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Identifying Potential Rainwater Harvesting Sites of a Semi-arid, Basaltic Region of Western India, Using SCS-CN Method

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Abstract Upper Karha watershed from semi-arid part of Deccan Volcanic Province, India was investigated to identify the potential sites to construct rainwater harvesting structures with the help of remote sensing and geographical information system. Attempt was made to understand the basaltic terrain in spatial context to find out the rainwater harvesting structures like farm ponds, percolation tank, check dams and gully plugs deriving from thematic layers, such as landuse/landcover, slope, soil, drainage and runoff from Landsat Thematic Mapper imagery and other collateral data. Subsequently, these layers were processed to derive runoff from Soil Conservation Service Curve Number (SCS-CN) method using Arc-CN runoff tool. The SCS-CN method shows that the high runoff potential is from water-body, agriculture land (including harvested land) and followed by settlement, open scrub, dense scrub and low for the open forest, dense forest area. Parameters like hydrogeomorphology, geology were considered as per Integrated Mission for Sustainable Development specifications for identification of the structures. The thematic layers overlaid using intersection based on these specifications. Derived sites were investigated for its suitability and implementation by ground truth field verification. In conclusion, the method adopted in present study deciphers the more precise, accurate and ability to process large catchment area than other methods.

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1 Introduction

The rapid industrialisation, population growth and agricultural activities resulted in overutilization of the fresh water resources leading to reduction of groundwater level. Rapid urbanization has resulted in less infiltration of rainwater and groundwater recharge potential has diminished (Ibrahim 2009). Many workers from all over the world have confirmed the potential of rainwater harvesting to enhance the water productivity (Handia et al. 2003; Concepcion et al. 2006; Sazakli et al. 2007; Abdulla and Al-Shareef 2009; Vohland and Barry 2009; Moon et al. 2012). Thus, rainwater harvesting becomes imperative to meet the inadequacy of water supply. To overcome this problem, construction of rainwater harvesting structures are proposed to augment both surface and sub-surface storage. Therefore, the construction of these structures decrease runoff rate, retard the soil erosion and recharge the aquifer (Ramakrishnan et al. 2009; Aladenola and Adeboye 2010). Considering the time consumption of conventional geographical surveys for identification of potential rainwater harvesting structures, the remote sensing and geographic information system have been used by several workers to delineate the potential rainwater harvesting structures (Winnaar et al. 2007; Pachpute et al. 2009; Kahinda et al. 2009; Jasrotia et al. 2009). However, few such studies have been carried out from semi arid, basaltic region of western India, Ramakrishnan et al. (2009), has covered very small portion (4 % of total area studied) of basaltic region from Gujarat state of India. In this, view present study is a pragmatic approach carried out for semi arid region representing Deccan Volcanic Province of peninsular India to identify potential rainwater harvesting structure.

To assess the rainwater harvesting potential, Upper Karha watershed has been selected as a representative of semi arid, basaltic region of western India. Water budget is balance between incoming rainfall and water loss by evapotranspiration, groundwater recharge and runoff of an entire watershed (Jasrotia et al. 2009). Out of which, runoff is one of the important parameter to predict potential rainwater harvesting sites. Furthermore, runoff is primarily dependent on soil type, landuse/landcover and antecedent moisture conditions of the area (Winnaar et al. 2007). Thus, a detailed understanding and analysis of various interrelated parameters mentioned above are functions of slope, rainfall and lithology (Kim et al. 2003).

Various methods such as water balance approach (Jasrotia et al. 2009); agricultural non–point source (Mohammed et al. 2004), Thiessel polygon (Kim et al. 2003) and Soil Conservation Service Curve Number (SCS-CN) method have been used to study the rainfall runoff of watershed. However, SCS-CN method is used to calculate runoff parameter and having its advantages over other above said methods, if integrated with advance tools such as remote sensing and geographical information system. This enhances the accuracy and precision of runoff prediction, eventually helps for better identification of potential rainwater harvesting structures for cost effective water resource management. This method accounts for many of the factors affecting runoff generation including soil type, land covers and land use practice, surface condition, and antecedent moisture condition (early moisture condition of the watershed prior to the storm event of interest), incorporating them in a single curve number parameter (Winnaar et al. 2007; Mishra et al. 2008; Bo et al. 2011). Although, SCS-CN method is originally designed for use in watersheds of <15 km^2, it has been modified for application to larger watersheds by weighing curve numbers with respect to landuse/landcover of area under study (Ramakrishnan et al. 2008).

Instead of above said use of SCS-CN method, many authors are used for various applications. Khaleghi et al. (2011) used SCS-CN method for the creation of a geomorphologic instantaneous unit hydrograph. Mishra et al. (2006) and Bhunya et al. (2010) used SCS-CN method to develop sediment yield models for various hydrological elements and watershed characteristics. Pachpute et al. (2009) applied SCS-CN for estimation of surface runoff in drought pond and subsurface runoff harvesting tank from rural catchment of sub Saharan Africa.

Constructions of rainwater harvesting structures are essential because majority of area from basaltic region of western India is semi arid and rain fed due to erratic nature of monsoonal rainfall. Available rainfall runoff has to be harvested in respective structures during water scarce periods for domestic, agricultural and industrial purposes. However, multi-formation basaltic lithology of Deccan volcanic province is posing its influence on the aquifer recharge due to impermeable red bole horizons (Widdowson et al. 1997). This warrants the development of surfacial rainwater harvesting structures to congregate water for need of inhabitants. This necessitates the identification of potential rainwater harvesting sites within less time span, higher accuracy and with proper geographical information system tool. In future, the conglomeration of several likewise studies give an opportunity to develop potential rainwater harvesting structure information system based on data base management of region or nation using geographical information system and remote sensing techniques. For this, baseline data generation is important step to proceed further.

For this intent, Upper Karha watershed from Deccan volcanic province is selected with the objectives to (1) estimate the runoff potential of an area using SCS-CN method, (2) identify potential rainwater harvesting sites controlling groundwater infiltration in a basaltic litho-environment and (3) compare derived rainwater harvesting site map with field investigation, to measure accuracy of method used.

1.1 Study Area

The study area (Fig. 1) is spread over 546 km^2 and bounded by the watershed of upper Karha river (part of Pune district), Maharashtra state of India entangling from 73°52′07″W to 74°15′ 06″E longitudes and 18° 25′ 8″ S to 18° 13′ 8″ N latitude. However, high elevation location situated in western part (1274 m) and lower elevation (634 m) is in easternmost part of study area. The area is characterized by semi-arid climatic conditions with moderate to high runoff potential and high evapotranspiration. Average temperature ranges from 39°C during April and May to about 8°C during December. The watershed receives an average annual rainfall of about 793.2 mm from June through September, rainfall records adopted from India Meteorological Department, Pune. The study area comprises of alluvial plain it contains soils type mainly predominated by clay, pediment zone characterized by denudational origin on Deccan trap. The plateau shows two types, based on height. Upper Plateau on basalt rising to heights over 950 m from plains and Lower Plateau on basalt rising to heights from about 730–950 m from plains and denuded hills comprising of massive rocks like basalt of high height.

