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Identification of groundwater potential for urban development using multi-criteria decision-making method of analytical hierarchy process

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Abstract

Detailed knowledge regarding the availability of potential groundwater sources is a prerequisite for the sustainable development of cities and towns in a planned manner. The present study is carried out to identify the potential groundwater sources for the growth of towns and cities around Virudhunagar district, India by integrated geospatial techniques and analytical hierarchy method. The groundwater potential zones are divided into four groups: low, medium, high, and very high. It is obtained that 1.71% and 51.86% fall under the low and medium zones, respectively. The area with high and very high groundwater potential accounts for 45.7% and 0.73% of the total area, respectively. Finally, potential areas identified for groundwater are validated with data on the potential yield of various wells, demonstrating a good correlation. The results of this research will help planners and decision-makers to better plan and develop future cities.

1. Introduction

Water is essential for all kinds of living organisms; groundwater found in the aquifer beneath the earth's surface is a precious source for mankind. Groundwater is the primary source of water for a variety of purposes, including industrial, domestic, and agricultural needs. The availability of water varies with space and it is characterized by a hydrological cycle. The increase in population has led to serious deterioration of surface and subsurface water. Groundwater is something that needs to survive, and also needs water for agriculture, domestic and industrial developments. Groundwater depletion occurs due to the frequent pumping of water from the ground with the use of bore wells. Pumping of water more quickly than it can replenish itself which in turn leads to the depletion of groundwater at a faster rate than it is not sustainable anymore.

Groundwater is the primary source of water used for domestic purposes in rural areas. Furthermore, it is the primary source of agriculture due to its greater distribution, low development cost, and good quality when compared to surface water [1]. The United Nations reveal an estimation that by the year 2025, two-thirds of the human population will face an acute shortage of freshwater across all parts of the world. According to a report by the United Nations Educational, Scientific, and Cultural Organization (UNESCO), India withdraws a significant portion of groundwater in comparison to other countries. It has also been stated that 21 major cities of India are in a critical stage of groundwater which would distress almost 100 million people.

Groundwater recharge mechanisms have been altered by rapid urbanization, necessitating a focus on new methods to increase groundwater recharge. This urban development is impacting the groundwater quality in major cities and downstream of the alluvial aquifer. Carmon and Shamir [2] discussed the water considerations for planning urban and regional areas. The author of [3] characterized the watersheds that bear dynamic structures with large land. Sustainable development requires the proper guidelines for urban planning which takes the effects on environmental resources including groundwater resources. In this paper, it is stressed that sustainable development also includes the development of urban settlements based on natural resources, which includes factors like

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groundwater availability, rainfall, rainwater harvesting, surface water availability, and planning of settlement based on natural resources.

Satellite images with high spatial resolution are provided by sensors onboard satellites launched by leading countries, e.g., US, Germany, France, India, etc. These images are used to create large-scale geo-referenced data, which are required to assess groundwater potential. The rapid advancement of computer technology and Geographic Information Systems (GIS) in the twentieth century enables more support in storing and analyzing large amounts of spatial and non-spatial data in a shorter period of time and with greater accuracy. Analytic Hierarchy Process (AHP) was proposed by [4] to solve complex decision-making through pairwise comparisons. Integration of remote sensing imageries, GIS, and AHP can help to handle a large number of geo-referenced data for the demarcation of groundwater potential zones (GWPZ) more accurately. Sajil Kumar [5] demarcated the groundwater potential zones in the Chennai River basin using the GIS-based AHP method. An integrated approach of RS, GIS, and AHP has been used by several researchers [6-9] for monitoring and assessing groundwater potential. As Virudhunagar is a rapidly developing district it is without a doubt an absolute necessity to find the regions having good groundwater resources and develop the settlements-based availability and sustainability of groundwater. The objective of the present study is to recognize the hydrogeology, and categorize the GWPZ of Virudhunagar district, Tamilnadu, India.

2. Study area

The current study was conducted in the Virudhunagar district of Tamil Nadu, India, over a 4126 km^2 region (Figure 1). It is one of the rapidly developing districts in Tamil Nadu as a nearby district of Madurai is turning into a smart city. Thus, the development of population settlement based on groundwater availability will be sustainable manner. Hence, this district was chosen as the study area. Minerals such as limestone, sand clay, gypsum, and granite abound in the studied region. The study area's climatic condition is semiarid tropical monsoon, and it has been experiencing hot and dry conditions. A maximum temperature of 28°C to 32°C was recorded in December, while 38°C to 42°C was recorded in June. The least temperature ranged from 17.6°C to 23°C experienced in the months of January. The Northeast monsoon is mostly responsible for the district's rainfall. The majority of the rain falls in the form of cyclonic storms brought on by depressions in the Bay of Bengal. The district's average yearly rainfall ranges from 724 to 913 mm. In the district's south-eastern corner, it is at a bare minimum. It progressively rises in the direction of the west, north, and northwest.

