Groundwater Resource Identification in the Eastern Ghats Terrain of the Maredumilli Mandal Area in East Godavari District,Andhra Pradesh,India, Applying AHP (Analytical Hierarchical Process) and WOA (Weighted Overlay Analysis)

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Research Highlights:

- The present study area comprises the Eastern Ghats Mobile Belt's hard crystalline rocks
- For a long period, residents in this area have been suffering from a severe water crisis. To solve this issue, we made the first attempt to determine the groundwater potential zones in the current study region.
- To explore groundwater, hydrogeological studies and remote sensing were combined.
- We used the methodology of Saaty's Analytical Hierarchy Process technique and the Weighted Overlay Analysis tool in Arc GIS for the generation of the resultant GWPZ map.
- The Receiver Operating Characteristic (ROC) curve has been used to cross-validate the results.The validation findings showed a respectable prediction accuracy of 83.33%.

Abstract: *The Maredumilli Mandal is the present study area consisting of hard crystalline rocks of the Eastern Ghats Mobile Belt. The residents of this area have been suffering from severe water scarcity. To overcome this problem, the authors of this paper have made attempt to integrate both Remote Sensing and hydrogeological data to identify the groundwater potential zones in this area.*
GIS analysis has been used to study the thematic layers related to geology, geomorphology, lineament density, land use/cover, slope. soil and drainage density. Based on their relative significance in affecting the groundwater recharge to supply potential aquifers, Saaty's Analytical Hierarchy Process (AHP) was used to calculate the weights of all thematic levels and the ranks of the pertinent subclasses within each layer. Weighted Overlay Analysis (WOA) was used to combine all of the theme layers and create the Groundwater Potential Zonation map for the research area. This map exhibits four distinct groundwater qualities viz., good, moderate, poor, and very poor. These four groundwater potential zones cover the areas of 14.94 sq. km, 402.85 sq. km, 517.80 sq. km, and 12.10 sq. km respectively. The Receiver Operating Characteristic (ROC) curve has been used for Cross-validation and the results revealed an accurate and impressive prediction. This integrated approach yields satisfactory results in terms of delineating groundwater potential zones in the area. These results may help the people living there in drilling bore wells which can produce water for their domestic needs. Only moderate potential zones are found in the study area's central region, where the Khondalite series of rocks serve as the main geological formations, and good groundwater potential zones are found there, where agriculture is practised on a type of soil with effective porosity and permeability.

Keywords:
GIS, Thematic Layers, Analytic Hierarchy Process, Receiver Operating Characteristic curves, Weighted Overlay Analysis, Groundwater potential zones.

Introduction:

Groundwater is an essential source of water for household, agricultural, and industrial uses. The shortage of groundwater is caused by abnormal climatic changes, particularly those that affect the amount and frequency of rainfall, the deterioration of surface waters, and increased population (Panahi *et al*., 2020; Nguyen *et al*., 2020). In hard rock terrains, The freshwater resources depend on the degree of fracturing/weathering as these rocks lack effective intergranular porosity Groundwater potential zones are defined using a range of conventional methods, including geology, hydrogeological, geophysical, and remote sensing techniques. (Lee et al., 2019a, b). Many scholars (Bhattacharya et al., 2020; Rajasekhar et al., 2020; Das, 2017;) have reported on the use of Geographic Information Systems (GIS) in groundwater monitoring and management, such as the identification of Groundwater Potential Zones (GPZ). several researchers worked on Multi-Criteria Decision Making (MCDM) models like Analytical Hierarchal Process (AHP) to determine the weights of parameters and used in determining groundwater potential zones in various parts of the world (Hamdani and Baali, 2020; Saranya and Saravanan, 2020; Arulbalaji *et al.*, 2019; Chakrabortty *et al.,* 2018;).

Validation of groundwater potential zone map was carried out with Receiver Operating Characteristic (ROC) curves by some researchers like Nguyen, 2020. Arc GIS packages provide a variety of tools to create an integrated groundwater potential zone map and each tool works on input data format and the algorithm used to generate that tool. The most widely used spatial analysis tools are Fuzzy Overlay, Weighted Overlay Fuzzy Membership and Weighted Sum. In the current investigations, the Weighted Overlay tool has been used to generate and Identify the possible groundwater zones of the Maredumilli mandal area.

