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GEOGRAPHICAL INFORMATION SYSTEM AND MULTI-INFLUENCING FACTOR TECHNIQUES FOR THE ASSESSMENT OF GROUNDWATER POTENTIAL ZONES OF TROPICAL WATERSHEDS: A CASE STUDY

IMTHIAZ AHAMMED[1]*, JAYAPAL G[1], T K PRASAD[1], SURESH S[2]

[1]Kannur University, Department of Geography, Kerala, India
[2]Sree Sankaracharya University of Sanskrit, Department of Geography, Kalady, Kerala, India
*Email: imtiazfaizi@gmail.com

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Abstract
The groundwater of a region is predisposed much by terrain factors along with climatic factors. Being a subsurface phenomenon groundwater cannot be observed directly, it had to be done indirectly based on the analysis of data of observable features collected through field observation and various geophysical techniques. Groundwater occurrence is a phenomenon which is heavily dependent on multiple parameters viz., geomorphology, geology, land use, slope, soil texture, drainage density, lineament density, relief, and vegetation. The present study intends to examine the need and prospect of assessing the groundwater potential of a tropical watershed on Geographical Information System (GIS) platform using the Multi-Influencing Factor (MIF) technique. A multi-influencing factor approach is used, where weights were assigned to each factor based on their level of influence and finally conducted weighted overlay platform to generate groundwater potential zones of the Perumba watershed, in the Kannur District of Kerala, India. Various parameters of groundwater have been analyzed from a geomorphological standpoint and potential zones were identified and categorized. The study signifies the application of MIF and GIS techniques in hydrological studies, as they qualify for comprehensive assessment and spatial analysis of various factors that affect the dynamics of groundwater. The study found that 59.75% of the study area has moderate groundwater potential followed by 22.10% area having high groundwater potential.

Keywords: Groundwater potential, Tropical watershed, Geographical information system, multi-influencing factor, Weighted overlay

1. Introduction

Groundwater serves as the most important source of freshwater as it is considered the least polluted source of water and most of the freshwater sources (lakes, ponds, and rivers) are not easily accessible to everyone and are unevenly distributed. But this led to a myth that groundwater is an unperishable resource which ultimately leads to its injudicious usage and overexploitation (Darnault, 2008). The availability of groundwater is influenced directly or indirectly by terrain factors including geomorphology and slope, vegetation, soil texture, etc… along with climatic factors like precipitation and temperature. Being a subsurface phenomenon groundwater cannot be observed directly, it had to be done indirectly based on the analysis of data of observable features collected through field observation and various geophysical techniques (Balasubramanian, 2007). However, the advancement of satellite technology has led to the availability of data related to terrain and atmospheric factors that influence groundwater resources. This satellite data coupled with relevant ground information can be used to delineate most of these terrain characteristics including slope, vegetation, land-use etc. (Dinesan et al., 2015) All of these characteristics influence groundwater at various levels some might be major influences and others minor, Geographic information system (GIS) facilitates the analysis of the influence of each factor and combines them by assigning ranks using the multi-influencing factor (MIF) technique and weighted overlay analysis (Suresh et al., 2019).

Groundwater is closely related to surface drainage as the surface water or drainage systems seep into underground and recharge the groundwater system and in return the groundwater discharges to the surface to supply the streams with baseflow (USGS, n.d.). Therefore, this relationship cannot be neglected and drainage basins or watersheds could be used as an ideal region for observing and studying groundwater characteristics.

A watershed can be defined as a natural unit of land upon which water from various sources and storages collects in a surface channel and flows downhill to a common outlet at which the water enters another waterbody like a river or sea (Black, 1996). Watersheds of tropical regions experience the same processes as in watersheds of temperate regions, but "they are characterized with high input of energy as Tropical climate is characterized with great input in solar energy" (Mwangi et al., 2016) due to their geographical location which in turn allows higher agricultural production and extreme hydrological cycles (Pereira, n.d.). Therefore, tropical watersheds play a major role in the development of countries in tropical regions. Owing to the functions it provides and containing rivers and streams which act as the lifelines of land, it is necessary to protect all aspects of the watershed including its biodiversity, groundwater, surface runoff, etc… This necessitates the need for management of watersheds (Mwangi et al., 2016).

The development of satellite technology and GIS software have made the watershed management process easier especially by helping with the planning process. GIS platform can be used for efficiently modelling watershed management systems as modelling requires multiple layers of information regarding the geomorphological, terrain, geological and climatic information and a GIS system can be used to integrate all these information (Gosain & Rao, 2004), the overlay and weighted overlay analyses in GIS can be used to integrate various aspects within the watershed like biodiversity, demography, drainage, groundwater, etc… for efficient watershed management. The present study intends to demonstrate this application by assessing the groundwater potential of the Perumba watershed, this study uses the platform of GIS using the MIF technique. MIF technique reduces the complexities involved in the field of hydrology especially in groundwater potential and recharge studies. Hydrology is an intricate field as existence of groundwater is heavily dependent on interplay of various factors. Using MIF all these factors can be examined and analysed individually finally giving the whole hydrological scenario of the region. Magesh et al., (2012) used MIF techniques coupled with GIS and remote sensing techniques to identify the groundwater potential zones of Theni district in Tamil Nadu, India, Siddi Raju et al., (2019) conducted a similar study for Mandavi river basin, a tropical basin in Andhra Pradesh, India. Pande et al., (2021) incorporated MIF techniques along with Analytical Hierarchical Process (AHP) and GIS techniques to assess the groundwater potential of a tropical river basin.