The study area is typified by moderately weathered simple type basaltic flows of Wai subgroup of Deccan volcanic province embracing multi-aquifer system estranged by thin tuffaceous layers. The subgroup is divisible into five different formations from base to top namely Poladpur, Ambenali, Mahabaleshwar, Panhala and Desur each separated by marker Giant Plagioclase Basalt flows (Bean et al. 1986). The lava flows from the study area have been divided into Poladpur Formation exposed towards low lying areas of upper Karha basin, which is overlain by Ambenali Formation covering higher elevation areas (Saswad and Jejuri) (Fig. 2) in the North–west (Bean et al. 1986; Subbarao et al. 1994; Khadri et al. 1999). The hydraulic

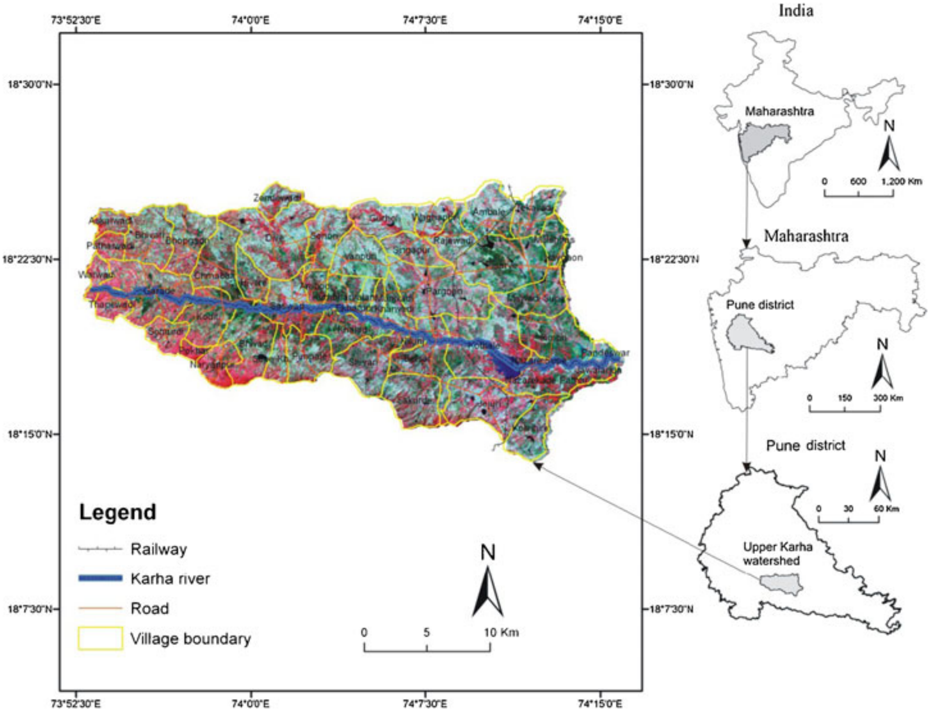

Fig. 1 Location map of upper Karha watershed

conductivity of study area ranges from low (9.65 m/day) to moderate (23.09 m/day), which is measure of water, can move through pore spaces or fractures. The geology and hydrogeomorphology is also used to identify potential site for its stability and storage.

2 Materials and Methods

Spatial data such as landuse/landcover map of 1:50,000 scale was derived from digital satellite data of Landsat Thematic Mapper of 16th October 2006 using supervised classification. Soil classification map (scale 1:500,000) was upgraded to 1:50,000 scales by Landsat data image ratios and principal component analysis) (Ramakrishnan et al. 2008). Further, soil classification of study area is reclassified on the basis of USDA soil classification system (1972). Geological map of Geological Survey of India (after 2001) (scale 1:250,000) was also used. Survey of India toposheets of 1:50,000 scales were used to derive base, contour and drainage map. Digital elevation model was derived from contour layer and validated with differential global positioning system surveyed points and survey of India toposheet. The drainage map was generated from the toposheets and updated using satellite data and digital elevation model using Arc soil water assessment tool (Arc SWAT). Horton (1945) method of stream ordering was adopted for giving order to drainage.

Climatic data was acquired from India Meteorological Department, Pune. Rainfall data of the watershed (Saswad rain gauge station) for the period from 1998 to 2007 was analyzed for recurrence of storm/flood event at 2-year intervals. Since the precipitation data has been

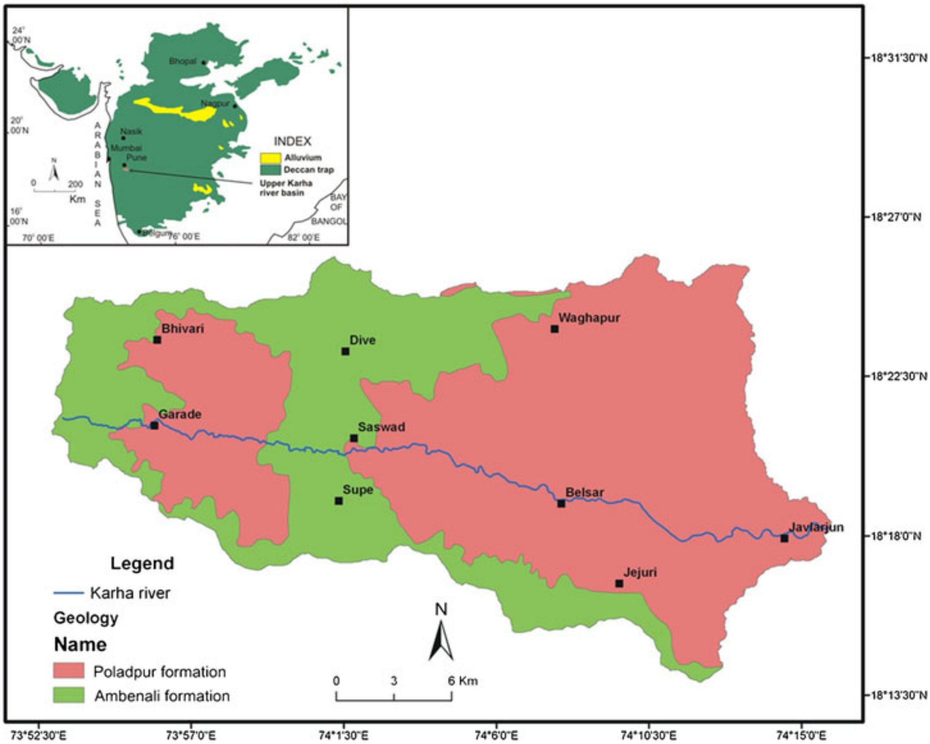

Fig. 2 Geology map of upper Karha watershed

collected from single available station, the variations in antecedent moisture conditions could not be accounted. Hence, antecedent moisture conditions II is considered for the entire watershed for the given storm event (Table 1). The runoff estimates for different combinations of soil group, land use classes and antecedent moisture conditions classes are estimated by following the procedure of SCS-CN method.

