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Identification of the Recharge Sites Using Remote Sensing and GIS in Hard Rock Terrain

P. Lakshminarayana[1] and B. Venkateswara Rao[2]

[1]*Central Research Institute for Dryland Agriculture, Hyderabad-500 059, Telangana*
[2]*Center for Water Resources and Director School of Continuing Distance Education, JNTUH, Hyderabad-500 082, Telangana*

Email: narayan_polak@yahoo.co.in

ABSTRACT: Upper Yerrakalava river basin, a part of the Kolleru-Upptuteru catchment lies between Krishna and Godavari river delta is experiencing fall in groundwater levels in recent years. It was identified that groundwater fall is more in sandstone terrain than in khondalitic terrain. To improve the groundwater levels, a study on multi layer analysis was conducted to identify the recharge sites. This included the rainfall and groundwater level analysis, preparation and integration of spatial maps like drainage, lithology, structures, geomorphology and land use/land cover. The final integrated layer was prepared by using weighted aggregation method and was classified into areas of high to low recharge using standard deviation as classification parameter. Remote sensing and GIS techniques were used in preparation of the thematic maps. Geologically, the area had three major rock types namely sandstones, khondalites and granite gneisses. Geomorphologically, 80% of the area was occupied by pediment deeply weathered and pediment moderately weathered material. Crop land and cropland mixed with plantation covered 59% of the area. Rainfall registered an increasing trend in most of the area. The final integrated layer had the recharge areas of very good (2.07%), good (7.15%), moderate (22.8%), poor (56.53%) and very poor (11.44%). Very good recharge locations were identified where fractures were available with good drainage in sandstone terrain, pediplain deeply weathered and double cropped lands. Very poor recharge locations were identified where no fractures and no drainage, steep slopes in khondalitic terrain occupied with forested lands.

Key words: Remote sensing, groundwater recharge, Yerrakalava

Groundwater, the largest available fresh water resource on planet earth is depleting faster in rural as well as in urban areas. In India, irrigation systems are expanding and converting rainfed agriculture into irrigated agriculture, improving the food security and economic growth but threatening the water resources sustainability. More than half of the net irrigated area in India (Deb Roy and Shah, 2002) is from groundwater irrigation and gives high crop yields than other irrigation sources (Dhawan, 2000). The groundwater use has increased in some states like Punjab, western U.P, Telangana and Andhra Pradesh due to subsidized electricity. A direct consequence of the overexploitation of the shallow crystalline aquifer systems is the long term drop in groundwater levels (Massuel *et al.,* 2013) which threatens farmer's livelihoods. Hard-rock and semi-arid regions are particularly sensitive to overexploitation. The storage is determined by aquifer geometry, hydraulic properties of the aquifer and also the recharge which are highly variable in these hard rocks (Maréchal *et al.,* 2006). Venkateswa Rao *et al.* (2011) has found that the deeper groundwater withdrawal, there is the possibility of more rainfall recharge and causing the less or no runoff to the downstream. In recent years, remote sensing (RS) and GIS techniques are playing very crucial role in mapping, analysis and modeling of water resources. Many studies have been undertaken on groundwater and recharge estimations (Batelaan and De Smedt, 2007; Dripps and Bradury, 2010; Engott, 2011 and 2007; Gingerich, 2008; Chatterji *et al.,*1979; Chatterji and Singh 1980a, 1980b; Agarwal *et al.,* 1992; Rao *et al.,* 2001) using remote sensing and GIS techniques. Saraf and Choudhury (1998) concluded that delineation of information on geology, geomorphology, land use/land cover and lineaments etc. will give the broad picture of the occurrence and movement of groundwater. Venkateswara Rao (2007) has employed the integrated geomorphological and geophysical techniques in identification of potential groundwater zones. Earlier Dee *et al*. (1973) have developed a methodology on environmental evaluation system (EES) for conducting environmental impact analysis of large water resources development projects. Aller *et al*. (1987) have proposed a system to evaluate groundwater pollution potential using hydrogeologic parameters. Venkateswara Rao (2009) has developed an improved methodology for identification of groundwater potential zones in a typical khondalitic terrain.

