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ORIGINAL ARTICLE

Identification of groundwater potential zones in southern India using geospatial and decision-making approaches

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Abstract

The present study was carried out to identify of the groundwater potential zones (GWPZ) in the northern part of the Anantapur district of Andhra Pradesh State, India using Remote Sensing (RS), Geographical information system (GIS), and Analytical Hierarchy Process (AHP) approaches. In this study, various thematic maps categorized viz. geomorphology (GM), lineament density (LD), drainage density (DD), geology, land use/land cover (LULC), soils, slope, and rainfall for assessment of GWPZs, which is generated using RS and GIS technique. Furthermore, the relative weights were allocated to various thematic maps using the AHP approach and the relative rank assigned to each sub-criterion based on expert advice. The combination of the eight thematic layers in ArcGIS resulted in a groundwater potential map, providing the information about very good 2.45% (87.06 km^2), good 12.76 (452.56 km^2), moderate 63.47% (2250.75 km^2), poor 15.99% (567.16 km^2), and very poor 5.32% (188.73 km^2) groundwater possible zones. The acquired outcomes were validated with the area under the curve (AUC/ROC) method. The results show that there is a strong positive correlation between the GWPZs with 78% validation high performance and decreases to the low yield potential with poor areas. This study concludes that the AHP model will be a more reliable for the assessment of the GWP. Any groundwater management project carried out in these favourable regions would benefit the stack holders.

Keywords Groundwater potential zones · Sustainable management · AHP · Remote sensing · GIS

Introduction

Groundwater is the important resources for industries, communities, and irrigation purposes in the world, due to its cleanness, chemical connections, constant temperature, and lower pollution. Presently, in urban and rural region, about 34% of the world's water resources is groundwater (Kadam et al. 2021a, b; Gaikwad et al. 2021). Many parts of world are having arid and semi-arid region with erratic rain, so the average precipitation is less than a third of the global average rainfall (Pinto et al. 2017). Therefore, for water resource investigation, the conventional geophysical techniques and boring soil tests for hydrological investigations prove to be costly and time-consuming (Ghosh et al. 2020; Chandra 2016; Moustafa 2017; Mukherjee et al. 2012). On the contradictory, complex groundwater studies are now being made easier using the RS and GIS comes out with more success in the delineation of GWP (Kadam et al. 2019; Shailaja et al. 2019). Remote Sensing offers a brief observation and high-resolution studies of thematic imagining of groundwater resources (Kaliraj et al. 2014; Javed and Wani 2009). Groundwater modelling using geospatial approaches is added advantageous than conservative methods, as a diversity of constraints can represent on a single map (Nithya et al. 2019; Magesh et al. 2011; Machireddy 2019; Kumar et al. 2020). Various decision-making approaches used along with RS and GIS in multiple studies for accomplishment additional real consequences in groundwater resources assessment. Some of them are AHP (Sener and Davraz 2013; Saranya and Saravanan 2020; Chakrabortty et al. 2018; Rajasekhar et al. 2019a; Mundalik et al. 2018),

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Fuzzy Logic (FL) (Kadam et al. 2019; Rajasekhar et al. 2019b), Artificial Neural Network (ANN) (Lee et al. 2018, 2020), Multi-influencing Factor (MIF) (Siddi Raju et al. 2019; Datta et al. 2020), Multi-criteria Decision Making (MCDM) (Machiwal et al. 2011). Groundwater exploration has become more advanced with the development of several GIS tools, such as the height above the nearest drainage (Rahmati et al. 2015). All these methodological approaches have made the study of groundwater simpler, economically, and time concise. Many researcher case studies shows the ability of three decision-making approaches, namely fuzzy logic (FL) frequency ratio (FR), and analytical hierarchy process (AHP) techniques in groundwater potentiality mapping (Kadam et al. 2018; Kumar et al. 2014; Şener et al. 2018; Das et al. 2018). The applicability of a model mainly depends on the assumption of judgment value (weight) for each parameter (Thapa et al. 2017). The application of the AHP model, along with RS and GIS techniques, is more popular all over the world due to its acceptance. A large number of research works with the best results have already been done on groundwater assessment by this model (Kumar et al. 2020). It is a challenging problem for geologists to solve, since it is found in hard-rock terrain. This method is applied on a cost-effective, proficient, and more reliable basis, with optimised approaches that build on existing and specialised geospatial expertise for effecting sustainable management of groundwater (Das et al. 2018).

In the study region, RS approaches have been used by many researchers (Rajasekhar et al. 2018c, 2020a, b; Siddi Raju et al., 2019) to map potential groundwater zones. The hydrogeological method, which was considered by numerous approaches, has rarely been used probably due to the cost of drilling or lack of secondary data. Therefore, a north-western part of the Anantapur District, Andhra Pradesh, India shows severe drought conditions every year, despite rainfall during the summer during the monsoons due to the semi-arid nature. A large part of the study area exhibits a severe drought condition every year despite of flighty rainfall occurrence during monsoon because of semi-arid nature. A large area of study area is covering agricultural land. Hence, irrigation for crop firming is a common practice. Due to semi-arid weather conditions, water is easier to consume only during the monsoon season. In the summer, the Anantapur district suffers from serious problems of drought and drinking water, an intense shortage of consumable surface water, which means that people depend mainly on underground resources. Subsequently, the main objective of the study is to identify appropriate GWPZs in the a north-western part of the Anantapur District, Andhra Pradesh, India, using AHP approach and compare these models to ensure effectiveness in implementation of artificial groundwater recharge potentiality (Rajasekhar et al. 2018c). Most parts are dependent on rain-fed agriculture and rain. The occurrence of drought is widespread in this district. The current research integrates remotely sensed geo-data with field data to provide a fast and cost-effective method for evaluating GWPZs in the Archean igneous rock dominated Anantapur region of Andhra Pradesh, India.

Study area

Anantapur district is part of Deccan Plateau and is an extension of Karnataka Plateau. It lies in the southwest corner of the state of Andhra Pradesh. The study area lies between latitude of 14° 26′ 00'' N to 15° 5′ 00'' and longitude of 76° 48′ 00'' to 77° 36′ 00'' E in the north-western part of the Anantapur district. The study area is having 3546.26 sq. km horizontal extents. The area is drained by streams which are tributaries of Vedavathi/Hagari River. The streams are mostly ephemeral. The drainage pattern is dendritic, rectangular-to-sub-rectangular due to the influence of geological structures. The average rainfall in the Mandal is 563 mm. The study area bounded by Tumkur and Bellary district of Karnataka on the west, Cuddapah district of Andhra Pradesh in the east. The rainfall during the Southwest monsoon season, i.e., June–September, accounts for about 85% of the total rainfall. The soils of the area have originated from the Peninsular Gneissic Complex (PGC) and Kurnool Group of the area. The present study region is bounded by outcrops of granite, granite gneiss, grey granite, and metabasalts along with kimberlite formations. The whole lithological parameters were allocated weights based on the influence on GWP. The colour of the soils in the area varies from brown to light grey and black. Soil also found to change its first property due to waterlogging (as in paddy fields) and the extensive use of fertilizers. Black-coloured soils observed in waterlogged areas like artificial tanks and paddy fields. The texture of the soil varies from place to place, depending on the topology and geology of the area (Rajasekhar et al. 2018a, 2019a). The significant Vedavathi/Hagari River, which drains from south to north, is the vital water supply. Besides this, minor and major tanks situated near Bommanahal, Kanekal, Uravakonda, Rayadurgam, and Gummagutta are the source of water. The water level depends upon the slope, lineaments, and condition of the aquifers. The water-level fluctuation from pre- and post-monsoons varies from 3.2 to 9 m. Groundwater prospects are tough especially in hard-rock terrain where primary porosity is absent.

