https://doi.org/10.1051/e3sconf/202340504021

Unlocking Hidden Water Resources: Mapping Groundwater Potential Zones using GIS and Remote Sensing in Kerala, India

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Abstract. The study describes a case study from an ecologically fragile region of Kerala, India, in which GIS and remote sensing techniques were used to identify groundwater potential zones (GWPZ). The study area has been adversely affected by pollution from various sources, and residents have become reliant on groundwater for their drinking water needs. Here, the Weighted Index Overlay Analysis method was used to identify the potential groundwater zones to assign ranking values to different classes of individual thematic maps based on their mediating and moderating influence on groundwater potentiality. Twelve thematic layers were used. The results of the GWPZ were validated by overlaying samples on the potential zones in the GIS environment. The study emphasizes the importance of GWPZ mapping for planning new abstraction well locations to meet increasing water demand and improve the awareness of groundwater availability for sustainable development.

Keywords: Groundwater Potential Zones, GIS, Remote Sensing

1 Introduction

Applications of GIS and RS for the assessment of groundwater potential zones (GWPZ) are made by various researchers around the world, and the results vary depending on the factors involved in determining the GWPZ [1,2]. Delineation of GWPZs using GIS and Remote Sensing is widely used in all parts of the world. The availability of satellite data, conventional maps, and rectified ground truth data to remove distortions has facilitated the creation of a starting point for assessing areas with groundwater potential [4]. Remote sensing provides a broad range of observations over space and time, covering large areas. This can result in significant time and cost savings for various applications [5]. In addition, it is extensively used to illustrate the earth's surface (such as drainage patterns, lithology, and lineaments) and examine the groundwater recharge zones [6]. Researchers worldwide utilize GIS and remote sensing for evaluating potential groundwater zones. The results they obtain can differ depending on the various factors considered when identifying these zones. One study illustrates that lineament for groundwater exploration [7], and others elucidate that combined diverse factors such as geomorphology, land use, geology, drainage density, slope, rainfall intensity, and soil texture were used [6, 8, 9]. The results obtained from GIS and remote sensing to assess groundwater potential zones are considered reliable, as they are validated through field surveys. However, the results can differ depending on the specific geo-environmental conditions of each region. Over the past few decades, there has been an increase in the utilization of groundwater resources, resulting in excessive groundwater consumption. This has led to a range of environmental issues, such as a decline in groundwater levels, depletion of water levels, contamination, and deterioration of water quality.

Hidden and unlocked water sources, like underground aquifers, wells, and small streams, can be vulnerable to pollution from various factors such as land use, human activities, industries, agriculture, and waste disposal systems. In many cases, hidden water sources may not receive the same level of monitoring and regulation as larger, visible water bodies. As a result, they may be more vulnerable to contamination and pollution. Some potential sources of pollution for hidden water sources are industrial pollution, agricultural runoff, improper waste disposal, oil and chemical spills, and illegal dumping. Addressing this pollution requires a multi-faceted approach which includes strengthening regulations and monitoring, public awareness and education, improved waste management, sustainable agricultural practices, and industrial compliance [10].

The Vembanad Lake (the lake surrounding the study area, too) and its surrounding areas have been negatively impacted by various sources of pollution, both from specific locations and more diffuse sources. These include human-made barriers, agricultural and industrial waste, sewage from households, tourism activities, as well as mining of lime shells and sand. As a result, water quality in and around the lake has been adversely affected [3]. Estimating water resources through groundwater potential information is necessary to effectively identify appropriate locations for groundwater use of suitable quality and quantity, groundwater prospects, and a management plan for the sustainable development of the study area. In the past, surface water was used as a drinking water source by the Kainakary residents. Along with above mentioned unscientific agricultural practices, sea-water intrusion during the summer season, seepage of diesel from the boat into surface water, and disposal of solid waste have also resulted in gross contamination of surface water. Therefore, the residents in this area have discarded the surface water sources, and they depend entirely on groundwater for drinking water needs. Thus, the need arises for the identification of potential groundwater zones.

