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RESEARCH ARTICLE

Assessment of Site Suitability for Artificial Groundwater Recharge using Geospatial Technology in Varthur Catchment Area of Bengaluru, South India

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ABSTRACT

The groundwater scarcity is due to increasing population, urbanization, and expansion of agricultural activities, so need to obtain more attention to groundwater resources. Artificial recharge of groundwater plays a vital role in the sustainable management of groundwater resources. This study aims to assess the suitable sites for the artificial recharge of groundwater were delineated using geospatial techniques in the Varthur catchment. Weighted normalization analysis was carried out in the following thematic layers viz. Land use/land cover, soil, slope, drainage density, lithology, and lineament density. Each thematic layer and individual classes were assigned proper weightage and a score based on their relative contribution to groundwater recharge. Finally, all the thematic layers were integrated by the weighted index overlay (WIO) method. The groundwater recharge map thus obtained was divided into five zones as very high (5.94%), high (22%), moderate (30.82%), least (28.82), and poor (13.02%). The least effective recharge potential is in the eastern parts of the study area due to the low infiltration rate. This is in order to overcome the water shortage and to improve the storage capacity of the groundwater aquifer as well as increase the level of the groundwater table.

Keywords: recharge conditioning factor, geospatial technology, normalized weight, Varthur catchment.

INTRODUCTION

Groundwater is one of the most important natural sources of water for irrigation, drinking, and other uses. In this regard, groundwater plays a vital role in overcoming this shortage. Due to over-exploitation of groundwater without proper recharge mechanism and scanty rainfall, the water table of the open or dug wells in the region are being gone into deeper parts of the surface and many a time even some of them were dried up. In order to increase the level of the water table of the regions, it was necessary to adopt newer methods of groundwater recharge. Artificial recharge and rainwater harvesting are suitable solutions to address groundwater scarcity apart from demand-side management. The refilling of an aquifer with water from the earth's surface is known as groundwater recharge. Groundwater recharge occurs naturally and artificially. The process of infiltration of water percolates from the surface into the aquifer layer results in natural recharge. Artificial recharge is the use of water to artificially replenish the water supply in an aquifer. In the recharge studies selection of sites for artificial recharge is a very important task (Das, 2003). Several studies have been conducted for the determination of areas most suitable for artificial recharge (Krishnamurthy and Srinivas 1995; Krishnamurthy et al. 1996 and Saraf and Choudhury 1998; Balachandar et al. 2010; Sarup et al. 2011; Amanpreet Singh et al. 2013; Rajasekhar et al. 2018; Mohanavelu Senthilkumar et al. 2019). The majority of the studies involving the identification of suitable sites for artificial recharge have utilized weighted index overlay methods (Saraf and Chowdary 1998; Agarwal et al. 2013). The weighted overlay index method has been implemented in several key groundwater provinces in India (Srivastava and Bhatacharya 2006; Ravishankar and Mohan 2005). For the various themes, a set of weights and their individual features was decided based on expert knowledge considering their relative importance from the artificial recharge viewpoint (Alivia Chowdhury et al. 2010).

Groundwater recharge zones are identified and explored using geospatial technology, which is an important technique for the water resources management system. In recent years, the role of remote sensing and GIS techniques has received much attention with regard to artificial recharge (Shobharam Ahirwar et al. 2020; Suresh et al. 2015). They considered a varying number of thematic maps, such as geology, geomorphology, drainage density, slope, aquifer, permeability, fluctuations of water level or depth to groundwater level and lineament density, etc. Various layers are prepared and weighted overlay analysis is performed to determine the sites suitable for artificial recharge. The groundwater in the major part of the area is being continuously exploited for the purposes of domestic and irrigations. Thus, proper planning for groundwater resources management of the area is required. Usually GIS based studies are employed to find out suitable areas for the augmentation of recharge to groundwater (Ramasamy and Anbazhagan, 1997; Krishnamorthy et al, 1996; Ravi and Mohan 2006; Anbazhagan et al, 2005). For identifying the recharge methods in the study area, a numerical Weighted Parameter Rating (WPR) and the weighted index overlay method was adopted to delineate the suitable sites for artificial recharge.