Upper Yerrakalava river basin which exists in West Godavari and part of Khammam district is experiencing the fall of groundwater levels in recent years. This was confirmed by groundwater level analysis in khondalites and sandstone terrains in the study area. To improve the groundwater levels, a study on multi layer analysis was conducted to identify the recharge sites. The objectives of the present study are (1) to study the variations in rainfall and groundwater levels, (2) to prepare and analyze the spatial maps on drainage, lithology, structure, geomorphology and land use/land cover and, (3) to prepare integrated map with different recharge areas varying from high to low recharge conditions.

Materials and Methods

Study area

Upper Yerrakalava basin is the part of Kolleru–Upputeru catchment lies in between Krishna and Godavari deltas of Andhra Pradesh, India. The basin occupies an area of 1208 km^2 and lies between 80° 53' 28" to 81° 23' 8" East longitudes and 17° 01' 46" to 17° 23' 34" North Latitudes (Figure 1). Physiographically, most of the area is covered by isolated hills with some undulating topography except the northeastern hilly terrain with steep slopes covered by thick forest. The elevation is ranging from 79 m in the south to 663 m amsl in the north east region. Soils in the area are red sandy and red loamy type. Geologically the area has three rock types namely sandstones, khondalites and granite gneisses. Agriculture is the prime source of income. Cropland and cropland mixed with plantations are occupying major area. The average annual rainfall is 1083.4 mm with a minimum assured rainy days of 55.

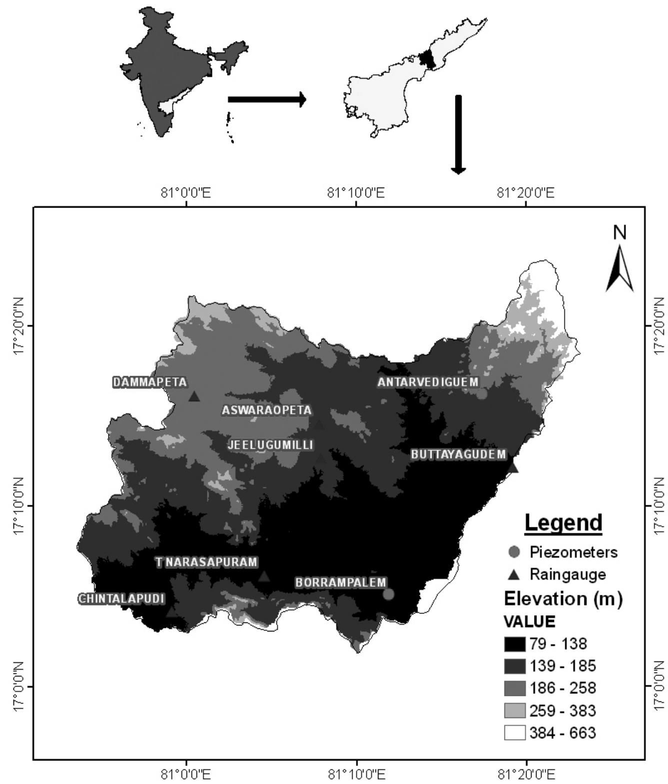

Fig. 1 : Location map of the study area

Collection of data

Rainfall data were collected from department of Economics and Statistics, Govt. of Andhra Pradesh. Monthly groundwater levels were collected from state groundwater department, Govt. of Andhra Pradesh. Satellite images were collected from NRSC, Govt. of India. While, toposheets from Survey of India. Geology map was collected from Geological Survey of India. The details of the data collected for preparation of thematic maps are depicted in Table 1.

Monsoon rainfall and groundwater levels

Rainfall and groundwater levels of the monsoon period of the study area were analyzed by selecting two wells in such a way that one well exists in khondalitic terrain and the other well in sandstone terrain. The rain gauges nearer to these wells were selected to measure the amount of monsoon rainfall. The monsoon groundwater levels are varying spatially and temporally. The temporal change in groundwater levels are calculated by subtracting the water level in the month of May from month of November.