2 Materials and Methods

This study uses geographic information systems and remote sensing to identify the potential zones of an ecologically fragile region of Kerala, India.

2.1 Study Area

Alappuzha, located in southern Kerala in India, is the smallest coastal district. Its latitude ranges from 9°51' N to 9°45' N, and its longitude ranges from 76°45' E to 76°1' E, as reported by Prasad et al. in 2021.

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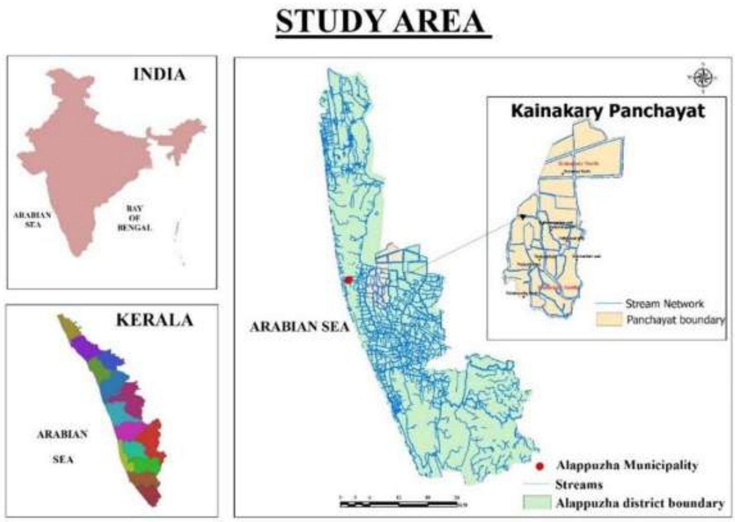

Fig.1. Location map of the study area

Kainakary Panchayat, the study area (Fig.1), is a village council in India located in the ecologically sensitive Kuttanad wetland ecosystem. It is also a popular tourist destination attracting millions from domestic and international locations. The geographical characteristics of the study area, including annual rainfall, temperature, geology, geomorphology, land-use pattern, and soil, are elaborated in author's earlier manuscript [5].

2.2 Estimating water resources

To improve the awareness of groundwater availability and determine the feasibility of conjunctive use in areas requiring conservative groundwater use, it is necessary to establish baseline information on GWPZ. Identifying appropriate locations for new abstraction wells is crucial in meeting the increasing demand for water, which can be achieved through the mapping of GWPZs. The geological and hydro-geomorphological features of an area play a vital role in the occurrence, distribution, and movement of groundwater. The accuracy of GWPZ mapping results is verified through field surveys, but they can differ across regions due to disparities in geo-environmental conditions.

GWPZ was determined by integrating thematic maps in ArcGIS 10.2.2 using a linear combination model. Weighted Index Overlay Analysis (WIOA) method assigns ranking values for each class of individual thematic maps based on its mediating and moderating influence on groundwater potentiality. The WIOA method evaluates the significance of parameters and the categories associated with each parameter. In contrast, the simple weighted overlay method lacks a standard scale, and criteria for the analysis must be established, with the significance of each parameter being subjectively assigned. The weightage of each class must be well thought out and appropriate, as the output depends on the weightage given to each thematic layer. Fig 1.a shows the flowchart for finding potential groundwater zones .

