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ORIGINAL ARTICLE

Application of remote sensing and GIS for identification of potential ground water recharge sites in Semi-arid regions of Hard-rock terrain, in north Karnataka, South India

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Abstract
Hydro-geomorphological characteristics, together with soil, slope, lineament density and Land use Land cover are signatures of potential ground water recharge areas, and are vital for water harvesting. In the present paper, Fifth order sub-basins in Semi-arid regions of the Varada River basin in South India is studied for selection of suitable area for recharge and prioritize the sub-basins using Indian Remote Sensing satellite (IRS) P6; Linear Imaging Self Scanning Sensor (LISS III) and ArcGIS 9.2. The Fifth order sub-basins of the Varada River spread in Hard-rock terrain and of different agro-climatic zones. The study shows that there are significant spatial variations in the fifth order basins with respect to their morphometric characteristics such as the basin area, drainage density, bifurcation ratio, and circularity ratio, constant of channel maintenance and slope of the basin. These variations reflect the differences in the hydrological process in the different Sub-basins. Based on the variations in the linear, aerial, relief as well as the slope, lineament density, and precipitation pattern rankings are assigned for each parameter with respect to ground water recharge within the Subbasins. Weighted sum overlay for precipitation, Land use, soil and Water table fluctuation are used to select the suitable areas of recharge within the sub-basins. Buffers created for lineaments and drainage networks were intersected with the suitable area of recharge for the probable tank's locations for recharge. The tank locations identified after intersection and having higher stream orders are further filtered for the identification of potential sites for ground water recharge. In the prioritized sub-basins SB-8, SB-10, SB-11 locations have been selected for recharge.

Keywords Drainage characteristics · Prioritization · Ground water recharge · Semi-arid region · Weighted sum overlay · Hard-rock terrain · ArcGIS

Introduction

Ground water is a significant source for irrigation, especially in semi-arid regions of southern tropical region of Asia (Narayanamoorthy 2010). In particular, the Southern India where large area is under semi arid climate, and agriculture is a dominant activity, due to moderate annual rainfall, there is increasing dependency on ground water for irrigation. However, groundwater scenario is not very encouraging primarily due to the imbalance between recharge and the groundwater exploitation. In order to arrest the depletion in groundwater table, several measures including artificial groundwater recharge have been suggested (Muralidharan and Shanker 2000; Bouwer 2002; Lerner 2002; Anbazhagan and Ramasamy 2006). For sustainable watershed development activities, to arrest depletion of ground water, and to

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augment groundwater resources, identification of potential groundwater recharge zones is vital (Mondal et al. 2011).

Ground water recharge processes are influenced by geologic formations in addition to precipitation, soil type, slope, Land use–Land cover and drainage characteristics. Drainage network architecture in a basin, in-turn is a function of climate, geology and relief of the basin, and is used to understand the ground water potential zones in the basin (Pakhmode et al. 2003; Odi Reddy et al. 2004). Especially at Sub-basin level, drainage characteristics along with the precipitation in the basin provide an insight to assess the ground water recharge potential. In addition, Land-cover and Land use pattern are also frequently indicated to be one of the main influencing factors of the groundwater percolation system (Klocking and Haberlandt 2002; Batelaan et al. 2003 and; Batelaan and De Smedt 2007; Dams et al. 2008). Therefore, ground water recharge is a complex process where natural processes are intersected by human induced process such as Land use–Land cover modifications and hence need to be integrated. One of the cost effective and rapid techniques to understand groundwater percolation system is to integrate various data on geo-information through the application of Remote-sensing data followed by ground truth verification (Jha et al. 2007). Satellite data is proved to be effective to generate spatial information required for such an endeavor. Therefore, in the present paper, an attempt is made to identify potential ground water recharge areas and for prioritization of the Sub-basin through integration of all the influencing parameters and remote sensing and Geographic Information System (GIS) technology.

Semi-arid regions in Hard-rock terrains of South India where large area is under agriculture is an ideal condition for such a study. In particular, in Northern Karnataka, aquifers have been alarmingly exploited. Many watershed management schemes are being implemented in the region, especially in the Varada River basin in Northern Karnataka, but they have not yielded the expected results. Often flashy floods also occur in the region. Therefore, the Varada River basin spread in Semi-arid regions of Hard-rock terrain is selected for the study.

Study area

The study area constitutes the Varada River basin which is a tributary of the Tungabhadra River in Karnataka. The Varada River (14°6′ 25″ N to 15°7′ 10"N latitude and 74°52′ 6″ to 75°43 10″ E longitude) originates from the Varadamoola in the Western Ghat region of Uttar Kannada district, Karnataka (Fig. 1). The river flows eastward through the Uttar Kannada, Haveri and Shimoga districts of Karnataka, covering an area of 5635.47 km^2 in Northern Karnataka. It is a non-perennial river, fed by small streams like the Dandavati, Dharma, Nallur, and the Dodda halla, and subsequently, the Varada joins the Tungabhadra River at Galaganath further north (not seen in Fig. 1).

Preliminary data required for an integrated approach of analysis for ground water recharge is knowledge of the geology of the area, climate, groundwater aquifer status etc. Geologically, the Varada River basin is dominated by north-northwest trending meta-greywacke–argillite suite of rocks of the Late Archaean age and locally covered by lateritic rocks. The meta-greywackes are hard and compact, and have undergone Low-grade green schist facies metamorphism (Hegde and Chavadi 2009) and at this grade of metamorphism rocks are brittle and hence chances of fractures are more common. In South-Western part of the Varada River basin, there is a circular dome of massive granite of Precambrian age (Gupta et al. 1988). Greywackes are jointed invariably. Argillites are fine grained, well foliated, and deeply weathered (Fig. 2). Majority of the lineaments follow north northwest–south southeast trend which suggest strike slip movement in the area.

Climate in the basin varies from sub-humid in the west to Semi-arid towards east. Rainfall in the basin varies from 2700 mm in the western Ghat region to 550 mm in plains on the east with an overall average annual rainfall of 1100 mm. Aridity index which is a ratio of precipitation and potential evapo-transpiration varies from 0 to 4 in the basin (Biggs et al. 2007) and suggests that the study area is characterized by a varied climate. Groundwater level is a direct consequence of precipitation, particularly in the monsoon season, when the groundwater withdrawal is less (Raj 2001; Public Works Department 2008). Normal rainfall values (average annual rainfall for 26 years 1980–2006, Department of Water Resources, Bangalore) for the 13 rain gauges within the basin is used to construct isopleths map for the basin. The distribution pattern of the rainfall indicates that the sub-basins in the south have high precipitation than in the north (Fig. 3) (Online Appendix Table 1). Annual pattern of rainfall in the basin indicates that 80% of the precipitation occurs during Southwest monsoon period (June–September) and 20% in Northeast monsoon period (October–December).