2. Materials and methods

Study area

Perumba or Peruvamba River is a major freshwater river in the Malabar region of Kerala state. It mostly flows through the Kannur district of Kerala. The Perumba watershed covers a total area of about 343 km2 lying between 12° 0' to 12°15' North latitudes and 75°10' to 75°20' east longitudes located in the Kannur and Kasargod districts of Kerala state (Figure 1 & 2). It is bounded by the Thalipparamba taluk of Kannur district and Hosdurg taluk of Kasargod district in the north, the Thalipparamba taluk of Kannur district in the south and east, and Arabian Sea in the west. The watershed covers 19 villages spread over 12 panchayats in 2 districts. The groundwater/hydrogeology of the study area in particular and the district in general: the major water bearing formations include weathered, fractured crystalline formations, laterites and recent alluvium (CGWB, 2020). "The district has a net annual groundwater availability of 479.11 MCM (Million Cubic Meter) (CGWB, 2020)." The Central Groundwater board, India have classified 2 administrative blocks in the region Kuthuparamba and Thalasherry as semi-critical regions in relation with groundwater over-exploitation and availability (CGWB, 2020).

Methodology

Groundwater occurrence is phenomenon which is heavily dependent on multiple parameters which themselves have varying levels of interdependence.

- Parameters used: geology, slope, geomorphology, lineament, landuse/landcover, soil texture, and drainage density. The data on these parameters were derived as raster data from various sources and parameters were imported and geo-referenced and converted into vector format in Arc GIS 10.4 platform. Multi-influencing factor (MIF) technique proposed by (Suresh et al., 2014) is adopted to generate groundwater potential in the study area.
- Based on the state of deciding groundwater potential strength weights were assigned to individual theme and for each feature within the theme.

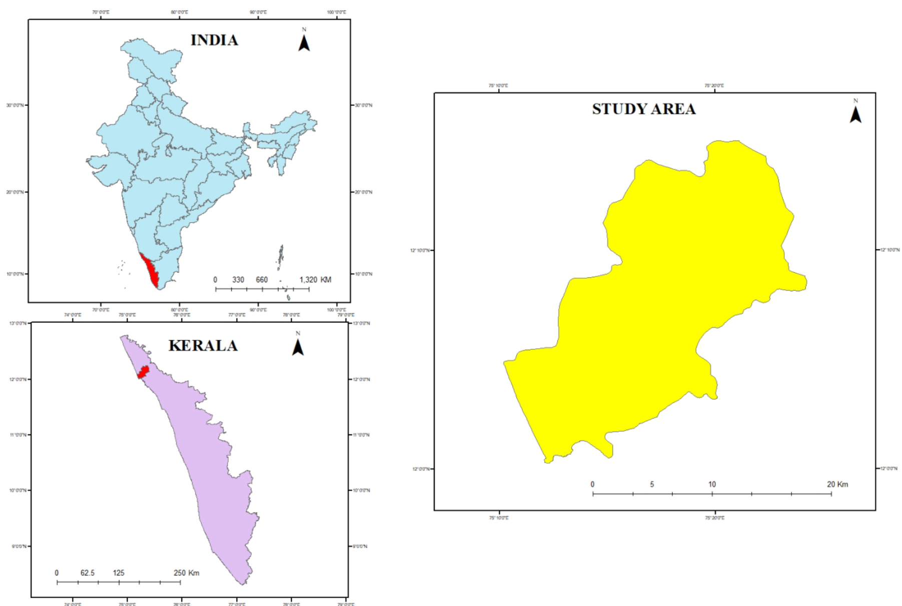

Fig. 1. Location map of Perumba watershed

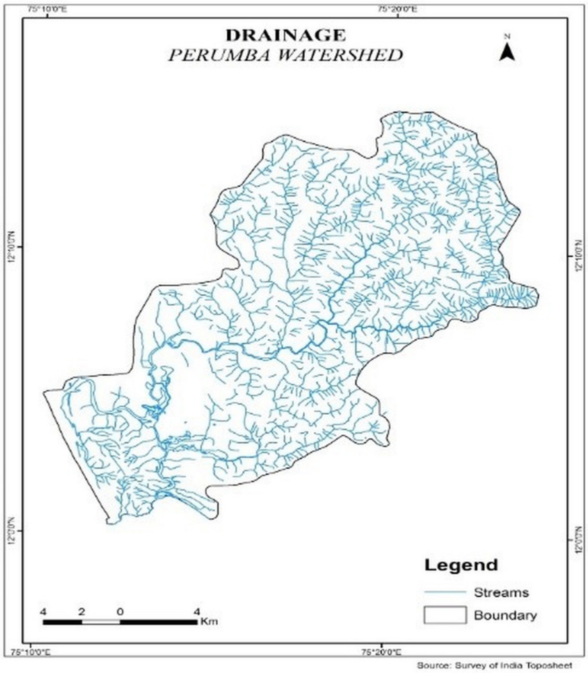

Fig. 2. Drainage map of Perumba watershed

A factor with a higher weight value indicates a larger impact whereas lesser weight value shows a smaller impact on groundwater.

- Overlay technique using Geographic Information System (GIS) have been used to delineate the groundwater potential zones.

Data for this study was gathered from several sources as there were multiple parameters for the study.