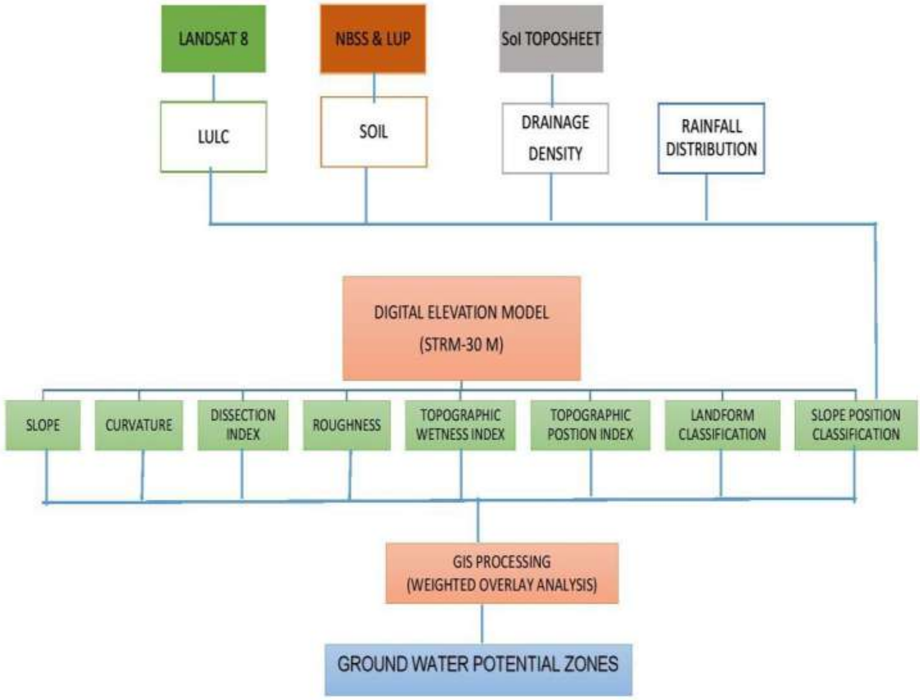

Fig 1.a Flowchart for finding potential groundwater zones

The relative importance of classes in assigning weightages contributes to a better representation of the actual ground condition. The quantity of information within each thematic layer is determined by its spatial resolution. Higher resolutions allow for more classes to be identified and weighted accordingly. Finer classes within each theme lead to more accurate results, which enable targeted interventions in the identified zones. On the other hand, coarse-resolution thematic layers generalize classes, which may result in the undue weightage of a particular class, leading to an incorrect priority rating, particularly over diverse landscapes with limited information. To validate the GWPZs, the samples are overlaid with the potential zones in the GIS environment. In order to determine GWPZ in Kainakary for better planning of water resources, the following 12 thematic layers were utilized.

3 Results and Discussion

Slope: 'Digital Elevation Model' derived from SRTM data with 30 m resolution is used to describe slope, classified into five classes (in degrees), i.e., 0- 0.69, 0.69- 2.00, 2.00- 3.83, 3.83- 7.06, 7.06- 22.23 and is illustrated in Fig.2. Classes with lower values are assigned a higher rank due to nearly flat terrain, while classes with higher values are categorized with a lower rank due to higher run-off.
Soil: The National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) was the source of the soil maps. Soils are categorized mainly based on their water-draining capability. Based on textural properties (i.e., sand, silt, and clay contents), soil in the study area is categorized into clayey, loamy, and sandy soils (Fig.3). Appropriate weightage has been assigned for GWPZ demarcation based on their infiltration rate.

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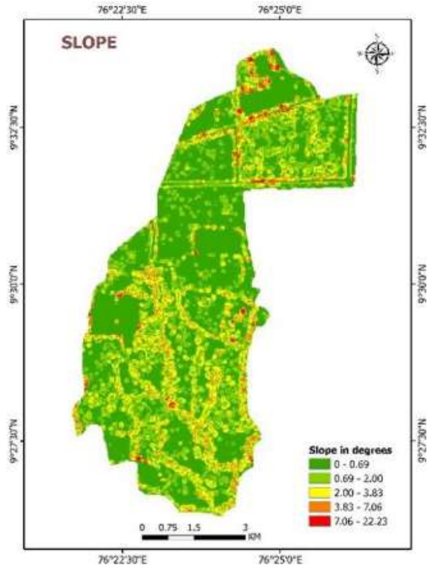