SCS-CN method is very sensitive to curve number values, necessitating accurate determination of this parameter. Curve number is again as a function of hydrological soil group, land use and antecedent moisture conditions. The antecedent moisture conditions are determined by total rainfall in the 5-day spell preceding a storm. As the soil moisture increases due to rainfall in early spell, runoff during storm event increases. Since, rainfall data used in this work derived from a single meteorological station, curve numbers were evaluated for antecedent moisture conditions II condition only (Geetha et al. 2007). Knowing the value of curve number, runoff from study area was computed from Eqs. 1 and 2.

Table 1 Classification of antecedent moisture conditions

AMC class	5 day total antecedent rainfall (mm)		Condition
	Dormant season	Growing season	
I	<12.5	<35	Dry
II	12.5 to 27.5	35 to 52.5	Normal
III	>27.5	>52.5	Wet

(Geetha et al. 2007)

This simplified assumption (Ponce and Hawkins 1996) resulted in the following runoff equation, where, CN (0≤CN≤100) (USDA 1972) represents a convenient representation of potential maximum soil retention (S):

$$\begin{array}{ll} \text{Runoff} = \frac{(\text{Rainfall}-0.2\ \text{S})^2}{\text{Rainfall}+0.8\ \text{S}} & \text{If Rainfall} > 0.2\text{S} \\ \text{Runoff} = 0 & \text{If Rainfall} \leq 0.2\text{S} \end{array} \quad (1)$$

For Indian condition,

$$\text{S} = (1000/\text{CN}) - 10 \text{ in inch and S} = (25400/\text{CN}) - 254 \quad (2)$$

in mm, SI units (Ramakrishnan et al. 2009).

In this study, curve numbers were weighed with respect to the watershed area (generally < 15 km^2) using following Eq. 3:

$$CN_W = \frac{\sum (CN_i \times A_i)}{A} \quad (3)$$

Where

CN_w is weighted curve number
CN_i is curve number from 1 to any number N
A_i is area with curve number CN_i; and
A is total area of watershed.

Traditionally, an area weighted average curve number for the entire watershed is used to study the runoff of a watershed. The details of the spatial variation in the watershed are often lost. However, ArcCN-Runoff extension of ArcGIS 9.3 is used for accurate and precise determination of runoff. It is mainly designed for any shape of landuse/landcover and soil polygon, in order to keep irregular boundaries unaltered and used to facilitate better runoff prediction. The processing time is reduced significantly due to application of dissolving techniques in ArcGIS. A reference table for curve number, based on soil and land use information provides a flexible way to use curve-number database for present study (Zhan and Huang 2004).

Soil and landuse/landcover data were processed for preparation of runoff potential map through the following steps: (1) Soil and landuse/landcover data were clipped to watershed boundary layer (study area). (2) To reduce processing time, the soil data was reclassify according to USDA soil classification system from six different classes to four classes (A, B, C and D). Landuse/landcover and soil data was intersected based on the attributes of 'soil type' in soil data and 'class name' in landuse/landcover data. Soil and landuse/landcover data were intersected to generate new and smaller polygons associated with soil type and landuse class name. This step keeps all the details of the spatial variation of soil and landuse, and therefore it is considered more accurate than using raster grid to calculate runoff or any average or dominant methods to determine curve number. (3) The intersected land-soil layer was assign the curve number (obtained from USDA-NRCS, Urban Hydrology for Small Watersheds TR-55, 1986) using ArcCN runoff tool by referring index file by simple matching landuse/landcover and soil layer. The detailed, stepwise operation of the runoff calculation by the ArcCN-Runoff tool in ArcGIS can be found in Zhan and Huang (2004).

In present study, decision rules are adopted as per integrated mission for sustainable development guidelines, Department of Space, Government of India. Various thematic layers such as landuse/landcover, slope, soil and runoff potential were intersected to identify the potential rainwater harvesting sites based on specification given by 'integrated mission for sustainable development'. All favorable sites for rainwater harvesting are checked by overlaying drainage map, for which, the availability of water for these structures are confirmed from ground truth investigation. Figure 3 depicts a detailed illustration of the methodology. Accuracy assessment was carried out by overlaying the existing structures identified at ground truth survey on derived potential rainwater harvesting map for their matching percentage.

3 Results and Discussion

3.1 Landuse/Landcover and Hydrological Soil Group

The study area comprises of semi-arid basaltic region showing eight types of landuse/landcover (Fig. 4). Landuse pattern of watershed influences the runoff and evapotranspiration of study area (Harbor 1994), as it is an important indicator for selection of suitable sites for rainwater harvesting. It is observed that majority of area comprise agriculture land, open scrub and dense scrub followed by harvested land (harvested crops like Rice, Bajara, Peas, and Maize) with stony waste (rock outcrops and boulders) (Table 2). In agriculture land the major crops are cultivated after rainy season such as Rice, Bajara, Peas, Tomato, Maize, Onion and Leafy vegetables, however, harvested land is the last phase of cropping season. Open as