Materials and methods

The Varada River basin is subdivided into 14 Sub-basins of the 5th order using Arc-hydro tools extension software of ArcInfo 9.2. Shuttle Radar Topographic Mission (SRTM) 90 m, digital elevation model is used to divide the basin into Sub-basins for each agro-climatic zone. Flow direction and water accumulations are derived using D-8 method (Fairchild and Laymarie 1991). Linear, areal and relief parameters of these 5th Sub-basins were derived from toposheets and satellite data; stream network of the Sub-basins was digitized from the Survey

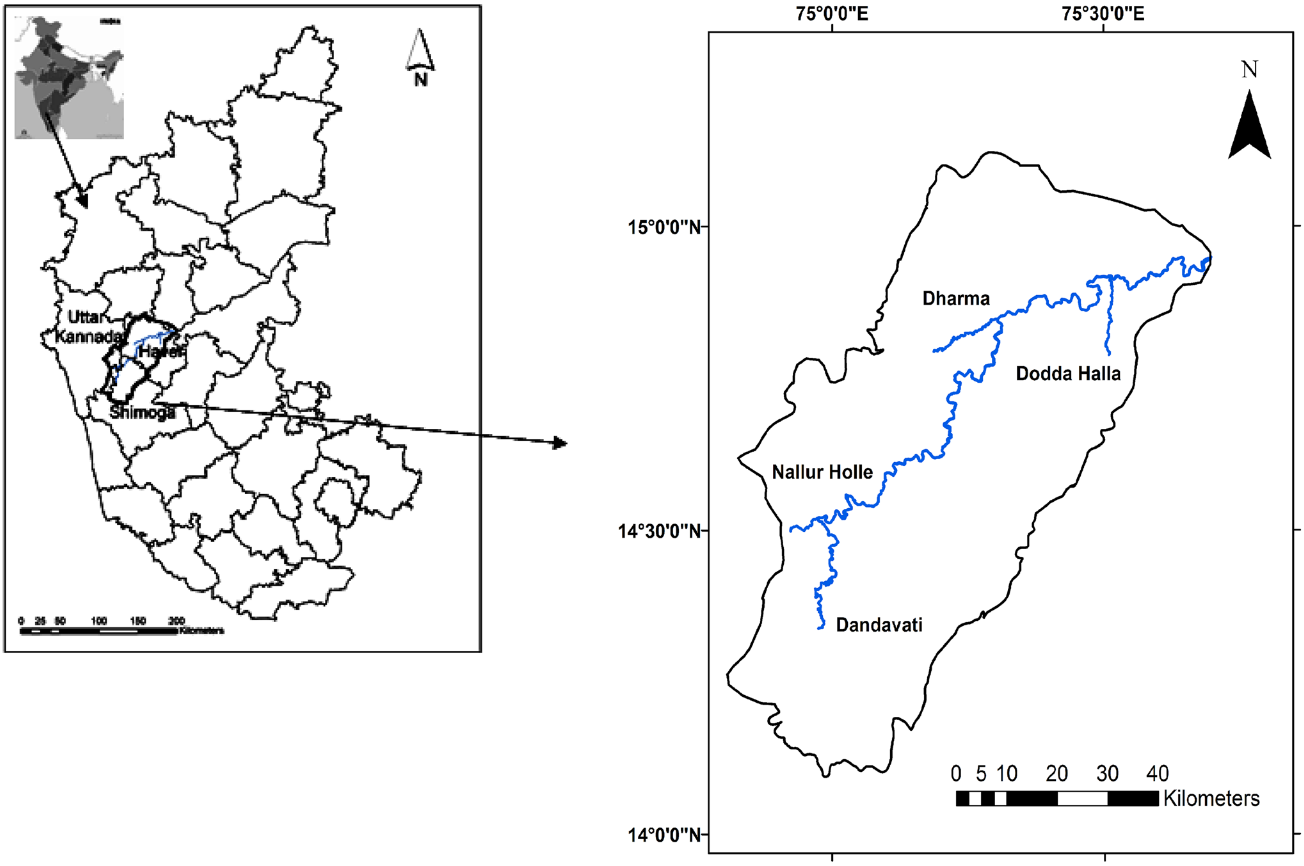


Fig. 1 Map showing location of the Varada River Basin in Central Karnataka, India and its tributaries Dandavati, Dharma, Nallur Holle, and the Dodda halla

of India toposheets of 1:50,000 scale using ArcGIS 9.2 version. Drainage characteristics such as drainage density, bifurcation ratio, constant for channel maintenance, stream frequency, length of overland flow, elongation ratio, circularity ratio, etc. were computed following the classical method (Horton 1945; Strahler 1957). Normal annual precipitation contours were generated using meteorological data. Ground water fluctuation map is derived from dug wells data of March and September for the 10 years (1992–2002) and pre and post-monsoon groundwater table fluctuation map for the basin is prepared. Based on the Indian Remote Sensing satellite (IRS P6) and Linear Imaging SelfScanning sensor (LISS III), employing image analysis techniques like image enhancement, edge enhancement and band combination, lineaments were traced and their directions were studied. Lineaments map generated using satellite image was superimposed on different thematic layers like the drainage, slope, etc. Rankings were given for each of the factors like annual rainfall distribution, soil type, land use, lithology, lineament density, and morphometric characteristics like topography, slope, and drainage density. The Watertable fluctuation map was overlaid on the Sub-basin and lineament density map to prioritize the sub-basins for ground water recharge. Prioritization rating of all the Sub-basins is carried out by calculating the compound parameter values.

Compound parameter is sum of the ranking assigned for parameters like drainage morphometry, lineament density, land use, soil, precipitation and watertable fluctuation, and defined as

$$\mathrm{Cf} = \sum wR_i, \quad (1)$$

where w is the weight assigned, R_i is the rank obtained for the parameters chosen.

All the parameters are given equal Weights. The sub-watershed with the lowest compound parameter value is given the highest priority. Weighted sum overlay for the sub-basins indicated the suitable areas of recharge within the sub-basins. Buffers created for lineaments and drainage networks were intersected for the probable tanks locations for recharge and were overlaid on the suitable area of recharge. The tank locations identified after intersection are considered as the potential sites for ground water recharge.