Physiography, relief, and drainage

Physiographically, Anantapur district can be divided into four major zones, namely, granite–gneiss landscape, schist landscape, sandstone landscape, and limestone landscape. These broad zones cover hill ranges and isolated hills, undulating and rolling hillside slopes, undulating to gently sloping pediments, and narrow valley floors. The area is 450–1200 m higher than the average sea level (ASL). West of the Seshachalam range, comprising Kalyandurgam, Rayadurgam, Gooty, and Anantapur taluks is undulating plain with many isolated hillocks, monadnocks, domes rises, and small ridges with elevation ranging between 450 and 600 m above ASL. To the east of this Seshachalam range with elevation ranging from 900 to 1200 m above ASL lies the basin is known as the Tadpatri-Pulivendla basin. This gently sloping concavity occupies the major portion of Tadipatri taluk with few monadnocks and inselbergs of granite–gneiss, quartzite, and sandstones. There are four river basins in the district, namely, Hagari, Pennar, Chitravathi, and Papagni, all of which finally forms a part of the Penner river system. Study areas have canals, tanks, and wells are the major sources for irrigation (Fig. 1).

Materials and methods

Present work is an attempt to fulfil the objective in identifying groundwater potential zones (GWPZ) from the northern parts of Anantapur district, Southern India using various thematic layers such as geomorphology (GM), Lineament Density (LD), Drainage Density (DD), geology, land use/land cover (LULC), soils, slope, and rainfall are assessed together through information-based weighted overlay analysis (WOA) through AHP approach, to prepare GWPZs map using methodology shown in Fig. 2.

