

Geospatial Technology and Analytical Hierarchy Process (AHP)-Based Discrimination of Groundwater Potential Zones in Vijayawada–Mangalagiri Region, Andhra Pradesh



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Abstract Groundwater is one of the principal sources that contribute to the total annual supply. Understanding the groundwater potential zones is significant for water management and planning for any city. Situated in Andhra Pradesh, the Vijayawada–Mangalagiri region is majorly known for its industrial and agricultural activities. However, the rapid urbanization, inappropriate land use methods, increased anthropogenic activities, and poor irrigation practices led to the depletion of groundwater during the last few years. This research aspires to discriminate the groundwater potential zones using the combination of geospatial technology and analytical hierarchy process (AHP) which augment the source of groundwater. Different thematic layers such as digital elevation model (DEM), drainage density, slope, soil type, land use/land cover (LULC), and rainfall pattern were prepared and analyzed by employing primary and secondary resources. The weighted overlay analysis has been performed on various thematic layers based on their importance using AHP. A groundwater potential map with five zones has been classified as poor, fair, good, very good, and excellent.

Keywords GIS · AHP · Groundwater · Overlay analysis

1 Introduction

Water has a pivotal role to play in the development of a country like India which drives an influential section of the economy is directed by agricultural and industrial activities [1]. The water need in India is immense for the domestic and irrigation sector and needs special attention to stop water scarcity. Harder than ever, access

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to safe water is crucial to maintain a healthy life balance for Indian families. More than 30% of the urban population and 90% of the rural population in India depend on groundwater for their drinking and household necessities [11]. The rate of water consumption during the summer season rises every year, and it is crucial to replenish the groundwater [17]. Groundwater being an incredible wealth to us has significance for its fresh quality. Groundwater flows below the land surface between the spaces of rocks, sand, and soil. It moves at different rates according to the geological formations and forms aquifers. Over the years, the extensive demand for groundwater has kept growing and is unlikely to conclude in the future [3]. Groundwater is advantageous over surface water in terms of immense quality, pollution-free, and large-scale spread [16]. Misuse of water has increased rapidly due to the uncertainty of the monsoon, which seriously affects the surface and groundwater resources [19]. Groundwater has been subsequently declining throughout the district with overexploitation, groundwater contamination, industrialization, and exponential population growth. Recent studies show that there is a huge demand for pure water for drinking, agriculture, etc., purposes due to the depletion of groundwater availability in our country [18]. Highly populated cities like Vijayawada–Mangalagiri, Andhra Pradesh, in recent years require finding new groundwater zones to serve the increasing population due to inadequate and unreliable municipal water supplies. To ensure the present-day standing of groundwater potential and sufficient quantity of recharge, potential zones of groundwater are to be identified where unnatural recharge approaches can be accustomed to raise the recharge extent [4]. Groundwater potential zones map assists as effective tools for accurate ground-based hydro-geological surveys which helps in suitable sites for bore wells/dug wells. Geospatial technology-based tools are helpful for the collection, storage, retrieval, and spatial data management for any application. The principal factors considered that affect the potential zone discrimination are drainage density, soil, elevation, slope, LULC, and rainfall. All these factors were assigned a satisfactory weight based on AHP to obtain a groundwater potential zone. These factors determine groundwater occurrence, hydrological properties, and geological formation [5].

2 Study Area

One of the fundamental requirements of human beings is having accessibility to fresh, potable drinking water [22]. Encircled by the hills of Eastern Ghats and canals, the Vijayawada–Mangalagiri region in Andhra Pradesh sprawls on the banks of the Krishna River. Telugu is the predominant language spoken by the residents of the study area [21]. Having a tropical climate, the annual mean temperatures range from 23.4 to 34 °C. The summers have more rainfall when compared with winter, and the annual rainfall ranges from 900 to 1100 mm. The broad range of land use practices in the study area includes settlements, agriculture, barren land, and forests. The major soil types in the region are loam, clay loam, sandy clay loam, and clay. Figure 1 represents the study area map.