The main objective of the present study is to locate Maredumilli Mandal's groundwater potential zones. The steep slopes and the hard surface basements in this region deteriorate the surface and subsurface resources. Therefore, it has become important to identify the potential groundwater locations to meet the demand of minimum requirements of people living there. Utilising the Weighted Overlay Analysis (WOA) and Analytical Hierarchy Process (AHP) techniques, the integrated analysis was conducted.and the results have been validated with Receiver Operating Characteristic (ROC) curves.

The Study Area:

Maredumilli Mandal area lies between 17° 46′ & 17° 86′ North Latitudes, and 81° 51′ & 81° 87′ East Longitudes covering an area of about 951.9 sq. km. (Figure 1). For the creation of the base map of the study region, toposheets at a scale of 1: 50,000 were used. The area elevation varies from 14 m to 1,368 m above mean sea level. The climate of this mandal is of tropical type. Rainfall is primarily caused by the southwest monsoon and the mandal typical annual rainfall is 152.34 cm.

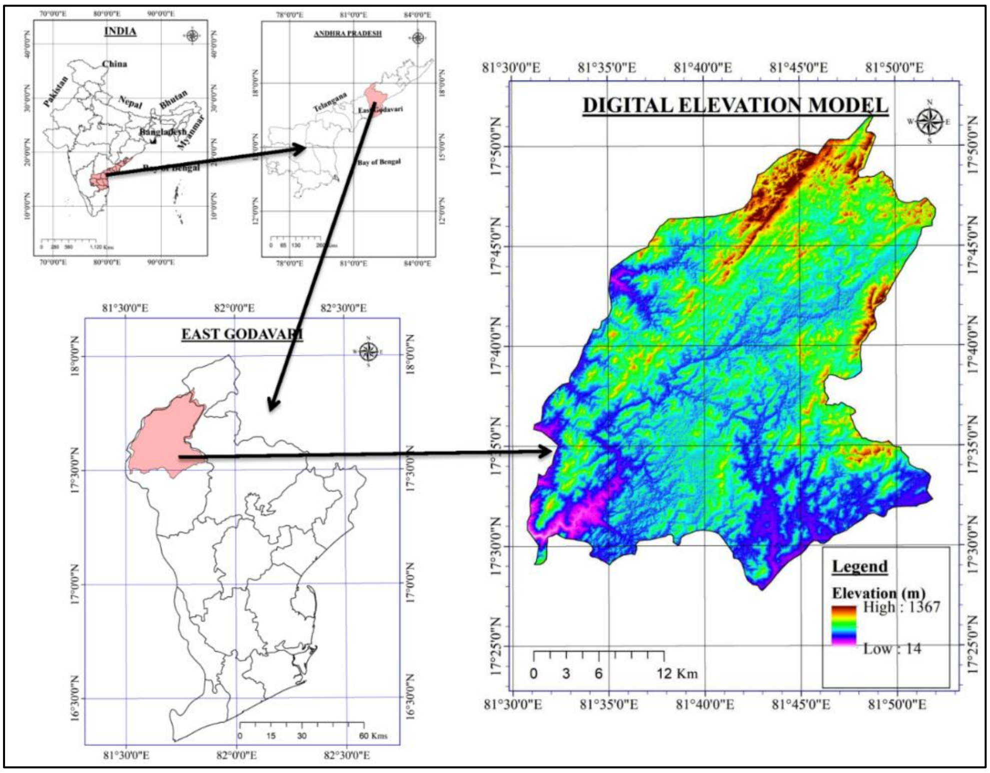


Figure 1. Geographic location with Digital Elevation Model (DEM) of Maredumilli Mandal

Groundwater resources are primarily responsible for meeting the drinking and agricultural needs of the residents of the Maredumilli mandal. They face many problems for water, and also walk for several kilometres to get drinking water from different areas wherever it is available. It has become evident that they can get the required water for their drinking and agricultural purposes. Hence, identification of groundwater potential zones in this area is needed. Which can be accurately determine by the combined interpretation of data obtained from the hydrogeological parameters (thematic layers) and aquifer parameters (VES).