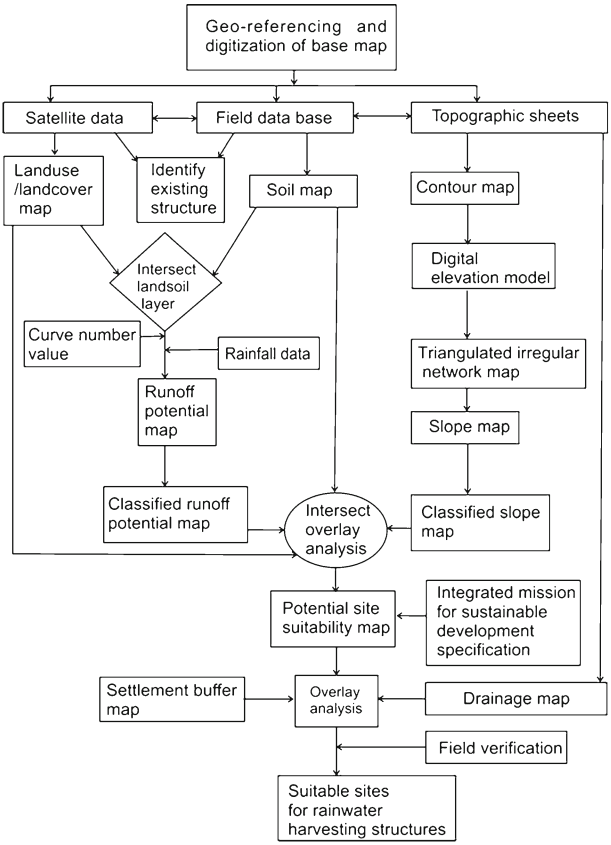

Fig. 3 Methodology flowchart

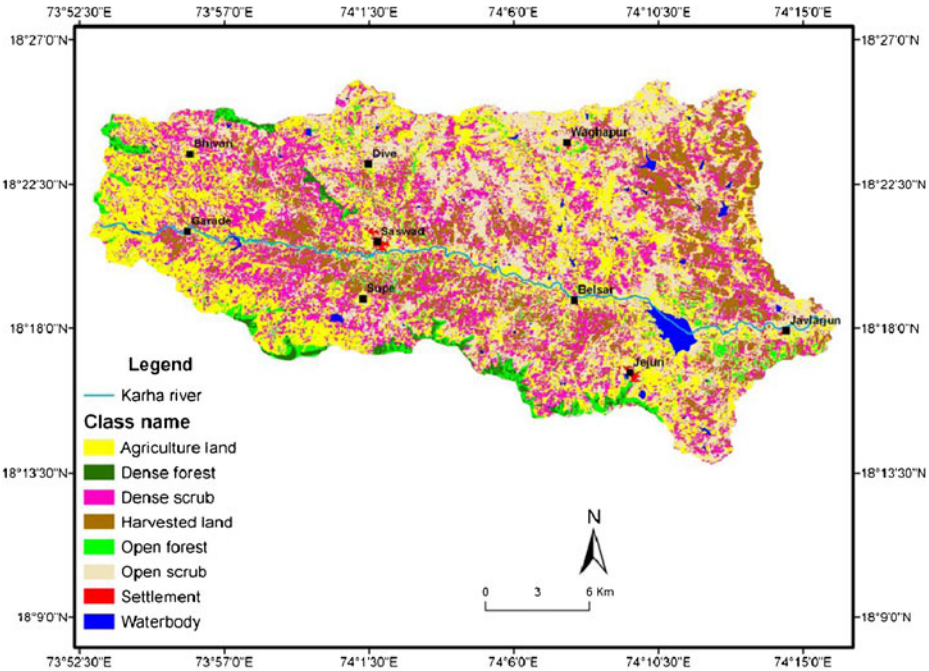

Fig. 4 Landuse/landcover map of upper Karha watershed

well as dense forests are occupied in meager areas of catchment indicating major contribution of anthropogenic disruptions (e.g. agriculture) around existing rainwater harvesting structures as well as possible obstacle in construction of newer structures. Further, open and scrub land have suitable site for possible rainwater harvesting structures in the study area because of availability of ample space and less public hindrance, observed at the time of ground truth survey.

Soil infiltration rate and its texture determine the structure to be located for its runoff potential (Jasrotia et al. 2009). The reference map of National Bureau of Soil Science and Land Use Planning is used to delineate the soil classes of study area which is based on USDA soil classification system (Fig. 5). Soil physical and chemical characteristics are the manifestation of disintegration of parent lithology, however, soil from study area is derived from basaltic rocks,

Table 2 Landuse/landcover of study area

Sr. no.	Landuse/landcover	% area	Significance	Recommended rainwater harvesting structures
1	Agriculture land	30.84	Unsuitable	–
2	Harvested land	11.01	Suitable	Farm pond
3	Open forest	1.57	Suitable	Gully plug, Check dam
4	Dense forest	1.18	Suitable	Gully plug, Check dam,
5	Dense Scrub	24.91	Suitable	Percolation tank, Check dam, Farm pond
6	Open scrub	28.53	Suitable	Percolation tank, Check dam, Farm pond
7	Water body	1.26	Unsuitable	–
8	Settlement	0.69	Unsuitable	–

IMSD (1995)

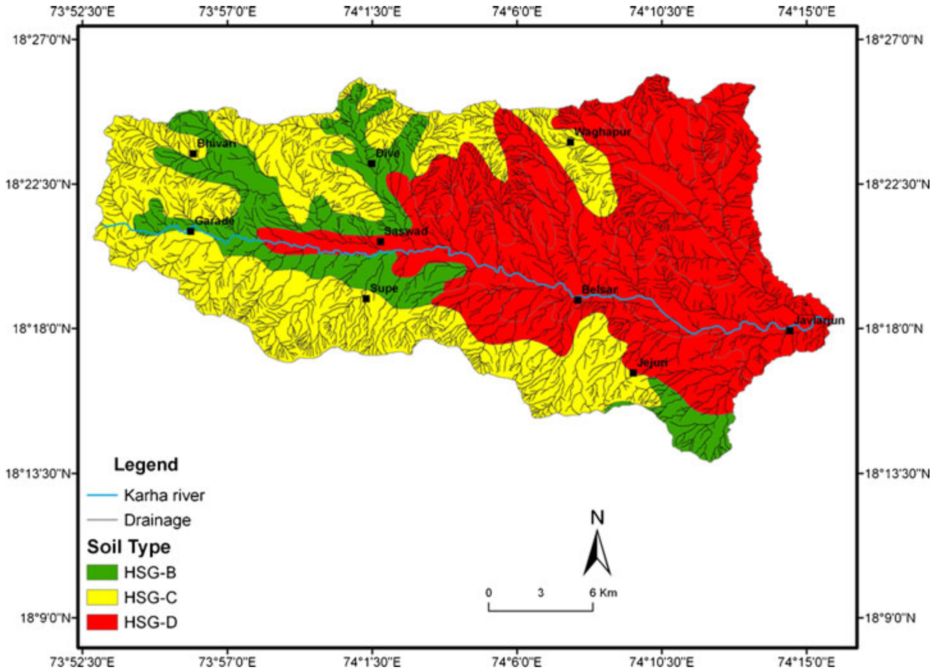

Fig. 5 Soil map of upper Karha watershed

shows alkaline nature due to presence of alkaline earths (Kale et al. 2010). The typical basaltic soils show reddish brown color rich in iron and ferric oxide content are present in higher regions and these are medium textured silty soils having high permeability (Pawar 1993). Moderately thick black soils rich in organic matter and humus content comprises high water holding capacity (Kale et al. 2010). Sporadic patches of grayish soils were developed along the gentle slopes. These are rich in $CaCO_3$ (calcareous soils) as observed in lower reaches (Pawar 1993). As the basalt is fine-grained and contains olivine, pyroxene and calcium-rich plagioclase feldspar, therefore it weathers rapidly and produces clay minerals. The final weathered product is therefore predominantly clay (Kale and Gupta 2001), which is used to construct the rainwater harvesting structures like check dam and percolation tanks. This fine grained basaltic soil is effective in construction of soil barriers for above said rainwater harvesting structures, by reducing water losses to downstream part of those structures. In view of this, the hydrological soil group A (sandy soil) is absent in the study area as it comprises of fine grained basaltic rock. The study area comprises of B, C and D hydrological soil groups (Table 3) predominantly having shallow soil layer. However, specific characters responsible to affect water holding and permeability capacity of each hydrological soil groups are shown in Table 3.

3.2 Slope

Slope is considered as an important criterion for selecting and implementation of rainwater harvesting sites (Ziadat et al. 2006; Winnaar et al. 2007). Slope plays a key role in the groundwater occurrence as infiltration is inversely related to slope (Fig. 6) (Table 4) (Mondal et al. 2009). The break in slope from steep slope to gentler slope increases the groundwater infiltration (Todd and Mays 2005). The slope (%) was derived from digital elevation model.