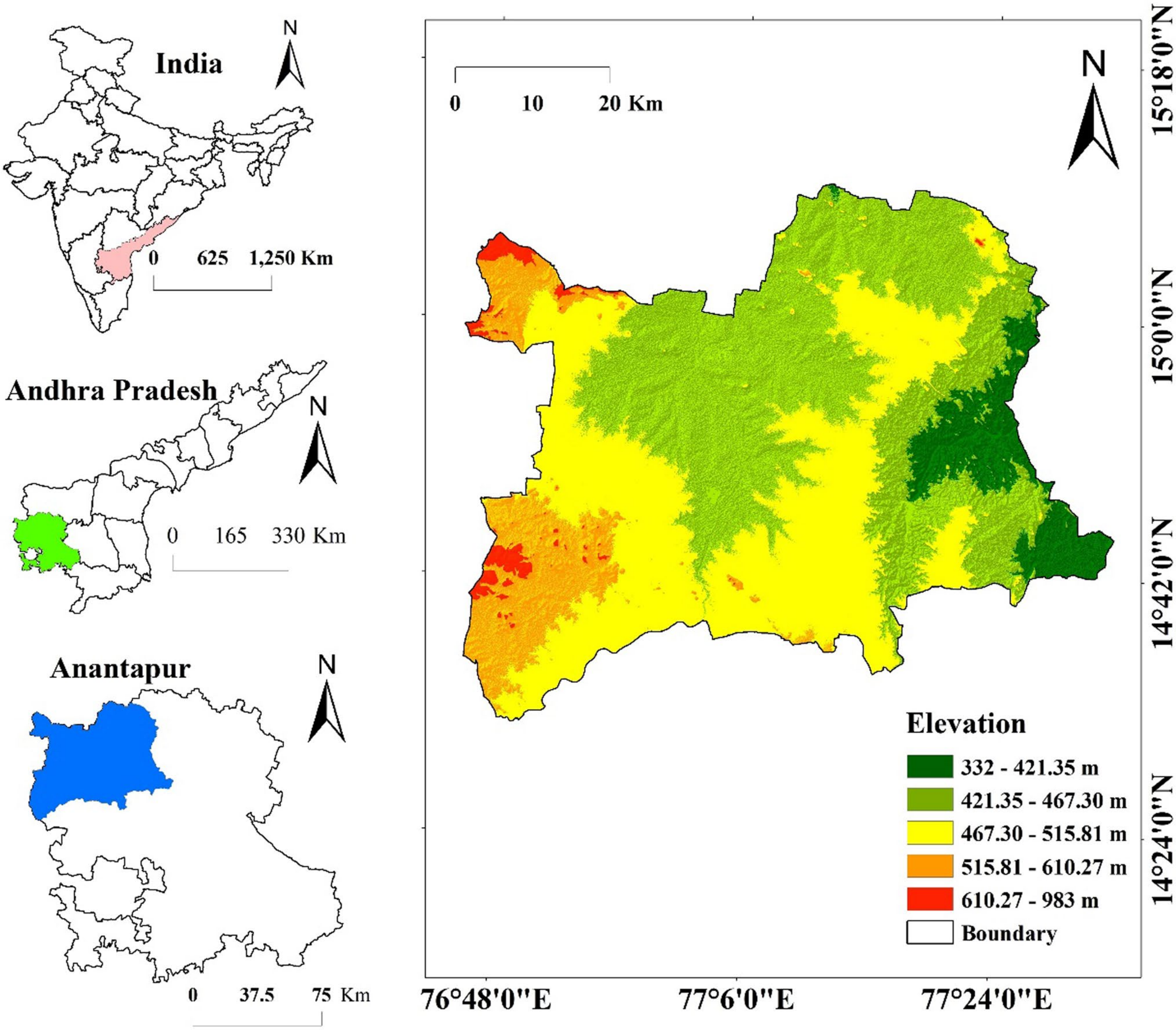


Fig. 1 Study area: north-western part of Anantapur

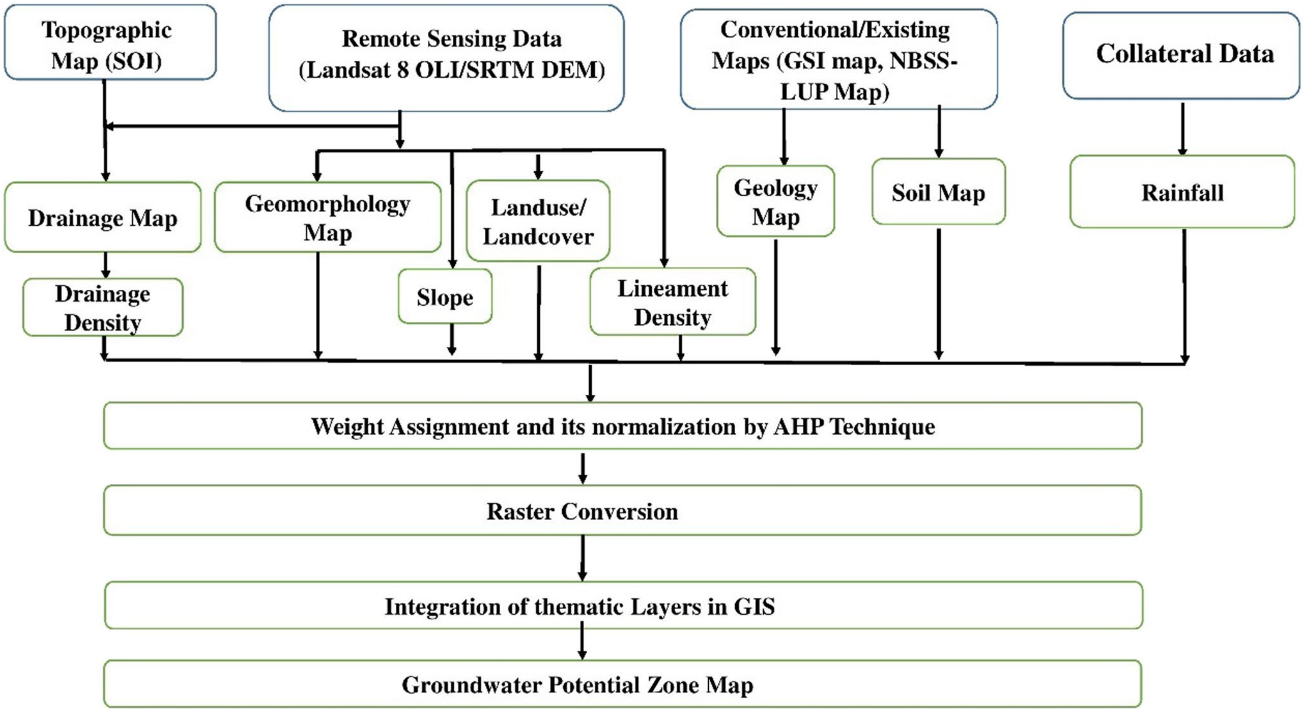


Fig. 2 Methodology

Preparation of thematic maps

In this present study, various thematic maps such as GM, LD, DD, geology, LULC, soils, slope, and rainfall were prepared using the ArcGIS environment and conservative field data. The LULC layer was prepared using Landsat 8 satellite dataset with the help of the image classification technique in ERDAS Imagine a (Rajasekhar et al. 2017, 2018c). The drainage density was prepared using topographical sheets from Survey of India (SOI). The soil map was prepared using the district soil resource map by the groundwater department, Anantapur. The slope map was derived from the Cartosat DEM data from the NRSC Bhuvan website. The rainfall and groundwater fluctuations data were collected from the Groundwater Department, Anantapur for rain gauge stations for the period from 1998 to 2018 which was used. The lineaments from satellite imagery were digitized using the ArcGIS environment (Chowdhury et al. 2010). An aggregate of eight thematic layers with their inter-relationship, which is inferred to incite the recharge potential in the Anantapur District, was chosen.

Geology

The area examined is mostly under soil cover with isolated hills and hillocks in the central part and discontinuous outcrops and small ridges of Penakacherla towards the eastern part from Velpumadugu under soil cover extends the northwest of Paramadevanahalli. Sandur to the west and Bellary Mountains form the hill ranges in the north-western part of the region. Penner–Hari is an NNW–SSE to N–S inclining fold in the syncline east of Velpumadugu Valley. This linear schist belt with scanty outcrops of volcano-sedimentary suite in general with pyroclastics traced to the south of railway crossing over the Hagari River. The Haematite Quartzites are not conspicuous, nor persistent in the strike length of schist belt is witnessed around, Chellakuriki and east of Velpumadugu. The banded ferruginous Quartzite (BFQ) on the crest of the low hillocks of Chellakuriki and east of Velpummadugu are persistent and indistinguishable from the sheared volcanic rocks below. The present study region is bounded by outcrops of granite, granite gneiss, grey granite, and metabasalts along with kimberlite formations. The whole lithological parameters were allocated weights based on the influence on GWP (Table 1) and the banded ferruginous Quartzites often merge into haematite Quartzites, which are minutely banded and frequently contorted (Fig. 3). The western margin of the schist belt shows profuse granitic intrusions. Vidapanakallu granite is one of them in the area, and the schist belt swerves at this place, and these granites thought to be of the diapiric type of intrusion. Though there is no clear-cut contact of schist belt with banded/migmatite gneiss on the western part, the mere occurrence along the west of margin considered as a part of the basement for the supracrustals of the belt. The first generation of folding consists of sample synclines in each

Table 1 Criteria, sub-criteria, and AHP weights for GWPZs

Theme	Weight	Normalized weight	Class	Sub-score
Geology	13	0.13	Amphibolite	1
			Granite and granodiorite	3
			Grey granite/pink granite	3
			Hornblende–biotite gneiss	4
			Kimberlite	1
			Metabasalt	1
			Quartzite; BIF/BMQ	2
			River	Res
Geomorphology	11	0.11	Waterbodies	Res
			Structural origin-Moderately Dissected hills	1
			Structural origin-low Dissected hills	1
			Pediment–PediPlain complex	4
			Denudational origin-Moderately Dissected hills	3
			Anthropogenic Terrain	2
			Aeolian plain	3
Land use/land cover	15	0.15	Forest, Evergreen	3
			Agriculture, Cropland	4
			Forest/Scrub Forest	3
			Agriculture, Fallow land	4
			Waterbodies/Rivers	Res
			Barren/Wastelands	1
			Built-up Land	1
Drainage density	15	0.15	0–4.09 km/Km^2	1
			4.09–8.18 km/Km^2	2
			8.18–12.27 km/Km^2	3
			12.27–16.36 km/Km^2	4
			16.36–20.45 km/Km^2	5
Soils	13	0.13	Clayey-Skeletal	1
			Coarse loamy	5
			Fine, mixed & loamy-skeletal	4
			Fine, Montmorillonitic	3
			Loamy, Mixed	3
			Loamy-Skeletal	3
			River/Canal	Res
			Rock lands and Clayey-Skeletal	1
Slope	9	0.09	0–1%	5
			1–3%	5
			3–5%	4
			5–10%	4
			10–15%	3
			15–35%	2
			> 35%	1
Lineament density	9	0.09	0–0.05 km/Km^2	1
			0.05–0.12 km/Km^2	2
			0.12–0.18 km/Km^2	3
			0.18–0.25 km/Km^2	4
			0.25–0.32 km/Km^2	5
Rainfall	15	0.15	187.40–220.19 mm/year	1
			220.19–280.55 mm/year	2

Table 1 (continued)

Theme	Weight	Normalized weight	Class	Sub-score
			280.55–350.70 mm/year	3
			350.70–420.70 mm/year	4
			420.70–535.70 mm/year	**5**

Res restricted

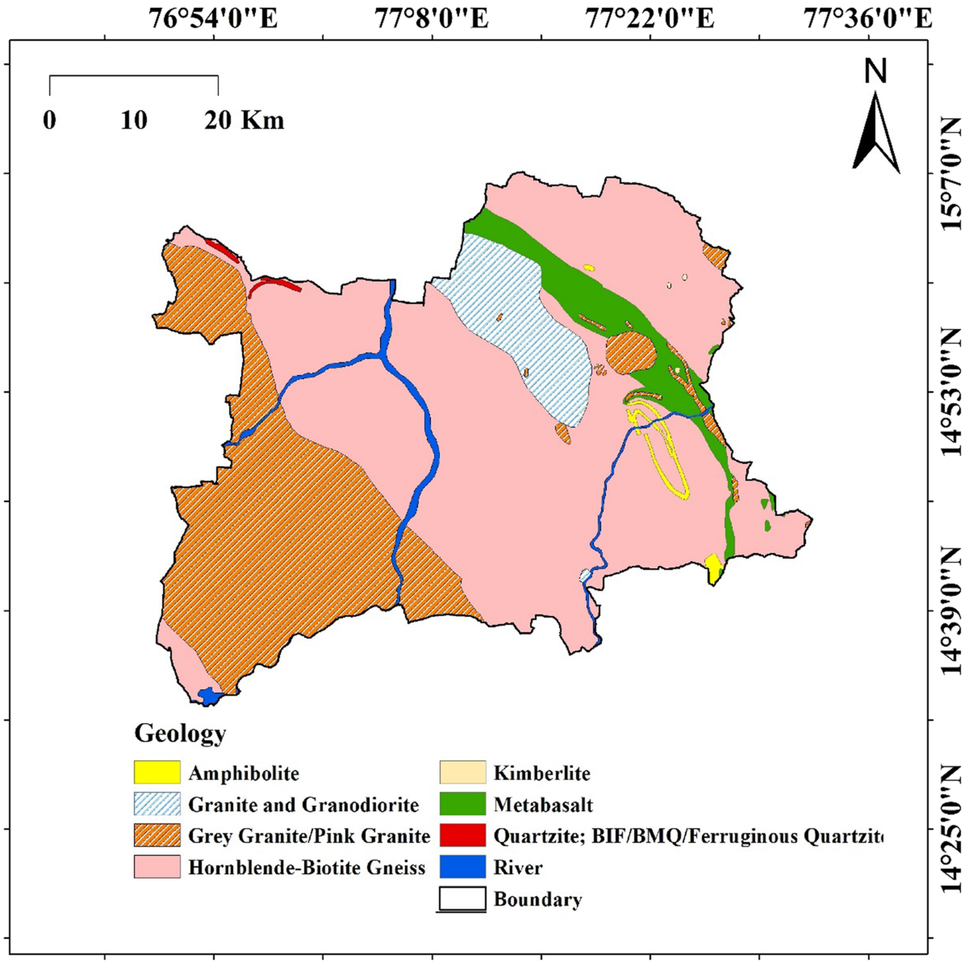


Fig. 3 Geology

of the schist bands (Penner–Hagari belts) with their axes generally plunging in an NNW direction. Because of the high weathering due to the extremely fragmented situation in the sample region, the maximum weightage was allocated to weathered hornblende biotite gneisses and the minimum weightage was assigned to metabasalts, amphibolites, and kimberlite in terms of porosity and permeability.