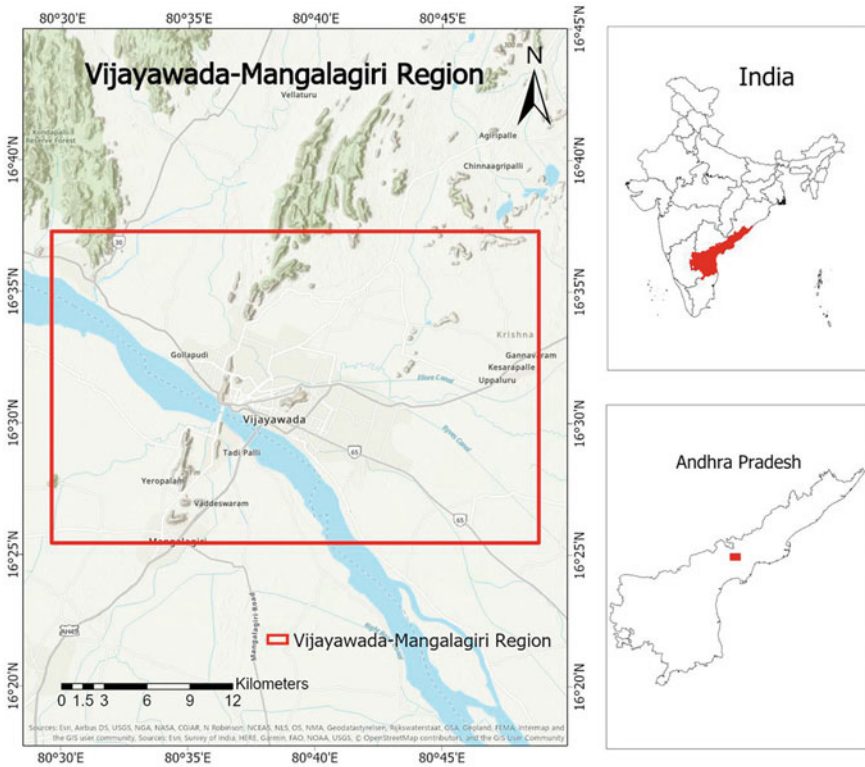


Fig. 1 Study area map

3 Data Requirements and Methodology

The study was pursued by taking into consideration various layers say drainage density, elevation, slope, soil, land use/land cover (LULC), and rainfall. These data sets have been composed of various primary and secondary sources and are redefined in the geospatial environment to create the database. The shapefile layer of India was obtained from Diva GIS, an online repository for GIS data. Digital elevation model (DEM) is extracted from the Aster Global DEM V3 to prepare slope, elevation, and drainage density layers. Cloud-free Sentinel-2 data of 10m resolution has been chosen for performing random forest classification for land use/land cover extraction using Google Earth Engine. The rainfall data in grid format has been downloaded from Climate Research Unit (CRU).

The methodology involves the collection and preparation of various remotely sensed data layers which were processed using ArcGIS software. Understanding potential zones of groundwater by geospatial technology has numerous benefits, especially defining the features spatially [20]. A geo-database has been created for

