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Delineation of Groundwater Potential Zones in Korayar, Varattar and Valayar Watershed Through Geo-Spatial and MIF Techniques

Dr Roobina A*, Dr Reshma C U, Nazrin Begum S****

*Associate Professor, **Assistant Professor
Department of Geography, Government College Chittur, Palakkad, Kerala, India
Mail ID: reshmageography[at]gmail.com, roobinageo[at]gmail.com, nazrinbegumgeo[at]gmail.com

Abstract: ***Groundwater is a critical and finite natural resource that sustains domestic, agricultural, and industrial activities, particularly in semi-arid and hard-rock regions. The present study aims to delineate groundwater potential zones in the Korayar, Varattar, and Valayar watersheds of the Chittur taluk, Palakkad district, Kerala, using an integrated Remote Sensing (RS), Geographic Information System (GIS), and Multi-Influencing Factor (MIF) approach. Seven key thematic layers-slope, geology, geomorphology, soil type, drainage density, lineament density, and land use/land cover (LULC)-were generated from Survey of India toposheets, Geological Survey of India maps, LANDSAT satellite imagery, soil survey reports, and DEM data. All layers were converted into raster format with a spatial resolution of 30 m and analyzed using a weighted overlay technique in the ArcGIS environment. The relative importance of each factor influencing groundwater occurrence was determined using the MIF technique. The resulting groundwater potential map classifies the study area into very good to good, moderate, and poor potential zones. The results reveal that approximately 24.87% of the area falls under very good to good groundwater potential zones, 60% under moderate potential zones, and 13.28% under poor potential zones, while rivers and water bodies occupy the remaining area. Favourable zones are predominantly associated with gentle slopes, pediplains, loamy soils, low drainage density, and agricultural or forest land use, whereas poor potential zones correspond to steep slopes, denudational hills, exposed rock surfaces, and impermeable lithology. The study demonstrates that the integrated RS-GIS-MIF framework is an effective, cost-efficient, and reliable tool for groundwater resource assessment and can support sustainable groundwater management and planning in data-scarce regions.***

Keywords: Groundwater potential zones, Remote sensing, GIS, Multi Influencing Factor (MIF), Weighted overlay analysis

1.Introduction

Chittur, located in Kerala's Palakkad district, has been identified as a crucial place for groundwater extraction. In order to address the pressing issues of excessive groundwater removal and the consequences of continuous reclamation operations, a comprehensive groundwater model is now being developed. This model uses an integrated methodology that combines Geographic Information System (GIS) and Remote Sensing (RS) techniques to assess groundwater potential zones inside the Chittur block. The Multi Influencing Factor (MIF) technique is used in the process to produce a composite map with multiple theme layers. High-resolution satellite imagery is used to determine key biophysical and geological parameters, including slope, geology, geomorphology, soil type, drainage density, lineament density, and land use/land cover (LULC). These elements are crucial for accurately assessing the groundwater potential in the study area. The weighted overlay technique is then used to analyze these thematic layers in the ArcGIS 10 environment once they have been converted into raster format with a 30-meter spatial resolution. The weights assigned to each parameter are determined using the MIF technique, which considers the relative significance of each factor on groundwater occurrence. Each of the thematic levels' classes is further evaluated according to its significance for groundwater recharge and retention. Groundwater potential zones can be classified as very poor, poor, moderate, good, or outstanding. The combined influence of the contributing factors, particularly the capacity of geomorphic units to transport and store groundwater, is the basis for these divisions. The produced groundwater potential zone map is a crucial tool for the sustainable management of groundwater resources in the Chittur region.

Water is required for drinking, irrigation, industrial and commercial purposes. Sustainable Development Goal no 6 aims to “Ensure availability and sustainable management of water and sanitation for all” (UN Resolution). One of the most precious natural resources, groundwater is the main source of fresh water that is found underground and supports ecological diversity, human health, and economic growth. In recent years, the increase in domestic agricultural and industrial, activities have increased the demand for good quality water to meet the growing needs.