Geomorphology (GM)

Geomorphologically, most of the area is covered by a denudational hill that comes under reserved forest. Pediments are formed all around the structural hills and the denudational hillocks. Small residual hillocks and domal structure are formed by the peninsular gneisses and granitic body and dolomite with chert, Shale which falls on the northern side of the toposheet.

The western parts flowing Vedavathi/Hagari River form the main drainage in the western to southern parts of the area. Besides this, several seasonal streams are draining into some large tanks situated near Bommanahal, Vidapanakallu, Nimgagallu, Honnur, and Uravakonda. The hill ranges exhibit sub-parallel drainage patterns, whereas the plains and isolated hillocks show sub-dendritic and sub-parallel drainage patterns, and sub-dendritic and sub-radiating drainage patterns. The region's northern, north-eastern, and south-western parts are enclosed in a pediment–pediplain matrix. The study area's pediment and pediplain regions suggest a strong GWPZs. In the central and south-western regions of the study area, waterbodies, canals, and rivers are visible, indicating a rather good GWPZs. Structural/Denudational dissected hills are often present in the north-eastern and south-western areas of the area, with low and moderate groundwater occurrences attributable to hard-rock structures with strong run-off and little infiltration (Fig. 4).

Soils

The soil of the area has originated from the schist belts and the granite gneisses underlying the area. Red soils are generally found associated with the granite gneisses, and Quartz porphyry and the darker soils are associated with the basic and ultra-mafic rocks of the dolomite, Shale, basic flow, and schist belts. The soil colours observed are mainly reddish, yellowish, blackish, brownish, creamish, and greyish. The Most common colour observed is Reddish colour varies from light brown to dark red, indicating that the soil is Fe rich in composition. Black-coloured soils are observed in paddy fields. The texture of the soil differs from place to place reliant on the topology and geology of the area. The pediplain in general has thin-to-medium soil cover. The thickness of soil cover differs but generally 0.5–1 m thick soil cover is common in the area. The soils in the present study categorized into four categories, namely loamy-skeletal, fine-montmorillonite, rock lands, and clayey soils (Fig. 5). A soil's rank has been determined by its infiltration rate. Since loamy soils have a high rate of infiltration, they are given a higher priority, whereas clayey soils have a low rate of infiltration and are thus given a lower priority (Jhariya et al. 2016) (Table 1).

Drainage density (DD)

DD is an inverse function of permeability, and therefore, it is a significant factor in identifying the GWPZs. The drainage map of the present study is used for preparing the DD map (Fig. 6). High DD values are favourable for run-off and hence indicate low GWP. DD is an inverse property of

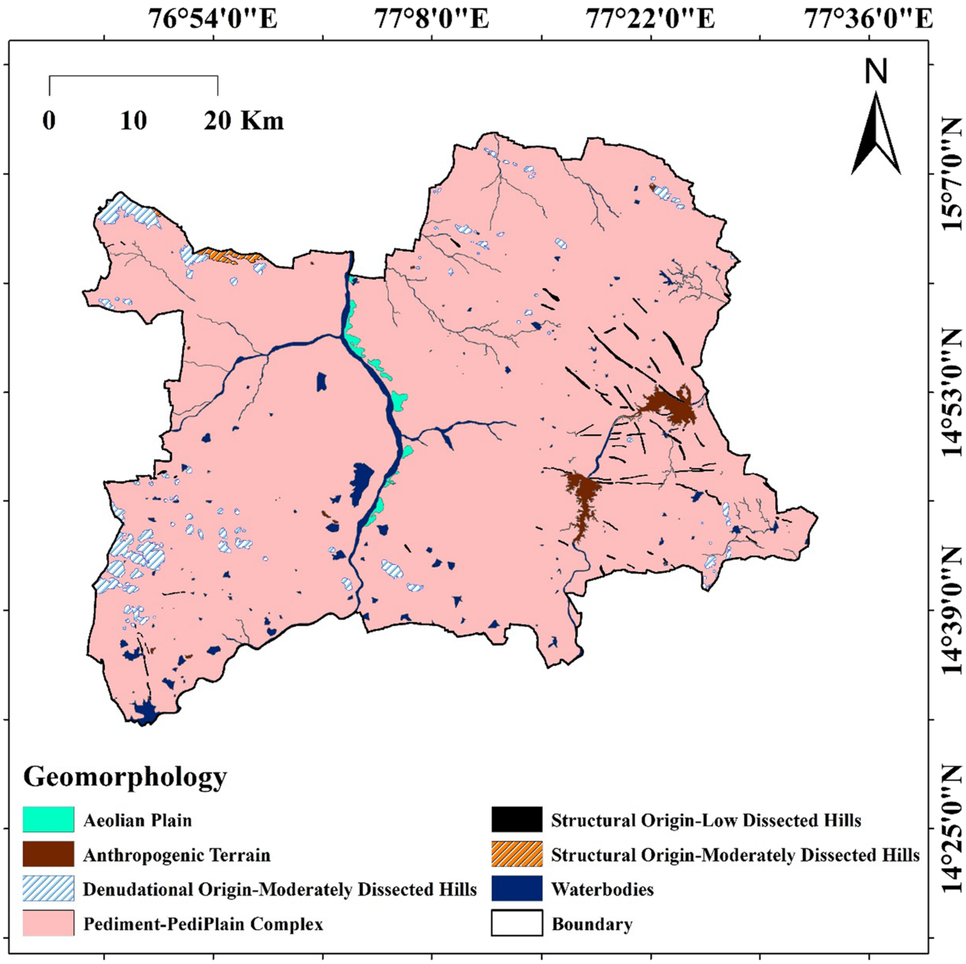
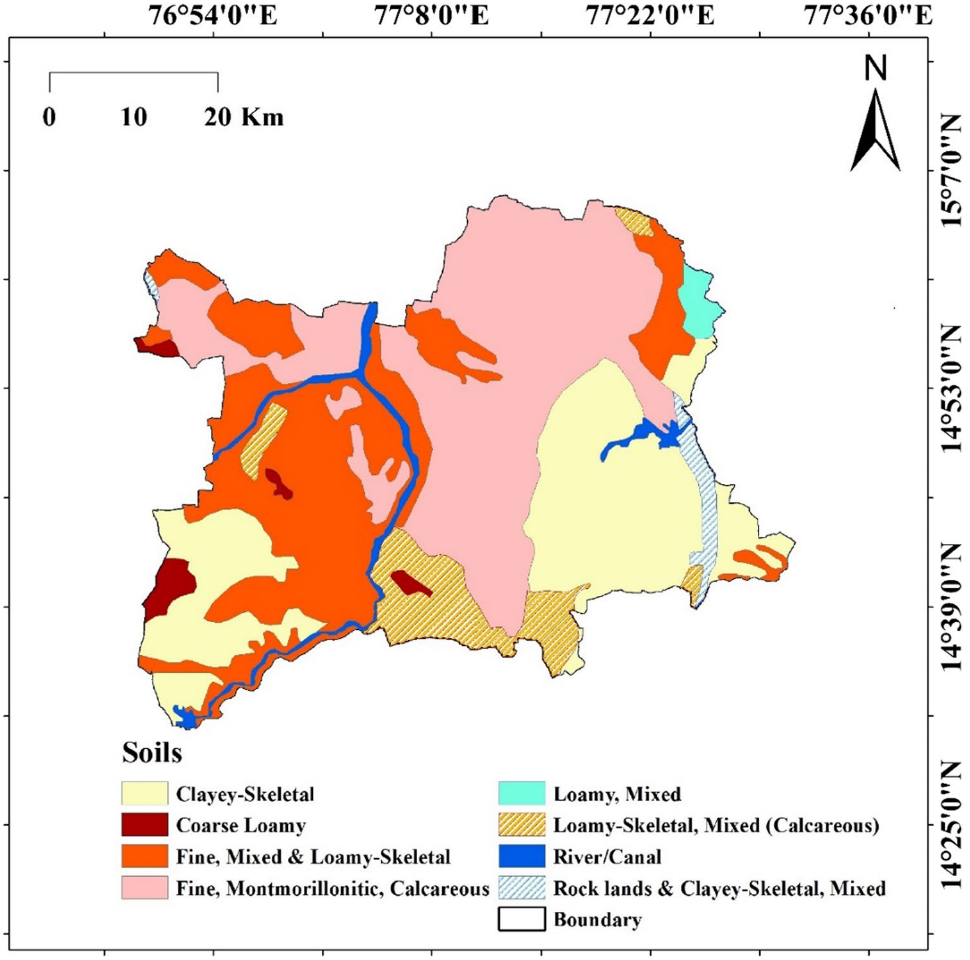