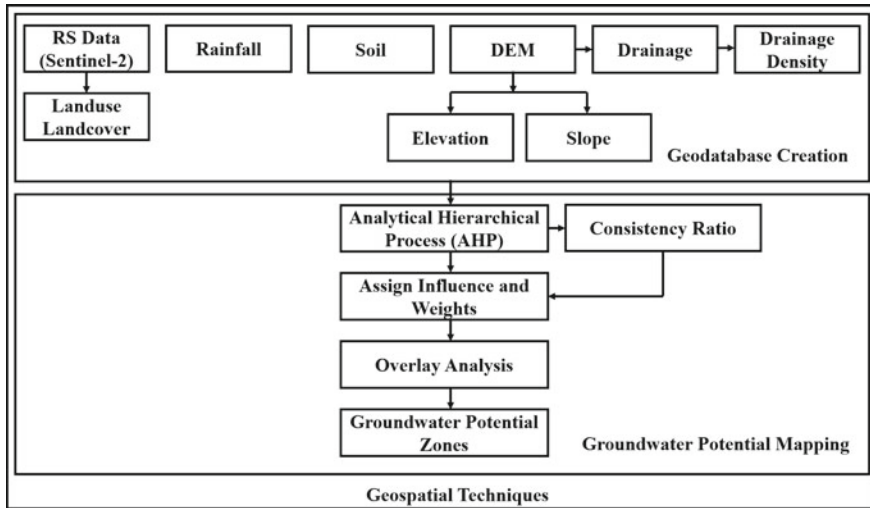


Fig. 2 Methodological flowchart

all the layers and georeferenced to the UTM zone 44N. Supervised classification has been performed for classifying different features in the study area using Sentinel-2 data. An automatic drainage map has been generated from the DEM. All the layers were assigned ranks and weights based on the multicriteria decision-making technique [6]. While calculating the weights, the number of layers was given as 6, and the pairwise comparisons were made to calculate the priorities based on the analytical hierarchy process. Table 2 shows the importance of values [7]. It helps to identify and repair logical inconsistencies. The pairwise comparison results are presented in a matrix form, and the first normalized right eigenvector of the matrix yields the weighting. The eigenvalue determines the consistency ratio [8]. The obtained matrix is said to be consistent if the consistency ratio is below 0.1. After assigning the determined weights, the layers were subjected to weighted overlay analysis. The scale preference for each class is decided by how important the layer and its class with the attribute are. Figure 2 represents the methodology flowchart followed in this research.

4 Analysis of Results

The potential zones of groundwater having a direct or indirect impact are based on the six parametric layers investigated for the study. Based on the overlay analysis, the effect of one layer on to the other layer was determined by assigning suitable weights [13] (Table 1).

Table 1 Satty's relative importance scale

Value	Indication	Description
1	Similar importance	Contribution of two parameters is same
3	Average importance	One parameter is chosen slightly over the other
5	Strong importance	Strongly supports only one parameter
7	Very strong importance	One parameter dominates the other
9	Extreme importance	Highest degree of dominance of one parameter over the other
2,4,6,8	In-between values	When settlement is essential

4.1 Drainage Density and Soil Map

Drainage density plays a vital role in understanding groundwater contamination and accessibility. The drainage density influences the rate of infiltration and runoff. The digital elevation model (DEM) collected from Aster Global DEM V3 with the 30-m spatial resolution has been employed to acquire the study area drainage density map. The drainage density was achieved by computing the flow direction and flow accumulation of the region and thereby clustered into five classes. From the drainage density map, it was observed that the elevated drainage density is due to less infiltration and does not endorse the potential zones of groundwater, and the depressed drainage density is due to high infiltration and indicates groundwater potential zone. Figure 3 represents the study area drainage density map. Soil types play a crucial role in the water quantity that can infiltrate into the subsurface and thereby affect the recharge of groundwater [9]. The main constituents regarded for the estimation of infiltration rate are hydraulic properties and texture of the soil [8]. The water quantity approaching the water table relates to the scope of the aloof lying underneath the soil. Figure 4 represents the soil map of the study area. The Vijayawada–Mangalagiri region includes different soil types such as loam, clay loam, sandy clay loam, and clay.

4.2 Elevation and Slope Map

The elevation and slope maps of the study area were derived from Aster Global DEM V3 with a 30-m spatial resolution. The elevation signifies the undulations of the ground surface available for sink storage. The study area elevation ranges from 8 to 326 m of mean sea level. Figure 5 represents the study area elevation map. The slope is a vital terrain feature that signifies the ground surface steepness [10]. The slope of the region affects the rate of infiltration and surface runoff. A steeper slope indicates higher runoff [11]. During rainfall, large slopes offer less recharge as the water flows swiftly down a steep slope. The study area slope ranges from 0 to 57.11