Throughout the arid and dry regions of the country, the people depend on the groundwater resource to meet their water requirements because groundwater is an important, finite resource and is an essential part of the hydrological cycle. Hence, it becomes very imperative for everyone in general and administrators in specific to understand the hydrological cycles manage the diminishing resource of groundwater (Anu et.al. 2012; Rehman et. al., 2024). The worldwide abstraction of groundwater from the aquifers far beyond the natural renewal rate (Gleeson et al, 2012) on one end; the erratic precipitation rate owing to the climate change and alterations in the earth’s temperature on the other end; greatly threatens the quantity of available groundwater resources. Moreover, growing urbanization and industrialization (Jha et.al, 2006) reckless waste deposition, exponentially increasing production and use of synthetic chemicals put the groundwater resources under growing pressure.

As such, the groundwater resources are encountering quantitative and qualitative problems. Ultimately it poses a greater risk to health of the groundwater ecosystems and the groundwater dependent ecosystems such as rivers, lakes and wetlands. (Inayathulla et.al, 2013) reported India will encounter serious water scarcity problems in the near future. Given that groundwater resources are the most essential for the sustenance of life forms, a quantitative understanding at various spatial and temporal scales is required for sustainable protection and management of these resources. The understanding of the unharnessed groundwater potential, the progressive decline in the groundwater table, prevailing water use patterns, the gaps in the demand and supply, socio-economic importance is termed as water literacy, which is indeed the need of the hour (Agarwal, 2008). During the last 3 decades, the framework has been evolving from purely conceptual towards solution-oriented and ready to support decision-making. As such, there is a growing need for cost and time effective techniques for assessment, monitoring and management of the groundwater resources (Sundarapandiyan et.al, 2013).

The recent technologies like Remote Sensing (RS) and Geographical Information System (GIS) provides a range of tools which eases the human efforts, saves time and money, and yields effective outputs which can be readily used for decision making. In the recent past, several studies proved that, integrated use of RS and GIS tools along with conventional surveys is an efficient approach for studying geological, structural and geo-morphological conditions together with conventional surveys (Solomon et.al, 2006; Thapa et.al, 2008; Rao et.al, 2009; Nagarajan.et.al, 2009; Mayilvaganan et.al, 2011; Nag et.al, 2011; Neelakantan et.al, 2012; Arkoprovo et.al 2012; Pandian et.al, 2013; Chuma et.al, 2013; Suganthi et.al, 2013; Kamal et.al, 2014; Senthilkumar et.al, 2014; Suresh et al, 2014; Waikar et.al, 2014). Number of researches was carried out around the world with regard to the specific applications of RS and GIS tools in delineating groundwater potential zones. From such researches it was understood, the factors involved in determining the groundwater potential zones such as geology, geo-morphology, slope, intensity of rainfall, soil-texture, lineaments etc. vary according to the given area and hence the results will also vary with the given geo-environmental conditions (Teeuw 1995., Sander et. al, 1996; Das, 2000; Sener et.al, 2005; Ganapuram et.al, 2008). The present study is also a similar study, which primarily focuses on the integral use of RS, GIS and conventional surveys to delineate of groundwater potential zones in a small mountain Taluk, Devikulam of Idukki district, Kerala.

2.Study Area

The Korayar, Varatter, and Walayar rivers are the main tributaries of the Bharathapuzha, the second-largest river in Kerala, South India. Kalpathypuzha hails from Chenthamarakulam, located deep within the Palakkad district in the highlands north of Walayar on the higher slope of the Western Ghats. The Korayar, Varattar, and Valayar watersheds are included in the Eruthempathy, Kozhinjambara, and Vadakarapathy Gram panchayats, which are a part of the Chitturtaluk and certain parts of the Palakkad taluk. The study area has an area of 231 Km2 located in the Eastern part of Palakkad district the Eastern part of the study area is bounded by Coimbatore district in Tamil Nadu the study area stretches between the latitude of 10°45'0" N to 10°50'0" and longitudes of 75°40'0" E to 76°55'0"E.