Fig.2. Slope

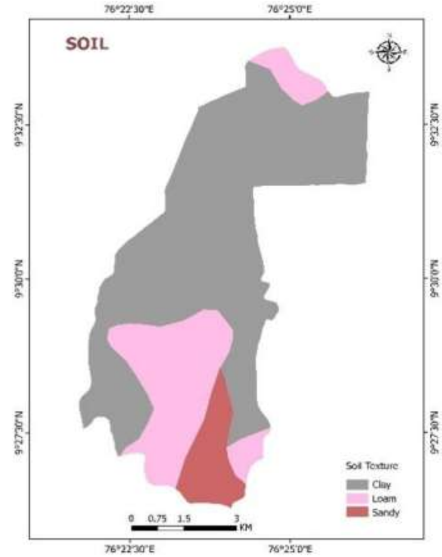


Fig.3. Soil

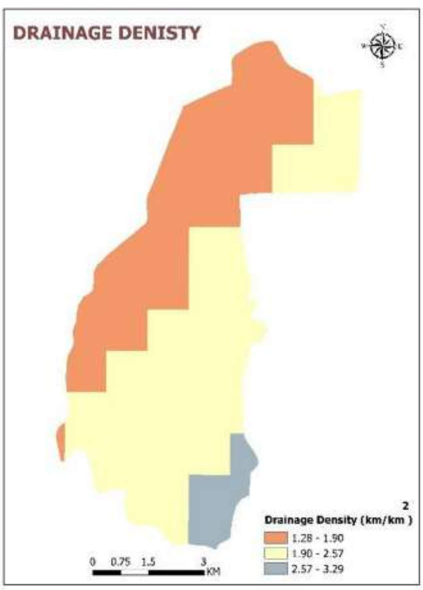
Drainage Density: Drainage density is a key determinant for determining GWPZ and is the inverse function of permeability. The drainage density of the watershed in a given region is calculated using the following equation:

$$Dd = L/A$$

where, Dd is the drainage density of the watershed, L is the total length of the drainage channel in the watershed (km), A is the total area of the watershed (sq km.).

When a rock is not very permeable, it allows less rainwater to seep through, forming a well-developed drainage system. The density of drainage in an area can indirectly indicate the potential for groundwater, as it is related to surface runoff and permeability. If the drainage density value is high, there is much runoff, which suggests that the area has a low potential for groundwater occurrence. High drainage density is not conducive to groundwater existence, and conversely, less/no drainage density suggests high GWPZ [11]. If there are only a few drainage courses in an area, it suggests that the rock is very resistant and permeable. On the other hand, if there are many drainage courses, the rock is weak and not very permeable [12, 16]. When exploring groundwater potential zones, areas with low drainage density were given a higher rank, while areas with high drainage density were given a lower rank. The drainage density of the study area varied from 1.28 km/sq km to 3.29 km/sq km (Fig. 4).

LULC: The map of land use and land cover (LULC) reveals the scope of groundwater demand and usage in the study area. The use of remote sensing technology has provided a comprehensive view through multi-spectral data, which has been employed to classify the LULC. Landsat 8 satellite image was utilized to create LULC map. This map was created through geo-referencing and atmospheric correction of the image, followed by a Maximum Likelihood Classification algorithm to classify each pixel according to its LULC category. The main LULC classes identified in the study area include waterbodies, waterlogged areas, paddy fields, mixed vegetation, uncultivated land, built-up areas, and sandy area (Fig.5). Water bodies in an area promote the recharge of groundwater, while fallow land hinders recharge [13, 14]. Regions with water bodies provide better potential for groundwater recharge than areas with fallow land, which have poor potential for recharge [13,15].