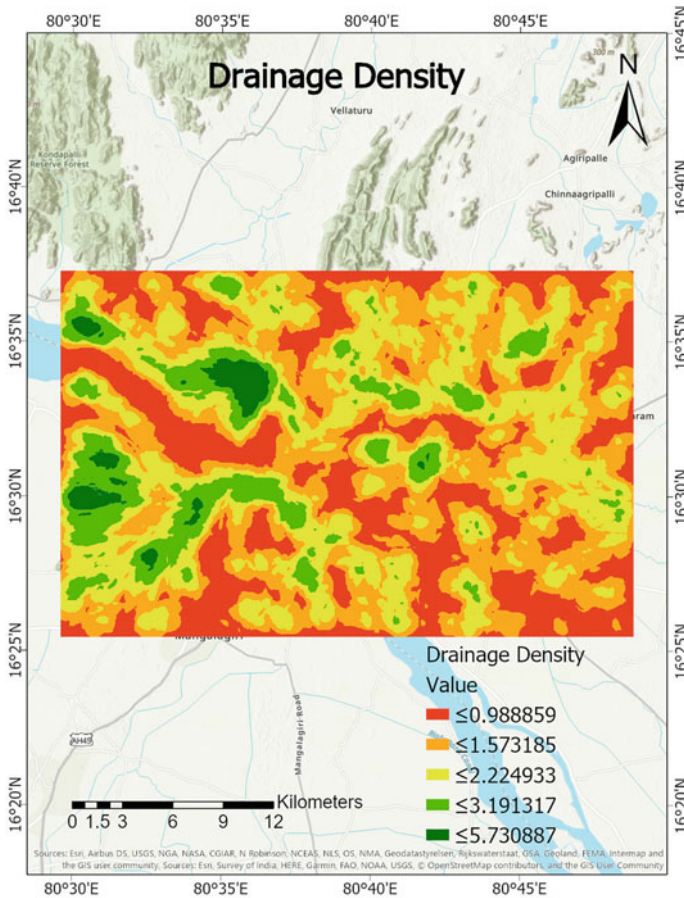


Fig. 3 Drainage density map

degrees, classified and represented in five classes based on the slope value. Figure 6 represents the slope map of the study area.

4.3 Rainfall and Land Use/Land Cover Map

Rainfall is the principal and dominant factor of groundwater recharge. The rate of infiltration depends on the amount and period of rainfall [12]. The rainfall data of 2020 has been used for the current study. The annual rainfall ranges from 948 to 1075 mm. The rainfall spatial distribution map was developed using the Kriging interpolation technique. The rainfall data set has been reclassified into five categories based on the maximum and minimum values ranging from very low (948–980