Table 3 USDA-SCS soil classification

Hydrological soil group	Type of soil	Runoff potential	Infiltration rate	Significance	% area
HSG B	These soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.	Moderate	Moderate	Moderate rate of water transmission	9.18
HSG C	These soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture.	Moderate	Moderate	Moderate rate of water transmission	15
HSG D	These soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material.	High	Low	Moderate rate of water transmission	75.82

(USDA 1972)

The standard guidelines referred from the All India Soil and Land Use Survey and IMSD are derived for seven classes of slope (Fig. 6). The study area is bounded by the hillock (fringe area) at western side, which is also watershed divide boundary of study area. Majority of

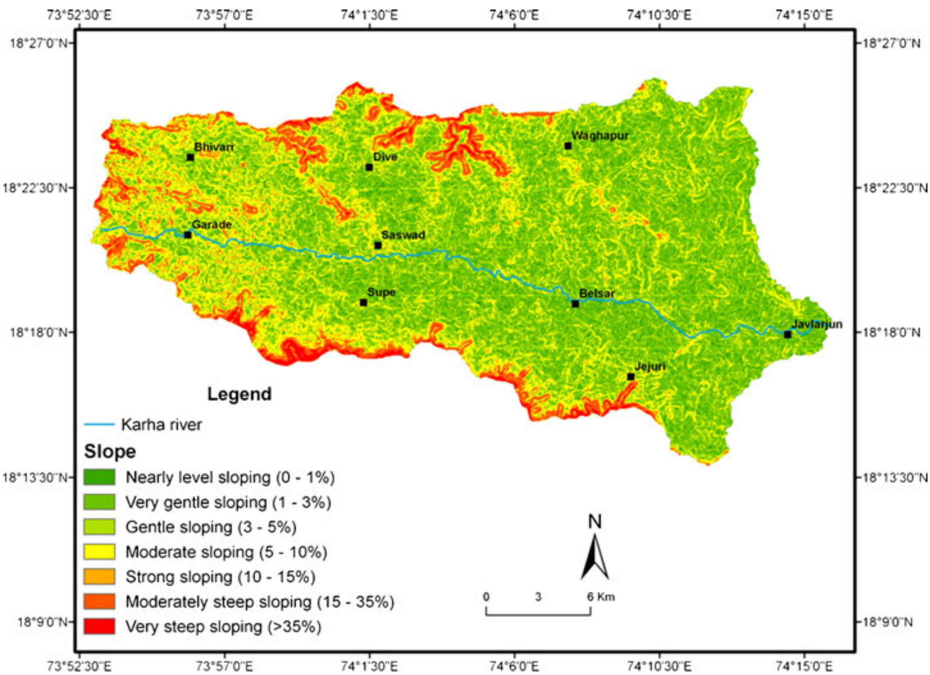

Fig. 6 Slope map of upper Karha watershed

Table 4 Slope classes of upper Karha watershed

S. no.	% Slope	% Area	Significance
1	Nearly level	5.76	Low surface runoff
2	Very gentle	33.13	Low surface runoff
3	Gentle	27.68	Low surface runoff
4	Moderate	18.19	Medium surface runoff
5	Strong	4.34	Medium surface runoff
6	Moderately steep	5.33	High surface runoff
7	Very steep	1.58	High surface runoff

IMSD (1995)

study area falls under very gentle to gentle slope class (Low and Medium surface runoff) indicating water retention for longer time and thus enhancing the chance of infiltration and recharge (Pawar et al. 2008). This is suitable for construction of rainwater harvesting structures such as check dams and percolation tanks along drainage.

3.3 Runoff Potential

The computed runoff values are shown in Table 5, highlighting the pediment, plain areas with soil group D having water body as a landcover accounts high runoff potentiality (790 mm). The hill shows reserved forest with soil group B revealing least runoff potential (30.42 mm). On the basis of histogram distribution, the runoff potential map was classified into three classes (Fig. 7). However, 57.83 % of the area is dominated by moderate runoff potential zones, where as high runoff potential zone covered an area of 20.62 % (Fig. 7). High to Moderate runoff potential zones were suitable for selecting rainwater harvesting structure. Maximum runoff potential is observed in the eastern side as well as lower reaches of study area is due to higher density of water bodies (Fig. 7). It is interesting to know that the region is dotted with higher density of water bodies which in turn results in filling up of existing watershed structure made for the irrigation with the help of mechanically lifted water from outside the basin have influenced the runoff potential. Irrigated agricultural practices may increase the clay content of surface layers usually under seasonal tillage. The irrigation of such lands also causes the upward movement of soluble salts and thereby causes compaction of surface soils.

3.4 Site Specifications

Rainwater harvesting practices helps in recycling water for raising agro-horticulture crops. Rain water harvesting decreases the soil erosion in the region and in addition, directly influences the temporal discontinuity between the availability of rainfall and crop moisture demand. In spite of promoting large irrigation projects, rainwater harvesting is well suited to the soils and mountainous topography of the region (Chowdary et al. 2009). Study area is dominated by moderate to high runoff having the suitable rainwater harvesting sites were identified by integrating different thematic maps using geographical information system. Maps of different thematic layer were integrated using intersection tool based on priority. Different structures were identified (Fig. 8) on the basis of specification adopted from Table 6. Settlement buffer map was overlaid to check that no rainwater harvesting structure lies within 500 m of settlement area.

In normal condition surface water storage structures shows loss of water (20–35 %) due to seepage and evaporation (Dahiwalker and Singh 2006). Study highlights the suitable sites for rainwater harvesting cover an area of nearly 84 % of the total area (Fig. 8).

Table 5 Runoff estimated for different landuse/landcover and hydrological soil group using Arc-CN Runoff tool

S. no.	Soil type	Class name	Curve number	Runoff (mm)
1	B	Dense forest	55	30.41
2	B	Dense scrub	58	48.67
3	B	Open forest	58	48.67
4	B	Open scrub	61	69.96
5	B	Settlement	66	112.55
6	B	Agriculture	77	243.35
7	B	Harvested land	77	243.35
8	B	Water body	100	790.89
9	C	Dense forest	70	152.09
10	C	Dense scrub	71	164.26
11	C	Open forest	71	164.26
12	C	Open scrub	74	203.80
13	C	Settlement	78	258.56
14	C	Agriculture	83	343.73
15	C	Harvested land	83	343.73
16	C	Water body	100	790.89
17	D	Dense forest	77	243.35
18	D	Open forest	78	258.56
19	D	Dense scrub	78	258.56
20	D	Open scrub	80	292.02
21	D	Settlement	83	343.73
22	D	Agriculture	87	425.86
23	D	Harvested land	87	425.86
24	D	Water body	100	790.89

3.5 Ground Truth Verification of Dive Watershed

To assess the suitability of selected sites for rainwater harvesting, field investigation was carried out for Dive village watershed (54 km^2) as a representative area. It is approximately 10 % of total area and selected for ground truth survey. The details of the site investigated are given in Fig. 9.