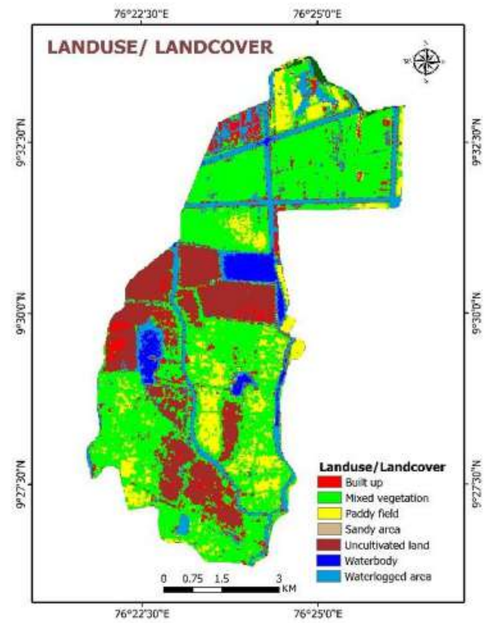


Fig.4. Landuse and landcover **Fig. 5.** Drainage density

Rainfall Distribution: A map displaying the distribution of rainfall has been created using data obtained from the Climate Hazards Group InfraRed Precipitation with Station data (Fig.6). The distribution of rainfall, along with the slope or gradient of the terrain, has a direct impact on the rate of water infiltration, which in turn affects the potential for groundwater occurrence in a particular area.

Dissection Index: The Dissection Index (DI) measures the degree of dissection or vertical erosion in a watershed, indicating the stage of development of landforms in that area [8, 17]. DI is a calculation obtained by dividing the relative relief, which refers to the total difference in elevation within a given basin, by the absolute relief, which represents the maximum elevation difference within that same basin., expressed as a value between '0' (flat topography with no dissection) and '1' (vertical cliff topography or hillslope). In some cases, the value of '1' may be occasional, such as vertical cliffs on the seashore or hillslopes. The lower the DI value, the higher the groundwater potential of that area. Fig. 7 illustrates the dissection index of the study region.

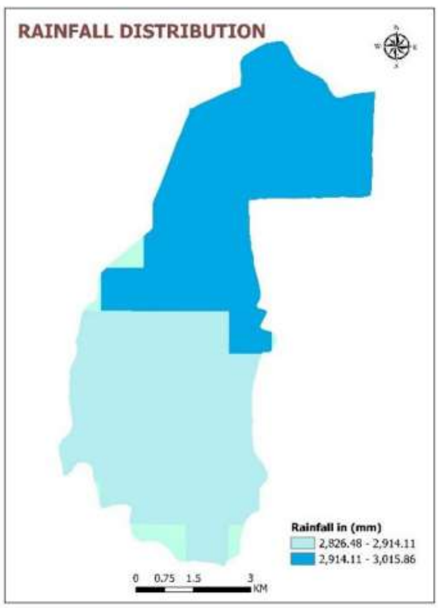


Fig.6. Rainfall Distribution

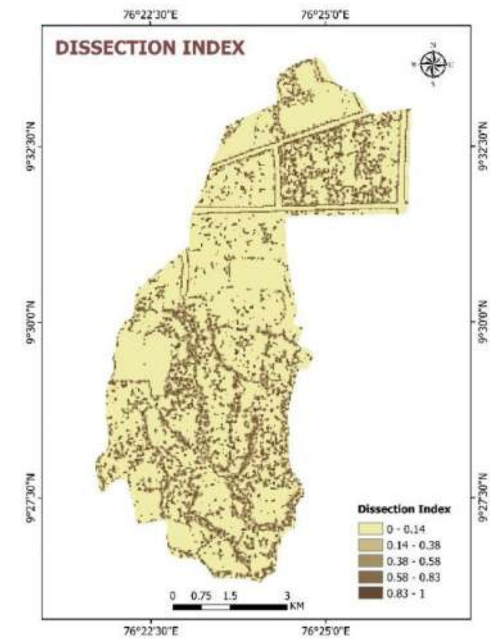


Fig.7. Dissection Index

Roughness: The degree of undulation in a given region is expressed in roughness. The state of Kerala has an undulated terrain. A rolling or undulating topography typically characterizes a hilly region where the processes of weathering and erosion gradually transform the landscape into a smooth and even surface. A significantly thick weathered zone indicates a limited potential for groundwater occurrence compared to a highly rugged terrain where only a thin layer of weathered zone exists, which means there is no potential for groundwater occurrence [18]. The roughness of the study area ranges from 0 to 3.25 (Fig. 8).