- The base map was prepared using two Survey of India toposheets of the region numbered 48 P/8 and 48 P/4 of the scale 1:50000.
- Geology, soil, and geomorphology data was sourced from maps released by Kerala State Geology Department and land use from state landuse board.
- Landsat 8 OLI (Optical Land Imager) DEM (Digital Elevation Model) satellite imagery with 15 m panchromatic resolution and 30 m multi-spectral spatial resolution was used to create NDVI, slope, and relief maps. The drainage data was sourced from both satellite imagery and the toposheet. All digital data were either in .shp (shapefile) format or image format.

Thematic maps were created for each of the parameters and analysed individually before performing the weighted overlay analysis

Parameters used to assess groundwater potential

Geomorphology, geology, lineament density, landuse/landcover, drainage density, stream junction, slope, soil texture and normalized differential vegetation index (NDVI) are the parameters used to assess the groundwater potential in this study. The analyses of the parameters are:

Geomorphology

Geomorphology or the physical features on the land surface defines the direction of surface flow and rate of infiltration. Geomorphology of a region is the result of interplay between various physical and climatical factors. Most of the study area

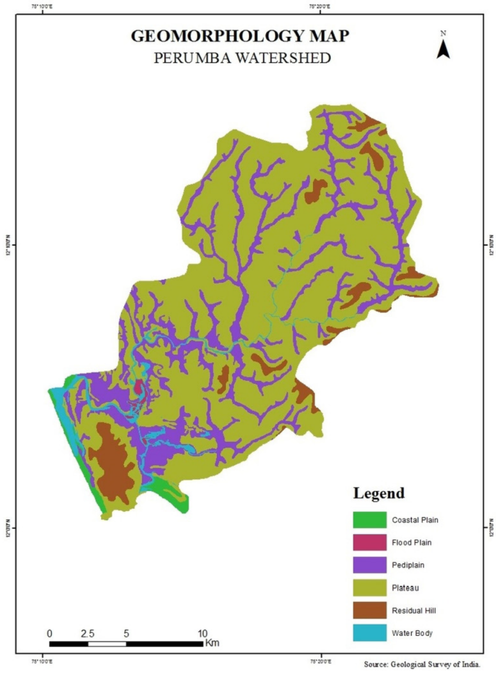

Fig. 3. Geomorphology of Perumba watershed

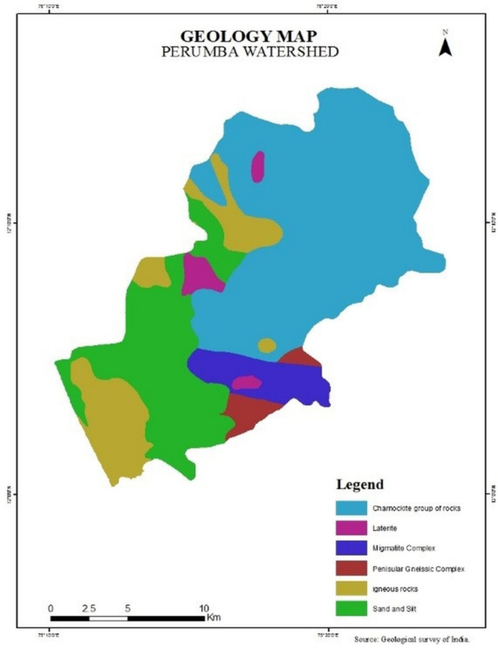

Fig. 4. Geology of Perumba watershed

is composed of plateau region (68.7%), mostly laterite plateaus which allows good percolation of groundwater (Langsholt, 1992) followed by Pediplain (21.03%) which also has a good potential for groundwater infiltration and percolation (Murmu et al., 2019) regions mostly concentrated in western part and spread across the study area (Figure 3). "Variations in the surface terrain and landscape units' characteristics dramatically impact the local micro-scale infiltration pattern which ultimately decides groundwater potential" (Letz et al., 2021).

Geology

Underlying geological structure of a region heavily influences the infiltration as well as the quality of groundwater. The rock type basically decides the level of percolation of water as the primary porosity of the rock is depended on the rock type. Primary porosity refers to the space between grains in a rock (Earle & Earle, 2015). Secondary porosity, induced by fractures and joints after the formation of rock also affects the water percolation (as in the case of igneous and metamorphic rocks). A large portion of the study area is covered by Charnockite rocks (54%) concentrated in the eastern highland region of the study area which is metamorphic in nature and has very low primary porosity followed by sand and silt (23%) in western side which has a very high primary porosity and igneous rock complex (13.2%) having very little porosity (Figure 4).

Lineament density

Lineaments refers to natural surface features in landforms such as faults, joints, bedding planes or foliations which can be directly interpreted from satellite images or aerial photographs (Al-Nahmi et al., 2016). In metamorphic and igneous rock terrains lineaments are the primary agents which facilitate ground water percolation (secondary porosity). As a huge portion of the study area is composed of hard rock geological features, therefore the groundwater potential of such regions is