Methodology:

Exploration and exploitation of groundwater is based on its source, occurrence, and mobility which are affected by topographical factors either directly or indirectly (Jha *et al.*, 2007). For the purpose of locating and evaluating the groundwater potential zones in the Maredumilli Mandal, the following factors were taken into account: drainage density, geology, slope, lineaments, land use/land cover, soil, and geomorphology (thematic layers). Thematic maps of the above-mentioned parameters were prepared using different tools of data management in Arc GIS. The Geological Survey of India (GSI) provided the geological map of the research region. From Bhuvan's site (Indian-Geo Platform of ISRO, NRSC), the geomorphic characteristics, land use/land cover, and lineaments were observed using Web Map Service (WMS) in the Arc GIS platform. The United States Geological Survey (USGS) earth explorer portal was used to download the ASTER Global Digital Elevation Map (ASTER-Global DEM) with a 30 m spatial resolution and used to produce a drainage density map. The data for different types of soils of the area were obtained from the District Survey Report of the Government of Andhra Pradesh Department of Mines and Geology. The Weighted Overlay tool in the Arc GIS package has been used in combination with the weights of thematic layers derived from Satty's Analytical Hierarchy Process (AHP) to obtain potential groundwater locations.

According to how important each parameter is in relation to the others, the Analytical Hierarchy Process (AHP) is a technique used to analyse and compare the parameters (Saaty, 1980 & 1990). It was developed as one of the multi-criteria decision-making techniques. In this procedure, each parameter is originally given a set of weights, which are subsequently normalised. Using the equations 1 and 2, to assess their dependability, these weights are get from computed the Consistency

Index (CI) and Consistency Ratio (CR) values (Rao *et al.*, 2021; Gyeltshen *et al.*, 2022). According to Saaty, 1990, the computed CR must be significantly small (less than 10%) in order for the normalised weights to be considered valid.

$$CI = (\lambda_{max} - n) / (n-1) \quad (1)$$

$$CR = CI/RI \quad (2)$$

Where "n" is the number of components to be taken into consideration, and λmax denotes the consistency vector's total. Table 1 shows the Random Index (RI), which is the predicted CI from a matrix of order values. According to Saaty's AHP, the pairwise comparison (Table 2) and normalized matrices (Table 3) were prepared for the above parameters based on their respective significance for the flow and storage of groundwater. From this analysis, the computed CI and CR values are 7.53 % and 5.80 %, respectively. Here, the calculated consistency ratio (CR) is below 10 As a result, the calculated weights are acceptable according to Saaty, 1980 & 1990. The average weight of each thematic layer when multiplied by 100 gives the weightage (Table 4) of the respective parameter of the thematic layers.

Table 1.Values of Random Index (RI) (Saaty, 2008)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.56	0.80	1.11	1.22	1.30	1.40	1.46	1.48

Table 2. Pairwise Comparison of Thematic Layers

	GL	GM	LD	LU/LC	SL	SO	DD
GL	1.00	1.00	1.50	2.00	2.00	3.00	3.00
GM	1.00	1.00	0.50	1.50	1.50	2.50	3.00
LD	0.50	0.50	1.00	1.50	1.50	2.50	3.00
LU/LC	0.32	0.51	0.68	1.00	1.50	2.00	2.51
SL	0.50	0.34	0.50	0.68	1.00	1.52	2.00
SO	0.32	0.68	0.66	0.50	2.00	1.00	0.50
DD	0.50	0.34	0.50	0.51	0.50	2.00	1.00
Sum (W_s)	4.14	4.37	5.34	7.69	10.00	14.52	15.01

(GL: Geology;GM: Geomorphology; LD: Lineament Density; LU/LC: Land Use/Land Cover, SL:Slope; SO: Soil; DD: Drainage Density.)

Table 3. Matrix of Normalized Comparison

Thematic layers	GL	GM	LD	LU/LC	SL	SO	DD	Average weightage (W)
GL	0.25	0.23	0.29	0.26	0.20	0.21	0.21	0.231
GM	0.24	0.23	0.09	0.20	0.15	0.17	0.20	0.183
LD	0.1	0.12	0.19	0.20	0.15	0.17	0.20	0.163
LU/LC	0.08	0.12	0.13	0.13	0.15	0.14	0.17	0.129

SL	0.12	0.08	0.09	0.09	0.10	0.10	0.13	0.102
SO	0.08	0.15	0.13	0.07	0.20	0.07	0.03	0.104
DD	0.11	0.08	0.09	0.07	0.05	0.14	0.07	0.087

(GL: Geology;GM: Geomorphology; LD: Lineament Density; LU/LC: Land Use/Land Cover;

SL:Slope; SO: Soil; DD: Drainage Density.)