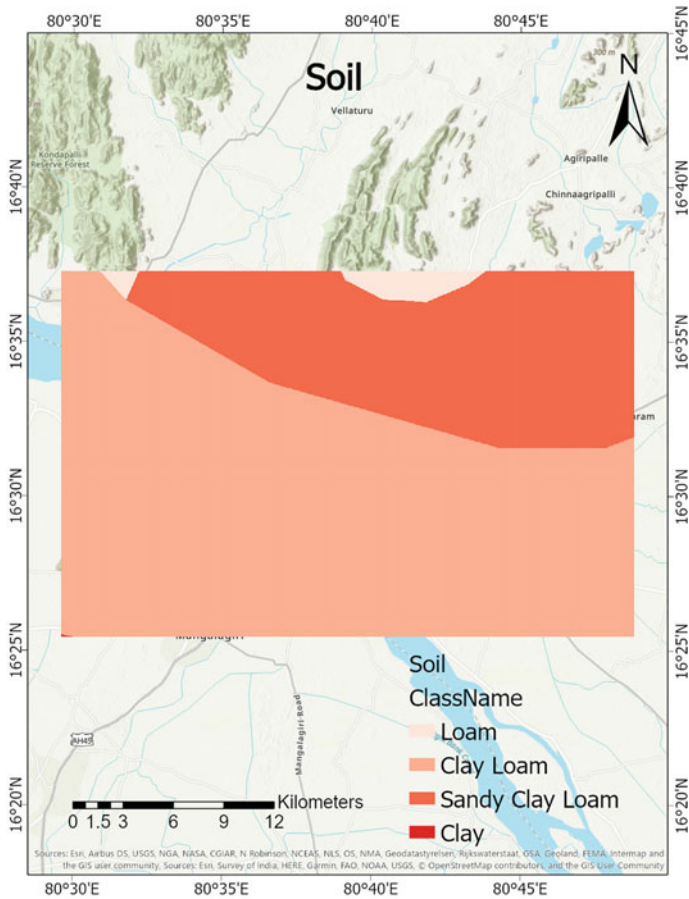


Fig. 4 Soil map

mm), low (980–1000 mm), moderate (1000–1019 mm), high (1019–1041 mm), and very high (1041–1075 mm). Short span and high amounts of rainfall indicate more surface runoff and less infiltration. Higher weights are assigned for high rainfall, and lower weights are assigned for low rainfall. Figure 7 represents the study area interpolated rainfall map. The land use/land cover provides the necessary information regarding groundwater demands along with surface water, infiltration, soil moisture, etc. [14]. The study area has been classified into five major classes which include water, agriculture, settlements, barren land, and scrub forest. The land use/land cover types in the study area are delineated from Sentinel-2 satellite data with a 10-m resolution. The highland area is comprised primarily of scrub forests. The midlands and lowlands are dominated significantly by agricultural land and settlements. The agricultural land and scrub forest carry extensive water proportions of water than the settlements and barren land. So, the weights were assigned based on the available

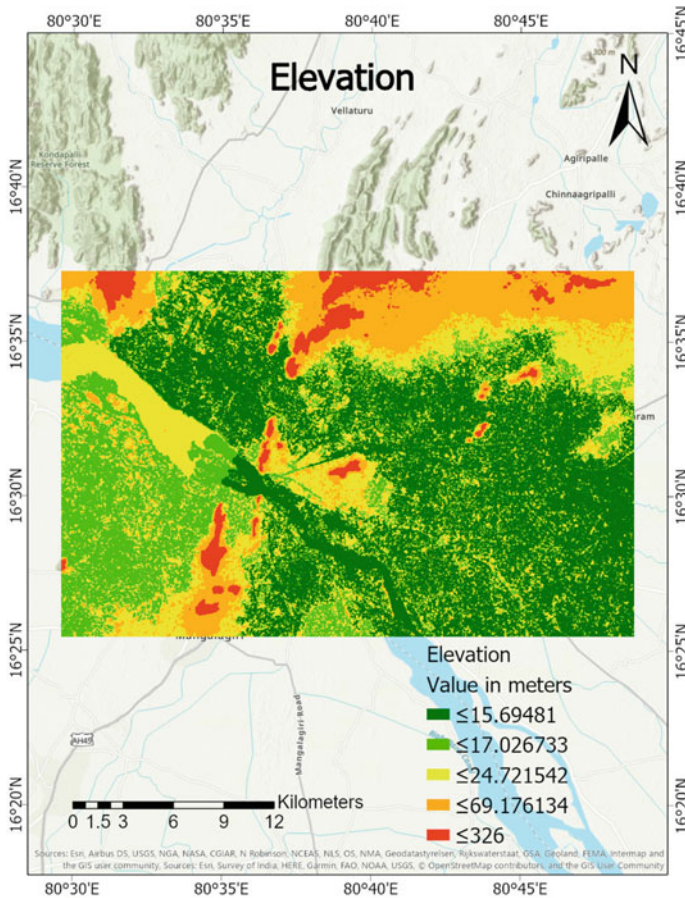


Fig. 5 Elevation map

water quantity for recharge concerning the topography. The high weight is assigned to the water and agriculture, and the low weight is assigned for the settlements, barren land, and scrub forest. Figure 8 represents the study area land use/land cover map.

4.4 Analysis of Groundwater Potential Zones

The six data sets were generated in the geospatial environment, and the suitable weights have been determined by the analytical hierarchy process (AHP) technique. The weights were later attributed based on the weighted overlay analysis, one of the powerful decision-making tools that solve multicriteria issues [15]. The weights for each thematic layer were selected based on Saaty’s scale (1–9) of relevant importance.