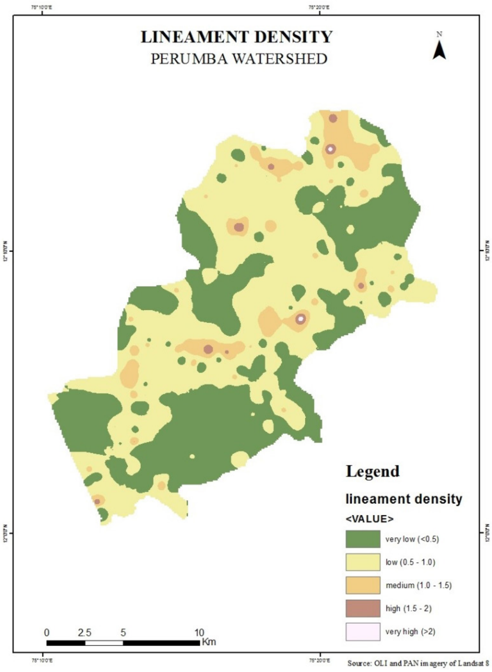

Fig. 5. Lineament density

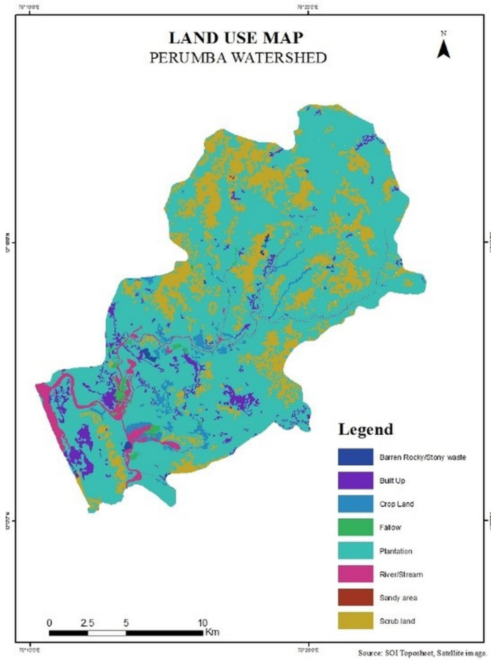

Fig. 6. Land use map

heavily depended on lineament density of the region. The study area is having generally lower lineament density with higher density regions scattered across the region. The lineament density of the region is divided into 5 classes: Very low density (<0.5), Low density (0.5 – 1.0), Medium density (1.0 – 1.5), High density (1.5 – 2), Very high density (>2.0) (Figure 5).

Landuse/landcover

Even though the natural features are the mainly responsible for the groundwater potential of a region, the land surface modified by thousands of years of human settlement and interaction cannot be ignored. Landuse of a region can influence the groundwater percolation greatly, for example, a well built-up human settlement can reduce the groundwater percolation even if all other natural features are favourable. Landuse map of the study area is created using Google earth platform, Landsat 8 satellite imagery along with respective topographical maps. A large part of the study area is covered by plantations (70%) which generally supports the percolation of groundwater (Ilstedt et al., 2016) followed by scrub lands (20%) which have comparatively lesser infiltration capacity as the vegetation is isolated and unevenly spread. The built-up region in the study area accounts only for 3.86% which makes the landuse of the study area generally favourable for groundwater potential (Figure 6).

Drainage density

Horton (1932) introduced the drainage density as an important indicator of the linear scale of landform elements in stream eroded topography. Higher the drainage density the lesser the infiltration capacity i.e., low void ratio of the terrain leads to soil erosion (Dragičević et al., 2019). This is because much of water coming as rainfall goes as runoff. Drainage density of Perumba watershed is classified into 5 from lowest to highest: Very low density (<1.5), Low density (1.5 – 3.0), Medium density (3.0 – 4.5), High density (4.5 – 6.0), Very high density (>6.0) (Figure 7). Most of the study area comes under low drainage density, followed by medium density.

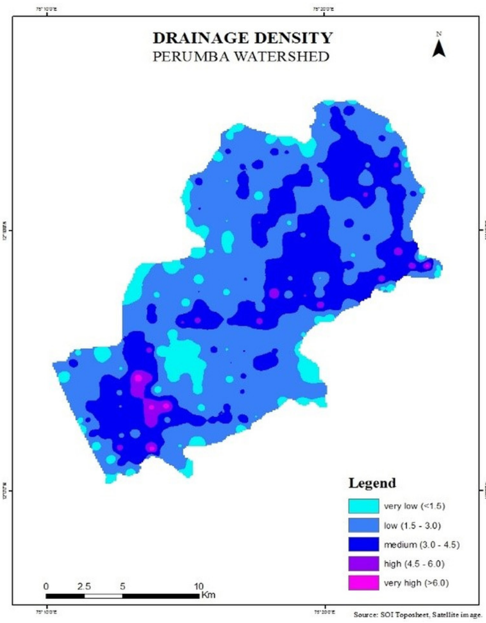

Fig. 7. Drainage density

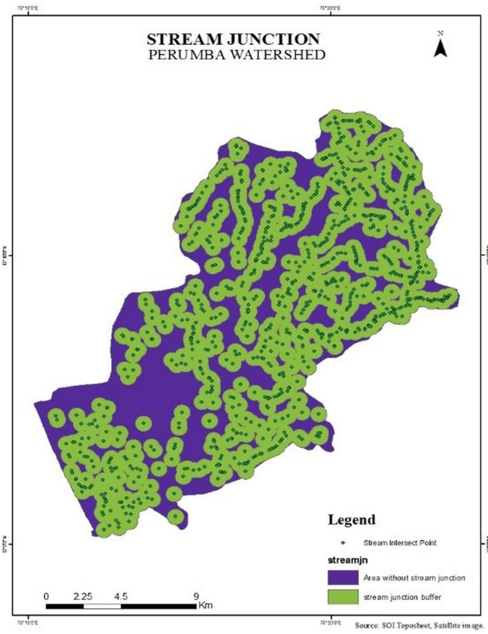

Fig. 8. Stream Junctions

Stream Junction

Stream junctions are the points where two or multiple channels/streams join. Perumba river with multiple channels and braided streams have multiple stream junctions. The point where streams meet positively influences the groundwater percolation (Suresh et al., 2019) as the junctions reduces flow velocity. There are numerous stream junctions across the study area with most concentrations in eastern and western regions of the watershed (Figure 8).