Ground truth survey was carried out to authenticate as well as measure the accuracy of SCS-CN method for larger watershed (>15 km^2). As depicted in Fig. 9, the farm pond structures were located on plateau region on first order stream with soil type C. Total 16 farm ponds were identified, out of which four were existing and 12 were potential site. As study area shows moderate to high runoff, 40 check dams were identified at the first to third order stream along soil type C, while nine potential sites were identified. Check dams are recommended across the 2nd and 3rd order streams, with low to moderate slopes. It is expected that check dams may help in improving the irrigation potential for the area under double cropping system and agro-forestry on the plateau top by further reducing the denudation process (Chowdary et al. 2009). Five existing percolation tanks were identified along fourth order stream with soil type D and four potential sites were identified. The performance of percolation tanks is attributed to drainage pattern with catchment characteristics or closed watershed conditions are available within study area (Shankar and Mohan 2005). Ground truth survey authenticates that most of derived gully plugged sites were duly

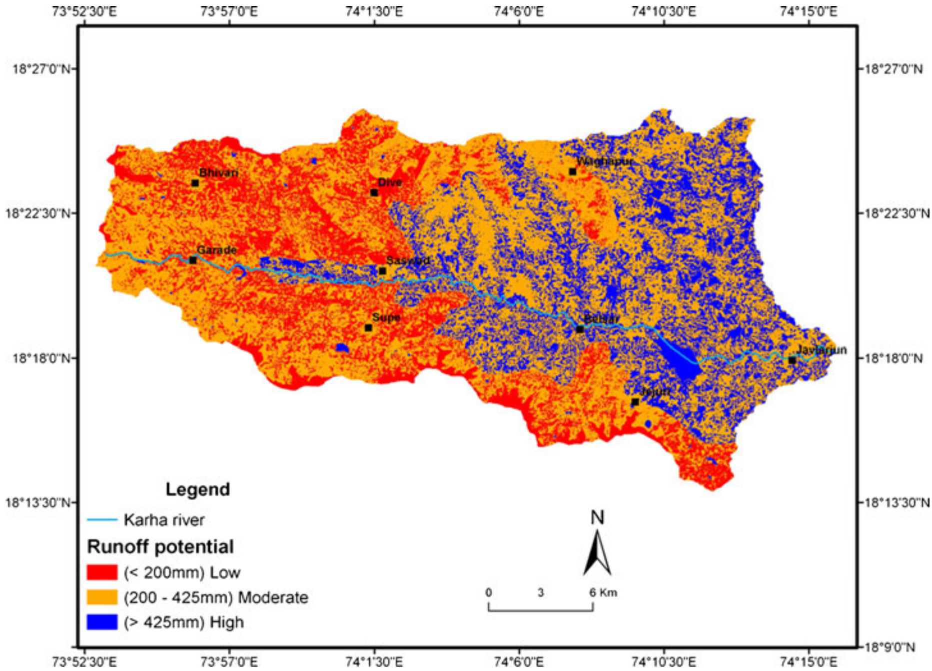

Fig. 7 Runoff potential of upper Karha watershed

constructed, while eight potential sites were identified. The gully plugs were identified on C and D soil type on the first order in hilly region with high slope and high runoff potential.

3.6 Accuracy of the Results

The landuse/landcover classification accuracy evaluated by confusion or error matrix, showed 89 % and 91 % accuracy for the producer and the user estimates respectively. Higher accuracy is maintained by using Landsat thematic mapper imagery of 30 m resolution to identify possible rainwater harvesting sites.

Accuracy assessment was carried out by overlaying the existing structures identified at ground truth survey on potential rainwater harvesting map (Table 7). Such a higher accuracy of the study (75–100 %) offers a good guidance for field implementation.

3.7 Future Management of Harvested Rainwater

The present study has best exemplifies the integrated approach of remote sensing and geographical information system in water resource development. Semi arid basaltic region is experiencing frequent water scarcity events usually strike in summer months as well as in drought years. Agriculture is prime resource of income for local inhabitants to meet their livelihood needs. The main constrain for agricultural production is availability of ample water in late summer months and rainwater harvesting practices may extend the periods of water availability in summer period. So, there is urgent need for construction of suitable rainwater harvesting structures to meet the water requirements of agriculture, and domestic use. Sometimes, droughts may generate severe water shortage for drinking purposes due to decline of groundwater table.

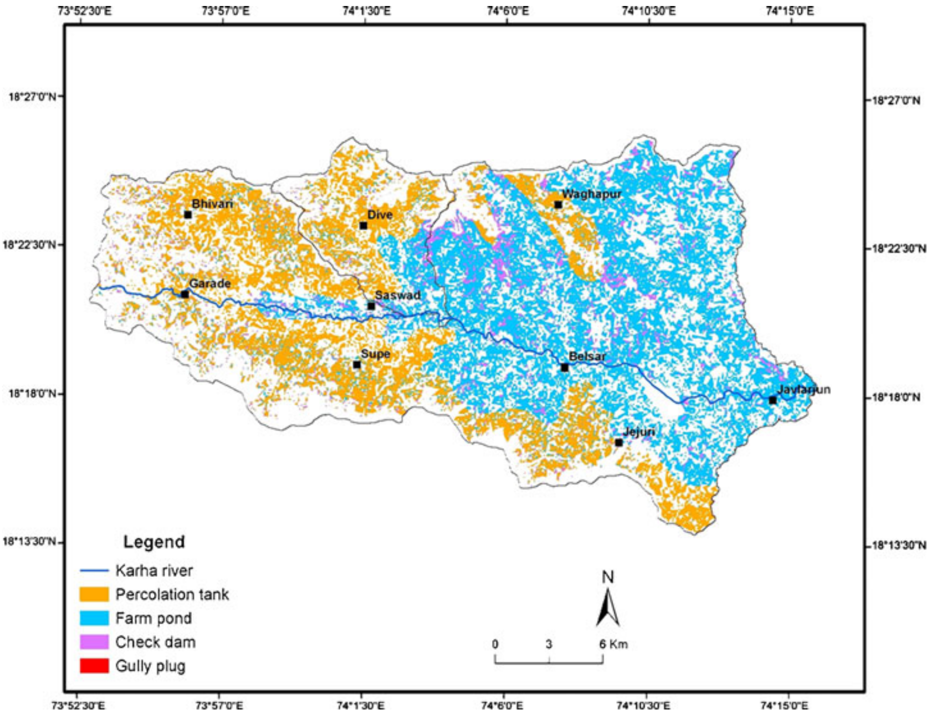

Fig. 8 Potential rainwater harvesting site map of upper Karha watershed

Identifying the suitable rainwater harvesting structures with the help of survey is one of the giant tasks for planner, so the advance method discussed in present study will definitely give correct idea about possible locations of rainwater harvesting sites. The harvested water may be supplied to nearby agriculture with the help of surface channels otherwise to be percolated for groundwater recharge. The availability of sufficient irrigation water in late summer months will definitely increase the crop yield and eventually improves the economy of the region.