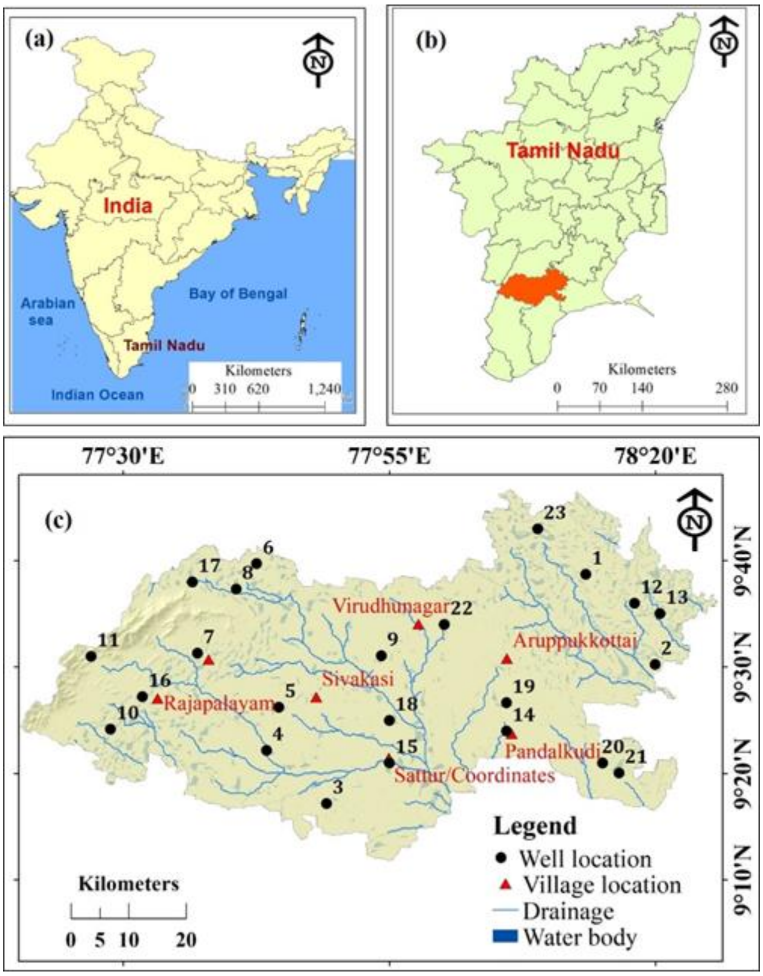

Figure 1. Study area illustrating (a) overview of India with different states; (b) Overview of Tamil Nadu state divided with district boundary; (c) The actual area covered by Virudhunagr district includes drainage streams, water bodies, town, and monitoring well locations

3. Materials and Methodology

3.1 Data collection

Slope, geology, drainage density, roughness, topographic wetness index, geomorphology, land use, lineament density, and soil were examined and selected for determining GWPZ across the Virudhunagar district based on numerous studies [10,11]. These parameters were collected from various sources such as the Bhuvan website, the Geological Survey of India (GSI), the USGS earth explorer, and the National Bureau of Soil Survey (NBSS). Cartosat-1 Digital Elevation Model (DEM) (30 m) downloaded from the Bhuvan thematic map web portal is used to create different thematic maps such as slope, drainage, roughness, and topographical wetness index. Geological Survey of India and Linear Imaging Self Scanning III (LISS III) satellite images are used to create geology and lineament density maps. The soil information of the Virudhunagar district was derived from the National Bureau of Soil Survey's (NBSS) map. The geomorphology and land use maps were collected from Bhuvan thematic map web portal which was updated with LISS III satellite image and verified with field investigations.

3.2 Methodology

The general methodology used in the current study is clearly illustrated in Figure 2. This work structure is grouped into three: geo-reference database preparation, identification of GWPZ, and validation of identified sites. In the first step of the geo-referenced database, the data was derived from satellite imagery, and secondary data was collected from GSI and NBSS. Then, weights are assigned to individual sublayers based on the manual and AHP methods. Further, rank was given to each geo-referenced data and determined the GWPZ. The results of delineated zones of groundwater potential were validated with the available groundwater head data.