Study area

The study area Varthur Lake is located in southern Karnataka, between 12°48′24.52″ and 12°53′59.85″ North latitude and 77°24′59.95″ to 77°30′6.72″ East longitude, and covers an area of 241 square kilometres. (Figure 1) with an annual precipitation total of roughly 900 mm, it receives precipitation from both upper east and southwest storms. Parts of the Arkavathi river watershed to the west and the South Pennar River to the east have decreased Bengaluru's water supply. Weathering, fracture pattern, geomorphological setting, and rainfall all influence the adaptability, presence, and aquifer replenishment of groundwater events. The Bangalore urban district has a crystalline storm cellar, which is made up primarily of gneisses and rocks that are influenced by important dykes. Along the city's eastern outskirts, these arrangements have been changed to laterite. The city's household and business needs are heavily reliant on groundwater.

METHODOLOGY

In the present study, geospatial techniques were used for the identification of suitable sites for artificial recharge zones by considering various thematic layers such as available space for recharge, geology, slope, geomorphology, , drainage density, lineament density, and aquifer thickness have been prepared in ArcGIS obtained from various data sources. According to their proportional importance in groundwater occurrence, migration, and infiltration, each thematic map and class were assigned a proper weight and ranking. Then, all the thematic maps were converted into raster format so that they can be easily integrated and processed in a GIS environment. Finally, all the thematic maps were integrated and reclassified into very high, high, moderate, least, and poor groundwater recharge sites by weighted overlay analysis in ArcGIS 10.2.

Normalized Weights

The normalised weight is a groundwater potential indicator based on a multi-parameter analysis. The normalised weight was calculated by dividing the allocated weight of a parameter feature class by the geometric mean. The formula is written as follows:

Normalized weight=(Assigned weight of a parameter)/(Geometric mean) …1

The groundwater recharging zone is indicated by the normalised weighted map. The class with the highest weight is considered a very high suitable zone, while the class with the lowest weight is considered a less suitable or unsuitable zone for groundwater recharge. The map of each theme layer was categorised using normalised weights of distinct attributes of thematic layers. Ranks attributed to certain aspects of the many themes.

Recharge Condition factors

Ten groundwater conditioning factors were classified based on expert knowledge and literature review. Then, the rank of each condition factor class was determined according to expert knowledge and, subsequently, feature normalized ranks were extracted (Rahmati et al. 2014The normalised weights and ranks attributed to distinct aspects of the individual components were supplied individually.

Available Space for Recharge: Available space is one of the factors, which affects the artificial recharge of groundwater. Available space between the ground surface and water table is crucial, because it is the storage space for induced recharge. Water bearing capacity of an aquifer mainly depends upon the available space in the aquifer. The space between the ground surface and water table is called as the available space. Available space is the most important parameter because it serves as potential storage space of induced recharge. Below the water table, the pore spaces will be filled with water and hence no space will be available for the storage of water. The recharged water has to be stored at a depth from the ground surface otherwise it will create swampy or marshy condition. The space between the water table and at 4 m below the ground surface is the available space and it is found out by subtracting a value of 4m from the mean yearly depth to water table. The volume of empty space that is available for recharging per square kilometre is found out from the thickness and the area (Table 1). In the study area, the available space was found from the average annual depth to water table and was divided into fiveclasses and ranked from 1 to 5 (Fig.2).

Geology: It is a well-known fact that the geological setting of a region has a significant impact on the distribution and occurrence of groundwater (Krishnamurthy and Srinivas, 1995). The two types of rock in the study area are classified peninsular gneiss and dolerite dyke. Texture of the rock is the most important factor to hold and transmit capacity of water through the rocks (Table 2). The study area geology is assigned weightage as 5 and ranks are also assigned based on the recharging capacity (Fig.3).

Slope: Slope is one of the important factors controlling the infiltration of groundwater into subsurface. In the gentle slope areas, the runoff is slow which enhance the percolation into subsurface, whereas, high slope areas facilitate high runoff and hence less infiltration (Prasad et al. 2008). So the slope parameter has been assigned 10 ranks are assigned in subclass of the study area (Table 3). The present study area is highly undulating and slope varies from less than 0 to >6. In the study area, slope is divided into five classes and respective ranks are also given (Fig.4).