To construct the proposed rainwater harvesting structures one has to rely on the government funding, however villagers can raise the funds with the help of nongovernmental organizations as well as from private sectors. If rainwater harvesting structures like percolation tanks requires huge amount. Government agencies can implement the rainwater harvesting program in

Table 6 Adopted specifications for potential rainwater harvesting structures

Structure	% Slope	Runoff potential	Landuse/landcover	Stream order	Catchment area (ha)	Soil type
Farm pond	0–5	Moderate/High	Scrub land	1	1 to 2	Sandy clay loam
Check dam	<15	Moderate/High	Scrub land/River bed	1 to 4	> 25	Sandy clay loam
Percolation tank	<10	Low	Scrub land	1 to 4	25–40	Clay
Gully plug	15–20	High	Scrub land	1	–	Sandy clay loam/clay

IMSD (1995)

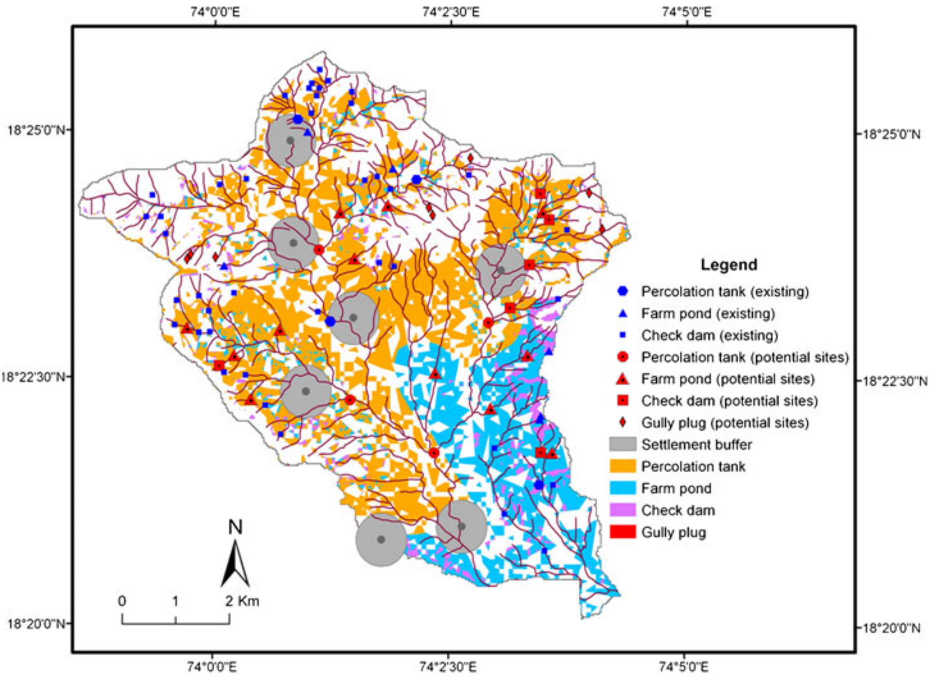

Fig. 9 Potential watershed area indicating analytically derived and ground truth validated sites for 'Rainwater harvesting structures' (Dive watershed)

Collaboration with international funding agencies such as World Bank, World Health Organization, Food and Agriculture Organization and UNICEF. To facilitate the phase wise implementation by the government and nongovernmental organizations, such watersheds needs to be prioritized. For planned use of harvested water, watershed prioritization is helpful to provide supplemental irrigation and ensure minimum submergence as most of the land use is under agriculture practices.

The final planning for construction of rainwater harvesting structures is taken by government agencies such as forest, agricultural and irrigation department. However, final decision lies with the farmer society who are suffers as well as beneficiaries of rainwater harvesting structures. Plan of potential rainwater harvesting structures put in front of village forum for final confirmation. Then execution of plan must be forwarded to concern governmental agencies. Villagers can also participate in implementation of rainwater harvesting structures by public participation program and raising funds for construction as well as maintenance of rainwater harvesting structures.

The prime advantage of these structures reduces the runoff velocity there by minimizes erosion and allow the retained water to percolate and thus results in increased recharge in the dug wells located downstream of the rainwater harvesting site. Potential sites can be built upon

Table 7 Accuracy of derived rainwater harvesting structure map of Dive watershed

Structure	Existing site	Potential site	% accuracy
Farm Ponds	4	12	80
Check Dams	40	9	75
Percolation tank	5	3	100
Gully Plug	–	8	90

Accuracy = % of existing sites matched with sites of derived map native agricultural systems and are with appropriate technology available in semi arid areas. However, spillway should be provided in the check dam to allow passing extra rainwater during monsoon season. The post monsoon flow is captured in the rainwater harvesting structures such as check dam and percolation tank. The present study can be replicated with minor adaptation for such areas all over.

4 Conclusions

SCS–CN method integrated with geographical information system is proved as an effective method in identifying suitable rainwater harvesting sites. This method has been effectively used in remote areas where less secondary data is available for identifying rainwater harvesting sites. As, semi arid basaltic region facing frequent water scarcity years due to erratic south–west monsoon, there is scant influx of recharge water at surface as well as subsurface aqueous system, warrants the extensive development of rainwater harvesting structures. The upper Karha basin of basaltic region mainly shows moderate to high runoff potential, which is suitable for potential rainwater harvesting structures.

The result shows that though 84 % of area suitable for potential rainwater harvesting structures and accuracy of method ranges from 75 to 100 % with potential rainwater harvesting structures map. Average accuracy of SCS-CN is 86.25 %, considering accuracy of farm pond, check dam, percolation tank and gully plug. In addition to this, field investigation of geology and hydro-geomorphology is also a prerequisite to authenticate the stability and storage of potential rainwater harvesting structures. In conclusion, SCS-CN method is effectively proven as a better technique, which consumes less time, higher accuracy and ability to handle extensive data set as well as larger geographical area to identify preliminarily rainwater harvesting potential sites.

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References

Abdulla FA, Al-Shareef AW (2009) Roof rainwater harvesting systems for household water supply in Jordan. Desalination 243:195–207

Aladenola OO, Adeboye OB (2010) Assessing the potential of rainwater harvesting. Water Resour Manage 24:2129–2137

Bean JE, Turner CA, Hooper PR, Subbarao KV, Walsh JN (1986) Stratigraphy, composition and form of Deccan Basalts, Western Ghats, India. Bull Volcano 48:61–83

Bhunya PK, Jain SK, Singh PK, Mishra SK (2010) A simple conceptual model of sediment yield. Water Resour Manage 24:1697–1716

Bo X, Qing-Hai W, Jun F, Feng-Peng H, Quan-Hou D (2011) Application of the SCS-CN model to runoff estimation in a small watershed with high spatial heterogeneity. Pedosphere 21:738–749

Chowdary VM, Ramakrishna D, Srivastava YK, Chandran V, Jeyaram A (2009) Integrated Water Resource Development Plan for Sustainable Management of Mayurakshi Watershed, India using Remote sensing and GIS. Water Resour Manage 23:1581–1602