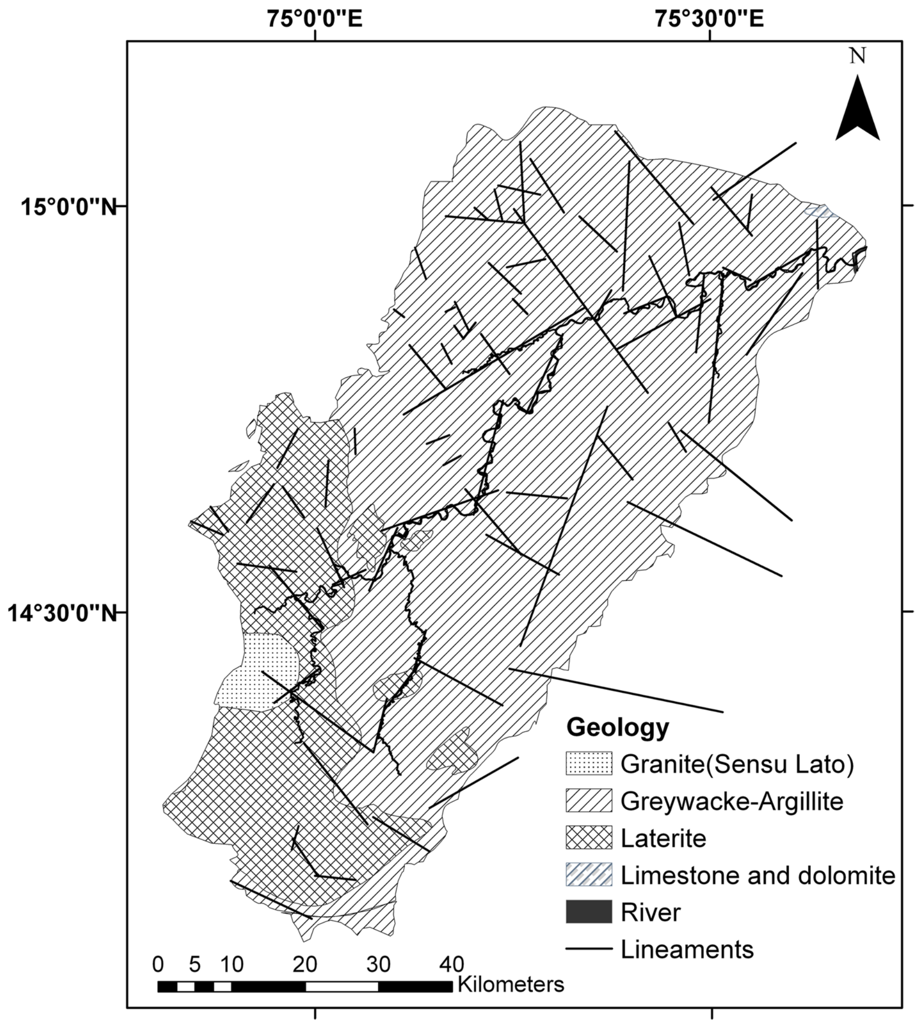


Fig. 2 Lithology of the Varada River basin showing dominance of meta-greywacke in the basin and Lineaments indicating structurally controlled drainage

Results and observations

Prioritization of the Sub-basins for groundwater recharge is a qualitative assessment of the watershed for management developmental works. Morphometric characteristics of the watershed are useful for characterizing watersheds (Nag 1998; Vittala et al. 2004) for prioritization of the micro-watersheds (Nookaratnam et al. 2005), and development of groundwater resources (Sreedevi et al. 2009).

Morphometric characteristics

Stream pattern and stream length:

Runoff potential from a basin for a given rainfall pattern is largely controlled by morphometric characteristics represented by drainage network/pattern, length, slope of the basin and area of the basin. The Varada is a 6th basin covering a drainage area of 5635.47 km^2. Drainage pattern of the basin indicate a dendritic type in the east, subdendritic towards the south, and parallel in the southwest (Fig. 4). Stream length is one of the most significant hydrological features of the basin. For the given basin relief, increase in length of the basin increases time of concentration. Higher time of concentration exposes the water intercepted by basin for longer durations of infiltration (and evaporation process and hence reduction in the runoff volume). Maximum length of the basin is 114 km. Ratio of the basin area to the basin length can be a measure of effectiveness for the percolation. For the Varada river basin, this ratio is 49.4:1 which is fairly high, hence scope for percolation.

Stream frequency (Fs)

Stream frequency or channel frequency (Fs) is the total number of stream segments of all the orders per unit area (Horton 1932). The average stream frequency value of the basin is 1.41. The stream frequency in the sub-basins ranges from 0.96 to 2.22 (Table 1). For 7 Sub-basins out of 14, stream frequency is below the average of the basin as a whole implying large spatial variability in drainage characteristics.

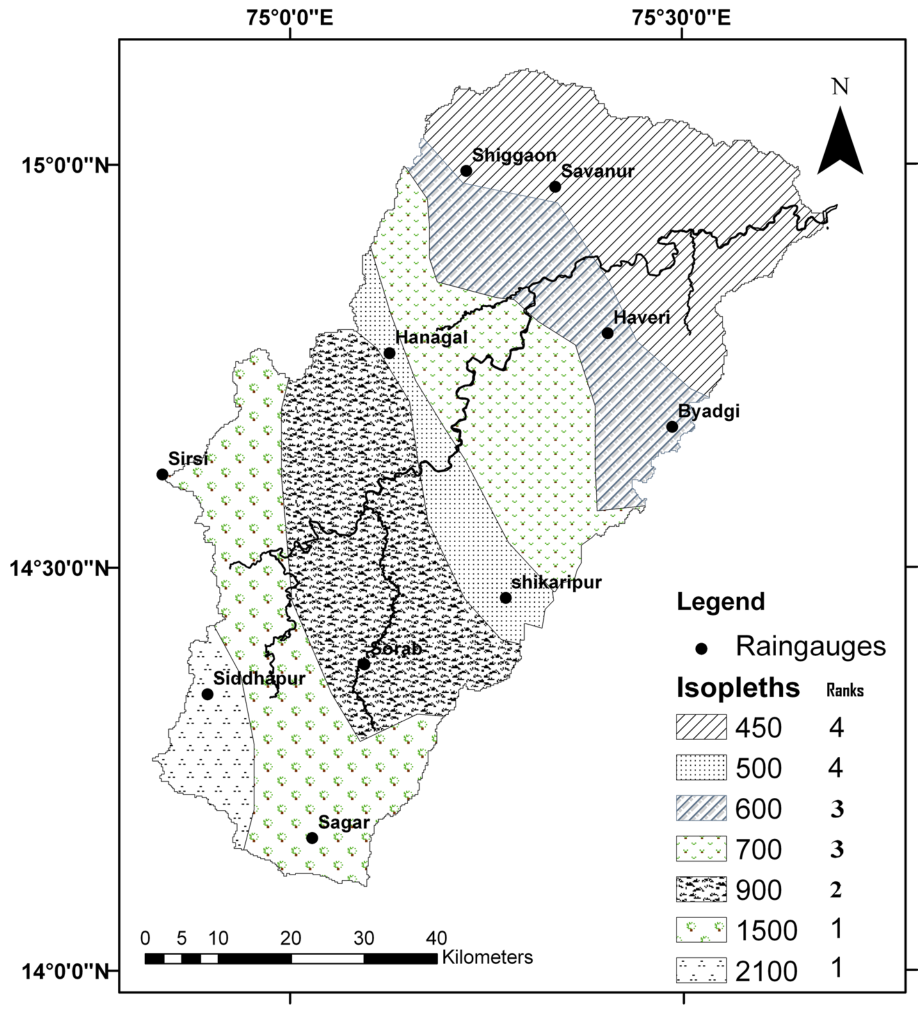


Fig. 3 Rain gauge locations in the basin, and Isopleths generated based on the data recorded at the rain gauges. Isopleths showing decreasing rainfall from west to east in the Varada River basin

Drainage density (D)

Drainage density (D) is the ratio of total channel segment lengths cumulated for all the orders within a basin to the basin area (Horton 1932). The drainage density of the basin is 1.15 despite of a large drainage basin, and for the sub-basin, it ranges from 0.91 to 1.92 km/km^2 (Table 1). It has been observed from the drainage density over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant subsoil condition (hard to carve many drainages) or highly permeable subsoil material (not many channels is required to drain out the water), under dense vegetative cover, and where relief is low (due to low energy of the flow to carve channels) while, high drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. In the study, area drainage density is low as compared to those in the western Ghat region or farther east. Therefore, low drainage density along with drainage frequency implies more percolation, hence potential for ground water recharge (Table 2).