Fig. 4 Geomorphology

Fig. 5 Soils



permeability, it plays a significant role in defining GWPZs, and the drainage layer of the present study is used for preparation of DD map towards the identification of GWP (Fig. 6). The drainage density of the region has a straight relation with the landscape, the geomorphological patterns, the subsurface geology, and the land use in the extent. Stream order is enhanced the condition suitable localities of protection measures regarding groundwater storage capacities (Horton 1932, 1945). The DD map discloses the density values from 0.021 to 20.45 km/km^2 (Fig. 6). High rankings are assigned to areas with a poor drainage density, and vice versa. (Table 2). High DD results in the very poor-to-poor GWPs and moderate and low DD results in the moderate-to-high GWPs.

Slope

Slope plays a significant part in determining land-use form and suitability which distresses the agriculture practice in several topography (Worqlul et al. 2017; Zolekar and Bhagat 2015). The slope map has been prepared from Cartosat DEM and divided into seven classes based on IMSD (Integrated Mission for Sustainable development 1995) classification (Fig. 7). The slope plays important role in soil properties such as soil depth, GM, LULC, as well as run-off of the present study (Bandyopadhyay et al. 2009; Kadam et al. 2018; Tsui et al. 2004; Sahu et al. 2018). The high degree of slope is noticed in the south-western part of the area due to the presence of hilly regions where low GWPs due higher run-off and low infiltration. The class with the lowest value (gentle) is assigned a higher rank due to almost flat terrain, whereas the class with the highest value (steep) is assigned a lower rank due to relatively high run-off.

Land use/land cover

The present study is mainly covered by pediment–pediplain with SE–NW-trending strike ridges also covered by residual hills and thick reserve forest trending SW–NE in the diagonal part of the area. The major part of the area is mostly utilized for agriculture purpose and some area is utilized by human settlements, and rest of the area is covered with hillocks, mounds, ridges, reserve forest, and some wasteland with bushes and scrubs. Depending on