3.Data Used and Overall Methodology

Subsurface recharge has a major role in determining the water table level in a given area. It is the process by which water percolates through the layers of rock and soil from lakes, rivers, rain, or irrigation is known as subsurface recharge. It helps replenish underground water supplies in aquifers. The water table is the uppermost surface of this subterranean water. As a result, when recharge is higher, the water table rises, and when recharge is lower, it falls. In short, the quantity of subsurface water available in that area is controlled by subsurface recharge. In general, a higher rate of recharge is linked to a higher water table. The introduction claims that aquifer recharge varies greatly across space and is influenced by several interrelated factors, including rainfall, land-use/land-cover (LULC) patterns, geological conditions, geomorphology, and soil characteristics (Scanlon et al., 2002). The current study has included key factors such as slope, geology, geomorphology, soil type, drainage density, lineament density, and LULC in order to assess recharge potential. The methodological framework employed in this study is depicted in Figure 2. Relevant spatial data layers were geo-referenced and vectorized from a variety of authoritative sources, including Survey of India toposheets (scale 1:25,000), Geological Survey of India maps, satellite imagery from LANDSAT 7 and 8, reports from the Soil Survey Organization, and visual interpretations from Google Earth. These thematic layers were then converted to raster format with a spatial resolution of 30 meters and analyzed using weighted overlay techniques in the ArcGIS 10 environment. Each parameter's relative importance (weights) was evaluated using the Multi-Influencing Factor (MIF) technique (Shaban et al., 2006).

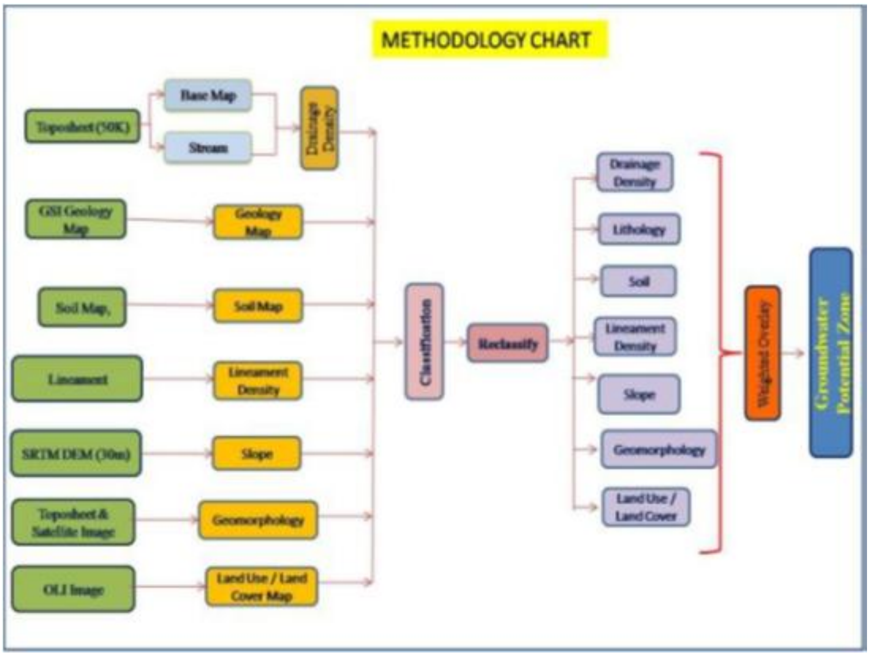


Table 1: Thematic Layers and Their Data Sources

Thematic Layer	Description	Data Source	Format Used
Slope	Degree of surface inclination	Derived from DEM / Toposheets (SOI)	Raster (30m)
Geology	Rock types and structures	Geological Survey of India Maps	Vector
Geomorphology	Surface landforms and features	Satellite Imagery / Geological Maps	Vector
Soil Type	Soil classification and texture	Soil Survey Organization Reports	Vector
Drainage Density	Stream frequency per unit area	Toposheets (SOI) / Satellite Imagery	Vector
Lineament Density	Linear features such as faults and fractures	Satellite Imagery / Google Earth	Vector
Land Use / Land Cover	Vegetation, water bodies, built-up area	LANDSAT 7 & 8 Imagery / Google Earth	Raster

4.Results and Discussion

Drainage Density

Drainage density was first suggested by Horton (1932) as a critical statistic that reflects the linear size of landform components in terrain that has been degraded by streams. Because of reduced vacancy ratios in the topography, higher drainage densities typically translate into lower infiltration capacities, which generally lead to greater surface runoff and heightened vulnerability to soil erosion. It is an important indication of hydrology. This is explained by the fact that a significant portion of rainfall does not be absorbed by the earth but instead runs off as surface runoff. Drainage density was determined in this work using the ArcGIS environment's Inverse Distance Weighted (IDW) spatial analysis approach. The drainage density classification for the whole study area is displayed in Figure 3. According to stream ordering studies, the Korayar, Varattar, and Valayar watersheds collectively make up a 4th order drainage basin, indicating a somewhat complex fluvial system with important geomorphological implications.