Preparation of thematic maps

Thematic maps on drainage, geology and structures, geomorphology, and land use/land cover have been prepared by integrating the information from topo sheets, remote sensing images and ground truth data in GIS platform. Visual image interpretation techniques have been employed in delineating the thematic maps. In the preparation of theme maps, specific guidelines prepared by NRSC under Integrated Mission for Sustainable Development (NRSC, 1995) and Rajiv Gandhi National Drinking Water Mission Project (NRSC, 2007) have been followed. The methodology includes (1) interpretation and mapping of data on trace paper, (2) scanning of trace paper and geo-rectification, and (3) digitization and creation of database in GIS. Two software's namely ERDAS Imagine 9.1 for image analysis and Arc GIS 9.3 for mapping and integration of the information have been used.

Table 1 : Summary of the data used in the study

Type of data	Data description	Data period	Source
Topo sheet	65C15, 65C16, 65G3, 65G4, 65G7 and 65G8 on 1:50,000 scale	1972 to 1987	Survey of India, Govt. of India
Satellite data	IRS-P6 LISS-III FCC Geocoded hard copy data on 1:50,000 scale of *rabi* season and digital data of *kharif* season	*Kharif* season: 19-11-2004, 24-11-2004 and *Rabi* season: 28-02-2005, 19-03-2005	NRSC, ISRO, Govt. of India
Geology	Geological and minerals map on 1:2,50,000 scale	1996	Geological Survey of India
Rainfall	Daily rainfall data	2000-2011	Department of Economics and Statistics, Govt. of Andhra Pradesh
Groundwater	Monthly groundwater readings	Khondalite terrain: 2001-2011 Sandstone terrain: 2004-2011	State Ground Water Department, Govt. of Andhra Pradesh

Results and Discussion

Trends in rainfall and groundwater levels

The graph in Figure 2, shows that the groundwater levels are following the rainfall trend. However, it has also been observed that, there is a long term rise in the groundwater levels in the khondalitic terrain (Figure 2A) with increase in rainfall, while in the sandstone terrain (Figure 2B), there is a fall in groundwater levels with increase in rainfall. The fall in groundwater levels in the sandstone terrain may be due to extensive and intensive agriculture development in recent years.

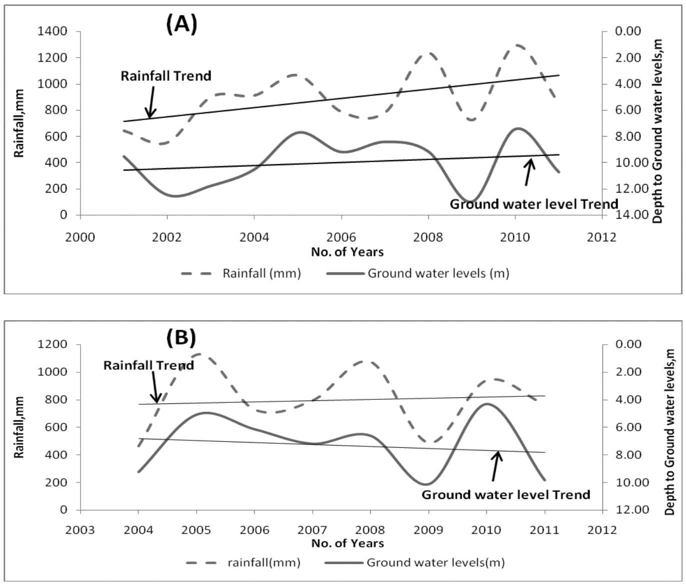

Fig. 2 : Long term trends in rainfall and groundwater levels of monsoon season in (a) Khondalitic terrain and (b) Sandstone terrain

Geology and structures

Geological setup of an area plays a very vital role in the distribution and occurrence of groundwater (Krishnamurthy and Srinivas, 1995). The study area is having Chintalapudi sandstones (Gondwanas) and its sub-classes covering an area of 81.65%, khondalites with 16.81% and granite gneisses with 1.54%. Table 2 gives the details of each rock group and its coverage in the study area.

The central part of the study area is occupied by sandstone with major and minor fractures and having the possibility of more recharge. Khondalites cover the north-eastern part with moderate fractures occupied with thick forest. Granites are located in south western part as a small patch. Fracture zones which control the occurrence and movement of groundwater were classified as major and minor based on the length. The fractures with a length of 3 km or more are called major fractures and less than 3 km are called as minor fractures. The geology and structural map is shown in Figure 3.