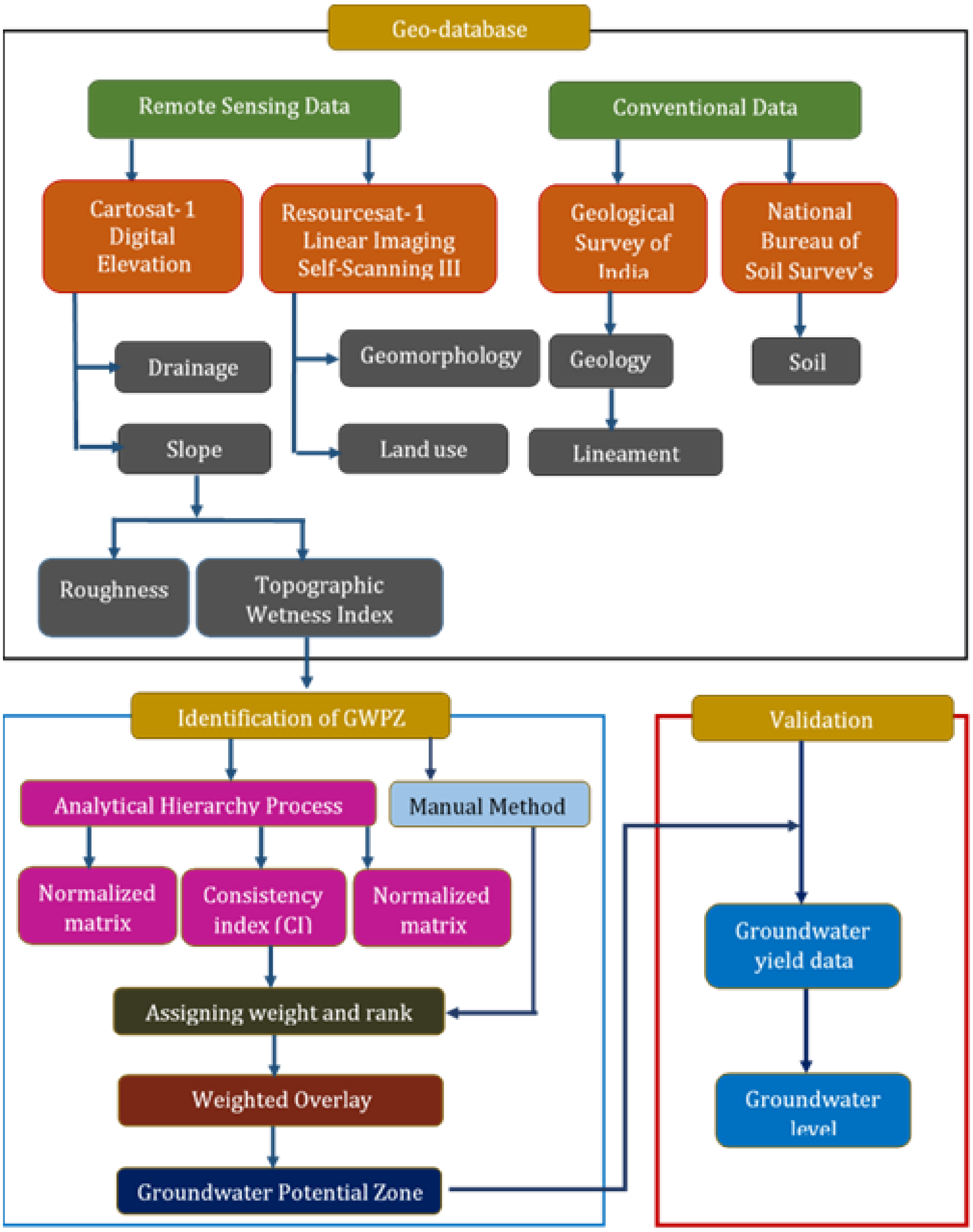

Figure 2. Flowchart represents the methodology adopted to delineate groundwater potential

3.2.1 Creation of geo-database

The slope is the difference in ground elevation that is used to locate a good source of groundwater. Rainwater may have drained away from the steep slope, causing soil erosion. Rainwater has enough time to contact the ground surface in the leveled ground and gentle slope regions, resulting in water recharge. The slope map for this study area was created using a Cartosat DEM with a spatial resolution of 30 m.

Drainage is the path where the rainwater flows on the ground. It normally flows from higher elevation to lower elevation and lithology. Drainage density is defined as the rate of drainage lines flow per square km of the area. This is one indicator that shows groundwater availability, which means higher drainage lines, more runoff, and less infiltration. Thus, groundwater recharge is inversely proportional to drainage density. The groundwater source is less in the high drainage line region; it shows a negative impact on groundwater potential. Because low drainage density equates to high infiltration, it contributes more to groundwater potential. The drainage density map was generated from a digital elevation model of CARTOSAT with a resolution of 30 x 30 m. The first flow direction and flow accumulation map were prepared in ArcGIS using the Hydrology tool. Then the drainage line was generated which was further taken as input to create a drainage density map.

The amount of elevation variation between consecutive cells is expressed by the roughness index of a digital elevation model (DEM). The roughness index often describes the topography's undulation. The rougher the surface, the more undulation there is, and vice versa. Over time, weathering and erosion processes smooth out a rocky landscape into a flat surface. Then, the surface roughness was created from slope data.

The Topographic Wetness Index (TWI) is a measurement of the potential for groundwater infiltration due to topographic parameters. It is frequently used to evaluate topographic control over hydrological processes. TWI was created in ArcGIS 10.2 using slope data. This was accomplished by using Equation (1) and (2) to calculate the rate of change of an aspect of a cell grid within its neighborhood [12]. The impacts of slope, elevation, and geomorphologic on groundwater development were integrated using the TWI map [13]. Then the TWI was calculated in ArcGIS.

$$TWI = \ln\left[\frac{a}{\tan(\beta)}\right] \quad (1)$$

$$a = \frac{A}{L} \quad (2)$$

Where A is the catchment area, a is the specific catchment area, tan(β) is the slope and L is the contour length

The LISS III image was used to update the geology supplied by the Geological Survey of India. Lineaments are delineated from the geological data and satellite imagery. Then, a lineament density was generated using the line density tool in ArcGIS 10.2 software. The lineaments are the joints and fractures present in the study region; hence these joints and fractures allow the water to infiltrate into the ground.