The 348 stream segments in the watershed were found to be dominated by lower-order streams, with first and second-order streams making up about 85% of the entire stream network. All stream segments, which are anticipated to be 170 kilometers long, have an average drainage density of 0.88 km/km². Surface runoff patterns and stream channel construction are influenced by drainage density differences throughout the basin, which are primarily determined by slope gradients and local terrain. Tiny, juvenile streams make up the majority of the catchment. Streams with a drainage density of 0.88 km/km² and a length of 170 km cover the region. In this area, stream formation and water flow are determined by the steepness and structure of the ground.

Geomorphology

Studies on geomorphology provide an orderly and accurate description of various landforms and land forming processes

(Parthasarathy et.al, 2010). In order to understand the physical setting, knowing geomorphic processes and their work is much essential. The geo-morphological attributes were prepared from SOI toposheets and ETM+ satellite imagery. The Korayar, Varattar and Valayar watershed is located in the east of the Palakkad district. The study area is included within the rain shadow regions in the district. Kozhinjampara, Vadakarapathy and Eruthempathy are the major rain shadow regions in the Kerala- Tamil Nadu border in Chittur taluk is becoming the vegetable hub of the state. These regions are included in the midlands of Kerala, which is more suitable for the vegetable cultivation. More than 60% of the area are the gently sloping plain and flat surfaces. High plains or tablelands are spread over the Sothern part of the study area. Structural hilly regions are found in the northern part of the study area, which include the areas of Valayar reserved forest (Fig.4)

Geology

The present study area comes under the Western Ghat region. Geology is the science which deals with the physical structure and substance of the Earth, their history and the processes which act on them. The geological setting of a region affects various human activities of that area. The major geological unit of the Korayar, Varattar and Valayar watershed is Migmatite rocks. More than 96% of the area is covered by the Migmatite rocks. Khondalite group of rocks is the second major group which can be mostly seen in the high land region. The Khondalite group of rocks is made up of Quartzo-Feldspatic Gneiss and its variants (fig.5)

Slope

Slope is the upward or downward inclination of surface between hills and valleys and forms the most significant aspect of landscape assemblages (Prasannakumar, 2007). A high sloping region causes more erosion and less infiltration and thus has poor groundwater prospects compared to the low slope region. Slope is one of the most important factors which directly influence the land use pattern of a region. The nature of the slope exhibited by a region determines its susceptibility to erosional hazards. The slope and its elevation are governed by several environmental factors such as lithology, climate, vegetation and the nature of intensity of various weathering processes operating along slopes. The slope characteristics, or more specifically the slope steepness, are one of the most important factors which directly influence the farming practices prevailing in a region. The slope map of the study area shows that most of the regions are strong and moderately slope. Very steep slope regions are found in the northern part of the study area include the areas of Valayar reserved forest and hilly regions (Fig.6).

Soil Type

One of the basic vital parts of our environment is soil. It influences the distribution of plant species and provides a habit for a wide range of organisms. It controls the flow of water and chemical substances between the atmosphere and the earth, and act as both a source and store for gases like oxygen and carbon dioxide. Soils not only reflect natural processes but also record human activities both at present and in the past. They are therefore part of our cultural heritage. It is constantly changing and developing through time. Soil is always responding to changes in environmental factors, along with the influences the influence of man and land use. The soil of Palakkad district is mainly 4 types namely peaty, laterite, forest and black soil. In the study area more than one half (68.42%) of the area is covered by loamy soil, which is very suitable for the paddy cultivation (Fig.7).

Land use / Land cover

Land cover and land use changes are one of the four major environmental problems globally, together with biodiversity, atmospheric composition and climate change (Walker and Steffen, 1997; Walker, 1998). Therefore, it is always important to monitor land use change within a certain period of time and predict patterns of future land use changes on a spatial basis (Nurmiatyet.al., 2014). Mapping is the most efficient method for projecting changing land use (Mani, 2012). Standard visual interpretation methods were applied to identify and interpret the land use pattern of the area and the land use/land cover map of study area shows that more than 80% of the area is used for agricultural purposes. The areas including Kozhinjampara, Vadakarapathy and Eruthempathy panchayat are the vegetable hub of the state. Other 20% areas are covered by forest, built up areas, waste lands and water bodies (Fig.8).