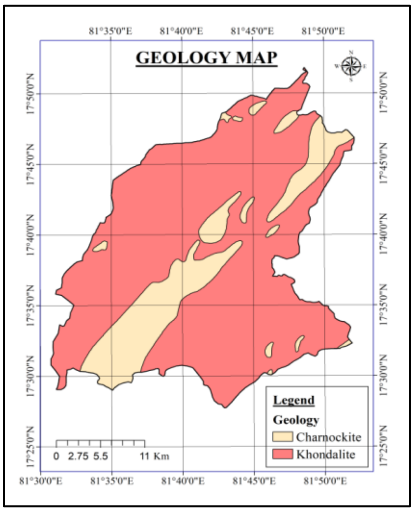
With Arc GIS processing capabilities, overlay analysis can be carried out in a variety of ways, including fuzzy membership, fuzzy overlay, weighted overlay, and weighted sum. In the current issue, Weighted Overlay Analysis (WOA) has been employed often. (Thangasamy *et al.*, 2020; Rao *et al.*, 2021; Gandhi and Patel, 2022). This tool requires the thematic layers of considered parameters in a raster format of the same spatial resolution and weightage of each parameter derived from AHP analysis. It works on the algorithm developed from the equation 3 suggested by Malczewski, 1999, and the raster map with Groundwater Potential Zones (GWPZ) is obtained using this tool.

$$\text{GWPZ} = \sum_{j=1}^{m} \sum_{i=1}^{n} W_j X_i \qquad (3)$$

where "Wj" is the weight of the j^{th} parameter, "X"i is the rank of the i^{th} parameter layer sub-feature, m is the total number of parameters, and n is the total number of parameter layer sub-features.. Each sub-feature of all the thematic layers has been assigned ranks from 1 to 9 in the reclassification process based on the relative value of groundwater recharge, with 1 being the least beneficial and 9 being the most beneficial (Table 4).

Geology of the Study Area:

The most crucial factor in determining the location of the groundwater resources is the geology of the area.. The Maredumilli mandal occurs in the Eastern Ghats terrain which extends from Nilgiris in the south to the border of Odisha and Bengal in the northeast consisting of the important rock types such as khondalites, charnockites, and granite gneisses. Different types of soils also occur here. Therefore, the geology of the research region represents the same rock types as the Eastern Ghats. Figures 2 show the geology of the study area, which is mostly covered by Khondalite series of rocks, Charnockite group of rocks (Source: GSI). The occurrence of effective porosity is more common in Khondalites as they are influenced by intense weathering and fracturing and because of their medium to coarse-grained texture. Thus, these rocks are highly favourable for the occurrence of groundwater than the Charnockites which resist weathering, The soils are also characterized by intergranular effective porosity (Table 4).



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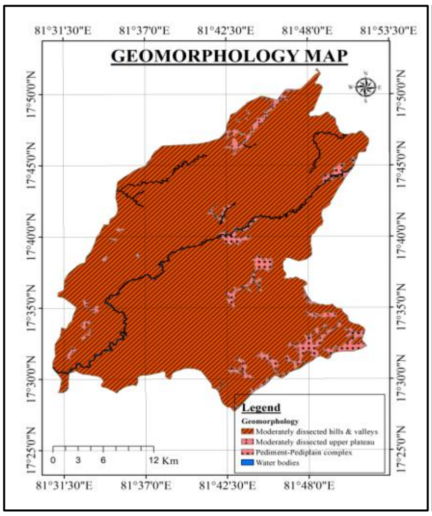

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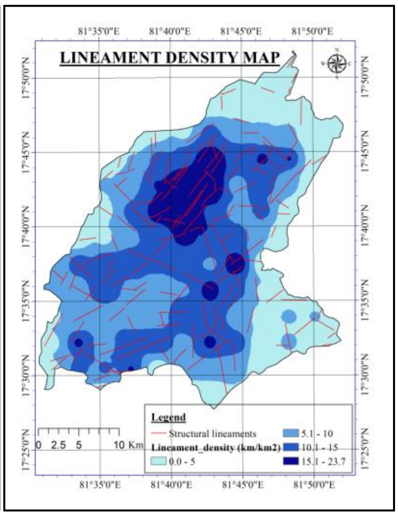
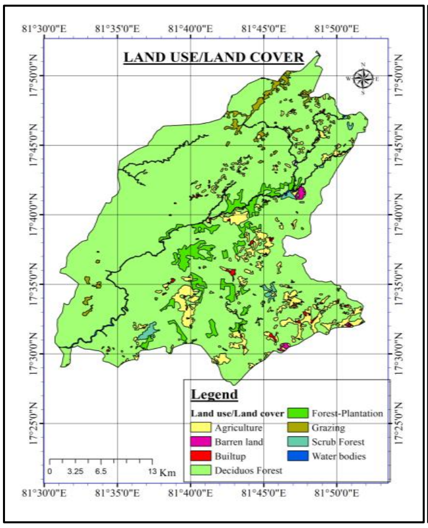