The recharge of groundwater is based on this land use map. LISS-III satellite data and extensive field verification were used to construct these land use classes [14]. Moderate medium red tone and fine/medium texture were used to identify agricultural land [15]. Water bodies were shown in a black tone and had high groundwater sources [16]. Forest plantations were pale reddish-brown in color, with a fine medium texture and uneven shape and size. Wasteland had a light to dark bluish tone with coarse texture, whereas built-up land had a pale bluish-white color with fine texture and uniform shape and size [16].

Soil is another major factor that influences the store and distribution of sub-surface water, as well as the recharge of groundwater, hence affecting groundwater recharge [17]. The texture of the soil and its hydraulic qualities are important considerations for determining infiltration rates. Soil texture, an important part of analyzing the physical characteristics of the soil, is closely related to the structure, porosity, adhesion, and consistency of soil qualities. The data collected from the NBSS includes seven different types of soil.

3.2.2 Identification of GWPZ using AHP method

Multi-Criteria Decision Analysis (MCDA) of AHP is an important and commonly used methodology to delineate groundwater prospecting zones [18]. AHP technique was employed to assign significance to each thematic layer for zoning groundwater potential recharge region in this study. Saaty's scale is used to figure out the relative significance of each parameter of scale 1-9, with a score of 1 indicating the equal value of both thematic layers and a score of 9 indicating the exceptional significance of one layer over the other [19]. According to Saaty's relative importance scale, a value of 9 indicates extreme importance, 8 indicates very to very strong importance, 7 specifies very extreme importance, 6 specifies strong plus, 5 shows strong importance, 4 shows moderate plus, 3 shows moderate importance and 2 shows weak importance. The higher weights are assigned based on the stronger influence of one thematic layer on another thematic layer, that is the relative importance between the thematic layers is high [20,21].

The themes were described using Saaty's scale of rank and priority, which assists in the hierarchical arrangement of the criteria using a pair-wise comparison matrix. The expertise in the field of hydrogeology helps to find out the weight allocation of the various thematic maps and their respective classes. The suitable ranks and weights were assigned to determine a good source of groundwater location [22]. Detailed literature surveys were done before assigning ranks and weights in order to get a thorough knowledge of the ranking of thematic layers under various environmental conditions in the current study [23,24]. The principal Eigenvalue and the index of consistency (Equation 3) in the AHP determine the likelihood of uncertainty. The following equation gives the Consistency Index (CI), which is a measure of consistency.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (3)$$

Where λ_{max} is the significant eigenvalue of the pairwise comparison matrix, and n is the number of thematic layers used in this analysis. Consistency ratio (CR), described as the indicator of consistency between pairwise comparison matrix, is calculated to regulate the assessment of consistency analysis (Equation 4) and scale.

$$CR = \frac{CI}{RCI} \quad (4)$$

Where RCI = Random consistency Index value, whose values were attained from Saaty's standard. According to Saaty, a CR of 0.10 or less is appropriate for further analysis. Each layer and its corresponding classes are given ranks and weights based on their proportional groundwater potential contribution (Table 1).

Table 1. Weightage and rank assigned based on AHP method

Thematic Layer & Weight (%)	Sub-layer / Class	Ranks (High = 5; Low = 1)
Slope (Degree) & 9 (%)	Flat (0 - 4.7)	5
	Gentle (4.8 - 14)	4
	Moderate (15 - 23)	3
	Steep (24 - 33)	2
	Very steep (34 - 63)	1
Drainage Density (km/km²) & 9 (%)	Very low (0 - 0.08)	5
	Low (0.09 - 0.23)	4
	Moderate (0.24 - 0.36)	3
	High (0.37 - 0.49)	2
	Very High (0.50 - 0.84)	1
Roughness & 7 (%)	0.03 - 0.30	5
	0.31 - 0.42	4
	0.43 - 0.49	3
	0.50 - 0.56	2
	0.57 - 0.85	1
Topographic wetness index & 8 (%)	4.03 - 7.60	1
	7.61 - 9.58	2
	9.59 - 10.96	3
	10.97 - 12.78	4
	12.79 - 18.06	5
Geology & 13 (%)	Charnockite	1
	Gneiss	2
	Limestone / Marble	3
	Quartzite	4
	Sand and Silt	5
	Shaly sandstone	4
Lineament density (km/km²) & 11 (%)	Very low (0 - 0.07)	1
	Low (0.08 -0.19)	2
	Moderate (0.20 - 0.31)	3
	High (0.32 - 0.43)	4
	Very high (0.44 - 0.72)	5
Land use & 15 (%)	Agricultural land	4
	Built-up land	1
	Forest	3
	Waste land	2
	Water body	5
Geomorphology & 17 (%)	Hills and Plateaus	-
	Pediment	2
	Plateaus	3
	Sedimentary High ground	1
	Structural Hills	1
	Valleys	5
	Alluvial Plain	5
	Bajada	3
	Deflection slope	2
	Denudational hills	1
	Flood Plain	4
Soil & 11 (%)	Alfisols	3
	Entisols	5
	Forest unsurvey	1
	Hill soil	2
	Inceptisols	5
	Reserve forest	2
	Vertisols	4