Fig. 6 Drainage density

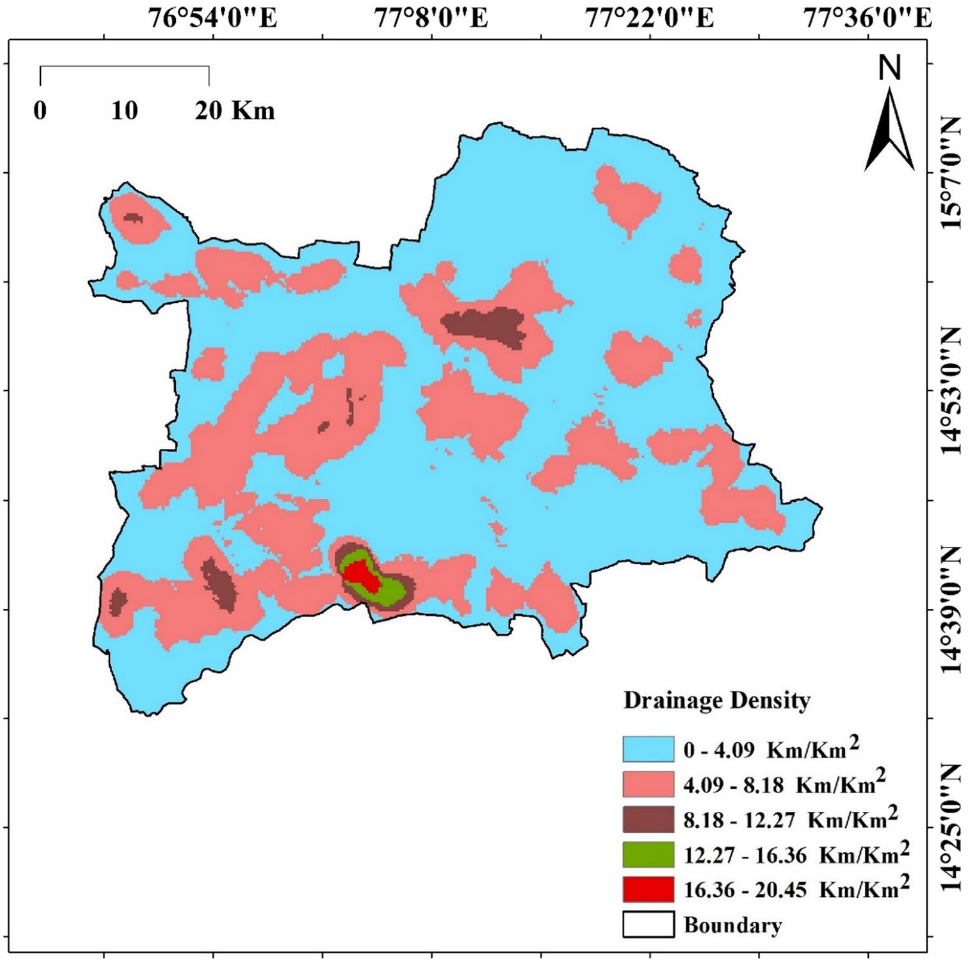


Table 2 Groundwater potential zones

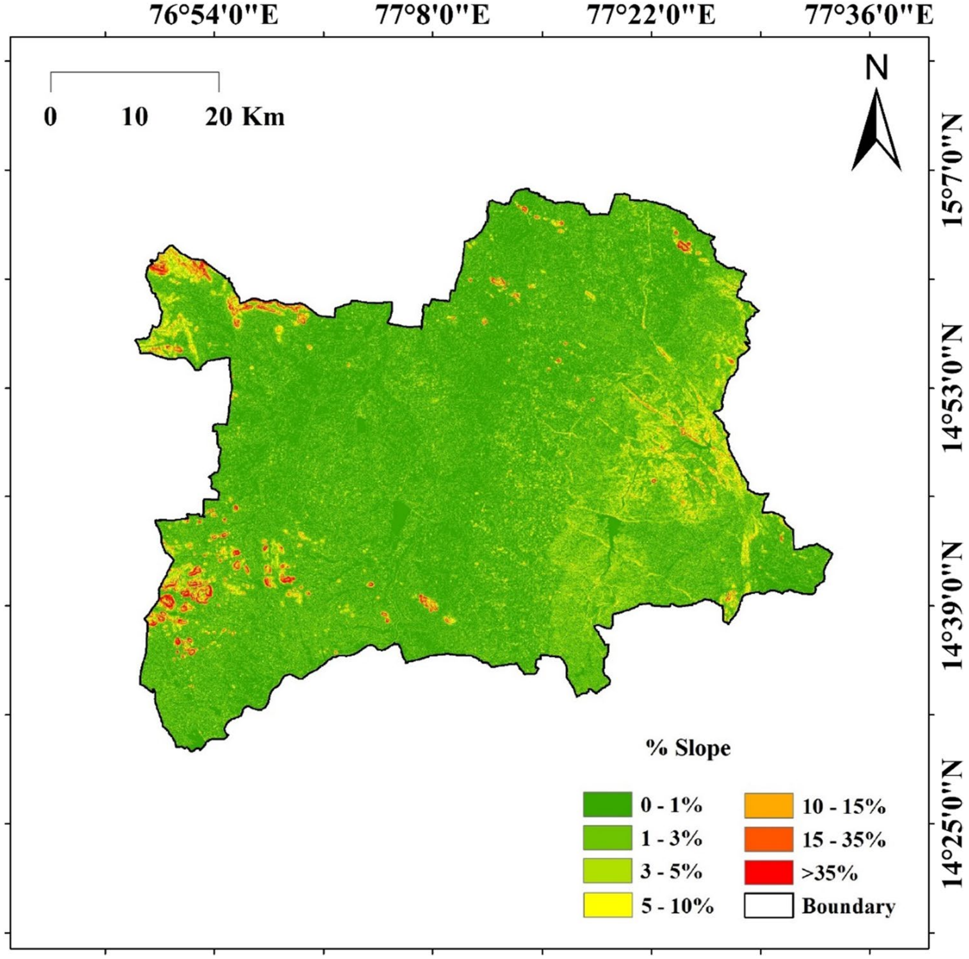
GWPZ	Area (Km^2)	Area (%)
Very poor	188.73	5.32
Poor	567.16	15.99
Moderate	2250.75	63.47
Good	452.56	12.76
Very good	87.06	2.45

the availability of groundwater, tank water, wet crops, and seasonal crops are being raised in this area (Rajasekhar et al. 2018b). The present study involves the semi-arid area indicating seven kinds of LULC patterns (Fig. 8). Run-off and evapotranspiration in the study area impact LULC as it a critical marker determination of reasonable potential rainwater-harvesting structures. It's seen that most of the region indicates a cultivated area (groundnuts, red grams, Bengal grams, paddy, cotton, and vegetables, etc.) results the good GWPs. Since vegetation and agricultural fields are ideal locations for groundwater discovery, they receive the highest ranking. Sandy fields are known to have favourable groundwater potential, while waste land and built-up areas have inadequate GWPs (Rajasekhar et al. 2019a, 2019b).

Lineament density (LD)

The LD can be calculated as the whole length of lineaments per unit degree. It manages a many-esteemed land actuality about the high quality of structural alteration, rupturing and shearing, and groundwater conceivable outcomes. In this manner, the control of LD is a noteworthy and helpful strategy to catch many connected lithological features and reasonable thematic layer and cautious perception bid additional accuracy if there should be an occurrence of lineament convergence of a zone (Rajasekhar et al. 2018a). The LD map discloses the density values from 0 to 2.92 km/km^2 (Fig. 9). For high LD, assigned high weightages results the very good-to-good GWPs and low LD assigned low weightages through decision-making tools as AHP results low GWPs (Table 1).

Fig. 7 Slope



Rainfall

The rainfall accessibility was reflected as the main cause of recharge. The rainfall significantly affects the GWP and the proficiency of AHP (Rajasekhar et al. 2019b; Rahmati et al. 2015; Rajasekhar et al. 2020a, b). The monthly rainfall information regularly collected from CM dashboard, Govt. of Andhra Pradesh, India for the present study for a time of 1 decade (i.e., 2008–2018). The rainfall map was reclassified into five main categories: 187.40–220.19, 220.19–280.55, 280.55–350.70, 350.70–420.70, and 420.70–535.70 mm/year (Fig. 10). In resultant map is the normal yearly precipitation in the upland regions is generally higher than low reaches. The N–E region depicts higher rainfall results higher weightages indicates the very good-to-good GWPs and central and N–W part having moderate-to-low rainfall indicates the lower weightages results the moderate-to-poor GWPs. Since high rainfall is conducive to a high groundwater capacity, it is given a higher priority.

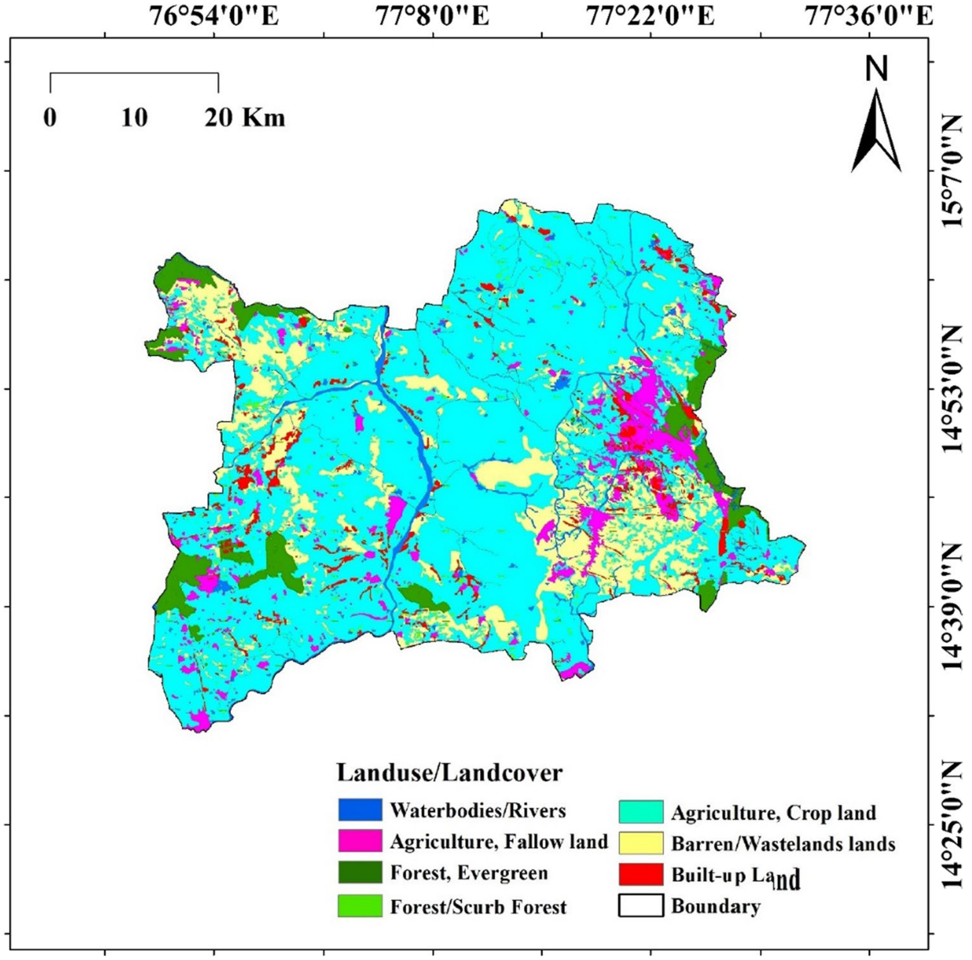
Decision-making approach

AHP approach

Assigning weights The AHP simplifies the parameters of the PCM and is dependent on the assigning of experts about the significance of the influencing factors. AHP is one of the most common approaches in decision-making analysis. This process also can analyse proportionally various datasets through the PCM analysis of each parameter and flexibility in the situation of intentions (Kumar et al. 2016; Rajasekhar 2018a; Shailaja et al. 2019). Saaty (1977) initially carried out this systematic exercise to show sustainability and the consequences in a multilateral decision-making system. The matrix structure of AHP offers the possibility to quantify and synthesize different features of the multilateral decision-making process hierarchically.