Figures 4



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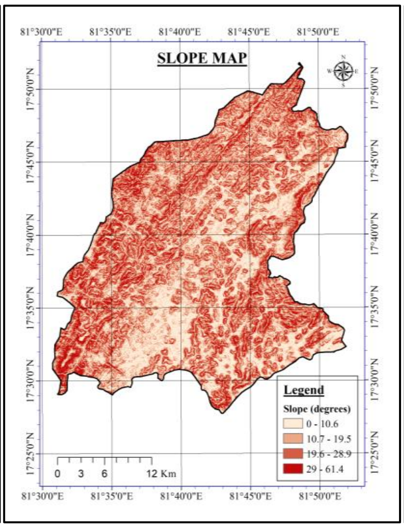

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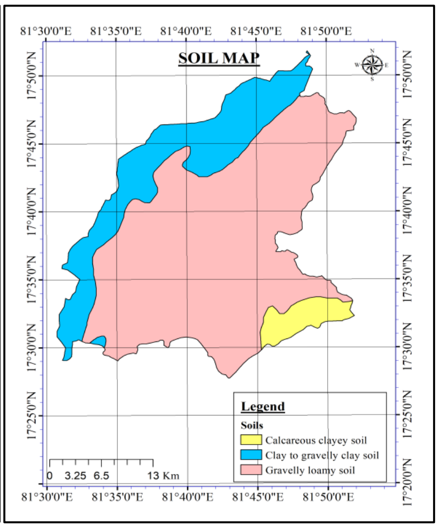

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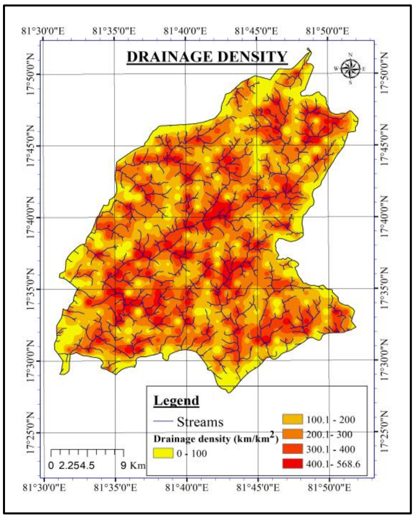

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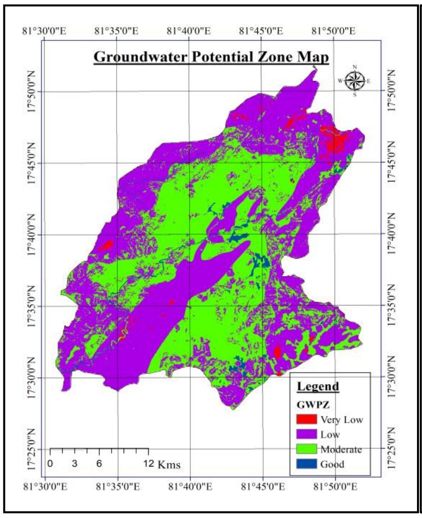

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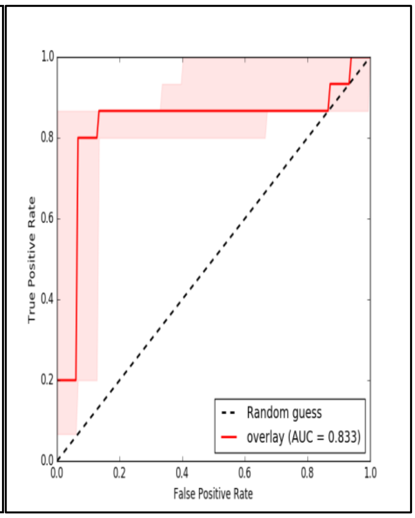