Curvature: The curvature of a surface profile, whether it is concave upward or convex upward, is a quantitative representation of its nature. In general, gentle slopes tend to exhibit a concave upward profile. In areas where the profile is concave upward, water has a tendency to collect, which is also true for groundwater [19, 23]. The curvature of the study area, as shown in Figure 9, ranged from -1.74 to 5.58.

Topographic Position Index (TPI): TPI is a method for categorizing a landscape's upper, middle, and lower parts based on its topography. It works by comparing the elevation of each cell in a Digital Elevation Model to the average elevation of a defined surrounding area, and then subtracting that average from the elevation value at the center of the cell [20, 21].

$$TPI_i = M_0 - \sum_{n-1}(Mn/n)$$

Where, M_0 = elevation of the model point under evaluation, Mn = elevation of grid, n = the total number of surrounding points employed in the evaluation

The TPI of the study area is given in Fig. 10. High TPI values are typically found near hilltops, while low TPI values are found at the valley's bottom. TPI values near zero would be found on flat ground or in mid-slope. For the prospects of groundwater potentiality, a high ranking was given to areas with low TPI values.

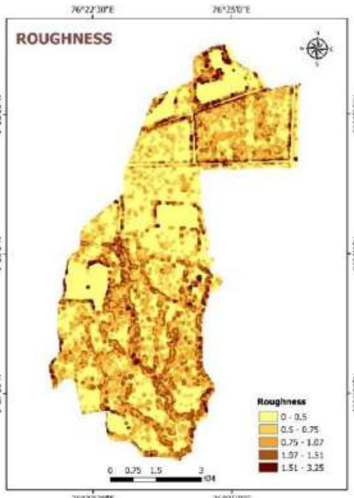


Fig.8. Curvature

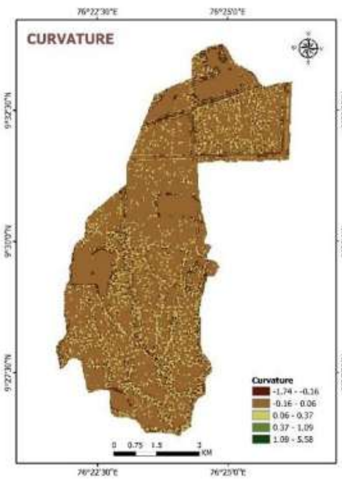


Fig.9. Roughness

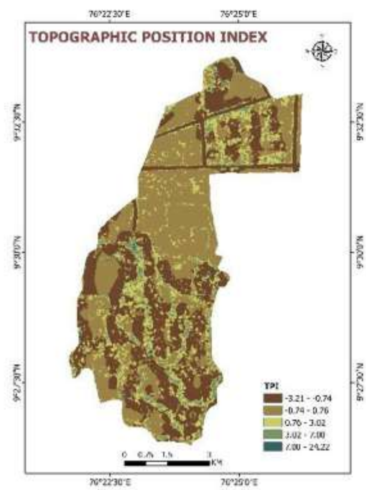


Fig.10. Topographic Position Index

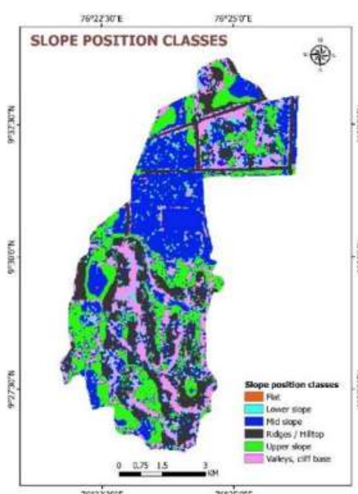


Fig.11. Slope Position Classes

Slope Position Classification: The TPI values were utilized to classify landscapes based on their slope positions. This classification is determined by the severity of the TPI values and slope at each point. A TPI threshold value of ±1 standard deviation was used to differentiate between hilltops and valley bottoms, with the standard deviation value calculated from all elevation values. A slope threshold of ±6° was employed to distinguish flat areas from mid-slope areas. The slope position classification of the study area can be seen in Figure 11.