Geomorphology: The landforms are the result of the various endogenic and exogenic forces operating on the Earth crust, which directly or indirectly affect the hydrological conditions (Reddy and Gajbhiye, 2004). The geomorphologic units of the basin are divided into structural hills, residual hills, shallow pediment, moderately pediment, pediment inselberg complex and valley fills (Table 4). Among these, valley fills and flood plains are very good locations for induced recharge. The landforms usually undergo a series of evolutionary changes and the final shape, geometry, interior and exterior properties and structures, etc., are the end result of such evolutionary changes. Hence, few landforms are able to store groundwater and some others are unstable to do so. Those land forms which are able to store a considerable amount of groundwater can promote artificial recharging of groundwater. So, the geomorphic land forms are assigned 10 weightage and ranks were assigned against the recharging capacity of the landforms. Various land forms are identified and grouped into four classes and ranks are also assigned (Fig.5).

Drainage Density: The drainage density is an expression of the closeness of spacing of channels and it provides quantitative measure of length of stream within a square grid of the area expressed in terms of length of channels per unit area (km/sq.km). Drainage density characterizes the run off or the quantum of rain water that could infiltrate. Drainage density is significant in the case of artificial recharge because it indirectly indicates the permeability and porosity of the terrain. More the drainage density, the higher would be runoff and vice versa. So, the drainage density is the important parameter for artificial recharge, hence 10 weightage has been assigned (Table 5). In the study area, the drainage density ranges from < 1 to > 6.9 km/km2. It is classified into 3 classes and the ranks assigned to them (Fig.6).

Lineament density: Linear features such as drainages, linear vegetation, weaker plains, secondary porosity, and permeability influence groundwater availability and flow directions. Remote sensing data provides a synoptic view of a broad surface region, which aids in the understanding of lineament's occurrence. Landsat TM data was used to create a linear features spatial map. The higher the lineament density, the better the groundwater prospecting prospects. Lineament density in the research area ranges from 0 to 186 km/sq.km, as indicated in Table 6. It is categorised into five classes using the equal interval approach, with 94.22-186.29 km/sq.km receiving the highest weight and 0-15.64 km/sq.km receiving the lowest. (Fig.7).

Aquifer thickness: Aquifer thickness plays a vital role in the distribution and occurrence of groundwater. The porosity and permeability of aquifer rocks are both affected by the aquifer (Ayazi et al. 2010; Chowdhury et al. 2010). Weathering and fracturing, as well as secondary porosity, transformed the rocks into aquifers (Sener et al. 2005). The thickness of the aquifer was determined using the geophysical resistivity method. (Table 7, Fig.8).

Groundwater recharge integration

The groundwater recharge zones is a dimensionless quantity that applies to perform the groundwater recharge mapping in an area. The weighted linear combination technique was used to determine the groundwater recharge as follows (Adiat et al. 2012; Shekhar and Pandey 2014)

$$GWP = Asr_{Nr} + Geol_{Nr} + Sl_{Nr} + Geom_{Nr} + dd_{Nr} + ld_{Nr} + At_{Nr} \quad (2)$$

The groundwater recharge values were grouped into five classes of poor, least, moderate, high, and very high using the ArcGIS quantile classification method. In this classification method, each class contains the same number of features. Also, quantile method was applied by several researchers due to its efficiency (Nampak et al. 2014; Tehrany et al. 2014).

Numerical Weighted Parameter Rating (WPR)

The various thematic layers were integrated with one after the other through GIS using the numerical weighted parameter rating (WPR) and weighted index overlay method. The following order of sequence has been adopted to derive the final integrated map:

Available space for recharge (I1)	+	Geology (I2)	= O1
O1	+	Slope (I3)	= O2
O2	+	Geomorphology (I4)	= O3
O3	+	Drainage density (I5)	= O4
O4	+	Lineament density (I6)	= O5
O5	+	Aquifer thickness (I7)	= O6

Where, I1, I2… and O1, O2… are the input and output layers respectively

In the first step, Available space for recharge (I1) and geology (I2) layers are integrated by the union option. The integrated output layer (O1) comprises polygons of the drainage density layer and polygons of the slope layer and after union it resulted in new polygons having attributes of both the layers. Adding these two layers derived the weight of each polygon in the integrated layer (O1). In the next step, the O1 layer was intersected with the geomorphology (I3). In this step, the integrated layer O2 was generated by adding drainage density. The O2 layer was integrated with polygons of the geomorphology (I4). Layer I5 involving polygons made around the available space was integrated with layer O3 by the union option. The polygons in the integrated layer (O4) contain the composite detail of all the thematic layers together numerically having maximum weight of 2.66 and minimum weight of 0.85 with standard deviation 2.5.