Slope

Slope of a region influences the flow of surface water of a region which in turn influences the groundwater percolation. The elevation in the watershed ranges from 20 m to 340 m above sea level. Lower the slope percentage higher the possibility of good groundwater potential, which means the level gentle slope, has the highest possibility of good groundwater potential (Hasanuzzaman et al., 2022). The slopes of study area are divided into 5 classes: Level gentle slope (0 – 5 %), Moderately sloping (5 – 15%), Moderately steep to steep slope (15 – 35%), Strongly sloping (35 – 70%), Very steep sloping (>70%) (Figure 9). Most of the study area is of level gentle slope especially in the western part, towards the eastern regions of the study area the slope becomes steeper.

Soil texture

Soil texture plays a major role in groundwater potential analysis. Coarser the texture more the groundwater percolation (Suresh et al., 2019). It is texture of soil which plays a major role in deciding whether water logs or flows or percolates easily or just stays to get evaporated. Three major textures namely gravelly clay, gravelly loam and sandy are found in the study area. Most of the watershed comes under gravelly clay soil texture which allows moderate percolation while other types occupy very minute areas (Figure 10).

Normalized Differential Vegetation Index (NDVI)

NDVI helps in understanding an overall picture of vegetation cover of the study area.

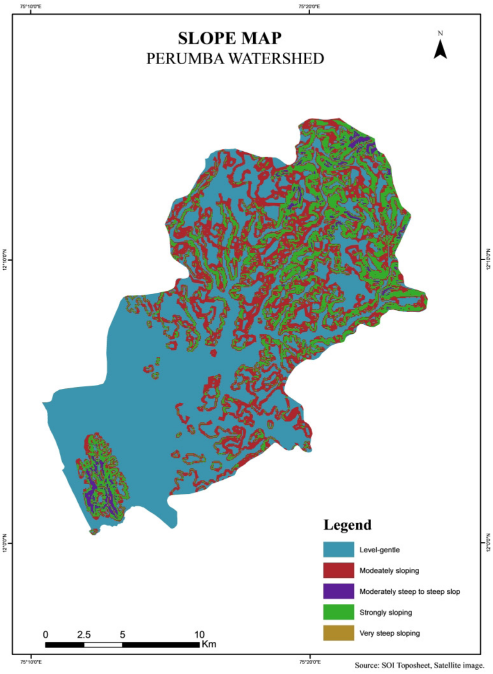

Fig. 9. Slope

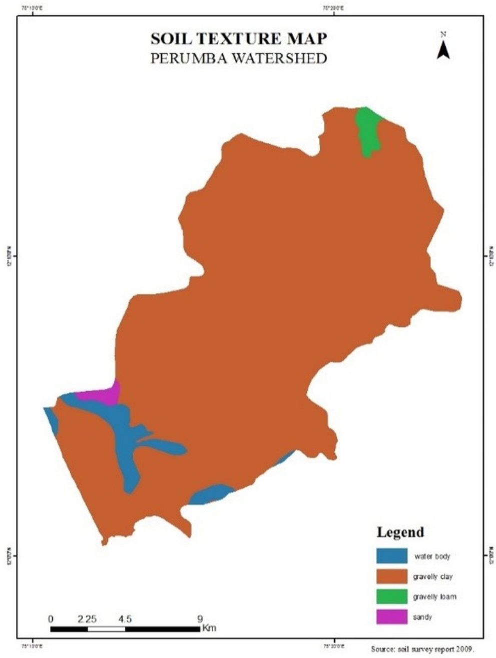

Fig. 10. Soil Texture

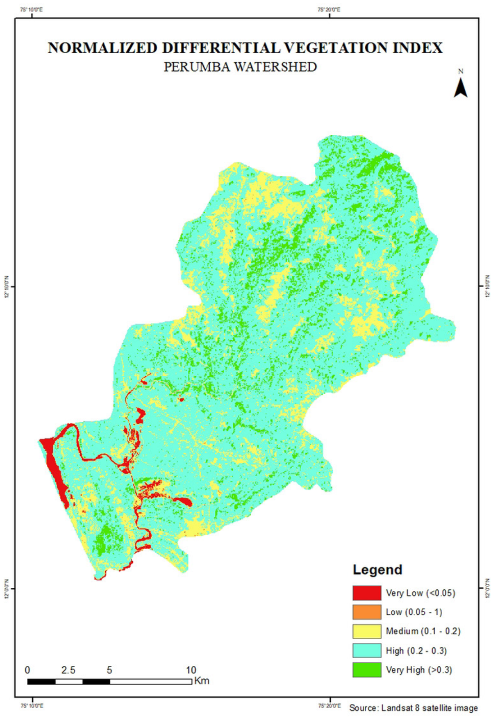

Fig. 11. Normalized differential vegetation index (NDVI)