Concepcion RN, Contreras SM, Sanidad WB, Gesite AB, Nilo GP, Salandanan KA, Manalang KM, de Vera SV (2006) Enhancing multi-functionality of agriculture through rainwater harvesting system. Paddy Water Environ 4:235–243

Dahiwalker SD, Singh RP (2006) Optimal design of intermediate storage for adoption of micro irrigation in canal command area, IE (I). Journal AG 18:19–24
Geetha K, Mishra SK, Eldho TI, Rastogi AK, Pandey RP (2007) Modifications to SCS-CN method for long- term hydrologic simulation. J Irrig Drain Eng 133(5):475–486
Handia L, Tembo JM, Mwiindwa C (2003) Potential of rainwater harvesting in urban Zambia. Phys Chem Earth 28:893–896
Harbor MJ (1994) A practical method for estimating the impact of land-use change on surface runoff, groundwater recharge and Wetland Hydrology. J Am Plan Assoc 60(1):95–108
Horton RE (1945) Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Geol Soc Am Bull 56:275–370
Ibrahim MB (2009) Rainwater harvesting for urban areas: a success story from Gadarif city in central Sudan. Water Res Manage 23:2727–2736
IMSD (1995) Technical guidelines, integrated mission for sustainable development, national remote sensing center (NRSC) Department of Space, Government of India
Jasrotia AS, Abinash M, Singh S (2009) Water balance approach for rainwater harvesting using remote sensing and GIS techniques, Jammu Himalaya, India. Water Res Manage 233:35–55
Kahinda JM, Taigbenu AE, Sejamoholo BBP, Lillie ESB, Boroto RJ (2009) A GIS-based decision support system for rainwater harvesting (RHADESS). Phys Chem Earth 34:767–775
Kale VS, Gupta A (2001) Introduction to geomorphology. Orient Longman Ltd., Calcutta
Kale SS, Kadam AK, Kumar S, Pawar NJ (2010) Evaluating pollution potential of leachate from landfill site, from Pune Metropolitan City and its impact on shallow basaltic aquifers. Environ Monit Assess 162:327–346
Khadri SRF, Subbarao KV, Walsh JN (1999) Stratigraphy, form and structure of the east Pune basalts, western Deccan Basalt Province, India. Geol Soc Ind Mem 43:72–202
Khaleghi MR, Gholami V, Ghodusi J, Hosseini H (2011) Efficiency of the geomorphologic instantaneous unit hydrograph method in flood hydrograph simulation. Catena 87:163–171
Kim SJ, Kwon HJ, Jung IK, Park GA (2003) A comparative study on grid-based storm runoff prediction using Thiessen and spatially distributed rainfall. Paddy Water Environ 1:149–155
Mishra SK, Tyagi JV, Singh VP, Singh R (2006) SCS-CN-based modeling of sediment yield. J Hydrol 324:301–322
Mishra SK, Pandey RP, Jain MK, Singh VP (2008) A rain duration and modified AMC-dependent SCS-CN procedure for long duration rainfall-runoff events. Water Resour Manage 22:861–876
Mohammed H, Yohannes F, Zeleke G (2004) Validation of agricultural non-point source (AGNPS) pollution model in Kori watershed, South Wollo, Ethiopia'. Int J Appl Earth Observ Geoinform 6:97–109
Moon SH, Lee JY, Lee BJ, Park KH, Jo YJ (2012) Quality of harvested rainwater in artificial recharge site on Jeju volcanic island, Korea. J Hydrol 414–415:268–277
Mondal MS, Pandey AC, Garg RD (2009) Groundwater prospects evaluation based on hydrogeomorphological mapping using high resolution satellite images: a case study in Uttarakhand. J Indian Soc Remote Sens 36:69–76
Pachpute JS, Tumbo SD, Sally H, Mul ML (2009) Sustainability of rainwater harvesting systems in rural catchment of Sub-Saharan Africa. Water Resour Manage 23:2815–2839
Pawar NJ (1993) Geochemistry of carbonate precipitation from the groundwaters in basaltic aquifers: An equilibrium thermodynamic approach. J Geol Soc India 41:119–131
Pawar NJ, Pawar JB, Kumar S, Supekar A (2008) Geochemical eccentricity of ground water allied to weathering of basalt from the Deccan volcanic province, India: insinuation on CO_2 consumption. Aqua Geochem 14:41–71
Ponce VM, Hawkins RH (1996) Runoff curve number: has it reached maturity? J Hydrol Eng 1:11–19
Ramakrishnan D, Durga Rao KHV, Tiwari KC (2008) Delineation of potential sites for water harvesting structures through remote sensing and GIS techniques: a case study of Kali watershed, Gujarat, India. Geocarto International 23(2):95–108
Ramakrishnan D, Bandyopadhyay A, Kusuma KN (2009) SCS-CN and GIS-based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin. India J Earth Syst Sci 118 (4):355–368
Sazakli E, Alexopoulosb A, Leotsinidis M (2007) Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. Water Res 41:2039–2047
Shankar MNR, Mohan G (2005) A GIS based hydrogeomorphic approach for identification of site-specific artificial-recharge techniques in the Deccan Volcanic Province. J Earth Syst Sci 114(5):505–514
Subbarao KV, Chandrasekharam D, Navaneethakrishanan P, Hooper PR (1994) Stratigraphy and structure of Parts of the central Deccan Basalt Province: Eruptive Models. In: Subbarao KV (ed) Volcanism-Radhakishnna Volume. Wiley International, pp 321–332
Todd DK, Mays LW (2005) Groundwater hydrology, 3rd edn. Wiley, New York

U.S. Dept. of Agriculture (USDA) Soil Conservation Service (1972) National engineering handbook, Section 4, hydrology. Chapters 7, 8, 9, and 10. U.S. Govt. Print. Off. Washington, DC

U.S. Dept. of Agriculture (USDA) (1986) Technical Release 55: Urban Hydrology for Small Watersheds

Vohland K, Barry B (2009) A review of in situ rainwater harvesting (RWH) practices modifying landscape functions in African drylands. Agric Ecosyst Environ 131:119–127

Widdowson M, Walsh JN, Subbarao KV (1997) The geochemistry of Indian bole horizons: palaeoenvironmental implications of Deccan intravolcanic palaeosurfaces. Geol Soc, Lond, Spec Publ 120:269–281

Winnaar G, Jewitt GPW, Horan M (2007) A GIS-based approach for identifying potential runoff harvesting sites in the Thukela River basin, South Africa. Phys Chem Earth 34:767–775

Zhan X, Huang ML (2004) ArcCN-Runoff: an ArcGIS tool for generating curve number and runoff maps. Environ Model Softw 19:875–879

Ziadat FM, Mazahreh SS, Oweis TY, Bruggeman A (2006) A GIS based approach for assessing water harvesting suitability in a Badia benchmark watershed in Jordan. In: Fourteenth International Soil Conservation Organization Conference: Water Management and Soil Conservation in Semi-Arid Environments, Marrakech, *Morocco*, 14–19 May