Composite Suitability Index (CSI)

The delineation of places that are ideal for the development of water harvesting systems has been aided by grouping high-ranking polygons from all thematic layers. Based upon the standard deviation, the polygons were grouped into classes suitable for construction of groundwater recharge structures. A Composite Suitability Index (CSI) has been calculated for each composite unit by multiplying weightage with the rank of each parameter and summing up the values of all the parameters. Categorization of the CSI is achieved by ranging the CSI into 5 classes.

Class 1	Maximum >	CSI >= 3 σ
Class 2	3σ >	CSI >= 2 σ
Class 3	2σ >	CSI >= 1 σ
Class 4	1σ >	CSI >= Minimum

Where σ standard deviation

Those polygons, having cumulative weight 0.85 to 2.66 in the final integrated layer were classified as unsuitable for artificial recharge. The polygons classified as least suitable category have the cumulative weight 1.61 to 1.85, whereas moderately suitable category has the weights 275 to 337.5. The polygons classified as highly suitable category have the cumulative weight 1.85 to 2.04.

RESULTS AND DISCUSSION

The index values calculated for each class are used to delineate various groundwater recharge zones, while overlaying the individual thematic layers one over the other. Based on the analysis, the study area has been divided into five classes with respect to the scope for artificial recharge to augment groundwater conditions. The four classes are poorly suitable, least suitable, moderately suitable, highly suitable and very highly suitable for artificial recharge (Fig.9). The highly suitable zones for artificial recharge are observed in the northwestern and central parts, and less suitable zones are found in the northern and southern parts of the study area. For prioritization of recharge zone the high and moderate zones are further classified into Priority-I and less and unsuitable classified into Priority-II (Table 8).The classified artificial recharge zone further divided in the three classes for prioritization of recharge zones. The most suitable zones classified for priority I, the suitable and moderately suitable zones classified for priority II and least suitable and poorly suitable zones are further classified into Priority-I for sustainable development in the study area (Fig.7.4).

CONCLUSIONS

Varthur catchment of was selected for groundwater management studies using remote sensing and GIS technology. In the present study, the delineation of artificial recharge methods, such as analytical weighted parameter rating approach and weighted index overlay method were used to delineate suitable sites for artificial recharging. A value is derived from the rank and weights. This value was used to mark out various priority zones sites for artificial recharging. Overall, it can be concluded that RS, GIS and MCDM techniques are powerful tools for evaluating groundwater potential which can help prepare a suitable and cost-effective groundwater exploration plan for a basin or catchment areas. The groundwater resource map and sustainable watershed management plan is very useful to maintain Varthur catchment for sustainable environment in future.

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Table 1 Rank and weights of the Available Space for Recharge

Class	Assigned rank	Feature Normalized Weight (Nr)
4.70-7.44	1	0.067
7.44-9.08	2	0.133
9.08-10.76	3	0.200
10.76-12.52	4	0.267
12.52-17.29	5	0.333
Total	**15**	

Table 2 Rank and weights of the Geology

Class	Assigned rank	Feature Normalized Weight (Nr)
Peninsular Gneiss	5	0.833
Dolerite dyke	1	0.166
Total	**6**	

Table 3 Rank and weights of the Slope

Class	Assigned rank	Feature Normalized Weight (Nr)
0-0.80	9	0.400
0.08-1.39	6	0.280
1.39-2.00	5	0.200
2.00-2.76	2	0.080
2.76-6.59	1	0.040
Total	**23**	

Table 4 Rank and weights of the Geomorphology

Class	Assigned rank	Feature Normalized Weight (Nr)
Deep pediment	9	0.237
Moderate pediment	8	0.211
Pediment inselberg complex	3	0.079
Residual hill	1	0.026
Shallow pediment	6	0.158
Structural hill	1	0.029
Valley fill	10	0.263
Total	**38**	

Table 5 Rank and weights of the Drainage density

Class	Assigned rank	Feature Normalized Weight (Nr)
0-0.43	9	0.375
0.43-0.99	7	0.292
0.99-1.56	5	0.208
1.56-2.24	2	0.083
2.24-4.12	1	0.042
Total	**24**	

Table 6 Rank and weights of the Lineament density

Class	Assigned rank	Feature Normalized Weight (Nr)
0-15.64	1	0.037
15.64-43.74	3	0.111
43.74-69.53	6	0.222
69.53-94.22	8	0.296
94.22-186.29	9	0.333
Total	**27**	