Weighted Overlay Analysis

As mentioned in the methodology section, slope, geology, geo-morphology, soil, drainage density, lineament density, land-use/land-cover are the parameters considered for the present study. Each parameter is interdependent on other parameters viz. each parameter has a major effect (A) and minor effect (B) upon other parameters. For each major and minor inter-related factor, a weightage of 1 and 0.5 is assigned respectively. A relative rate is calculated for each factor by cumulating all the weights of major and minor inter-related factors (A+B). A factor with higher relative rate shows larger impact on the groundwater potential zones and vice versa. This relative rate is further used to calculate a score for each influencing factor using the following formula:

$$\left[\frac{(A+B)}{\sum(A+B)}\right] X\ 100$$

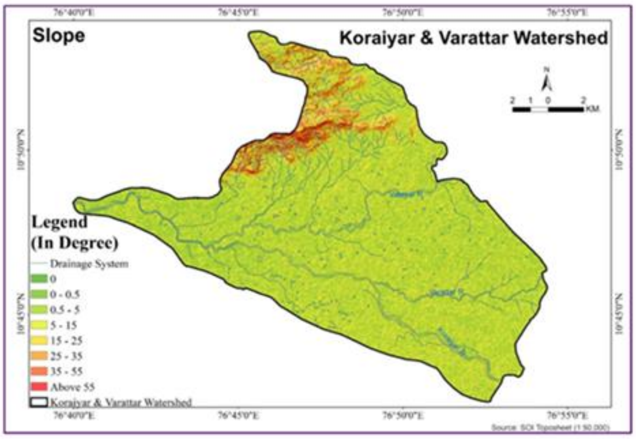
where,

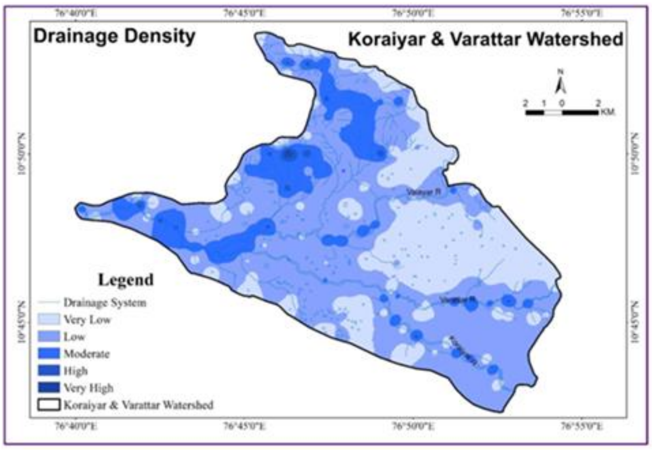
A is the major inter-relationship between two factors
B is the minor inter-relationship between two factors
A+B is the relative weight of each factor

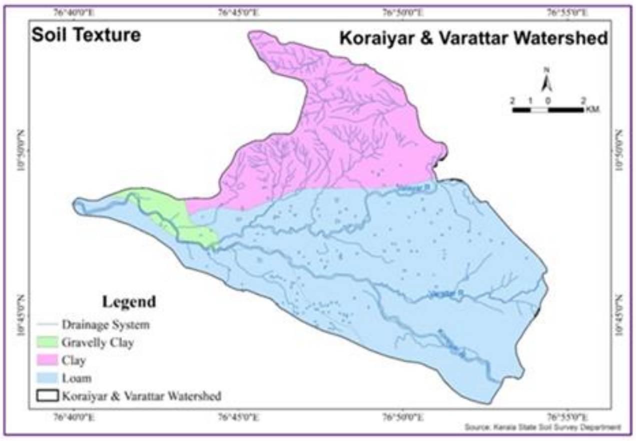
The inter-relationship between the parameters chosen for the present study, their relative weight and the scores derived for each parameter is detailed in Table 1.