3.2.3 Identification of GWPZ using manual method

The influence of thematic layers and their related classes in controlling the potential groundwater recharge over an area is first considered while reclassifying particular layers and assigning ranks. The objective of establishing numerous classes and their weights in groundwater regions is to demonstrate the best potential options. Rank and weights were assigned to each parameter and their sub-classes by manual method. This is accomplished by the author's knowledge and observations of existing literature, as well as the area-specific qualities in this study region [25,26]. The Equation 5 is used to carry out a raster-based weighted overlay of all of these layers using ArcGIS 10.2 software.

$$GWPZ = (SL_w x SL_r) + (DD_w x DD_r) + (R_w x R_r) + (TWI_w x\, TWI_r) + (G_w x\, G_r) + (LD_w x LD_r) + (GM_w x GM_r) + (L_w x L_r) + (S_w x S_r) \quad (5)$$

Where GWPZ indicates the groundwater potential zones, SL is the slope, DD is the drainage density, R is the roughness, TWI is the topographic wetness index, G is the geology, LD is the lineament density, GM is the geomorphology, L is the land use and S is soil, w is the normalized weight of the thematic layers calculated by AHP and r is the rank of individual features.

3.2.4 Validation

The groundwater potential zones obtained through AHP and manual method must be validated, so the result obtained is cross-verified by groundwater head which was officially gathered from the PWD Hydrology Department Virudhunagar during the process of data collection.

4. Results

4.1 Slope

The slope map was classified into five based on the degree of their gradient. The degree of gradient ranges from 0 degrees to 63 degrees present in this study region. The major areas fall under very low to low slope, nearly flat land with a slope less than 10 degrees (Figure 3a). The study area is assigned as very low (0 – 4.70 degrees); low (4.80 – 14 degrees); moderate (15 -23 degrees); steep (24 – 33 degrees); and very steep (34 – 63 degrees) based on the slope values calculated using the DEM data. As a result, approximately 95% of the total area seems to be gentle and nearly level land, allowing for maximum recharge rather than runoff.

4.2 Drainage density

The prepared drainage map shows the pattern of dendritic. Then drainage density was created from drainage data. The drainage density values vary from 0 to 0.84 per km^2. It was then divided into five classes (Figure 3b). These classes have been assigned to very good (0.50 – 0.84 /km^2), good (0.37 – 0.49 /km^2), moderate (0.24 – 0.36 /km^2), poor (0.09-0.23 /km^2), and very poor (0 - 0.08 /km^2) respectively. The central and northeastern parts of the study area have a high drainage density (0.84 /km^2) which indicates that the availability of groundwater resources may be low.

4.3 Roughness

The roughness map of the study area is shown in Figure 3c, with values ranging from 0.03 to 0.85. The values were divided into five groups: 0.03 -0.30, 0.3 - 0.42, 0.4 - 0.50, 0.50 - 0.56, and 0.57 - 0.85. Low roughness values are given high ranks and vice versa.

4.4 Topographic wetness index (TWI)

TWI-rich areas allow for the determination of locations with high soil moisture accumulation and infiltration potential, which are unique to foothills [27, 28]. The study area's TWI ranged from 4.03 to 18.06 (Figure 3d). The results were divided into five groups; 4.03 – 7.60, 7.61 – 9.58, 9.59 – 10.96, 10.97 – 12.78, and 12.79 – 18.06. The regions having high TWI are assigned to high ranks and weights, and vice versa.

4.5 Geology

The geology map of the study area is shown in Figure 4a. Sandstones and clays of recent to sub-recent and Tertiary age are among the porous formations. Alluvial formations, which mostly consist of sands, clays, and gravels, are limited to major drainage channels. The gneiss is a metamorphic rock created by high pressure and temperature acting on sedimentary and igneous rocks. Crystalline formations sorely missing primary porosity have different water-bearing properties depending on the degree of secondary intergranular porosity development. The availability and movement of groundwater in crystalline rocks are mainly limited. Even within short distances, these aquifers are very varied in nature due to huge variations in sub-surface lithology, soil texture, fold, fault, and joint features. At deeper levels, groundwater is found in unconfined conditions in the weathered portion and in semiconfined circumstances in the fractured regions [29].

4.6 Lineament density

The study region has a smaller number of lineaments. Figure 4b shows the lineament density map with values ranging from 0 to 0.72 km/km^2. It was then divided into five. These classes have been assigned to very good (0.44 – 0.72 km/km^2), good (0.32 – 0.43 km/km^2), moderate (0.20 – 0.0.31 km/km^2), poor (0.08-0.19 km/km^2), and very poor (0 - 0.07 /km^2) respectively. It shows that high lineament density can be found in the north, center, and western parts of the study area. Lineament density is ranked according to the distance between lineaments. For high-density groups, a high rank is assigned, while for low-density classes, a low weight is assigned.