Figures 10

Geomorphology of the Study Area:

Geomorphology provides essential details on processes including surface runoff, infiltration, and migration of groundwater in addition to the description of landforms and topography of a region. The Maredumilli mandal region has hilly topography. The geomorphological features developed in the studied area are water bodies, pediment pediplain complex, moderately dissected upper plateau, and moderately dissected hills and valleys shown in (Figure.3). The hilly regions consist poor groundwater potential zones due to enormous and rapid surface runoff along their steep slopes. About 94.94 % of the research region is covered by mountain landforms with valleys (894.06 sq. km). Water bodies cover nearly 8.28 square kilometers and these are awarded the highest rank 9 as the water is recharged to subsurface continuously until they become dry, while the pediment-pediplain complex (35.80 sq. km) was given rank 7 as it is characterized by the weathered/eroded material which infiltrates water into the underground layers. Due to their high degree of slopes, the moderately dissected upper plateau and moderately dissected hills and valleys, respectively, are given the ranks 4 and 3 (Table 4).

Table 4. Rankings and Weights for the Influencing Classes and the Factors Used in Groundwater Potential Mapping.

Hydrogeological parameters	Weights of parameters (%)	Sub-features	Ranks of sub-features	Area (sq. km)	Area (%)
Geology	23.14	Khondalites	8	772.55	81.175
		Charnockites	5	179.18	18.825
Geomorphology	18.32	Water bodies	9	8.26	0.87
		Pediment pedeplain complex	7	35.88	3.77
		Moderately dissected upper plateau	4	13.52	1.42
		Moderately dissected hills & valleys	3	893.04	93.94
Lineament Density	16.3	15.1-23.7	9	67.95	7.14
		10.1-15	8	328.13	34.48
		5.1- 10	7	374.29	39.22
		0- 5	6	182.33	19.16
Land Use/Land Cover	12.93	Water bodies	9	8.78	0.92
		Agriculture	7	59.54	6.26
		Forest plantation	6	37.54	3.94
		Scrub forest	5	5.8	0.62
		Deciduous forest	4	818.01	86.06
		Grazing land	3	13.43	1.41
		Barren land	2	2.41	0.25
		Built-up areas		5.19	0.55
Soil	10.21	Gravelly Loamy soil	8	683.93	71.76
		Clay to Gravelly clayey soil	7	226.09	23.76

		Calcareous Clay	5	42.68	4.48
Drainage Density	10.38	0- 100	9	12.66	1.33
		100.1- 200	8	87.47	9.09
		200.1- 300	7	371.75	39.06
		300.1- 400	6	399.73	42
		400.1 -586.6	5	81.1	8.52
Slope	8.72	0- 10.6	9	270.58	28.43
		10.7-19.5	8	286.68	30.02
		19.6-28.9	7	264.14	27.64

Lineament Density:

Lineaments are a representation of the underlying structural elements' surface topography. (Koch *et al.,* 1997; Chandra *et al.,* 2010). In hard rock terrains, Lineaments are the regions of faulting and fracturing that improve secondary porosity and permeability which are accurate indicators of the presence of groundwater (Kumar *et al.,* 2007). In the Maredumilli mandal area, a total of 159 structural lineaments have been identified (Figure.4). According to Chepchumba, 2019, zones with a high density of lineaments are more likely to include groundwater potential zones, and in the study area, high lineament density zones are given a higher rank (Table 4).

Land Use/Land Cover (LU/LC):

Surface runoff, which affects the rate of soil infiltration, is controlled by land use/land cover (LU/LC). Water bodies (8.78 sq. km), agriculture (59.54 sq. km), forest plantation (37.54 sq. km), scrub forest (5.80 sq. km), deciduous forest (818.01 sq. km), grazing land (13.43 sq. km), barren land (2.41 sq. km), and built-up areas (5.19 sq. km) are the eight categories used to classify the LU/LC map of the research region (Figure.5). Deciduous forest covers the largest area, accounting for 86.06 %. Agriculture lands covers 6.26 % of the research area which is in the form of forest plantations. Barren land makes up to 0.25 %, only 1.41% of the entire study area is grazing land, however (Table 4).