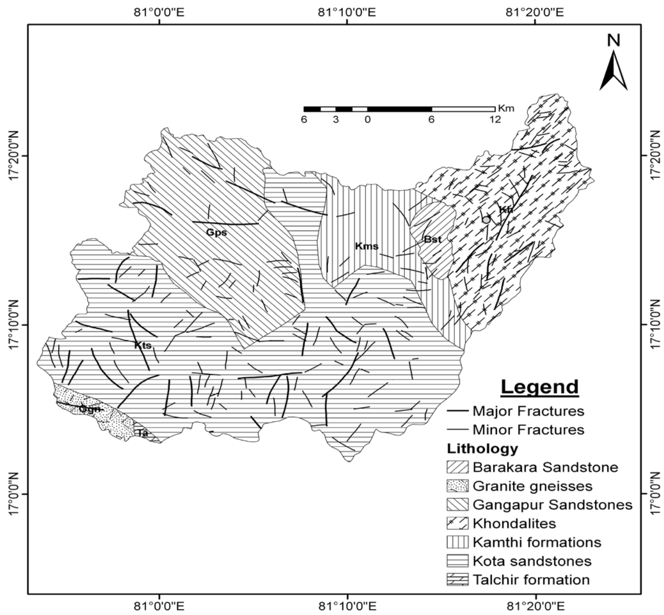

Fig. 3 : Geology and structures

Streams and water bodies

Stream patterns are extremely helpful in the interpretation of structural and lithologic control and also in the evolution of landforms. Detailed analysis of stream pattern may provide the clue about the groundwater potential in the area. The streams in the area represent mostly dendritic to sub-dendritic patterns in nature. Stream density is more with a value of 3.94 km/km^2 in north-eastern hilly terrain covered with khondalites and west central and central part covered with Kota sandstones. Stream density is medium in the southern part and very less in northern and south western part. Low drainage density in this area may be

Table 2 : Geology of the study area

Geological group	Geological unit	Area, km^2	Area, %
Archeans	Khondalites	201.64	16.81
	Granite gneiss	18.47	1.54
Sandstones	Talchir formation	2.49	0.21
	Gangapur sandstone	244.93	20.42
	Kamthi sandstone	113.72	9.48
	Kota sandstones	593.37	49.46
	Barakar sandstones	25.03	2.09

due to high infiltration rate of the soft rocks like sandstones. The area is covered by many storage structures such as, reservoirs and tanks. Two reservoirs namely Yerrakalava (Southern side) on Yerrakalava river, and Jalleru on Jalleru vagu (North-eastern side) were constructed for irrigation and flood moderation in downstream areas. Minor tanks are observed mostly on 1st and 2nd order streams and major tanks are observed on 3rd or 4th order streams. In south-western side, tanks without drainage are observed which may be due to high infiltration in the area. The drainage map of the study area is given in Figure 4.

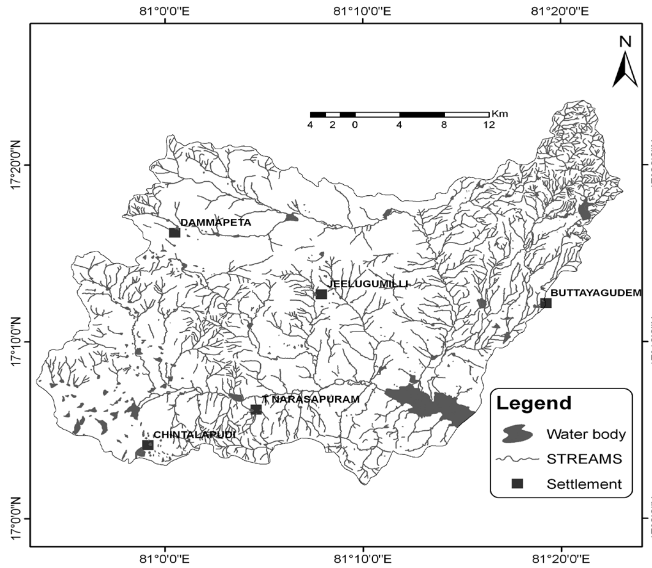

Fig. 4 : Streams in the study area

Geomorphology

Geomorphology of an area can give the indirect information about the groundwater potential. It is also helpful in selecting the artificial recharge sites (Ghayoumian, 2007). In the study area, various land forms have been identified. The list of geomorphic units with areas and corresponding geological units are given in Table 3. Figure 5 shows geomorphologic map of the study area.