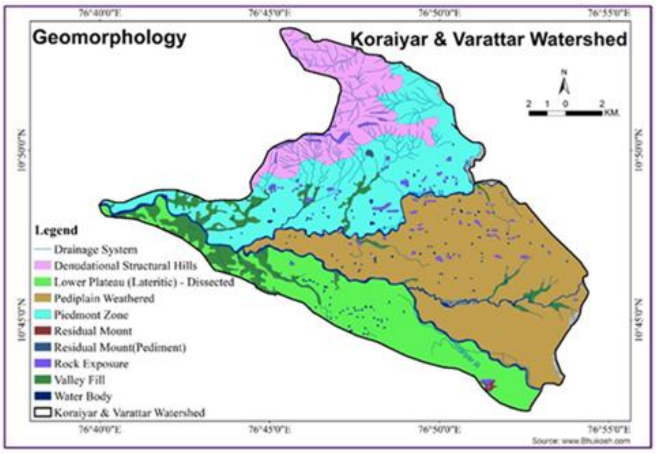
Table 2: Selected variables for Weighted Overlay Analysis

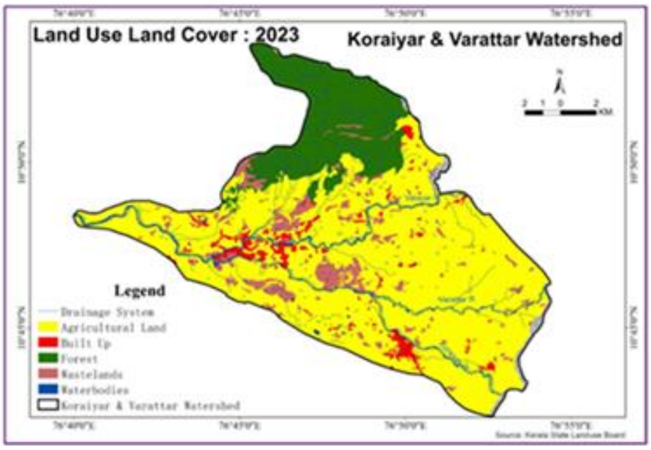
Factor	Major A	Minor B	Proposed relative rates (A+B)	proposed score for each influencing factor
Geomorphology	1+1+1+1	0.5	4.5	17
Geology	1+1	0.5+0.5+0.5	3.5	14
Slope	1+1+1	0.5+0.5	4	16
Drainage Density	1+1+1	0.5+0.5	4	16
Land use /Land cover	1+1	0.5+0.5+0.5	5.5	21
Soil	1+1+1	0.5+0.5	4	16
Sum			25.5	100

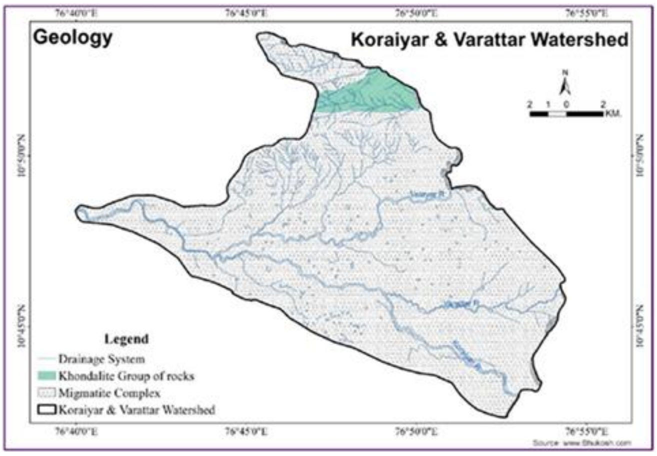


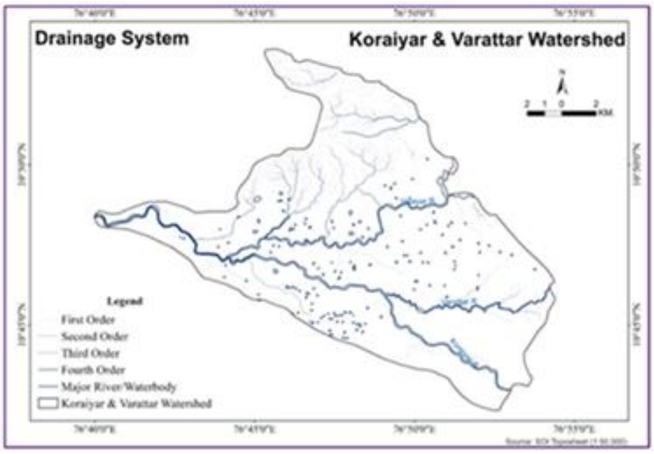












Effect of influencing factor, relative rates and score for each potential factor

The concerned score for each influencing factor was divided equally and assigned to each reclassified class:

Table 3: Classification of Weighted Factors influencing the Potential Zones

Erosion Parameters	*Sub- class of parameters*	*Class Weightages*
Soil	Water body	16
	Loam	12
	Gravelly Clay	8
	Clay	4
Slope	0 – 0.5 %	16
	0.5 – 2%	14
	2 – 5%	12
	5 – 9%	10
	9 – 15%	8
	15-30 %	6
	30 – 60%	4
	>60 %	2
Drainage Density	Very High	16
	High Density	12
	Medium Density	8
	Low Density	4
Land Use	Water bodies	21
	Forest	18
	Agricultural Land	15
	Wetland	11
	Waste Land	8
	Built-up Land	4
Geology	Migmatite	14
	Khondalite	7
Geomorphology	Tanks and Waterbody	17
	Rock Exposure	1
	Denudational Structural Hill	4
	Plateau	7
	Piedmont Zone	10
	Pediplain	14

Very Good to Good Groundwater Potential Zones

Areas with very good to good groundwater potential comprise about 24.87% of the whole research area. The majority of these regions are found in the Korayar, Varattar, and Valayar watersheds' southern and western regions. These zones are defined by a variety of beneficial hydrologic and physiographic elements, including landform type, geological structure, soil texture, slope gradient, land use, and drainage features.

Geomorphology: These areas are primarily Pedi plains (score: 14) and tanks/water bodies (score: 17), both of which are advantageous for subterranean water penetration and storage. While Pedi plains frequently include lengthy, weathered zones and gently undulating terrain that promote recharge, tanks and surface water bodies act as direct sources of infiltration.

The loamy soils (score: 12), which are distinguished by their moderate to high permeability and water-holding capacity, further enhance infiltration. Due to constant surface saturation, proximity to water bodies also supports consistent recharge (score: 16). Gently sloping terrain, particularly in the 0-2% range (scores: 16 and 14), results in significantly less surface runoff. Water has greater time to infiltrate into underground aquifers as a result. Land Use/Land Cover area consists of water bodies (score: 21), wooded areas (18), and agricultural land (15), all of which support groundwater recharge. Forests help retain moisture through canopy interception and reduced evapotranspiration, whereas agricultural fields commonly use irrigation systems that increase infiltration. Drainage Density is low to medium drainage densities (scores between 4 and 8) in these areas indicate a lesser degree of channelization, which is indicative of a higher capacity for infiltration and a reduced possibility for runoff. Geology consists of migmatite formation (score: 14), which underlies the underlying geology in these high-potential zones, promotes groundwater circulation and storage by improving secondary porosity caused by weathering, cracks, and structural deformation. These favourable combinations of physical elements create the optimal hydrogeological conditions for groundwater accumulation and long-term extraction. The regions in this zone, such as Padalikkad, Kottekad, Kanjikkod, Kozhinjampara, Chullimada, Pamplampallam, and Attapallam, can be prioritized for the development of water resources, including well siting, groundwater recharge structures, and sustainable irrigation planning.

Moderate Groundwater Potential Zones

Groundwater recharge and surface runoff interact in a balanced manner in the moderate groundwater potential zones, which make up about 60% of the watershed and are primarily located in its central and eastern sectors. These regions are distinguished geomorphologically by the existence of piedmont zones and pediplains, which offer somewhat favourable circumstances for subsurface water circulation. The predominant soil types, such as loam and gravelly clay, have a moderate permeability, and the mild to moderate slope gradients (2% to 9%) increase the potential for infiltration. Compared to more productive land covers like forests and waterbodies, the land use in these zones is mostly agricultural with wetlands scattered throughout, providing a moderate contribution to groundwater recharge. A balanced regime of runoff and infiltration is indicated by a drainage density that is typically medium to high. The modest groundwater potential is further influenced by the geological composition, which is primarily composed of migmatite with khondalite occurrences. Valayar, Valiyakuliyanpara, Tenakkulam, Eruthempathy, and Nattukal are important sites within these zones.