Table 7 Rank and weights of the Lithology

Class	Assigned rank	Feature Normalized Weight (Nr)
6.80-8.05	3	0.094
8.05-8.87	5	0.156
8.87-9.84	7	0.219
9.84-11.42	8	0.250
11.42-14.58	9	0.281
Total	**32**	

Table 8 Artificial recharge zones and their priorities

Sno	Artificial recharge zones	Area (sq.km)	Area (%)	Priority
1	Poorly suitable (0.87-1.61)	16.66	5.94	Priority-I
2	Least suitable (1.61-1.85)	61.73	22.00	Priority-I
3	Moderately suitable (1.85-2.04)	86.45	30.82	Priority-II
4	Highly suitable (2.04-2.24)	79.16	28.22	Priority-III
5	Very high suitable (2.24-2.66)	36.52	13.02	Priority-III
		280.53	100.00	

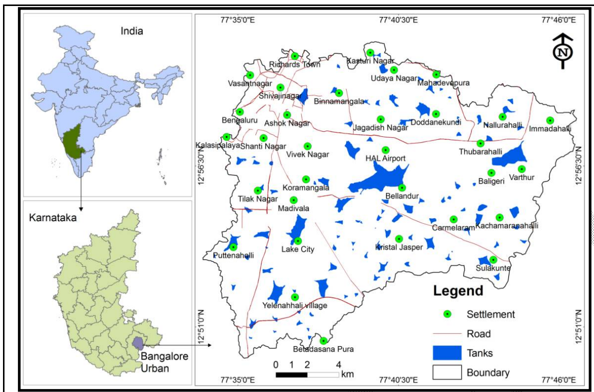

Figure 1: Location of the Varthur Catchment of Dakshina Pinakini River Basin, Karnataka