In this study, AHP is used to estimate the weight of all relevant parameters that influence the potential of groundwater recharge in the study region. AHP implies an assessment

Fig. 8 Land use/land cover



of the significance between the parameters, the normalization, and calculating the consistency ratio (CR). Depending on the hierarchical order constructed, it is decided that the priority of the influencing factors recognizes the significance of the features at various levels of the hierarchy (Kaliraj et al. 2014). To obtain qualitative data, the factors that influence each level are compared in pairs. The Saaty scale from 1 to 9 (Table 3) is used to measure the relative importance of the factor (Saaty 2008).

Pair-wise comparison matrix (PCM) In this way, a diagonal matrix is prepared by placing the values in the upper triangle and their reciprocal values are used to fill the triangular matrix. The expert's judgment was used for PCM (Zolekar and Bhagat 2015). Besides, the relative weights were normalized. The normalized principal eigenvector is obtained by averaging the order to verify the consistency of the priority vector. The principal eigenvalue is acquired by adding the products among every component of the eigenvector and the summation of the columns of the mutual matrix Table 4). This fundamental eigenvalue is used to degree the consistency of ideas through an analysis of the consistency ratio (CR) (Saaty 1980). A CR value lower than 0.1 can be considered as opinions with less uncertainty in weight determination (Kadam et al. 2018; Rajasekhar et al. 2019a; 2020b). The Consistency Index (CI) is calculated using the below equations and the comparison matrix to compare all parameters for calculating CR

$$\mathrm{CI} = \frac{\lambda\mathrm{max} - n}{n - 1}, \tag{1}$$

where $\lambda_{\max}$ = consistency vector;
n = criteria or factors.
CR is calculated using Eq. 2

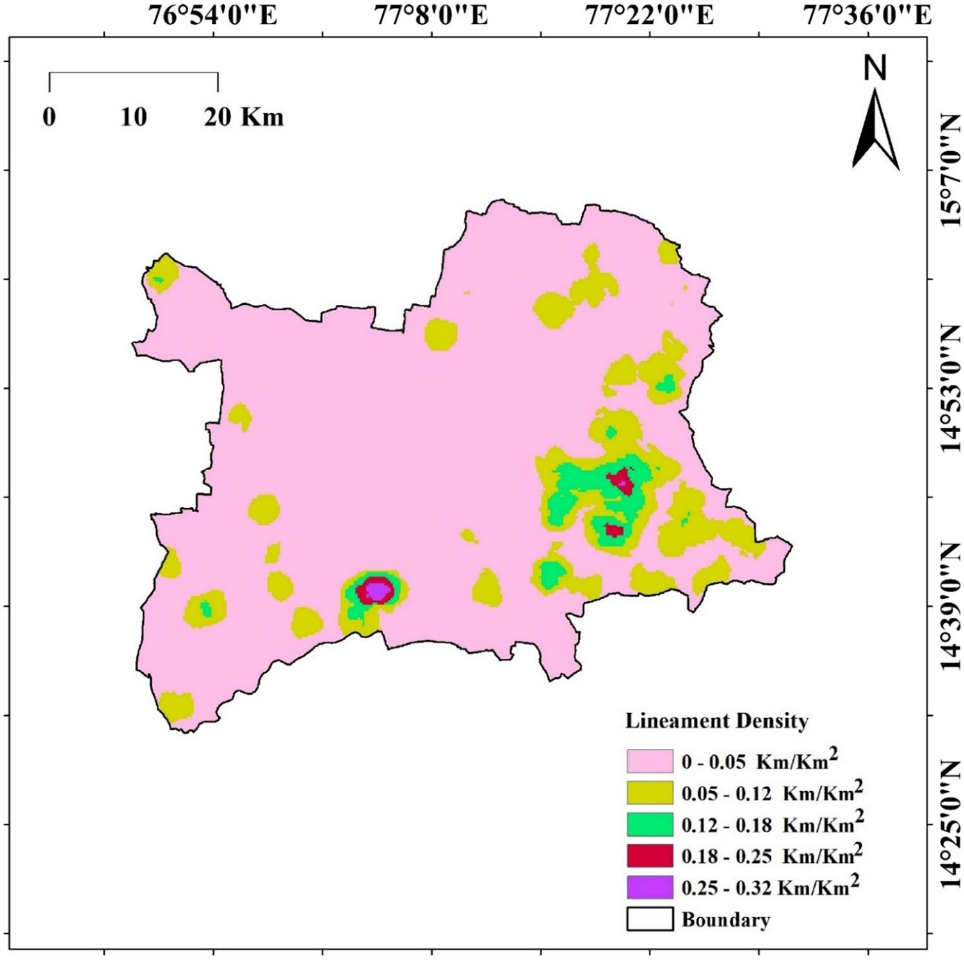
$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RCI}}, \tag{2}$$

where *RCI* random consistency index, provided by Saaty (2008) (Table 5).

Validation

The accuracy assessment of the results was carried out by AUC (Area under the Curve) and ROC (Receiver-Operating

Fig. 9 Lineament density



Characteristics) technique. Groundwater fluctuation values were obtained during dug well inventory and compared with the estimated groundwater recharge potential zones to calculate the accuracy. The AUC meaning varies from 0 to 1. A model with 100% incorrect predictions has an AUC of 0.0; one with 100% accurate predictions has an AUC of 1.0 (Elmahdy and Mohamed 2014).

Results and discussion

The GWPZs were evaluated in this analysis using an AHP-based approach that supports the relative significance of different thematic layers and their related groups affecting groundwater. The weight of each thematic layer is represented in Table 4 using the weights of their respective groups in AHP. The CI for the various thematic maps are CI = 0.1373 and CR = 0.09 (Table 4) which is lesser than the threshold value of 0.1, which shows a high level of consistency. Based on this criterion, the analyses and the rank of assigned to sub-criteria were used in the final WOI to map the GWPZ of the study area. GWPZ area is divided into five categories i.e., very poor, poor, moderate, good, and very good (Fig. 11a).

The GWPZ results indicated that 2.45% (87.06 km^2) of the area was classified to have very good groundwater potential and 12.76% (452.56 km^2) of the area was classified as good groundwater potential, with over 63.47% (2250.75 km^2) being moderate, 15.99% (567.16 km^2) is poor, and 5.32% (188.73 km^2) is of very poor groundwater potential (Table 2). The outcomes acquired here were quantified and this procedure retained the accuracy of the image by calculating the AUC based on the operational characteristics of ROC. The ROC charts are valuable for forming classifications and displaying their performance, as well as for defining AUC values when calculating and associating procedures. When classifications and instances are provided, the ROC validation technique offers four probable consequences, viz., positive, negative, false positive, and false negative. If the potential recharge area in the image is very high and is considered positive due to the low volatility of the groundwater, it is considered true positive. If it is categorized as negative due to high fluctuations in groundwater, it must be reported as a false negative. The ROC/AUC was