Landform Classification: A given point on the landscape with a negative small-neighbourhood TPI value and a positive large-neighbourhood TPI value signifies a minor valley on a higher hilltop and is classified as upland drainage. On the contrary, a point with a positive small-neighbourhood and a negative large-neighbourhood TPI value represents a small hill or ridge in a larger valley. As with the slope position classifications, high and low TPI values were distinguished by setting a threshold of ±1 SD [20, 22]. Figure 12 illustrates landform classification for the study area.

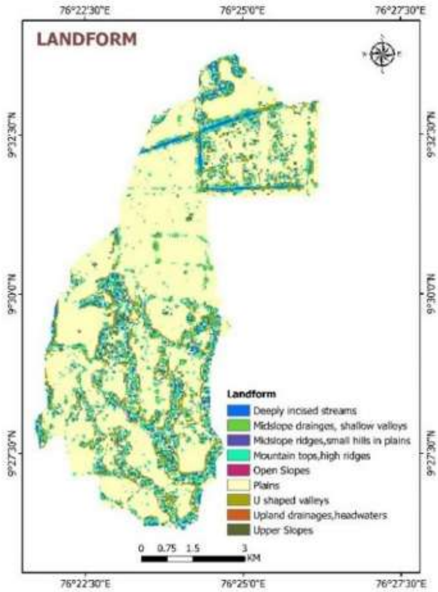


Fig. 12. Landform Classification

3.1 Groundwater Potential Zones in the study area

Based on the parameters' impact on GWPZ potential, ranking values have been assigned for each class of specific thematic maps, as shown in Table 2. The contributing factors and the ranks for identifying potential groundwater zone are given in Table 1.
WIOA method cumulatively analyzes multiclass maps by considering each parameter's relative significance and class. Fig. 13 illustrates the GWPZs identified in Kainakary, and these zones are classified into five categories – very low, low, moderate, high, and very high (Table 5.8). Nearly 5% of the study area is categorized as very low GWPZ. 20.65% of the study area falls into the common category GWPZ. A major part of the study area, 31.29%, is categorized as moderate GWPZ. 29.60% of the study area has a high GWPZ, and 9.72% has a very high GWPZ. The waterbody constitutes the remaining 3.54% of the land cover. Due to their interconnectivity, adjacent surface water bodies influence significant portions of GWPZs. Surface water contamination assessment is essential for designing water supply systems for consumption, demand, and conjunctive use, considering the floating population.