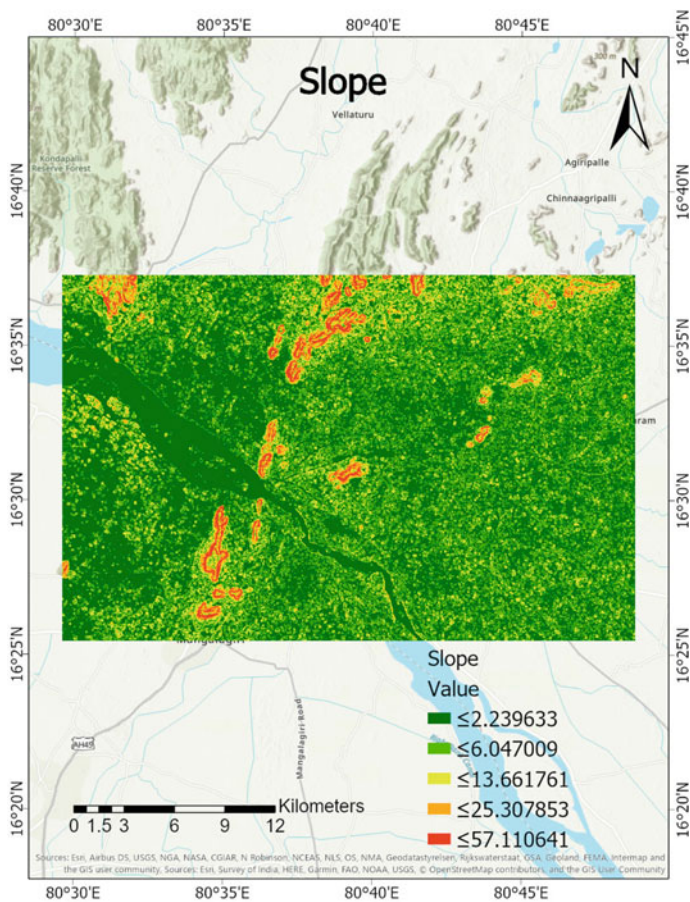


Fig. 6 Slope map

Table 2 AHP-based decision matrix

Class	DD	Rainfall	Slope	Elevation	Soil	LULC
DD	1	1	5	5	5	5
Rainfall	1	1	5	5	5	5
Slope	0.20	0.20	1	1	1	1
Elevation	0.20	0.20	1	1	1	1
Soil	0.20	0.20	1	1	1	1
LULC	0.20	0.20	1	1	1	1