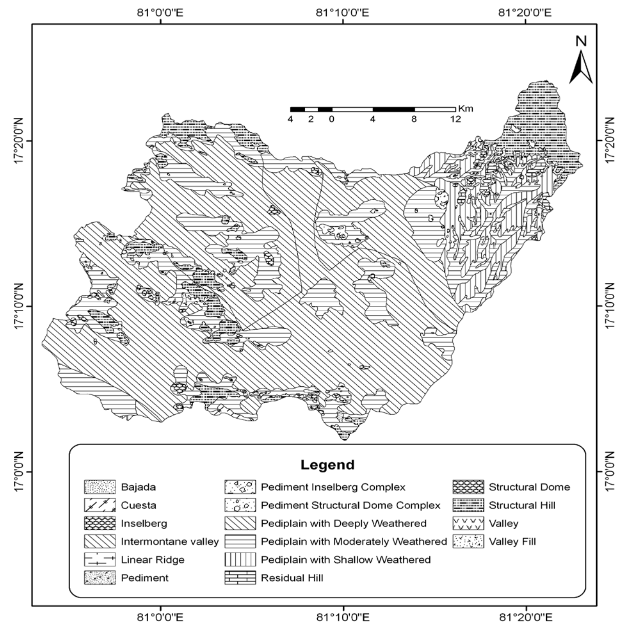

Fig. 5 : Geomorphologic map

Table 3 : Distribution of geomorphic units

Geomorphic unit	Geologic units	Area, km2	Area, %	Depth of weathering, m
Bajada (BJ)	Kh, Ggn	2.80	0.23	---
Cuesta (CU)	Kts	2.20	0.18	---
Inselberg (I)	Kh	3.60	0.26	---
Intermountain valley (IV)	Kh	1.08	0.09	---
Linear ridge (LR)	Gps, Bst, Kts	2.10	0.18	---
Pediment (PD)	Kh, Kts	1.91	0.16	---
Pediment inselberg complex (PIC)	Kh	1.69	0.14	---
Pedimont structural dome complex (PSDC)	Kms, Bst, Gps, Kts	7.45	0.62	---
Pediplain deeply weathered (PPD)	Gps, Kms, Kts, Ta	654.0	54.52	> 20
Pediplain moderately weathered (PPM)	Gps, Kh, Kts, Kms, Bst, Ggn	316.4	26.37	10 - 20
Pediplain shallow weathered (PPS)	Kh, Ggn	83.00	6.92	≤ 10
Residual hill (RH)	Kh	7.30	0.61	---
Structural dome (SD)	Gps, kts, Kms, Bst,	12.70	1.06	---
Structural hill (SH)	Gps, Kts	103.10	8.60	---
Valley (V) & Valley fill (VF)	Kh	0.80	0.07	≤ 10

Note: Kts-Kota sandstones, Gps-Gangapur sandstones, Bst-Barakar sandstones, Kms-Kamthi sandstones, Ta-Talchir formations, Kh-Khondalite, Ggn-Granite gneisses.

very poor or no recharge could occur in geomorphic units of cuesta, inselberg, linear ridge, residual hill and structural hills occupying 130.5 km^2 i.e. 10% of the total area. Eighty percent of the area is occupied by pediment deeply weathered and pediment moderately weathered material. Most of the PPD unit occurs in the central part of the watershed.

Land use/land cover (LU/LC)

Image interpretation and field checks have been used in mapping of different LU/LC units. Cropland mixed with plantation occupies an area of 31.83%. Cropland including both *kharif* and *rabi* crops occupies an area of 27.02%. Plantation with regular shape and smooth edges occupies an area of 8.11%. while forest land occupies 24.15%. Land with scrub is the land with undulating topography with thin soil cover and scattered trees/shrubs. Land without scrub is the land with undulating topography with thin soil cover and without any vegetation. Wasteland is the land without any use. Gullied and ravenous land occur as irregular, shallow to deep and broken shape due to entrenched drainage is classified as wasteland in the study area. The details of land use/land cover are given Table 4.