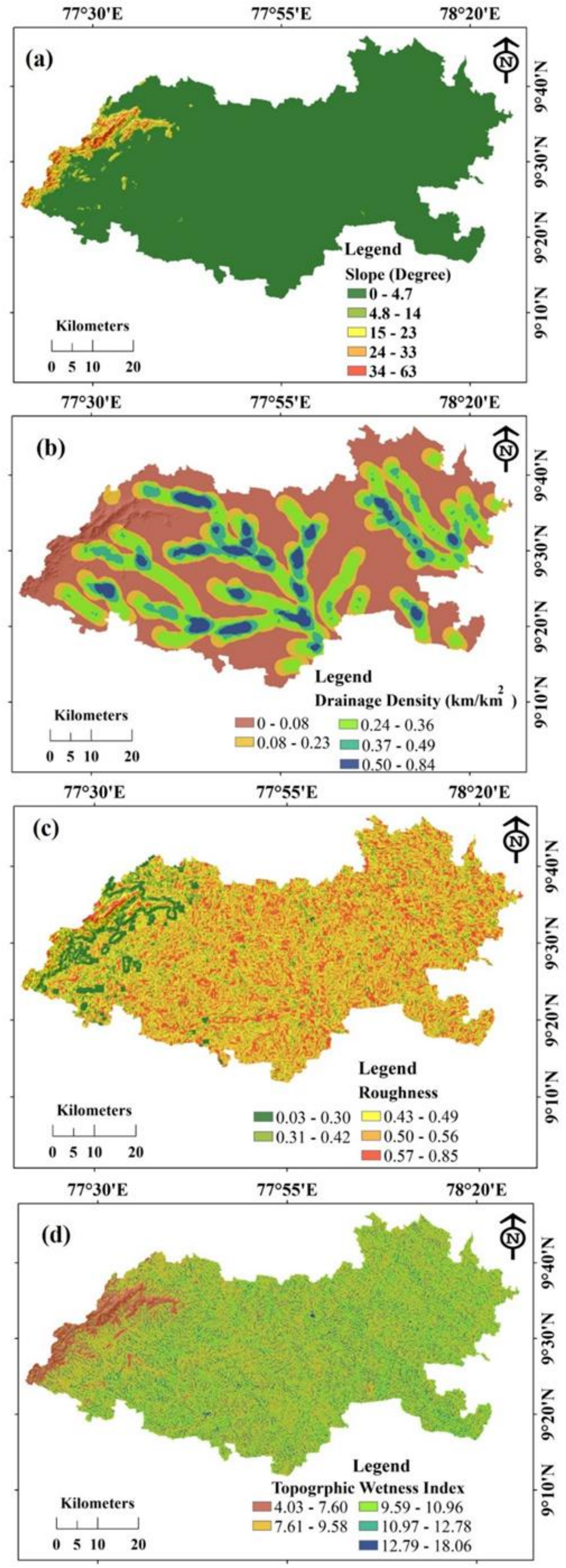

Figure 3. (a) Slope map derived from SRTM DEM data; **(b)** Drainage density; **(c)** Roughness map; **(d)** Topographic Wetness Index map of the study region

4.7 Geomorphology

The various geomorphological features namely pediment, hills and plateaus, structural hills, valleys, alluvial plain, sedimentary high ground, Denudational hills, flood plain, deflection slope, and bajada (Figure 4c) are formed in the study area. The study area comprises mostly of the pediment (76%) followed by Sedimentary high ground (10%), Flood plain (5%), and deflection slope (5%), and the remaining features are covered very less area.

4.8 Land use

The change in land uses significantly influences the dynamics of groundwater recharge and storage. The land use map is divided into agricultural land, built-up land, forest, wasteland, and water bodies (Figure 4d). Higher percentage of 75% of land in this district is covered by agricultural land. The crops grown are horticulture crops that are fruits crops like mango, banana, and guava, vegetables like tomato, brinjal, chilies, and onion, and spices like coriander. The water bodies and wasteland encompass each 8 % of the area. The built-up land and forest cover 3 % and 6.5 % of the area respectively.

4.9 Soil

The characteristics of soil play a major role in the control of groundwater recharge. Figure 4e represents the various soil groups. The different types of soil found in this study area are vertisols, inceptisols, alfisols, reserve forest, entisols, hill soil, and forest unsurvey. Vertisols cover 48 %, inceptisols cover 21 %, reserve forest covers 0.2 %, alfisols cover 20 %, entisols cover 4.3 %, hill soils cover 6 %, and forest unsurvey cover a very low portion of 0.09 % of the total area. Entisols and inceptisols were given higher rankings. Vertisols and alfisols are assigned a moderate ranking since they include a large amount of clay and expansive clay. Hill soils and reserve forest soils are given a low rank, indicating that they receive less groundwater recharge than other soils.

4.10 Manual method to delineate GWPZ

Weightage is assigned to each of these parameters using a manual method and different levels within the parameters are ranked according to the influence they have over groundwater potential. The delineated GWPZ by the manual method is shown in Figure 5a. GWPZ was classified into four i.e., low potential, moderate potential, high potential, and very high potential. The results revealed that 2837.31 km^2 of the area covers moderate potential which is 68.76 %, high potential covers 1231.06 km^2 (29.84 %), low potential covers 35.69 km^2 (0.87 %), and very high potential covers 22.17 km^2 (0.54 %) of the total area.