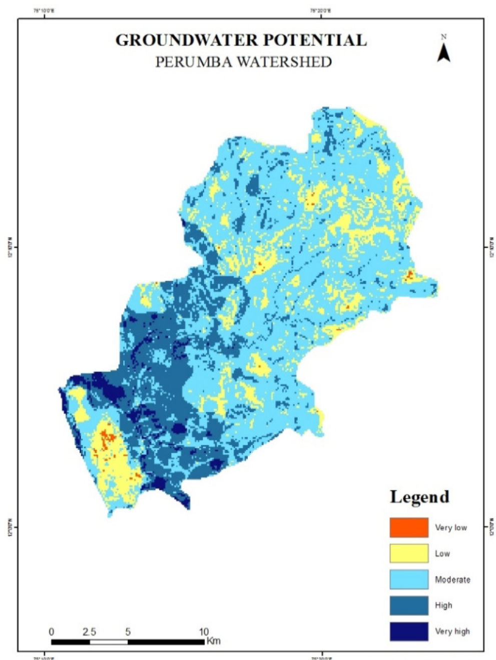

Fig. 12. Groundwater Potential map of Perumba Watershed

Table 1. Major and Minor Effects of Multi Influencing Factor

Influencing factors	Major effect (A)	Minor effect (B)
Lineaments	Drainage, Geology, Stream junction	Land use /Land cover, Slope, Geomorphology, Soil texture, NDVI
Geomorphology	Land use /Land cover, Geology, Slope, Soil texture, Stream junction	Lineaments, Drainage density, NDVI
Geology	Geomorphology, Drainage, Lineaments, Stream junction	Slope, Land use /Land cover, Soil texture, NDVI
Slope	Geomorphology, Drainage, Land use / Land cover,	Lineaments, Geology, Soil texture, Stream junction, NDVI
Drainage	Slope, Lineaments, Geology, Soil, Stream junction	Land use /Land cover, Geomorphology, NDVI
Land use /Land cover	Geomorphology, Slope, NDVI	Lineament, Geology, Drainage, Soil texture, Stream junction
Soil	Geology, Drainage, Slope, NDVI	Geomorphology, Land use /Land cover, Lineament, Stream junction
NDVI	Soil, Land use/Land cover.	Lineament, Geology, Geomorphology, Slope, Drainage, Stream junction
Stream junction	Drainage, Slope, Geomorphology, Geology, Lineament	Land use/Land cover, Soil, NDVI

Vegetation is a very decisive parameter in groundwater potential analysis (Ilstedt et al., 2016). As the area was extensive NDVI was the best method to get a picture of vegetation covered areas and is created using Landsat 8 satellite imagery of the region. NDVI is categorised into 5 by the intensity of vegetation: Very low (<0.05), Low (0.05 – 0.1), Medium (0.1 – 0.2), High (0.2 – 0.3), Very high (>0.3). Most of the watershed area is having High NDVI followed by medium and very high. Very low NDVI is found mainly in the western regions of the watershed (Figure 11). The areas with higher NDVI are given higher weights in groundwater potential analysis.

3. RESULTS AND DISCUSSIONS

Weightage calculation of parameters

To calculate the groundwater potential in Perumba watershed, Multi Influencing Factor (MIF) techniques are adopted. All factors namely lineament density, drainage density, soils texture, land use land cover, slope, geology, NDVI, stream junction and geomorphology are mainly interdependent. This technique emphasizes the fact that each parameter is interdependent in one way or the other and considers this interdependence for the analysis of groundwater potential.

The interrelationship between one factor with other remaining factors is explained in

Table 1. The effect of each major and minor factor is assigned a weightage of 1.0 and 0.5 respectively. The cumulative weightage of both major and minor effects is considered for calculating the relative rates. This rate is further used to calculate the score of each influencing factor is calculated by using the given below formula.

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

Where,

- A refers to the number of major multi influencing factors for each parameter.
- B refers to the number of minor multi influencing factors for each parameter.

Each factor was carefully examined and assigned an appropriate weight. These weighted factors may contribute to delineate the groundwater potential zones. Each influencing factors have major and minor effects (Table 2).

The groundwater prospect map of Perumba watershed is derived through the investigation of hydrologic factors (geomorphology, geology, soil, lineament, slope, land use / land cover, NDVI, stream junction and drainage density). Using raster calculator in spatial analysis module of ArcGIS, all the hydrologic factors added one over the other and there from final integrated groundwater prospect map is evolved. Before being added using raster calculator feature all those parameters were converted into raster files and were assigned weight accordingly.

Software used a technique called weighted overlay by calculating the weight differences between each parameter and superimposed the layers accordingly resulting in a groundwater potential map.

The resultant map was divided into 5 groundwater potential zones (Table 4):

- Very low potential
- Low potential
- Medium potential
- High potential
- Very high potential

The above said zones are indicators to the potential of groundwater in those zones. Very high potential refers to the best groundwater potential zones in the watershed region while the low and very low are poorest and are usually the problem regions especially in summer season.

Most of the watershed falls under the moderate groundwater potential accounting for 59.75% of the total area spread across the eastern regions (predominantly high land and mid-land regions) and the western coastal followed by high potential (22.10%) concentrated in the western regions of the watershed. The highest groundwater potential of the region (Very High) is found on the western most regions of the study area

Table 2. Effect of Influencing Factor, Relative Rates and Score for Each Potential Factor

Factor	Major (A)	Minor (B)	Proposed relative rates (A+B)	Proposed score for each influencing factor
Lineament	1+1+1	0.5+0.5+0.5+0.5+0.5	5.5	10
Geomorphology	1+1+1+1+1	0.5+0.5+0.5	6.5	12
Geology	1+1+1+1	0.5+0.5+0.5+0.5	6	12
Slope	1+1+1	0.5+0.5+0.5+0.5+0.5	5.5	10
Drainage Density	1+1+1+1+1	0.5+0.5+0.5	6.5	12
Land use /Land cover	1+1+1	0.5+0.5+0.5+0.5+0.5	5.5	10
Soil texture	1+1+1+1	0.5+0.5+0.5+0.5	6	12
Stream junction	1+1+1+1+1	0.5+0.5+0.5	6.5	12
NDVI	1+1	0.5+0.5+0.5+0.5+0.5+0.5	5	10
Total			53	100