Table 4 : Land use/land cover classification

Land use/Land cover unit	Area, km^2	Area, %
Cropland mixed with plantation	384.51	31.83
Cropland	326.45	27.02
Forest	291.74	24.15
Plantation	97.99	8.11
Land with/with out scrub	45.89	3.80
Water body	39.94	3.31
Built up land	14.40	1.19
Gullied and ravenous	7.13	0.59

Spatial arrangement of these land use/land cover units are given in Figure 6. The central part of the watershed is covering with extensive cropland and plantation utilizes the groundwater for irrigation. This may be the reason for falling groundwater levels in this area occupied by sandstones.

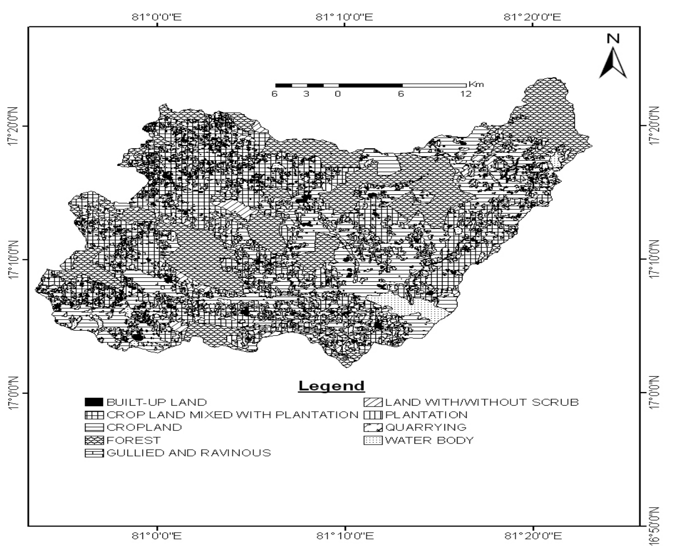

Fig. 6 : Land use/land cover map

Integrated study

The integration of the maps was done using weighted aggregation method. Thematic maps namely geomorphology, geology, land use, lineaments buffer, drainage buffer were assigned weights and ranks according to their relative importance in groundwater recharge following the Analytic Hierarchy Approach (AHP) developed by Saaty (1980). Weights were given to each layer according to its importance in recharge of groundwater. As such, geomorphology is assigned the weight of 20. Likewise, geology-15, lineament (fracture)-25, drainage-25, land use/land cover-18. The rainwater is expected to infiltrate faster through the fracture and recharge the groundwater. Ranks have been assigned to each feature in the layer ranging from one (low recharge) to four (high recharge). As such, in the geomorphic unit, a highest rank 4 is assigned to pediplain with deeply weathered feature as it supports infiltration and storage of groundwater while rank one is assigned to the geomorphic freature such as cuesta, inselberg, etc. as they support little or no recharge. While giving rank in the case of lineaments, maximum rank of 4 is allotted to the areas covering 50 m on either side of the lineament and this area is termed as lineament buffer. Similarly, in the case of streams (drainage) maximum weightage 25 is assigned because the flowing water in the stream may influence the recharge to the groundwater on either side of the stream. The maximum rank of 4 is assigned to the areas covered on either side of the stream up to a distance of 50 m and is termed as drainage buffer. The least weightage of 15 is assigned to the parameter namely geology because already much of the infiltration characteristics of the rainwater or surface water are governed by the parameters like geomorphology, land use/land cover, drainage buffer and lineament buffer. Score for each feature is calculated by multiplying weight of the thematic layer with rank of the feature in that layer. For example, geomorphology has weight 20 and the feature valley fill has rank 4, then the score is 80 (20×4). Likewise, for each layer score is calculated and is given in Table 5.

The final output is obtained by integrating the thematic maps namely drainage, lineaments, geology, geomorphology and land use/land cover. The final output has features with scores ranging from a maximum of 397 to a minimum of 15 with a standard deviation (σ) of 78.11. The score 397 is assigned to the areas of fractures with good drainage in sandstones, pediplain deeply weathered and double cropped lands. The score 15 is assigned to the areas of no fractures and no drainage, steep slopes in khondalitic terrain occupied with thick forest. Standard deviation method defines the mean value of the data being used and then distributes the data into classes based on the standard deviation of that mean. Using the standard deviation (σ) of the different scores in the final map, the area has been classified as very good, good, moderate, poor and very poor or no recharge.