Form factor ratio (R_f)

Quantitative expression of drainage basin outline-form was made by Horton (1932) through a form factor ratio (R_f), which is the dimensionless ratio of the basin area to the square of the basin length. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of the area, perimeter, and length (Singh 1998). The form factor value of the basin is low (0.42) and represents an oval shape of the basin. The form factors of the sub-basins range from 0.172 to 0.813 (Table 1). The elongated basins with low form factors imply more contact time of the surface water with the ground, hence more chance for percolation.

Elongation ratio (R_e)

Stanley and Schumm (1956), used an elongation ratio (R_e), defined as the ratio of diameter of a circle of the same area as that of the basin to the maximum basin length. It is a very significant index in the analysis of basin shapes which helps to gain an idea about the hydrological characteristics of a

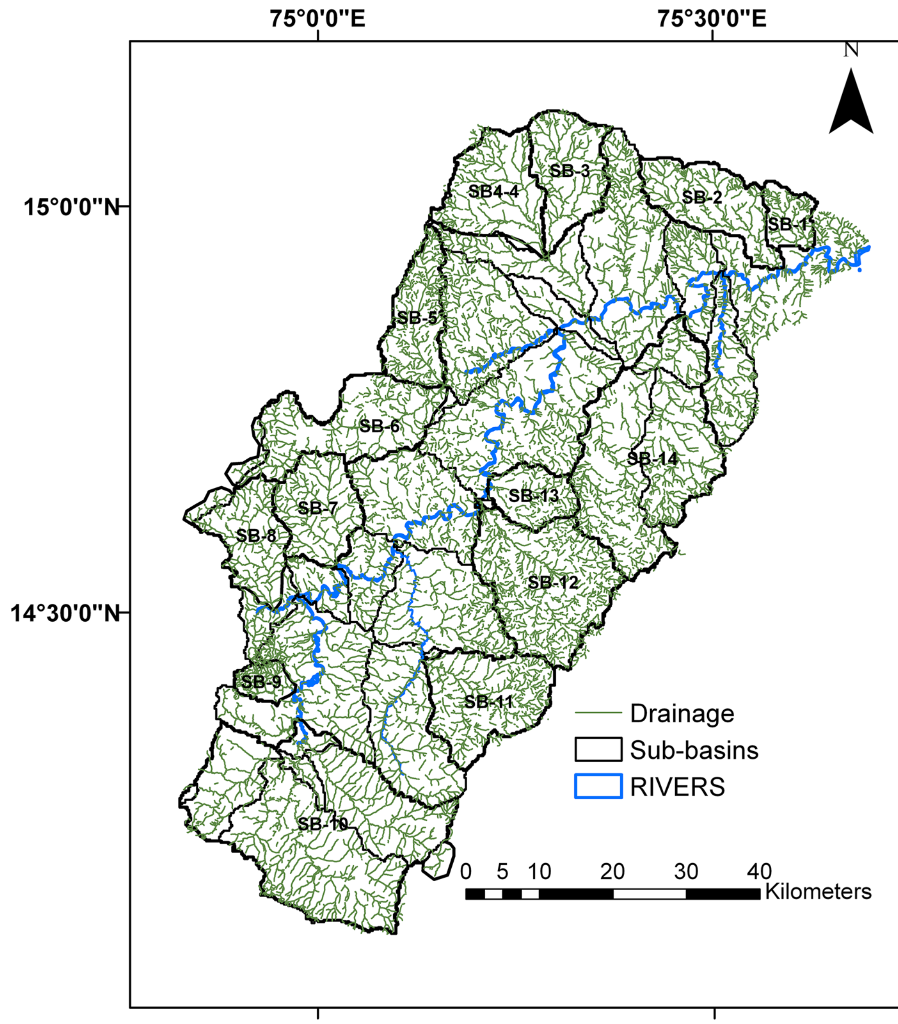


Fig. 4 Drainage map prepared for the Varada River basin based on the toposheets, SRTM DEM (90 m), and the Fifth order sub-basins delineated

Table 1 Morphometric properties of the Varada River basin and the Fifth order Sub-basins

	A	P	L	Fs	D	R_f	R_e	R_c	R_b	T	C_c
Basin	5325.5	385.5	114.7	1.41	1.15	0.41	0.72	0.42	3.2	6.63	
SB-1	51.43	39.11	9.75	2.35	1.71	0.54	0.83	0.42	3.13	2.20	1.54
SB-2	148.52	80.4	23.48	1.49	1.28	0.26	0.58	0.28	3.58	1.92	1.86
SB-3	142.76	74.4	18.9	1.35	1.25	0.40	0.71	0.32	3.44	1.79	1.76
SB-4	174.82	83.6	17.25	1.06	1.16	0.58	0.86	0.31	3.64	1.48	1.78
SB-5	131.84	74	19.31	3.19	1.68	0.35	0.67	0.30	4.98	4.11	1.82
SB-6	219.44	118.4	27.7	1.34	1.18	0.28	0.60	0.19	4.45	1.88	2.25
SB-7	137.12	64	14.82	1.17	1.25	0.62	0.89	0.42	3.51	1.91	1.54
SB-8	98.40	98.3	16.33	1.92	2.16	0.36	0.68	0.12	3.61	1.40	2.80
SB-9	68.12	22.3	7.8	2.03	1.21	1.12	1.19	1.71	3.31	4.34	0.76
SB-10	598.84	111.3	29.91	1.05	1.23	0.66	0.92	0.60	4.94	4.16	1.28
SB-11	194.52	83.2	17.86	2.00	1.33	0.61	0.88	0.35	4.35	3.65	1.68
SB-12	285	105.6	23.06	2.40	1.36	0.53	0.82	0.32	5.28	4.85	1.76
SB-13	137.12	64	14.82	1.17	0.91	0.62	0.89	0.42	3.51	1.91	1.54
SB-14	450.44	180.6	32.72	1.36	1.22	0.42	0.73	0.17	6.37	2.34	2.40

A area in Sq. km, *P* perimeter in km, *L* basin length in km, *Fs* stream frequency in No./ km^2, R_f form factor, R_e elongation ratio, R_c circularity ratio, R_b bifurcation ratio, *T* drainage texture, C_C compactness coefficient

Table 2 Prioritization for groundwater recharge based on drainage morphometry of the Fifth order Sub-basins

SB	Fs	Dd	R_f	R_e	R_c	R_b	T	Relief	Total	Ranking
SB-1	11	13	5	5	12	14	7	4	71	10
SB-2	7	8	14	14	5	9	8	1	66	8
SB-3	5	6	10	10	9	12	12	3	67	9
SB-4	2	1	4	4	7	7	13	12	50	4
SB-5	13	12	12	12	6	3	4	11	73	12
SB-6	4	2	13	13	3	5	11	2	53	5
SB-7	3	7	2	2	11	10	9	5	49	3
SB-8	8	14	8	8	1	8	14	13	74	13
SB-9	14	3	6	6	14	13	2	14	72	11
SB-10	1	5	1	1	13	4	3	8	36	1
SB-11	9	9	3	3	10	6	5	10	55	6
SB-12	12	10	7	7	8	2	1	9	56	7
SB-13	10	11	11	11	4	11	10	6	74	14
SB-14	6	4	9	9	2	1	6	7	44	2

Fs stream frequency, *Dd* drainage density, R_f form factor, R_e elongation ratio, R_c circularity ratio, R_b bifurcation ratio, T drainage texture

drainage basin. Values nearer to 1.0 are typical of regions of very low time of concentration resulting in peak flow and floods. The value Re of the basin is 0.72 and for the Sub-basins it ranges from 0.46 to 0.93 (Table 1) implying high spatial variability in the hydrological characteristics and hence needs to prioritize at the Sub-basins level for recharge program.