Built-up regions are intimately related to the poor groundwater potentiality. and rocky barren land areas as the rainfall that occurred over it is readily converted into surface runoff. Water bodies with high potential with rank of 9, and agricultural lands with a rank of 7 can be considered for groundwater prospects (Table 4). As the extraction of groundwater from the forest on hilly terrains is difficult, low rankings from 6 to 3 have been assigned to forest categories of plantation like the scrub forest, deciduous forest, and grazing lands. The barren land is given a rank of 2 and built-up areas are given the lowest rank of 1.

Slope:

The slopes of the study area (Figure.6) are very steep in some regions, moderately steep in some other regions, and almost flat still in some areas. As the runoff is high at steep slopes, the low values (i.e., 0° to 10.6°) are given a higher rank of 9, whereas the regions with higher slopes (29° - 61.4°) are given a lower rank of 6. (Table 4)

Soils:

Water infiltration and circulation depend on soils. The Government of Andhra Pradesh's department of mines and geology (DMG) has provided the thematic map of soil type for the entire East Godavari district. Three types of soils are identified in the research area (Figure.7). Gravelly loamy soils cover most of the study area (71.76 %), followed by Clay to Gravelly clay soils (23.76

%), and a small patch of calcareous clay (4.48 %) is observed at the eastern boundary (Table 4). The infiltration rates suggested by Ibrahim Bathis and Ahmed, 2016, were used to rank the soils in this area. Soils with higher infiltration rates have been given higher rankings (Table 4).

Drainage Density:

The drainage density is a crucial characteristic parameter to take into account while evaluating the region for the presence of groundwater because it is inversely related to the permeability of the geological formation. According to Yeh *et al.,* 2009, High drainage density values favour runoff. Hence, these areas are regarded as low groundwater potential zones. There are five zones in the research area. (Figure.8) and the zones of low drainage density are assigned high ranks, and vice versa (Table 4).

Results and Discussion:

The thematic layers of geology, geomorphology, land use/cover, soil, lineaments, slope, and drainage were combined to create a map of the groundwater potential zone. Initially, 30 m of common spatial resolution is applied to all of these thematic layers. In this process, each sub-feature of individual thematic layer is assigned different rank as discussed earlier. Later, the reclassified thematic layers have been given to WOA tool in Arc GIS by assigning them the weights derived from the AHP analysis. The resultant map of Groundwater Potential Zones (Figure 9) is generated with the same 30 m of spatial resolution. The four unique classes of groundwater potentials obtained by the natural break classification—good, moderate, low, and very low—have been used to illustrate the categories on the final map. According to the GWPZ results, 1.58 % (14.95 sq. km) of the area is classified as good groundwater potential, 42.64 % (405.6 sq. km) of the area as moderate groundwater potential, 54.5 % (518.8 sq. km) as low, and the Mandal has a very low groundwater potential of 1.28% (12.1 sq. km).The ROC curves used to validate the GWPZ map (Figure 10) produced a value of 0.833, which shows that the AHP and WOA combination technique provides a very good prediction in this case. An accuracy of 83.3 % is achieved in our research work

Validation of the GWPZ map with the ROC curves (Figure 10) revealed 0.833, and it is indicating that the AHP and WOA combined approach provides a very good prediction in this case. An accuracy of 83.3 % is achieved in our research work.

Acknowledgment:

We would like to convey our gratitude to the Andhra Pradesh Groundwater and Water Audit Department for supplying bore well data of the research area**.**

Author Statement:

The first author, V.Sulochana Rani, completed this research as part of her Ph.D. The APGWAD (Andhra Pradesh State Groundwater and Water Audit Department) supplied bore well data for this study. The first author downloaded the satellite data and processed it under the supervision of the second author, as well as assisting in the text and completion of the paper. The third author was involved in the manuscript draft preparation and finalization.

Declarations

Funding

This work does not have any funding.

Conflicts of interest/Competing interests

The authors declare that they have no conflicts of interest/competing interest.

Availability of data and material:

Not applicable.

Code availability (software application or custom code)

No specific code was developed for this work. The used algorithm was cited in the literature.

Authors' contributions

The first author downloaded the satellite data and processed it under the supervision of the second author, as well as assisting in the text and completion of the paper. The third author was involved in work analysis, manuscript draft preparation, and finalization.

Ethics approval

We have followed the ethics and integrity in carrying out this work. We agree to follow the COPE guidelines.

Consent to participate (include appropriate statements)

We agree to participate in the review process and also to follow COPE's rules.

Consent for publication

We declare our consent for publication within the guidelines of COPE.

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