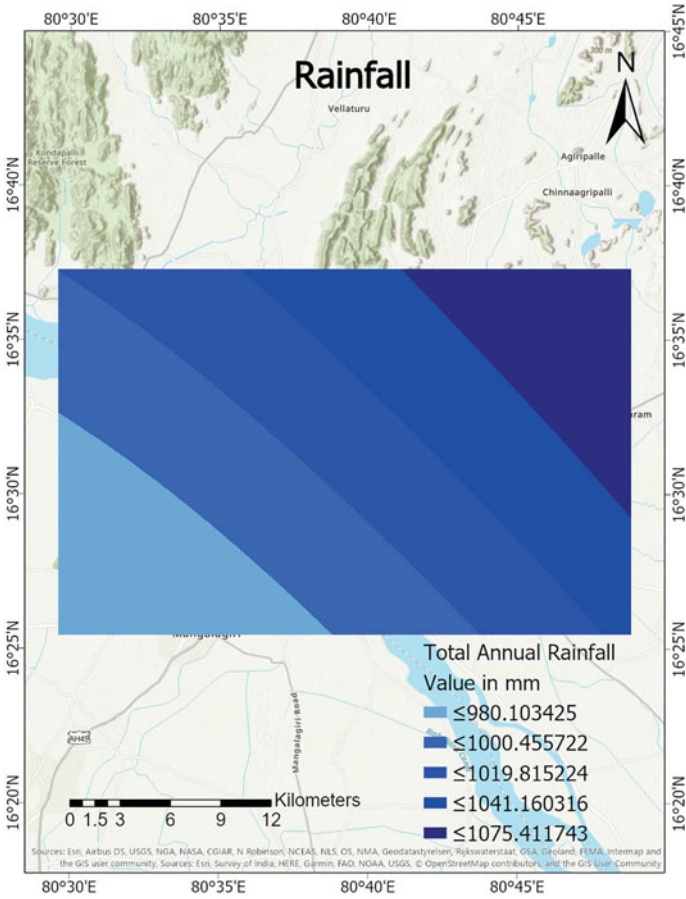


Fig. 7 Rainfall map

AHP scale ranges from 1—similar importance, 3—average importance, 5—strong importance, 7—very strong importance to 9—extreme importance (2,4,6,8 values are in-between values). The raster values are reclassified to a common agreement scale based on the importance of the layers by inputting the values in integer format. All the six thematic layers were correlated concerning each other in a pairwise comparison matrix form [8]. The high weight represents a thematic layer with a high influence, and the low weight represents a thematic layer with a little influence on groundwater potential. The result achieved was categorized into five classes ranging from very poor potential zone to very good potential zone as shown in Fig. 9. Most of the study area has a smooth terrain which confers the possibility of groundwater recharge. Initially, the principal eigenvalue (λ) was computed by the eigenvector method, and consistency index (CI) was determined from following Eq. 1, where RI = random consistency index value, n = number of parameters used in the study = 6

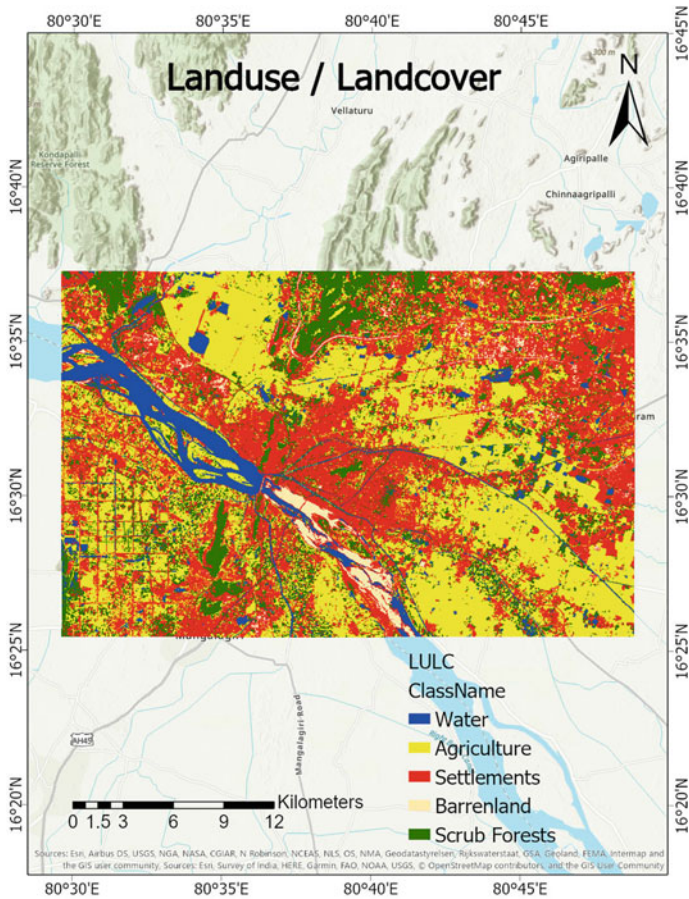


Fig. 8 Land use/land cover map

$$CR = CI/RI \tag{1}$$

$$CI = (\lambda \max - n)/(n - 1) \tag{2}$$

The consistency ratio acquired is 0% which indicates the perfect consistency level in pairwise comparison [7]. To generate the potential zones of groundwater in the Vijayawada–Mangalagiri region, all the six thematic layers were used based on Eq. 3:

$$GPZM = Dd_w Dd_r + R_w R_r + S_w S_r + E_w E_r + So_w So_r + Ll_w Ll_r \tag{3}$$

where GPZM is groundwater potential zone map, Dd is drainage density, R is rainfall, S is slope, E is elevation, So is soil, Ll is land use/land cover, r is rank assigned, and w is weight.