Circularity Ratio (R_c)

Miller (1953) defined a dimensionless circularity ratio (R_c) as the ratio of the basin area to the area of a circle having the same perimeter as that of the basin. He described the basins of the circularity ratios in the range 0.4–0.5 as strongly elongated and highly permeable. The circularity ratio of the Varada River basin is 0.42 which corroborate the fact that the basin is oval in shape characterized by low discharge, and subsoil condition is highly permeable. The circularity ratios for the sub-basins range from 0.14 to 0.43 (Table 1). The large range in the Circularity Ratio of the Sub-basins implies that there is a large spatial variation in percolation pattern. Hence, depending upon the Sub-basin characteristics, prioritization is essential for effective recharge and watershed management program.

Bifurcation ratio (R_b)

The term bifurcation ratio (R_b) is used to express the ratio of number of streams of any given order to the number of streams in the next higher order (Stanley and Schumm 1956). Bifurcation ratios characteristically range between 3.0 and 5.0 for the basins in which the geologic structures do not distort the drainage pattern (Strahler 1964). Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation within a basin among the drainages of different orders. Any significant variation within successive drainage orders implies drainage distortion such as due to lineaments, which can be potential sites for recharge; or due to climate or topography, then potential sites of floods. In either case, they are important for watershed management. In the study area, the mean bifurcation ratio for the basin is 4.66 while for the 5th order Sub-basins it varies from 1.13 to 5.38 (Table 1) which indicates that the basin is heterogeneous. Since at this basin scale, climate variation is less likely, hence possibly suggest structural control.

Texture ratio (T)

Texture ratio (T) which is dependent on the underlying lithology, infiltration capacity and relief aspect of the terrain, is an important factor in the drainage morphometric analysis. It is the ratio between the number of the First-order streams and perimeter of the basin. Coarse drainage texture in the basin facilitates ground water recharge than the fine texture. For the Varada river basin, the texture ratio is 6.63 and is categorized as moderate in nature. The Drainage texture in the Sub-basins varies from 0.45 to 4.85 (Table 1).

Compactness coefficient (C_c)

Compactness coefficient is used to express the relationship of a hydrologic basin with that of a circular basin. A circular basin has this value close to 1 and has less time of concentration and therefore less potential for ground water recharge. The compactness coefficient of the 5th-order basins vary from 1.52 to 2.63 suggesting that the basins have higher potential for groundwater recharge.

Relief parameters

The Varada basin is a flat terrain and the relief ratio in the sub-basins range from 0.004 to 0.014. The relief ratio may be defined as the ratio between the total reliefs of a basin to the longest dimension of the basin parallel to the main drainage line (Stanley and Schumm 1956). The slope of any terrain is one of the factors controlling the infiltration of groundwater into the sub-surface and also a suitability indicator from the groundwater prospect point of view. Higher slope area facilitates high run-off allowing less residence time for rainwater, whereas in the gentle slope area, the surface run-off is slow, allowing more time for rainwater to percolate and hence comparatively more infiltration. The low basin relief in the Varada River suggests high ground water prospects in the basin.

Ground water potential

Water-level fluctuation

In semi-arid regions of Hard-rock terrain where groundwater occurs in shallow weathered zones, the rise in groundwater level is a direct consequence of precipitation. The pre and post-monsoon water table fluctuation map (average of 10 years) indicates that, fluctuations above 4 m are in significant regions where ground water is exploited. Therefore, recharging these areas lead to sustainability. The Sub-basins SB7, SB-15, SB-17 have groundwater fluctuations more than 4m and therefore are priority basins (Fig. 5) (Online Appendix Table 2).

Lineament density

Lineaments are the linear, rectilinear, curvilinear features of tectonic origin and can be easily observed in a satellite image. These lineaments normally show tonal, textural, soil tonal, relief, drainage and vegetation linearity/ curvilinear

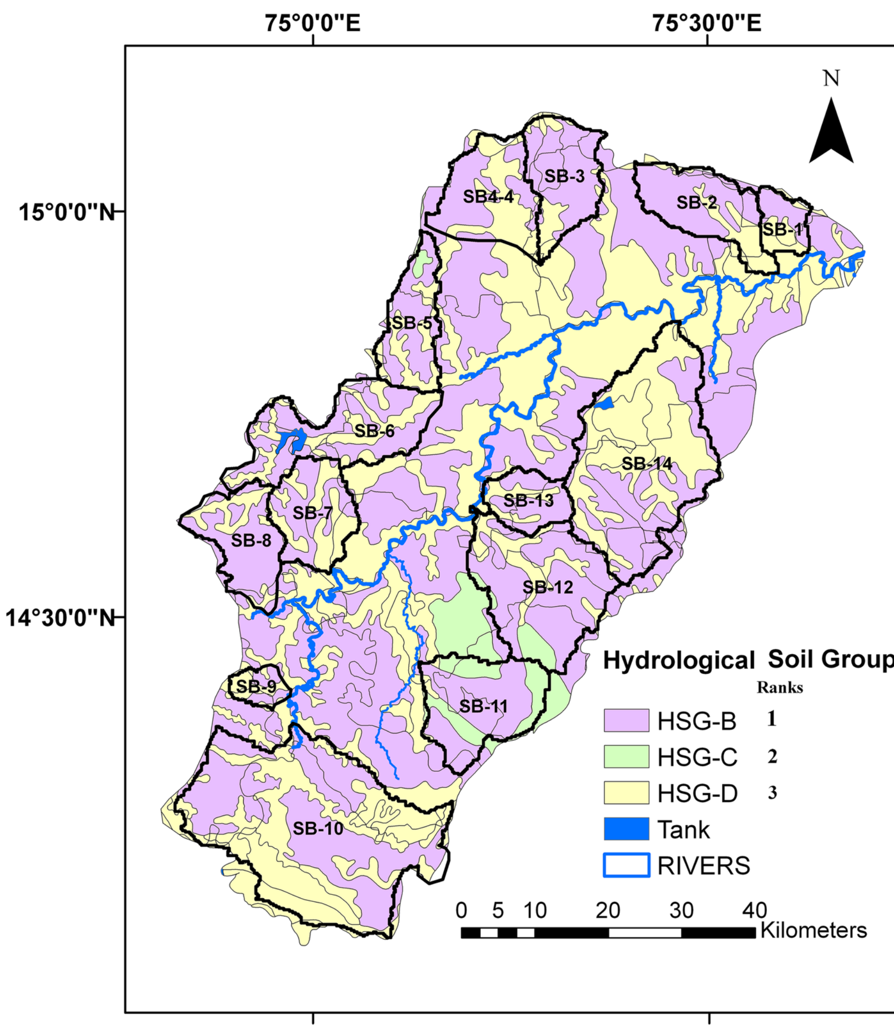


Fig. 5 Water-table fluctuations in wells within the Varada basin based on 10 years data. (Source: MGD, Karnataka)

in satellite data. They represent usually faults, joints, or boundaries between stratigraphic/lithologic formations and are considered potential areas for ground water percolation. All these linear features were interpreted from the IRS P6-LISS III satellite data and the lineament map is prepared for the Varada River basin. The lineament density is the total length of the lineaments per unit area. Higher the lineament density, higher is the percolation potential (Online Appendix Table 2). The lineament density in the Varada Sub-basins varies from 0.035 to 0.50 km/km^2.