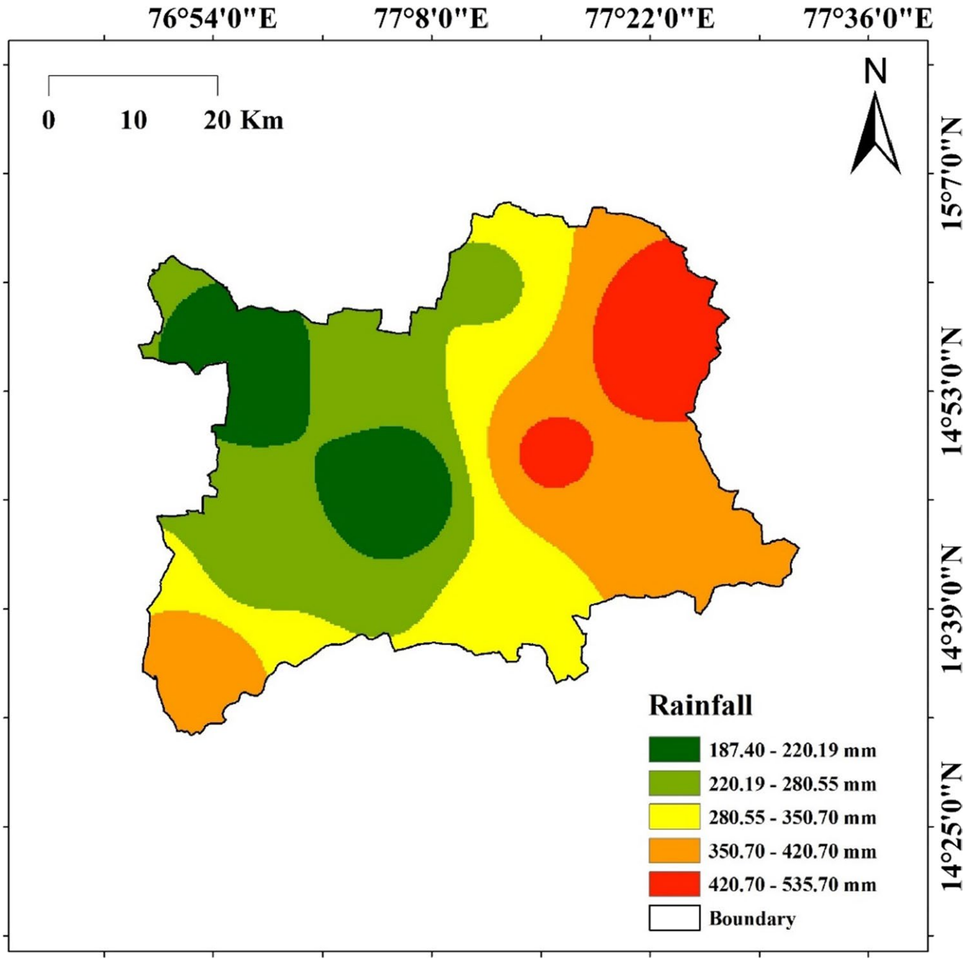


Fig. 10 Rainfall

Table 3 AHP scale (Saaty 2008)

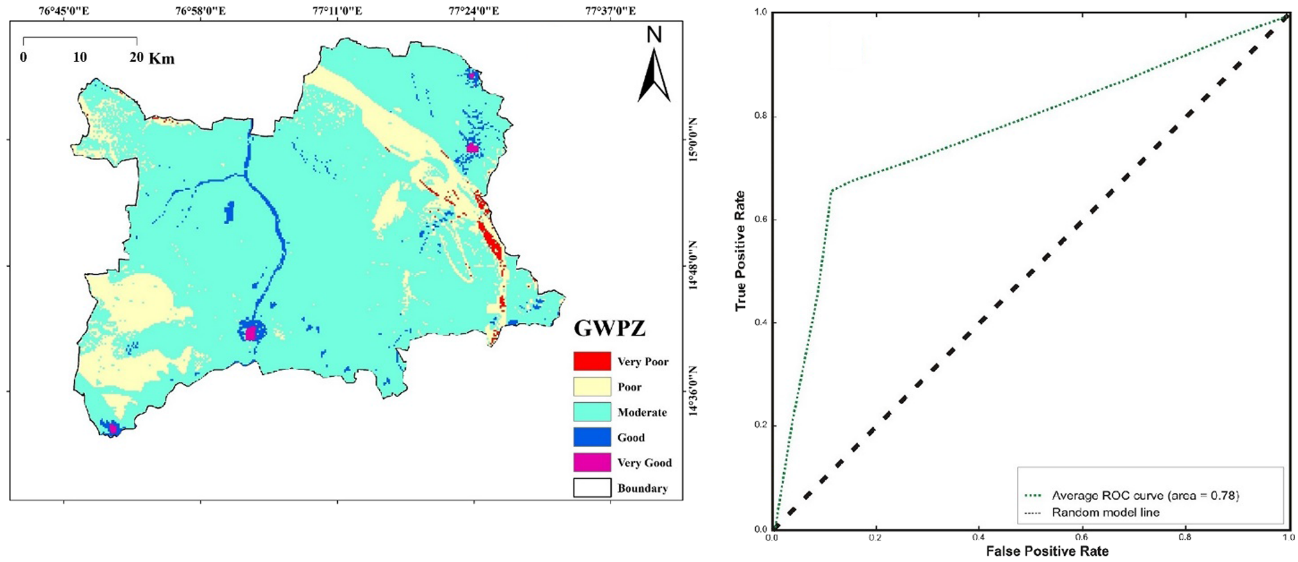
Scale	1	2	3	4	5	6	7	8	9
Importance	Equal	Weak	Moderate	Moderate plus	Strong	Strong plus	Very strong	Very, Very strong	Extreme

Table 4 Pair-wise comparison matrix

Thematic map	GM	GG	LULC	DD	LD	Soil	Slope	Rainfall	Normalized weight	CR
GM	1.00	0.50	0.50	4.00	4.00	0.50	1.00	0.20	0.11	0.09
GG	2.00	1.00	0.25	4.00	1.00	0.50	0.50	3.00	0.13	
LULC	2.00	4.00	1.00	5.00	2.00	0.33	3.00	0.25	0.15	
DD	0.20	0.25	0.20	1.00	0.33	0.25	0.20	0.33	0.15	
LD	0.20	1.00	0.50	3.00	1.00	0.33	2.00	1.00	0.09	
Soil	2.00	0.50	3.00	4.00	3.00	1.00	3.00	2.00	0.13	
Slope	1.00	2.00	0.33	5.00	0.50	0.33	1.00	0.20	0.09	
Rainfall	5.00	0.33	4.00	3.00	1.00	0.50	5.00	1.00	0.15	

Table 5 Random index values

N	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49



a Groundwater Potential Zones

b Average of ROC curve

Fig. 11 **a** Groundwater potential zones and **b** average of ROC curve

calculated by fluctuations in the groundwater level in wells that are collected from the study area and was estimated at 0.78 below the curve (Fig. 11b). Accuracy indicates an estimated success rate of 78% of the proposed GWPZs of the study area.

This results in a more accurate findings of the research area's groundwater capacity, which is used for the effective growth of groundwater resource management. Concerned policy makers should develop an effective groundwater utilisation strategy for the research region based on the study's findings.

Conclusions

The integrated RS and GIS technique is extremely effective in delineating the Groundwater Potential on a multidimensional scale. This study focuses on the use of MCDA in conjunction with geospatial approach to determine the spatial variation in GWPZs in the north-western part of the Anantapur district, Southern India. Now, water scarcity is a major concern in monsoon-dominated countries, owing to its widespread exploitation. According to the GWPZ findings, 2.45% (87.06 km^2) of the region has very good GWP, 12.76% (452.56 km^2) has good GWP, over 63.47% (2250.75 km^2) has moderate GWP, 15.99% (567.16 km^2) has low GWP, and 5.32% (188.73 km^2) has very poor GWP. To analyse the issue, multi-criteria and computational three decision-making models were utilized in the GIS condition under potential conditions. In this study, validation is performed to verify the accuracy of the GWPZs maps. A total of 130 wells were identified for the accuracy of each model using the analysis of the area AUC. The AUC for the fuzzy model is 78% for AHP analysis. The AHP method is depending upon determining the relative assessment of their importance, which requires considerable knowledge of the factors. The integrated GWP map created in this study may be beneficial for a variety of decision-making processes. The approach may be beneficial in developing successful groundwater extraction strategies, as well as predictive groundwater production and management strategies that ensure long-term sustainability.

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Data availability The raw data are obtained from NRSC Bhuvan and USGS website (https://bhuvan.nrsc.gov.in/ and https://earthexplorer.usgs.gov/) which is available free of cost and the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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