The areas with cumulative weight of 15-78 have very poor or no recharge; 78-156 with poor recharge; 156-234 with moderate recharge; 234-313 with good recharge and 313-397 with very good recharge. Classification of recharge zones are shown in Figure 7.

Table 5 : Assigning of weights and ranks to thematic layers

Geomorphology, weightage – 20		
Geomorphic feature	**Rank**	**Score**
Bajada	2	40
Cuesta	1	20
Inselberg	1	20
Intermontane valley	1	20
Linear ridge	1	20
Pediment	2	40
Pediment inselberg complex	1	20
Pediplain with deeply weathered	4	80
Pediplain with moderately weathered	3	60
Pediplain with shallow weathered	3	60
Pediment structural dome complex	1	20
Residual hill	1	20
Structural dome	1	20
Structural hill	1	20
Valley	3	60
Valley fill	4	80
Geology, weightage- 15		
Lithologic feature	**Rank**	**Score**
Khondalite rocks	1	15
Gangapur sandstones	3	45
Kamthi formations	3	45
Kota sandstones	3	45
Barakar sandstones	3	45
Granite gneiss	1	15
Talchir formation	3	45
Lineament buffer, weightage – 25		
Lineament type	**Rank**	**Score**
Lineament (buffer)	4	100
Stream buffer, weightage – 25		
River/streams type	**Rank**	**Score**
River/streams (buffer)	4	100
Landuse/land cover, weightage – 18		
Landuse feature	**Rank**	**Score**
Built-up land	1	18
Forest	1	18
Cropland mixed with plantation	1	18
Cropland	4	72
Gullied and ravinous	1	18
Land with/without scrub	2	36
Plantation	1	18
Quarrying	1	18
Water body	1	18

The study area has 2.07% area as very good recharge, 7.15% as good recharge, 22.8% as moderate recharge, 56.53% as poor recharge and 11.44% as very poor recharge categories (Table 6). Most of the area in the study region is occupied with poor and very poor recharge sites. Most of the recharge sites are visible along the drainage course.

Table 6 : Classification of recharge zone

Recharge zone	Score	Area, km^2	Area,%
Very good	313-397	24.80	2.07
Good	234-313	85.75	7.15
Moderate	156-234	273.56	22.80
Poor	78-156	678.25	56.53
Very poor or no recharge	15-78	137.21	11.44

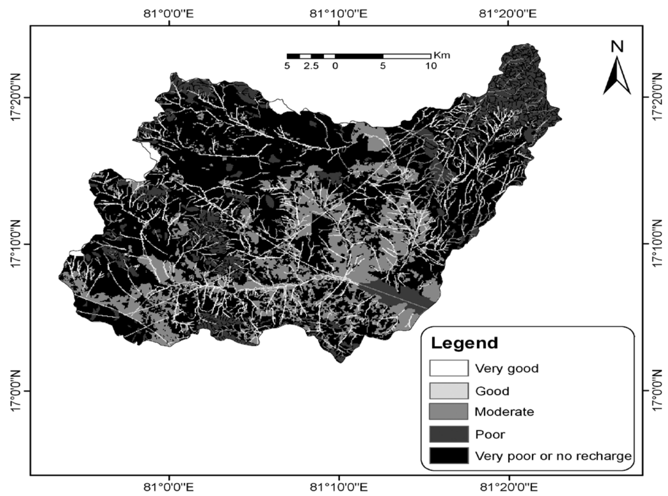

Fig. 7 : Spatial distribution of groundwater recharge area

Conclusion

Indian agriculture is more relying upon groundwater than surface and its overexploitation is leading to drying of open dug and bore wells. The study has policy implications and is very useful to the water resource planners and watershed programme implementers. In a basin, identification of suitable sites for recharge are the need of hour. Areas with high recharge potential in the upper Yerrakalava river basin having sandstone terrain have been identified. The investments on recharge structures need to be focused first on these sites having high recharge potential to maximize returns rather than spreading thinly on the entire basin.

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