Table 3. Classification of Weighted Factors Influencing the Potential Zones

Hydrological Parameters	Features	Groundwater Potential	Weightage
Drainage Density	Very Low	Very low	12
	Low	Low	8
	Medium	Moderate	6
	High	High	4
	Very High	Very high	1
Lineament Density	Very Low	Very Low	1
	Low	Low	4
	Medium	Moderate	6
	High	High	8
	Very High	Very high	10
Geology	Igneous rocks	Very low	1
	Migmatite complex	Low	3
	Charnockite group	Moderate	4
	Peninsular gneissic complex	Moderate	6
	Laterite	High	9
	Sand and silt	Very high	12
Geomorphology	Residual Hill	Very low	1
	Plateau	Low	4
	Pediplain	Moderate	6
	Coastal Plain	High	9
	Water body	Very High	12
Slope	Very Low	Very Low	10
	Low	Low	8
	Medium	Moderate	6
	High	High	3
	Very High	Very High	1
LU/LC	Barren rocky stony waste	Very Low	1
	Built up	Low	3
	Fallow	Moderately low	4
	Scrub land	Moderately high	5
	Plantation	Moderate	6
	Crop land	Moderate	7
	Sandy area	High	9
	River/stream	Very high	10
Soil	Gravelly Loam	Very Low	1
	Gravelly clay	Low	4
	Sandy	High	8
	Water body	Very high	12
NDVI	Very low	Very low	1
	Low	Low	4
	Medium	Moderate	6
	High	High	8
	Very high	Very high	10
Stream junction	Area without stream junction	Very low	6
	Stream junction buffer	Very high	12

Table 4. Effect of Influencing Factor, Relative Rates and Score for Each Potential Factor

Groundwater potential zone	Area covered (in Km^2)	Percentage
Very low potential	1.05	0.31
Low potential	50.6	15.08
Medium potential	207.58	59.75
High potential	74.12	22.10
Very high potential	9.25	2.76
TOTAL	342.6	100

in patches. Even though the general trend in groundwater potential is favourable for the region, regions of higher population density like Payyannur municipality in the western region of watershed and Ezhimala hill region and populated parts of the highlands in the east falls in low (15.05%) or very low (0.31%) groundwater potential (Figure 12).

4. Discussion

Due to lower built up and favourable physiographic features the groundwater potential scenario is generally good, but the problem is that the regions with larger population settlements such as Payyannur municipality in the west, regions of Kadannapalli-Panappuzha panchayath in east, Pariyaram and Pilathara in central southern part of the watershed falls under low to very low groundwater potential regions. This could be managed by effective water conservation measures and water could be harnessed from regions of higher potential. Geospatial technology has a wide spectrum of application in hydrological studies which is otherwise difficult to observe, MIF techniques can be applied in GIS platform to derive data on groundwater in map format. Resultant maps such as this groundwater potential map could be used as a base map for further groundwater related studies. As most countries in the tropics depend on agriculture, water is not only a daily need but also an economic need, identification of potential zones serves as the first step in management of groundwater resources. MIF and Geospatial technology aids in the visualization of these resources which in turn helps in taking informed decisions. This method in assessing groundwater potential of a region is very effective in tropical regions, especially regions with data scarcity. This approach can be used as a primary study to be based upon for further detailed investigations and ground studies for planning and management purposes.

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5. ReferencesS

Akhil, R., Prasad, T. K., & Vineethkumar, V. (2022). Analyzing the significance of morphometric parameters in runoff efficiency: A case study in Valakkayi Tode tropical watershed, Valapattanam River, Kerala, India. Journal of Sedimentary Environments, 7(1), 67–78. https://doi.org/10.1007/s43217-021-00083-2

Al-Nahmi, F., Alami, O. B., Baidder, L., Khanbari, K., Rhinane, H., & Hilali, A. (2016). Using remote sensing for lineament extraction in Al Maghrabah area - Hajjah, Yemen. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2-W1, 137–142. https://doi.org/10.5194/isprs-archives-XLII-2-W1-137-2016

Balasubramanian, A. (2007). Methods of Groundwater Exploration., Centre for Advanced Studies in Earth Science, University of Mysore.

Black, P. E. (1996). Watershed Hydrology, Second Edition. CRC Press.

CGWB. (2020). Ground Water Information Booklet of Kannur District.

Darnault, C. J. G. (2008). Overexploitation and Contamination of Shared Groundwater Resources: Management, (Bio)Technological, and Political Approaches to Avoid Conflicts. Springer Science & Business Media.

Dinesan, V. P., Gopinath, G., & Ashitha, M. K. (2015). Application of Geoinformatics for the Delineation of Groundwater Prospects Zones-A Case Study for Melattur Grama Panchayat in Kerala, India. Aquatic Procedia, 4, 1389–1396. https://doi.org/10.1016/j.aqpro.2015.02.180

Dinesh Kumar, P. K., Gopinath, G., & Seralathan, P. (2007). Application of remote sensing and GIS for the demarcation of groundwater potential zones of a river basin in Kerala, southwest coast of India. International Journal of Remote Sensing, 28(24), 5583–5601. https://doi.org/10.1080/01431160601086050

Dragičević, N., Karleuša, B., & Ožanić, N. (2019). Different Approaches to Estimation of Drainage Density and Their Effect on the Erosion Potential Method. Water, 11(3), Article 3. https://doi.org/10.3390/w11030593

Earle, S., & Earle, S. (2015). 14.1 Groundwater and Aquifers. https://opentextbc.ca/geology/chapter/14-1-groundwater-and-aquifers/

Gosain, A., & Rao, S. (2004). GIS-based technologies for watershed management. Current Science, 87.