Runoff potential

Runoff and percolation are influenced by soil and Land use/Land cover in addition to morphometric characteristics of the basin.

Soil

Soil conditions control the rate of infiltration and downward percolation of the water applied on the surface of the soil. The soil texture in the basin is cracking clay and fine clay loam. Soil types in the Sub-basins show large spatial variations. Gravelly clay is found in the uplands and clayey in the low lands in the northern part of the basin whereas in the South-eastern part, it is gravelly loam and gravelly clay. High porosity in the clay facilitates storage in the soil. Low permeability of clayey soils implies longer time for percolation of the ground water. Hydrological soil group classification (Source DRDO, Bangalore) (Fig. 6) indicates that most of the area comprises of Hydrological Soil Group (HSG) B and HSG D. HSG B has better percolation than HSG D (Bhagwat et al. 2011). Hence, HSG soil classification helps for decision making with regard to construction of recharge structure. Area weights are given for the soil hydrological groups in the basin (Online Appendix Table 3).

Land use and Land cover

Groundwater recharge is strongly influenced by the Land use pattern, and specific land use and irrigation patterns alter the groundwater recharge system (Mtembezka et al.

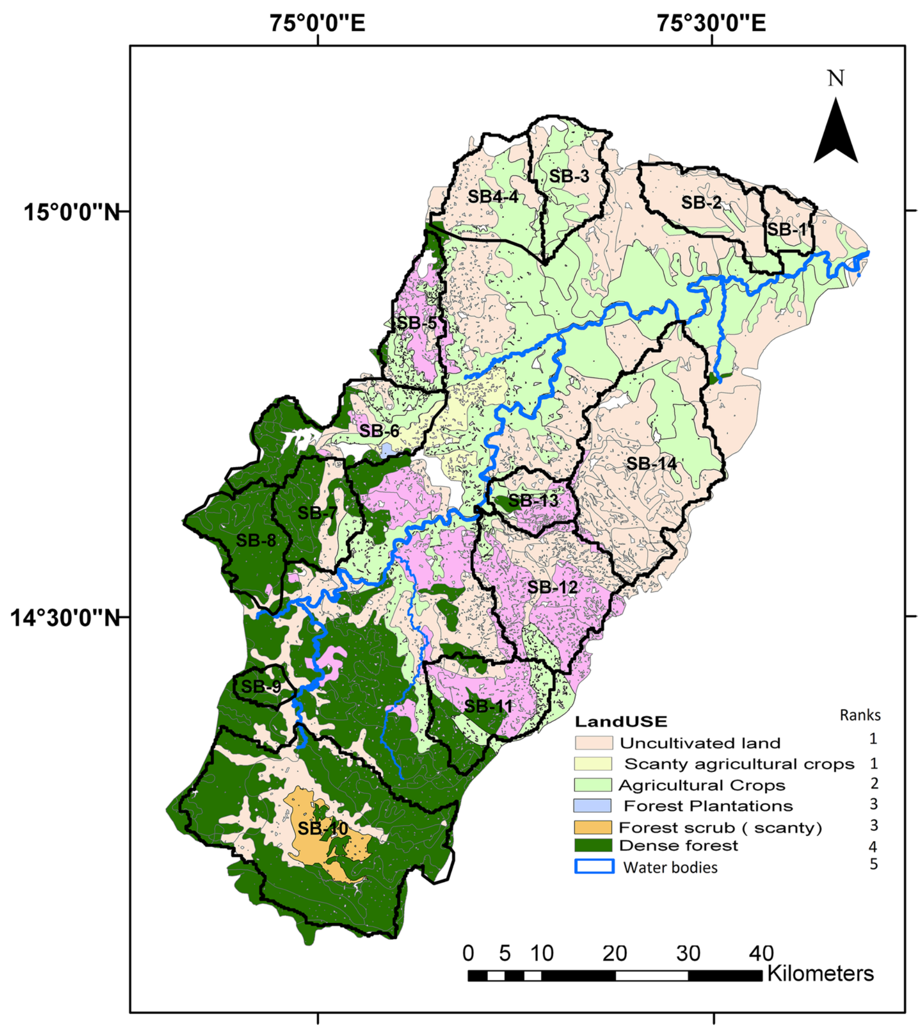


Fig. 6 Hydrological Soil Group (HSG) map of the Varada River basin used to understand soil group in the fifth-order sub-basins. (Source: WRDO)

1997). Changes in Land cover and Land use alter runoff behavior, and the balance that exists between evaporation, groundwater recharge and stream discharge in specific areas during and after precipitation events (Sahin and Hall 1996; DeFries and Eshleman 2004). These factors control the water yields of surface streams and groundwater aquifers and thus the amount of water available for both ecosystem function and human use (Mustard and Fisher 2004). Evapo-transpiration and interception (the storage of water on leaf surfaces) is higher in the forest cover areas than the grass or shrub-lands, all of which influence the amount of water available for direct drainage into streams or for aquifer recharge (Farley et al. 2005). The adjustment in the evapo-transpiration in deforestation/afforestation land, change is particularly acute. Trees generally have lower surface albedo, higher surface aerodynamic roughness, higher leaf surface area, and deeper roots than other types of vegetation, with each characteristics tending towards an increase in ground water recharge.

Land use map was prepared using field data set and IRS P6 image for the year 2006, and the basin is classified for level 1. Supervised maximum likelihood classification was adopted to categorize the land cover into five categories i.e. forest, forest plantation, agriculture crops, uncultivated land, and tanks. Land use/Land cover map of the study area indicates that tropical forests dominate the sub-basins located in the southern part of the basin while agriculture cropsland in the northern part of the Varada basin. Tropical forests, especially on the southern part the basin and agricultural cropland on the northern part of the basin suggest higher and lower potentials respectively, for ground water recharge (Fig. 7).