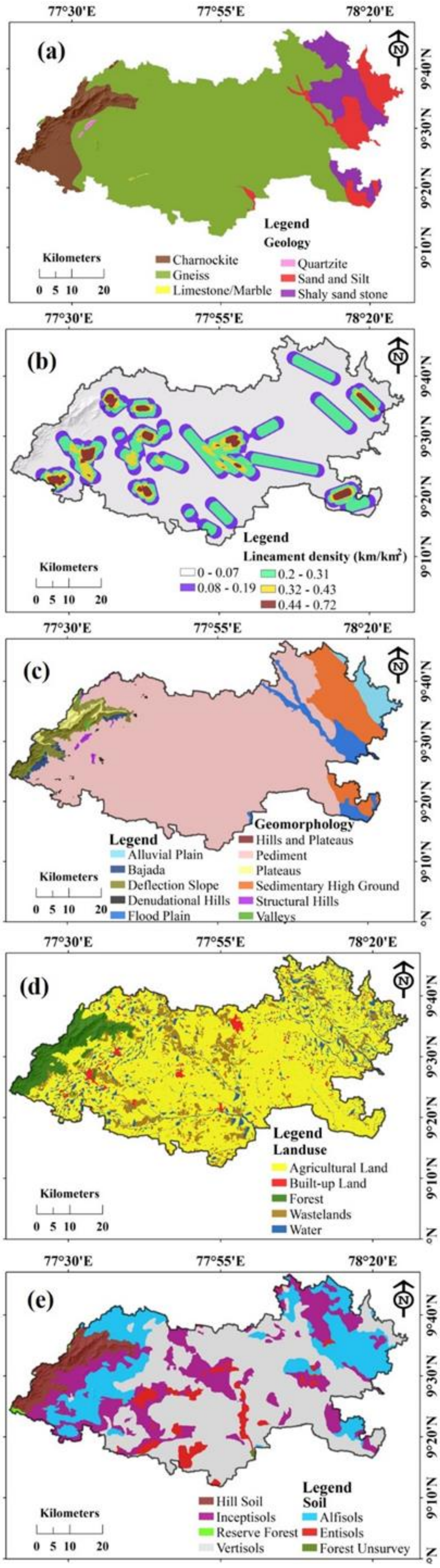

Figure 4. (a) Geology map; **(b)** Lineament density map; **(c)** Geomorphology map; **(d)** Land use map; **(e)** Soil map of the study area

4.11 AHP method to delineate the GWPZ

The parameters namely geology, geomorphology, lineament, drainage, land use, soil, and slope are comprehended in the ArcGIS platform and a groundwater potential zone map is prepared which is illustrated in Figure 5b. Four different classes such as 'less potential', 'moderate potential', 'high potential', and 'very high potential' are classified. The 'less potential' zones within the study area are spread randomly it covers over 70.45 km² which covers over 1.71% of the overall area, Low potential areas are not suitable for industrial and urban development. However, 'moderate potential' zones have the highest area coverage of 2139.83 km² which makes around 51.86% of the overall area spread almost all over Virudhunagar district. And 'high potential' zone has the second most area coverage with 1885.09 km² which is a 45.70% of the overall area. And 'Very high' zones are the least with 30.01 km² which is 0.73 % of the overall area.

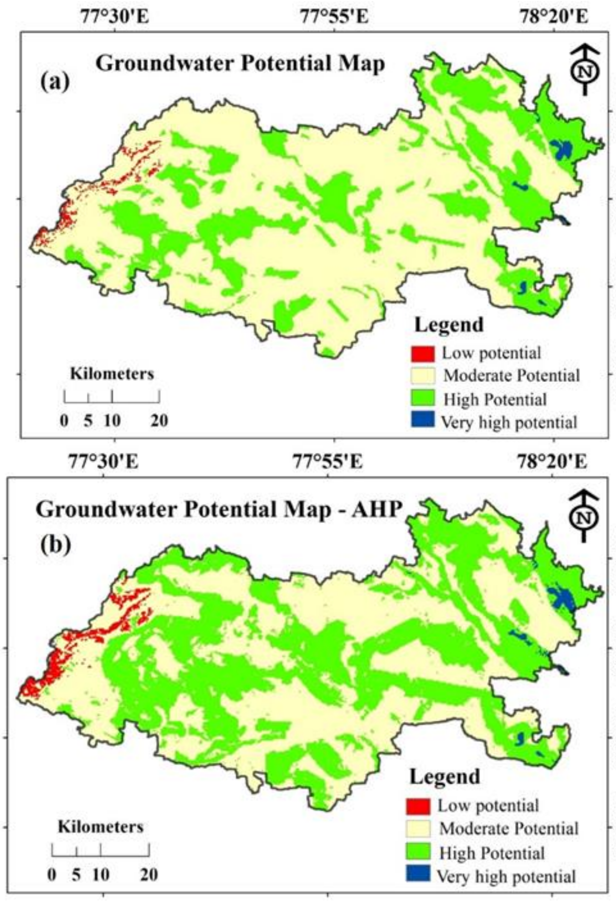

Figure 5. Groundwater potential map prepared by using **(a)** manual method; **(b)** AHP method

5. Discussion

The result of GWPZ created through manual and AHP methods are discussed in this section. Initially, the effects of each sub-layers of all the parameters related to groundwater recharge are explained here. The highly rough topographical regions may have a thin layer of weathered soil which shows less recharge of water to the ground. The regions where the weathered soil is thick have good groundwater recharge. High roughness equates to a lot of undulation. High-undulation regions are usually mountainous, with continuous weathering and erosion processes causing destruction on the terrain. The groundwater recharge rate is high in the low drainage density regions and vice versa.