Poor Groundwater Potential Zones

These zones are primarily found in the steep northern parts of the watershed, where land cover and topography provide the least support for groundwater recharge. The geomorphology of the area is dominated by exposed rock formations and denudational structural hills, which are primarily impermeable and encourage surface runoff rather than infiltration. The prevalent clayey or shallow soil types further restrict water percolation into underground levels. The topography has 15% to over 60% steep to very steep slopes, which greatly increase runoff and decrease the possibility of infiltration. Waste land and built-up zones, which are characteristics of land use in these places, both obstruct efficient groundwater recharging. A well-developed surface drainage network that speeds up runoff and reduces

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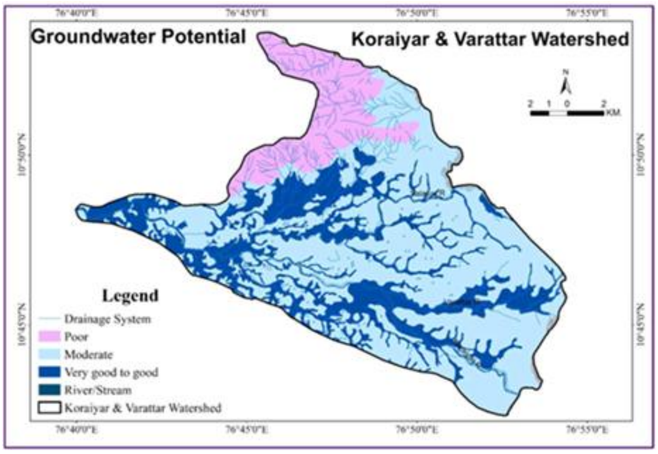
subterranean water storage is indicated by a drainage density that is usually very high. Groundwater potential is further limited by the geology of the area, which is mainly composed of khondalite formations, which are characterized by their low permeability. Areas around the Valayar Reserve Forest and Chemanthimalai are important sites within these low groundwater potential zones, where the combination of rough terrain, thick forest cover, and impermeable geological formations further restricts groundwater recharging. These areas are classified as having poor groundwater potential because they are prime examples of the northern hilly zone's typical features, which include steep slopes, shallow or clayey soils, and high drainage density. These factors all work together to cause rapid surface runoff and little infiltration.



Comparison of Groundwater Potential Zones

Parameter	Very Good to Good	Moderate	Poor
Geomorphology	Tanks, Pediplains (17, 14)	Pediplains, Piedmonts (14, 10)	Structural Hills, Rock (4, 1)
Geology	Migmatite (14)	Migmatite, Khondalite (14, 7)	Khondalite (7)
Soil	Waterbody, Loam (16, 12)	Loam, Gravelly Clay (12, 8)	Clay (4)
Slope	0–2% (16, 14)	2–9% (12, 10)	>15% (6–2)
Drainage Density	Low–Medium (4–8)	Medium–High (8–12)	Very High (16)
Land Use	Waterbodies, Forest (21, 18)	Agriculture, Wetland (15, 11)	Wasteland, Built-up (8, 4)
Area (%)	24.87%	60%	13.34%
Notable Locations	Padalikkad, Kanjikkod, Chullimada	Valayar, Eruthempathy, Nattukal	Valayar RF, Chemanthimalai

Based on hydrological and geomorphological features, the research area's groundwater potential-which spans 232 km²-is divided into four different categories. The highest percentage, or roughly 139 km2, or 60% of the overall area, is made up of moderate groundwater potential zones, which show a balanced interaction between recharge and runoff. A quarter of the watershed, or 58 km2, is made up of zones with very good to good groundwater potential. These zones are usually linked to favourable characteristics including low slope, permeable soils, and supportive land use.

Areas with limited groundwater potential, covering 31 km² or 13.28%, are predominantly located in mountainous regions characterized by high gradients and impermeable lithology. River courses and surface water bodies comprise the smallest group, accounting for 4 km² or 1.72% of the total area.

Table 6: Area under Groundwater Potential Zones

Sl.No	Category	Area km²	Area in %
1	Poor	31.00	13.28
2	Moderate	139.00	60.00
3	Very Good to Good	58.00	25.00
4	River and Water body	4.00	1.72
	Total	**232**	**100**

5.Conclusion

Geo-spatial approach for delineating groundwater potential proves to be efficient in terms of labour, money and time saving thereby it provides a precise result which enables quick decision making for effective water resources management. The geo-spatial and MIF techniques adopted in the present study is empirical, to identify the groundwater potential zones. This method also aids to identify suitable sites for harnessing groundwater. The method can also be adapted to various areas with rugged terrain. The results of the present study may also be used as guidelines for future artificial recharge projects. It is also a valuable practical tool for the regions of the developing nations, where data scarcity (in terms of quantity and quality) is often an obstacle for solving real-world water problems.

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