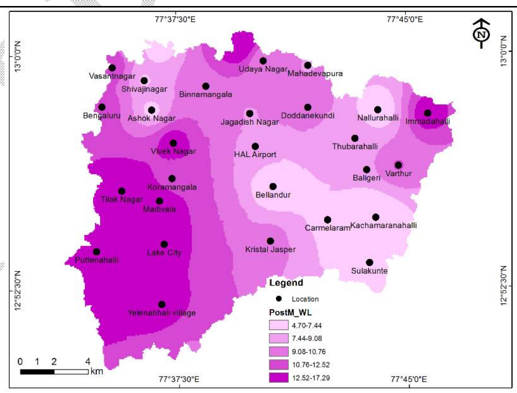

Figure 2: Available Space for Recharge in the study area

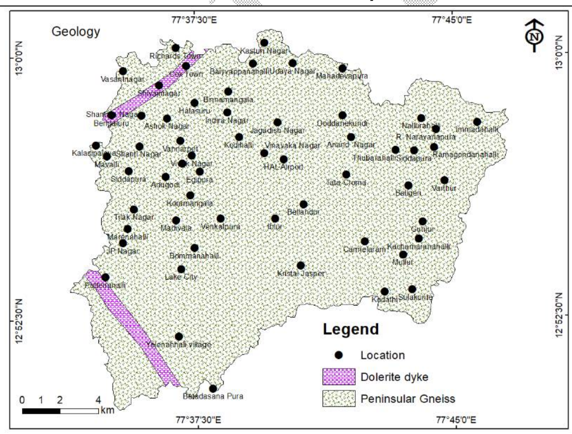

Figure 3: Geology of the study area

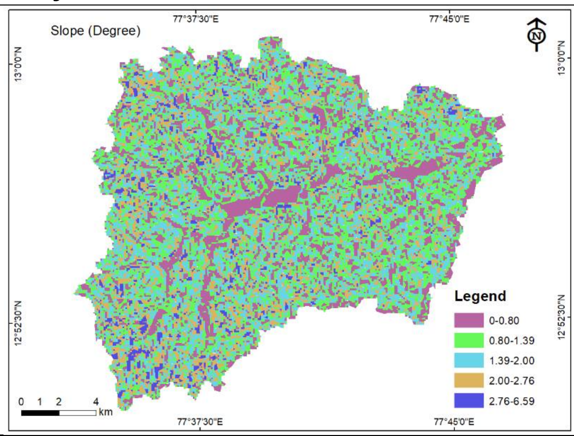

Figure 4: Slope (degree) in the study area

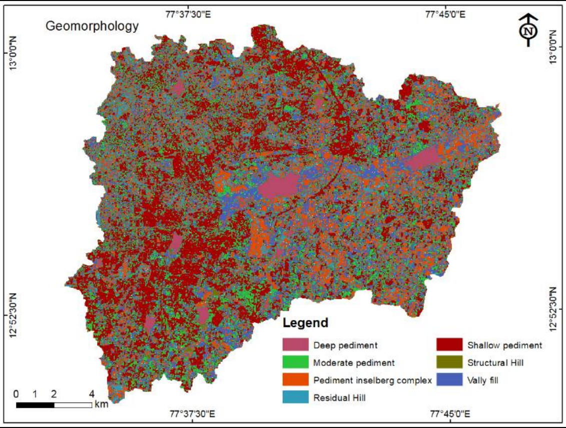

Figure 5: Geomorphology in the study area

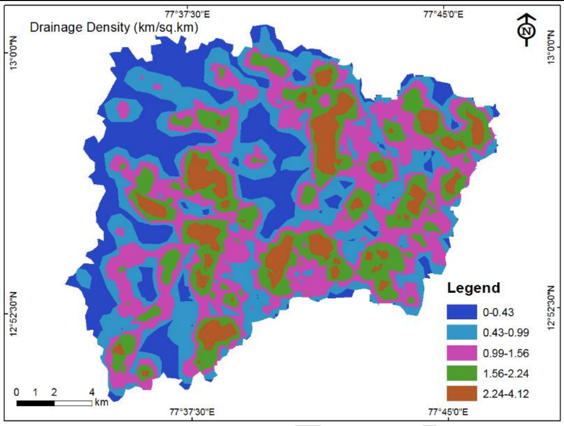

Figure 6: Drainage density in the study area

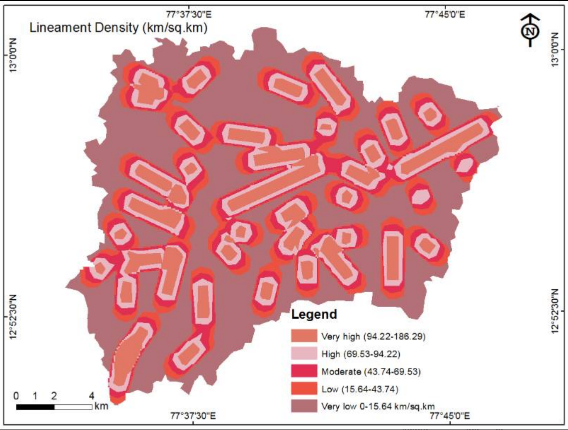

Figure 7: Lineament densities in the study area

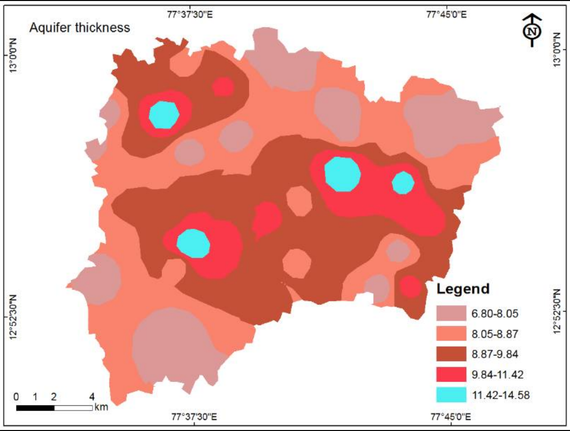

Figure 8: Aquifer thicknesses in the study area

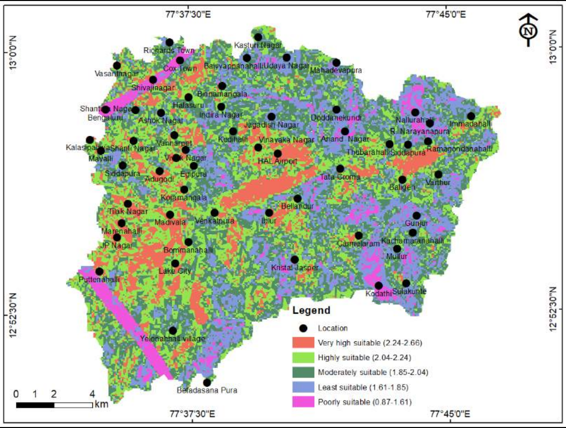

Figure 9: Groundwater artificial recharge zonation mapping in the study area