Hasanuzzaman, M., Mandal, M. H., Hasnine, M., & Shit, P. K. (2022). Groundwater potential mapping using multi-criteria decision, bivariate statistic and machine learning algorithms: Evidence from Chota Nagpur Plateau, India. Applied Water Science, 12(4), 58. https://doi.org/10.1007/s13201-022-01584-9

Horton, R. E. (1932). Drainage-basin characteristics. Transactions, American Geophysical Union, 13(1), 350. https://doi.org/10.1029/TR013i001p00350

Ilstedt, U., Bargués Tobella, A., Bazié, H. R., Bayala, J., Verbeeten, E., Nyberg, G., Sanou, J., Benegas, L., Murdiyarso, D., Laudon, H., Sheil, D., & Malmer, A. (2016). Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics. Scientific Reports, 6(1), Article 1. https://doi.org/10.1038/srep21930

Langsholt, E. (1992). A water balance study in lateritic terrain. Hydrological Processes, 6(1), 11–27. https://doi.org/10.1002/hyp.3360060103

Letz, O., Siebner, H., Avrahamov, N., Egozi, R., Eshel, G., & Dahan, O. (2021). The impact of geomorphology on groundwater recharge in a semi-arid mountainous area. Journal of Hydrology, 603, 127029. https://doi.org/10.1016/j.jhydrol.2021.127029

Magesh, N. S., Chandrasekar, N., & Soundranayagam, J. P. (2012). Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geoscience Frontiers, 3(2), 189–196. https://doi.org/10.1016/j.gsf.2011.10.007

Murmu, P., Kumar, M., Lal, D., Sonker, I., & Singh, S. K. (2019). Delineation of groundwater potential zones using geospatial techniques and analytical hierarchy process in Dumka district, Jharkhand, India. Groundwater for Sustainable Development, 9, 100239. https://doi.org/10.1016/j.gsd.2019.100239

Mwangi, H. M., Julich, S., & Feger, K.-H. (2016). Watershed Management Practices in the Tropics. In L. Pancel & M. Köhl (Eds.), Tropical Forestry Handbook (pp. 1897–1915). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-54601-3_155

Nair, H. C., Padmalal, D., Joseph, A., & Vinod, P. G. (2017). Delineation of Groundwater Potential Zones in River Basins Using Geospatial Tools—An Example from Southern Western Ghats, Kerala, India. Journal of Geovisualization and Spatial Analysis, 1(1–2), 5. https://doi.org/10.1007/s41651-017-0003-5

Pande, C. B., Moharir, K. N., Panneerselvam, B., Singh, S. K., Elbeltagi, A., Pham, Q. B., Varade, A. M., & Rajesh, J. (2021). Delineation of groundwater potential zones for sustainable development and planning using analytical hierarchy process (AHP), and MIF techniques. Applied Water Science, 11(12), 186. https://doi.org/10.1007/s13201-021-01522-1

Pereira, C. (n.d.). Management of Tropical watersheds. Retrieved October 3, 2023, from https://www.fao.org/3/ad085e/AD085e05.htm

Prasad, T. K. (2018). Landscape of Kannur: A geomorphological appraisal. Impact: IJRHAL, 6(7), 355–370.

Preeja K. R., Joseph, S., Thomas, J., & Vijith H. (2011). Identification of Groundwater Potential Zones of a Tropical River Basin (Kerala, India) Using Remote Sensing and GIS Techniques. Journal of the Indian Society of Remote Sensing, 39(1), 83–94. https://doi.org/10.1007/s12524-011-0075-5

Siddi Raju, R., Sudarsana Raju, G., & Rajasekhar, M. (2019). Identification of groundwater potential zones in Mandavi River basin, Andhra Pradesh, India using remote sensing, GIS and MIF techniques. HydroResearch, 2, 1–11. https://doi.org/10.1016/j.hydres.2019.09.001

Suresh, S., Mani, K., & S, R. (2014). Multi Influencing Factor Technique for Identifying Groundwater Vulnerable Zone in Pambar River Basin, Devikulam Taluk Using Geospatial Technology. Disaster, Risk, and Vulnerability Conference, Thiruvananthapuram.

Suresh, S., Selvaraj, R., & Mani, K. (2019). Delineation of groundwater potential zones in Devikulam taluk, Idukki district, Kerala, using remote sensing, GIS and MIF techniques. 13, 159–168.

Thomas, B. C., Kuriakose, S. L., & Jayadev, S. K. (2009). A method for groundwater prospect zonation in data poor areas using remote sensing and GIS: A case study in Kalikavu Panchayath of Malappuram district, Kerala, India. International Journal of Digital Earth, 2(2), 155–170. https://doi.org/10.1080/17538940902767393

USGS. (n.d.). Ground Water Development, Sustaninability, and Water Budgets. Retrieved October 3, 2023, from https://pubs.usgs.gov/circ/circ1186/html/gw_dev.html

Vijith, H. (2007). Groundwater potential in the hard rock terrain of western ghats: A case study from Kottayam district, Kerala using resourcesat (IRS-P6) data and GIS techniques. Journal of the Indian Society of Remote Sensing, 35(2), 163–171. https://doi.org/10.1007/BF02990780