Table 3 Groundwater Potential Zone Priorities

Category	Assigned weight	% Priority	Domain	Rank
DD	1	36	0-0.98	1
			0.98-1.57	2
			1.57-2.22	3
			2.22-3.19	4
			3.19-5.73	5
Rainfall	1	36	948–980 mm	1
			980–1000 mm	2
			1000–1019 mm	3
			1019–1041 mm	4
			1041–1075 mm	5
Slope	3	7	0–2.23	5
			2.23-6.04	4
			6.04–13.66	3
			13.66-25.30	2
			25.30–57.11	1
Elevation	3	7	8–24	5
			24–51	4
			51–101	3
			101–174	2
			174–326	1
Soil	3	7	Loam	1
			Clay loam	2
			Sandy clay loam	3
			Clay	4
LULC	3	7	Water	5
			Agriculture	4
			Settlements	3
			Barren land	1
			Scrub Forest	2

4.5 Decision Matrix

The groundwater potential zone discrimination using AHP involves assigning of principal eigen vector of the decision matrix which is shown in table 2. In tables 2 and 3, DD is drainage density and LULC is land use/land cover (Table 4).

Table 4 Area covered by groundwater potential zones

Class	Area (km)
Poor	5.5584
Fair	193.796
Good	389.406
Very Good	144.204
Excellent	0.0099

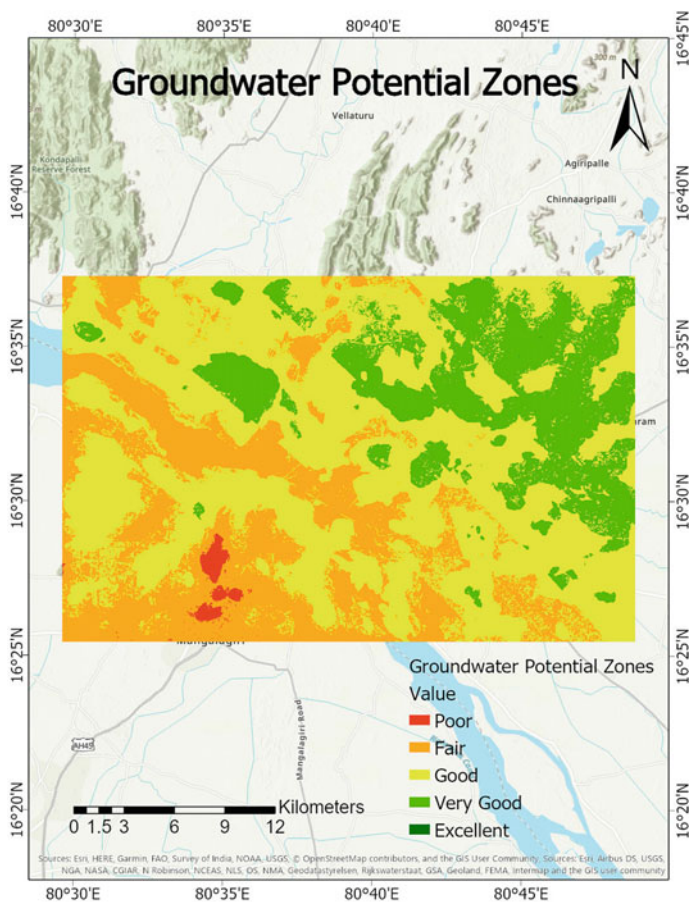


Fig. 9 Groundwater potential zones map

5 Conclusion

The geospatial technology involving remote sensing and GIS helps in deriving spatial and visual results more prominently. The present study discriminates the potential zones of groundwater using geospatial technology and analytical hierarchy process (AHP) in the Vijayawada–Mangalagiri region of Andhra Pradesh. A total of six thematic layers such as digital elevation model (DEM), drainage density, soil type, slope, land use/land cover (LULC), and rainfall pattern were used in this study, and appropriate weights are assigned to all the layers. The output map shows five categories of groundwater potential zones as poor, fair, good, very good, and excellent. The very good and excellent zones are situated in and around the Vijayawada city, and the poor zone is situated in and around Mangalagiri. This shows that special attention in the Mangalagiri region needs to be given to recharge the groundwater. Poor and excellent groundwater potential zones cover less than 1% of the total area. Fair groundwater potential zone covers an area of 26.44%, good groundwater potential zone covers an area of 53.12%, and very good groundwater potential zone covers an area of 19.67%. The potential zones map of groundwater in the current research contributes insights into decision-makers for groundwater management and planning agricultural and industrial activities.

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