistics of Land use and Land cover categories of the study area

Sl. no	**LU/LC category**	**Area(Sq. km)**
1	Dense Forest	122.848
2	Double Crop	11.189
3	Single Crop	10.642
4	Tank With Water	0.209
5	Dry Tank	0.277
6	Land With Scrub	4.285
7	Major Settlement	0.907
8	Plantations	1.148
9	Barren Rocky /Stony Waste/Sheet Rock Area	0.084
10	Dry River	0.75
	Total	**152.339**

The typical soil in the granitic gneiss is red soil having high permeability. SCS developed soil classification system that consists of four groups, which are identified as A, B, C, and D according to their minimum infiltration rate. Table 2 shows the hydrological soil group classification based on the infiltration rates. The runoff curve numbers (AMC II) for hydrologic soil complex are shown in table 3.

Table 3. Hydrological Soil Group Classification (Mc. Cuen., 1982)

Soil Group	Description	Minimum Infiltration rate (mm/hr.)
A	Soils in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. They consist of deep, well to excessively well drained sands or gravels. These soils have a high rate of water transmission.	7.62 - 11.43
B	Soils in this group have moderate infiltration rates when thoroughly wetted and consists chiefly of moderately deep to deep, well-drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.	3.81 - 7.62
C	Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine-to fine texture. These soils have a slow rate of water transmission.	1.27 - 3.81
D	Soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.	0 - 1.27

Table 4. Runoff curve numbers (AMC II) for hydrologic soil cover complex(Chow et al, 1988)

Sl No.	Land use	Hydrologic Soil Group			
		A	B	C	D
1	Agricultural land without conservation (Kharif)	72	81	88	91
2	Double crop	62	71	88	91
3	Agriculture Plantation	45	53	67	72
4	Land with scrub	36	60	73	79
5	Land without scrub (Stony waste/ rock out crops)	45	66	77	83
6	Forest (degraded)	45	66	77	83
7	Forest Plantation	25	55	70	77
8	Grass land/pasture	39	61	74	80
9	Settlement	57	72	81	86
10	Road / railway line	98	98	98	98
11	River / stream	97	97	97	97
12	Tanks without water	96	96	96	96
13	Tank with water	100	100	100	100

Slope is considered to be a crucial factor in choosing and implementing rainwater collection locations (Ziadet et al, 2006; Winnaar et al. 2007). The increase in groundwater infiltration occurs when the slope changes from steep to mild (Todd and Mays 2005).The standard guidelines referred from the National Remotes Sensing Agency are derived for 9 classes of slope. The emphasis is given to non-forest areas in the present study even though there is a high runoff is observed in the major portion of the study area i.e. forest area.

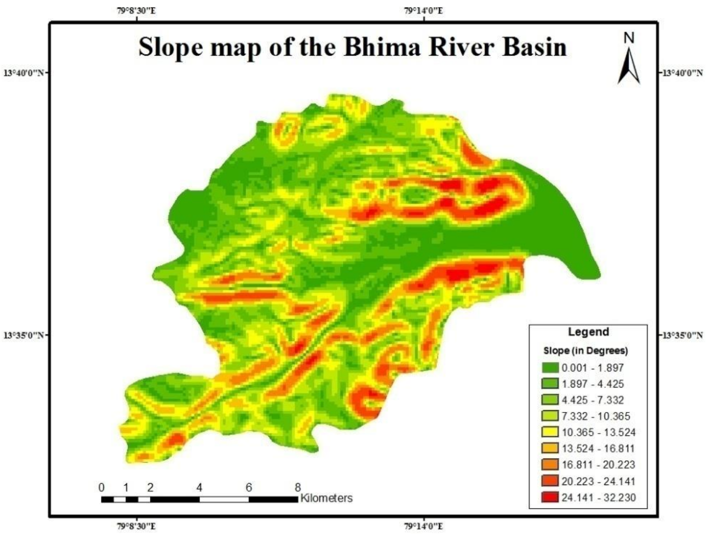


Fig. 4. Slope map of the Bhīma River basin

Run off Potential: Variation of runoff potential occurs with different land use / land cover and with different soil conditions. The computed runoff values are highlighting the high runoff potentiality in the slopes of the hill region which is 80% of the study area. Whereas moderate to low runoff potential zone covered an area of 14.22%. Runoff is maximum in the wasteland categories and minimum in the agriculture categories of LU/LC. Moderate runoff areas are noticed in scrub land areas to construct rainwater harvesting structures. Farm ponds and check dams are suggested in scrub lands where moderate to high runoff is noticed.

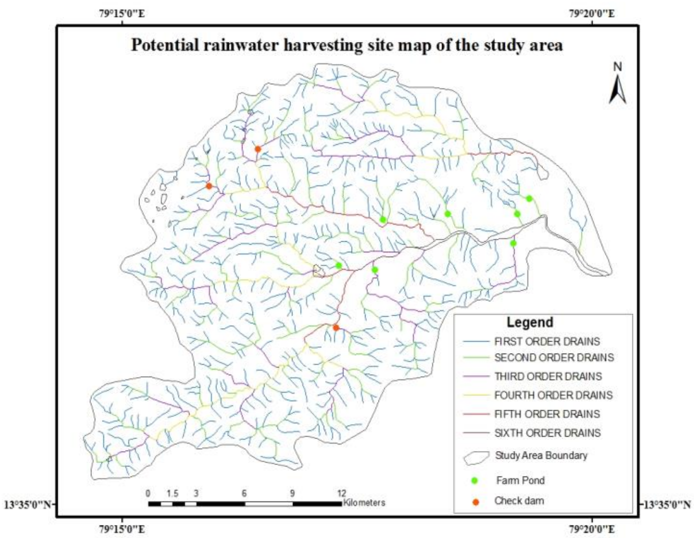


Fig. 5. Potential rainwater harvesting site map of the Bhīma River Micro watershed

Conclusions:

In this paper discussed the Due to unpredictable monsoons and insufficient recharge water at surface and subsurface aquatic systems, the semiarid hard rock region experiences numerous years of water scarcity. So recharge structures are became imperative in hard rock areas. Potential rainwater collection structures can be built in places with moderate to high runoff potential. Based on the integrated studies of thematic maps and infiltration studies the potential recharge structures suggested are check dams and farm ponds in this study area the SCS-CN method, which uses less time, is more accurate, and can study a greater region, is a better tool for identifying prospective locations for preliminary rainwater harvesting. These integrated studies are useful to develop potential rainwater harvesting structures information system of the study area to initiate watershed development activities by policy makers.

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