Table 1. Weight assigned to different factors of thematic layers

Factor	Class	Weight	Factor	Class	Weight
Slope	0 – 0.69	10	Soil	Clay	2
	0.69 – 2.00	8		Loam	6
	2.00 – 3.83	6		Sandy	8
	3.83 – 7.06	4	Slope Position Classes	Flat	6
	7.06 – 22.83	2		Lower slope	8
Landform	Deeply incised streams	10		Mid slope	4
	Mid-slope drainages/shallow valleys	8		Ridges/Hilltop	2
	Mid-slope ridges/ small hills in plain	1		Upper slope	1
	Mountain tops, high ridges	1		Valleys, cliff base	10
	Open Slopes	2	Curvature	-1.74 – -0.16	2
	Plains	4		-0.16 – 0.06	4
	U shaped valleys	8		0.06 – 0.37	6
	Upland drainages/ headwater	6		0.37 – 1.09	8
	Upper slopes	2		1.09 – 5.58	10
Drainage Density (km/sq km.)	1.28 – 1.90	10	Dissection Index	0 – 0.14	10
	1.90 – 2.57	8		0.14 – 0.38	8
	2.57 – 3.29	6		0.38 – 0.58	6
Elevation (m)	0 - 2	10		0.58 – 0.83	4
	2-4	8		0.83- 1	2
	4-7	6	Roughness	0 – 0.5	10
	7-12	4		0.5 – 0.75	8
	12-16	2		0.75 – 1.07	6
Rainfall distribution (mm)	2826.48 – 2914.11	8		1.07 – 1.51	4
	2914.11 – 3015.86	10		1.51 – 3.25	2
Land use	Waterlogged area	8	Topographic Position Index	-2.47	10
	Uncultivated land	4		-0.74 – 0.76	8
	Built-up	6		0.76 – 3.02	6
	Sandy Area	6		3.02 – 7.00	4
	Paddy Field	4		7.00 – 24.22	2
	Mixed Vegetation	7			

Table 2. Contributing factors and rank in identifying potential groundwater zone

Sl. No	Contributing factor	Rank
1	Landform	10
2	Land use	9
3	Soil	8
4	Slope	7
5	Drainage density	6
6	Rainfall distribution	6
7	Slope Position Classes	5
8	Curvature	4
9	Elevation	4
10	Roughness	4
11	Topographic Position Index	4
12	Dissection Index	4

Table 3. Area Statistics of groundwater potential zones

Zone	Area (sq km)	% of Area
Very low	4.74	8.73
Low	11.21	20.65
Moderate	16.99	31.29
High	16.08	29.6
Very high	5.28	9.72

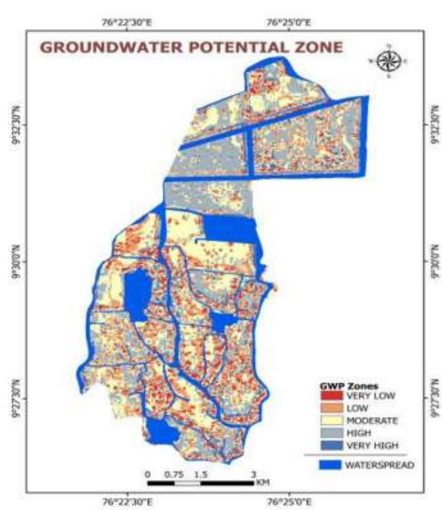


Fig. 13. Map showing potential groundwater zones in the study area

4 Conclusion

Creating maps of groundwater resources has recently become increasingly significant in addressing the growing need for an increased water supply. GIS technology is essential for various purposes, such as monitoring the environment, mapping geographical and geomorphological features, managing hazards, estimating resources, planning urban areas, studying agricultural practices, and assessing climatic conditions. Information collected through this technology is easy to use and multidisciplinary. The study discusses using GIS and remote sensing to delineate potential groundwater zones in an ecologically fragile region of Kerala for sustainable development. The study area, surrounded by the Vembanad Lake-a Ramsar site, has experienced significant water quality deterioration due to pollution from various sources, such as man-made bunds, agricultural wastes, industrial wastes, household sewages, tourism, lime shell, and sand mining. As a result, residents in the area have turned to groundwater as their primary source of drinking water.

To determine potential groundwater zones, 12 thematic layers were integrated with ArcGIS 10.2.2 using a linear combination model. The WIOA method was used to assign ranking values for each class of individual thematic maps based on their influence on groundwater potentiality. The study found that the potential groundwater zones were mainly located in the central and eastern parts of the study area, while the western part had a lower potential for groundwater. Nearly 70% of the study area has been identified with groundwater potential, indicating the need to protect and utilize groundwater responsibly for sustainable development. The study also found that drainage density, slope, and soil were the most important factors in determining the groundwater potential zones in the study area. The study results can be used to plan new abstraction of wells and manage groundwater resources for sustainable development.

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