Area weights are given for the land use in the basin based on land use which can retain water for longer period and thus has probability for percolation. Tanks serve as significant sources for ground water recharge and are assigned highest weights "5" whereas for Forest and Forest plantations weights four and three are assigned

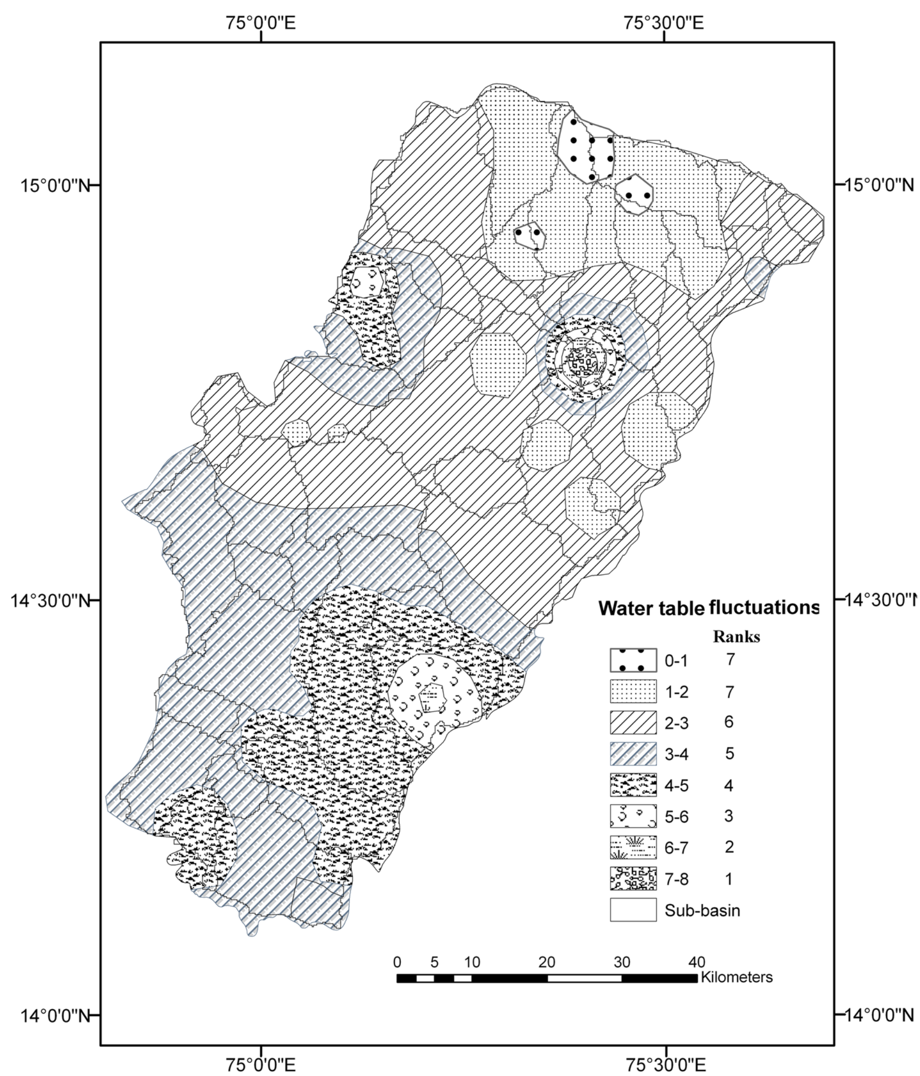


Fig. 7 Land use of the Varada basin in 2006. Map generated based on the supervised maximum likelihood classification of IRS P-6 Satellite data

respectively. Initial abstraction is more in vegetated land use than barren and hence high weight is assigned to vegetated land. Agriculture crops and uncultivated land are assigned weight two and one respectively.

Prioritization of the sub-basins for recharge

Based on parameters discussed above, compound factors are arrived and used for prioritization along with the other factors such as rainfall, and basins are identified for ground water recharge program (Table 3). Integration of the above with the morphometric parameters are used to select finally sub-basins for ground water recharge. The above exercise for sub-basins of the Varada indicated that among the 14 Fifth-order Sub-basins, Sub-basins SB 8, 10 and 11 are priority basins for ground water recharge as their ranking is high (Table 3) (Fig. 8).

Multi-criteria approach

Different approaches are followed for site suitability evaluation for water harvesting (c.f Malesu et al. 2007; Singh et al. 2009; Al-Adamat et al. 2010), etc. Malesu et al. (2007) used the criteria, which is largely governed by the FAO standards for the suitability for 4 different types of water harvesting systems viz roof-top, runoff tanks, ponds and pans, flood diversion and flow storage (i.e. sand dams), and in-field, techniques such as zai pitting and terracing are suggested. They opined that rainfall > 200 mm/annum is sufficient for all the above methods and slopes of < 2% are best suited to most of the techniques. However, ponds could be situated on slopes up to 8%, and in the present study, it is assigned highest priority. Singh et al. (2009) used the water balance approach together with the Integrated Mission for Sustainable Development (IMSD) guidelines for determining site suitability for water harvesting. These guidelines are specific to different types of water harvesting systems. Slopes up to 15% are considered suitable for some systems. The Varada River basin

Fig. 8 Priority sub-basins identified for groundwater recharge based on ranking

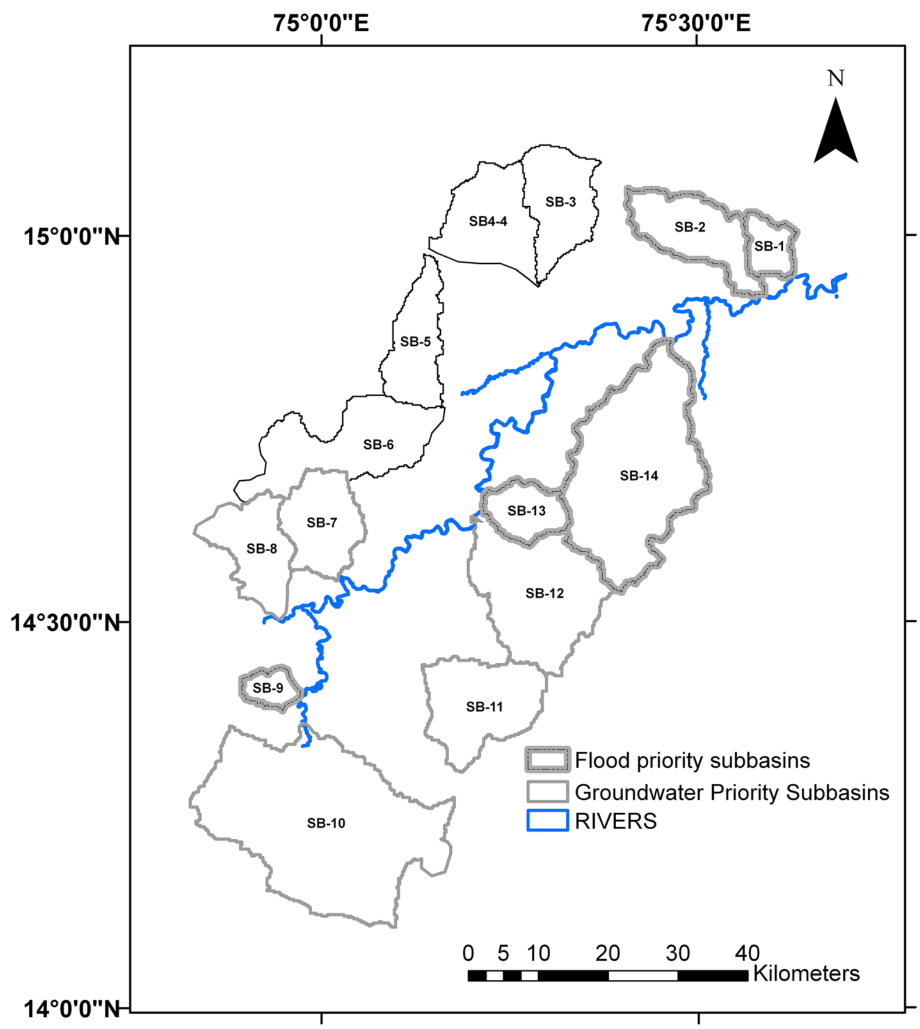


Table 3 Groundwater prioritization using drainage, soil, relief, lineament density, precipitation, and land use