TWI-rich areas allow for the determination of locations with high soil moisture accumulation and infiltration potential. A pediment is a gradually sloping surface created between the hill and the plain surface. These have a low potential for groundwater. Structural hills, denudational hills, hills, and plateaus features are covered in very small areas on the western side the groundwater potential is low. The groundwater source is moderate in Bajada. Flood plains, valleys, and alluvial plains percolated a good amount of water into the ground which has a good source of groundwater potential. Agricultural lands are considered to be high groundwater prospecting locations. The groundwater potential in forest areas was rated as low because despite the fact that these areas have good sources of groundwater. Entisols and inceptisols soil have more porosity which recharges high amounts of water. Vertisols and alfisols soil make moderate levels of recharge of water.

The very low potential is located in the western side of the area which is formed by Charnokite rock, low surface roughness, very low TWI, deflection slope of landform, forest type of land use, very low percentage of lineament density, and hill soil. Moderate groundwater potential encompasses of about more than 50 % of the total area, ie. 68.76 % shown in the manual and 51.86 % shown in the AHP method. High groundwater potential covers mostly in central, east, and northeastern sides of the study area. The high groundwater potential derived in the AHP method is greater than the manual method, which shows the GWPZ is determined more accurately by considering each sub-layers of all the parameters in AHP. Very high groundwater potential covers almost less than 1 % of the total area, i.e., 0.54 % in manual and 0.73 % in the AHP method. The AHP method result shows more area covers high groundwater potential which means these locations are suitable for urbanization. Proper sustainable plans and regulations must be put in place so that the available potential doesn't get overexploited.

6. Validation of groundwater potential zones

The groundwater potential thus obtained through AHP and the manual method was cross verified with pre-monsoon and post-monsoon groundwater heads (Figure 6). Around seven wells located in low (well No. 11), moderate (well No. (1,17,22), high (well No. 5, 6) and very high (well No. 13, 21) GWPZ were selected to represent the groundwater head. The plotted groundwater head clearly shows that wells located in low and moderate zones have very deep groundwater, and the fluctuation between pre-monsoon and post-monsoon is very small. The wells located in the high and very high GWPZ are recharged with more water, hence, the groundwater is available at a lower depth with more fluctuation, which means more water infiltrates after rainfall. Well number 5 is located in the moderate zone in the manual method of determination, and it is located in the high GWPZ in the determination of AHP. The groundwater head at well no. 5 shows less depth below ground level, which clearly shows that the AHP method of delineating groundwater potential zones is more accurate than the manual method.

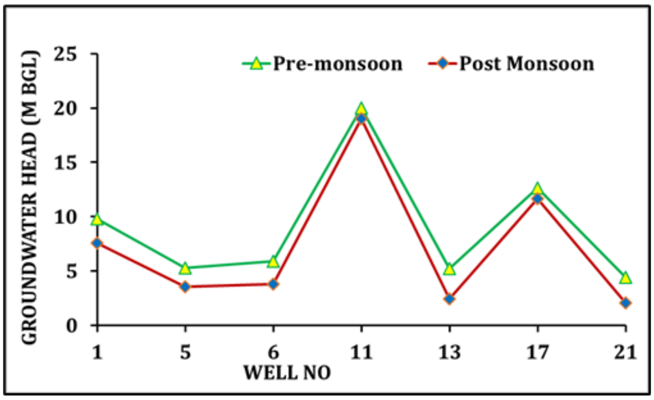

Figure 6. Groundwater head during pre- and post-monsoon

6. Conclusion

This study used the integrated approach of RS, GIS, and AHP for the delineation of GWPZ in the Virudhunagar district. As this district is a rapidly developing district, it is necessary to find regions having good groundwater resources. Nine different parameters of Slope, geology, drainage density, roughness, topographic wetness index, geomorphology, land use, lineament density, and soil were used to carry out weighted overlay analysis. In both, the method of GWPZ delineation results shows that more than 50 % of the land has moderate potential and less than 1 % of very high groundwater potential. There is a huge difference in the area of high groundwater potential determined by manual and AHP methods. AHP result is more accurate than the manual because it includes rank and weights for each sub-layers. The identification of groundwater potentiality zones for predicting built-up area development sites around the Virudhunagar district was emphasized in this study. The findings of this study will support the Virudhunagar municipality in the sustainable management of its water resources, including regional land use planning, future bore well construction, and groundwater protection.

Author contributions

Sundara Pandian Rajaveni: Conceptualization, Methodology, Analysis in Software, Writing-Original draft preparation; **Udayakumar Sidesh**: Data collection, Analysis in Software, Writing, Validation, Field study; **Kalyana Kumar Prasanna Balaji**: Writing-Reviewing and Editing, Data collection, Field work; **Ramabalan Lakshmi Narayanan**: Writing, Editing, Data collection, and Field work.

Conflicts of interest

The authors declare no conflicts of interest.

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