SB	D	LD	LU	S	P	WTF	Cf	Rank
SB-1	10	14	13	10	7	12	66	14
SB-2	8	7	14	6	7	14	56	12
SB-3	9	10	11	3	7	13	53	10
SB-4	4	1	9	9	7	8	38	7
SB-5	11	12	8	8	6	2	47	9
SB-6	5	11	5	1	5	11	38	6
SB-7	3	4	6	11	3	6	33	4
SB-8	12	9	1	4	1	4	31	3
SB-9	14	5	2	13	2	5	41	8
SB-10	1	3	4	12	4	3	27	2
SB-11	6	2	7	2	1	1	19	1
SB-12	7	6	3	5	6	7	34	5
SB-13	13	8	10	7	6	9	53	11
SB-14	2	13	12	14	6	10	57	13

SB sub-basin, *D* drainage, *LD* lineament density, *P* precipitation, *LU* land use, *S* soil, *WTF* Water Table Fluctuation, *Cf* compound factor

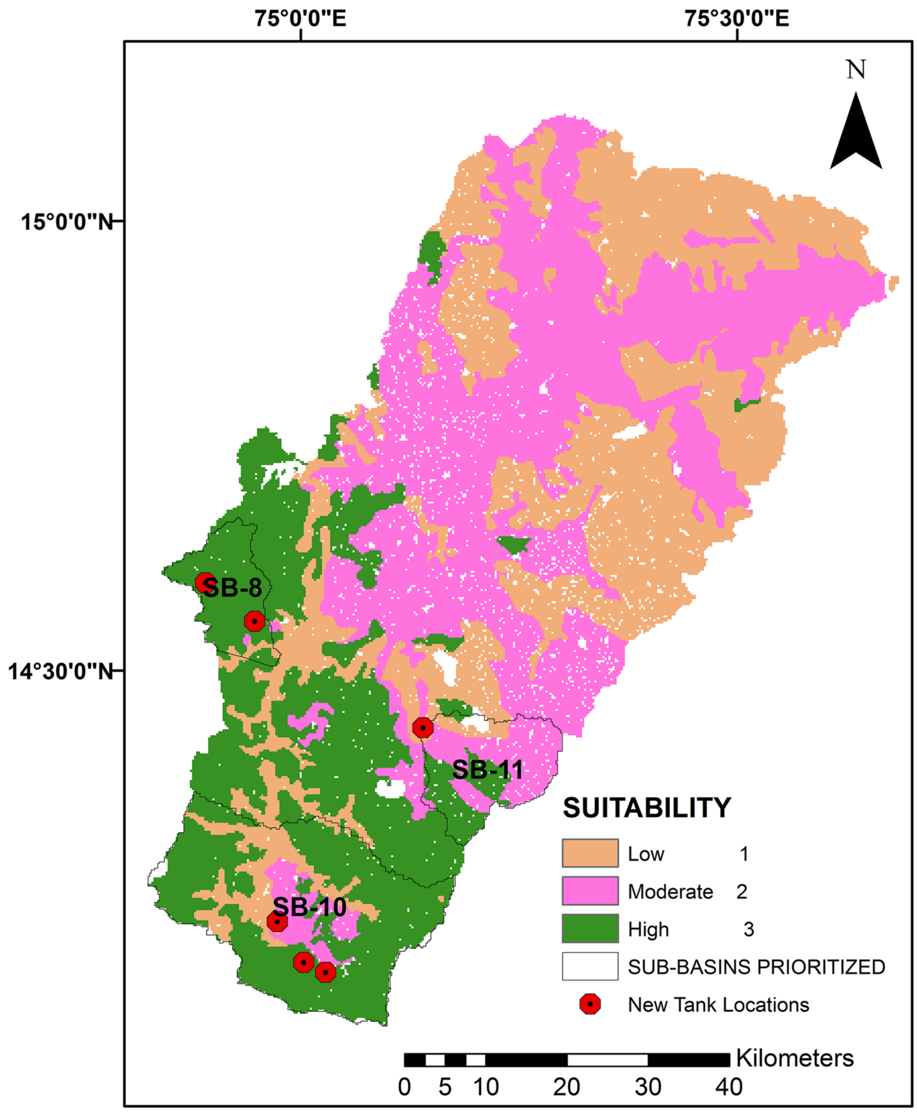
does have few areas where slope is more than 15%. Singh et al. (2009) also recommended Land use classes such as shrub land, barren land, or bare soils. Al-Adamat et al. (2010) proposed multi-criteria decision support system on a scale of 1–4 (with 4 being the most suitable) for harvesting. He ranked with rainfall < 100 mm/annum being least suitable and > 500 mm/annum most suitable, slope < 3% most suitable, while slopes > 10% least suitable; soils with clay content < 10% as least suitable and clay content > 35% most suitable. Experiences suggested that depending on the local conditions still sites are ranked as suitable, even though not all the selection criteria have been met (Al-Adamat et al. 2012).

In terrains like the Varada, with large spatial variability both in hydrological characteristics and slopes, and rain fall ranging from 550 to 2700 mm, and higher slope with high rainfall all are unique and challenging. Despite the higher slope, higher rainfall can facilitate percolation along the fracture system in Hard-rock terrain. Therefore in the present study we follow multi-criteria decision support system involving lineament density in addition to the slope, soil type, thickness of the soil cover, rainfall, etc in the scale of 1–5, 5 being the best suited. The results obtained are presented in the Fig. 8. On these, tanks distribution map is overlaid. Based on the inspection such as slope, lineament crossing, and drainage, locations are identified for new tanks for groundwater recharge (Fig. 9). If tanks already exist in the location, physical verification of the tanks is suggested for any improvement required such as maintenance etc. These tanks help not only for recharge, but also surface storage for supplementary irrigation and flood control as well.

Conclusion

From the above study, it can be concluded that in arid zone, due to high evaporation rates and moderate rainfall, there is water resources problem and artificial ground water recharge is the viable attractive option. In Hard-rock terrain percolation is localized i.e. at joints or lineaments/faults, and locations where lineaments intersect are the potential sites for artificial recharge. Drainage characteristics and morphometric characteristics are potential indicators of a basin response to hydrology. Percolation is also a function of Water-table fluctuation, soil cover thickness, Land use–Land cover and rainfall pattern in the basin. For identification of suitable area for recharge, all these parameters are to be integrated, and multicriteria approach enables us to select potential area for recharge. Integration of spatial and non spatial data for further targeting is suggested more appropriate locations such as lineament- intersection for artificial recharge program at a finer resolution. In the present study, employing these techniques and adopting ranking system, 3 Fifth-order sub-basins are identified within the Varada River basin for recharge program.

Fig. 9 Identification of new Tank locations within the Varada River basin for ground water recharge using multicriteria approach



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