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# Delineation of Groundwater Potential Zones in River Basins Using Geospatial Tools—an Example from Southern Western Ghats, Kerala, India

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**Abstract** The remote sensing and geospatial tools have wide applications in water resource assessment studies. Satellite images are increasingly being used in groundwater exploration because of their utility in identifying various geomorphic features. The present study has been carried out in two important river basins—the Ithikkara and the Kallada river basins, of Southern Western Ghats, Kerala, India. The groundwater potential zones are delineated from 14 thematic layers such as drainage density, geomorphology, slope, lithology, soil, land use/land cover, lineament density, topographic wetness index, rainfall distribution, roughness, curvature, dissection index, depth to water level and topographic position index using multi-criteria evaluation method. Integration of the factors has been performed in GIS platform using weighted overlay analysis. Different classes of thematic maps have been assigned weights based on influence on groundwater hydrology (through discussions with the experts in the field), and finally, factor ranks are assigned. The final map indicates the potentiality values of groundwater occurrence in the study area, which was classified into three categories—high, moderate and low. A total of 37.2% of the study area fall in low groundwater potential zone, 42.3% in moderate potential zone and 20.5% of the area in high potential zone. The groundwater potential zones delineated using the method are validated with data of springs and dug wells from field investigations, and it was found that the overlay method using GIS and remote sensing gives 95% accuracy.

## Introduction

The knowledge of groundwater potential zones is very essential for the wise use and management of water resources, especially when groundwater forms the main source for supply of water. The remote sensing data can provide useful information on the factors governing the potential and movement of groundwater. A systematic study of the different geo-environmental features could help in better delineation of groundwater sources in any region. Besides, identification of linear features, certain geomorphic units, soil moisture zones and topographic and vegetation indicators help in selecting potential areas for groundwater exploration.

A groundwater model using GIS has many advantages over traditional methods. The most important benefit of using GIS is that everything is defined within spatial context. The distribution of precipitation, surface water bodies, groundwater recharge zone, water table depth, groundwater yield data, etc., can be depicted on a single map. The relationship between these components is easily determined because geographical information system is essentially a database that can combine this information in an infinite number of ways. GIS is one of the advanced information system which can be used for scientific investigations, research and development. The use of different tools and modules such as ArcGIS with other software package will facilitate easy analysis which would have

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been otherwise tedious and time consuming. Frequency ratio model, Shannon's entropy model, multi-criteria decision making model, decision tree algorithms, weights-of-evidence (WOE) model and evidential belief function (EBF) models are some of the procedures applied for aquifer mapping (Naghibi et al. 2014; Duan et al. 2016; Guru et al. 2016; Nejad et al. 2016).

Water is one of the very precious natural resources of earth and is the primary source of life that sustains all human activities. It is essential not only for the sustenance of human life but also for the economic and social progress of a region. Due to scarcity of good quality surface water and growing need of water for domestic, agricultural and industrial uses, the demand for groundwater has increased over years. Hence, groundwater studies have become crucial not only for finding groundwater potential zones but also for monitoring and conserving this vital resource. Delineation of groundwater potential zones in different parts of India using various thematic maps has been done by many researchers (Magesh et al. 2012; Nag and Ghosh 2012; Waikar and Aditya 2014; Deepa et al. 2016). A cursory glance of literature reveals that a few studies are carried out in southwest India to delineate the groundwater potential zone in some of the river basins (Preeja et al. 2011; Ali et al. 2015; Jesiya and Gopinath 2015; Dinesan et al. 2015).

In the present study, the integration of remote sensing with GIS for preparing 14 thematic layers in a spatial province have been attempted for classification of potential groundwater zones in two important river basins—the Ithikkara and Kallada river basins—of Southern Western Ghats in Kerala State. The results will be useful not only in planning, operation, supervision and management of groundwater resources in the region subjected to the present study but also will be useful in regions having similar geo-environmental settings of the tropics and subtropics.

## Study Area

The study area—Ithikkara and Kallada river basin—lies between north latitudes 8° 45′–9° 15′ and east longitudes 76° 30′–77° 15′ (Fig. 1). The area is bounded by Tirunelveli district of Tamil Nadu in the east, Lakshadweep Sea in the west, Alappuzha and Pathanamthitta districts in the north and Thiruvananthapuram district in the south. The maximum distances between north and south and east and west are 38.7 and 77.3 km, respectively. The area has a coastline of about 37 km. About 20% of the total area chosen for the present study belong to the lowland–coastal plains, 63% belong to midland and rest belong to highland mountainous areas. In addition to the surface water sources, a considerable section of the people in the area also depends on well and springwater sources for their freshwater requirements. Groundwater of the study area

occurs in the porous granular formations (aquifers) such as alluvium, laterite, the Tertiary sediments and weathered and decomposed crystalline rocks as well as in the fissures, joints and fractures in the fresh crystalline rocks. The groundwater in the study area is mostly extracted through dug wells that are depended for domestic and agricultural purposes and to a lesser extent for industrial and irrigation purposes. According to CGWB (2013), the major groundwater problems and issues of the study area are (i) saline water ingression observed in the shallow alluvial aquifer in the western part of the district which is in hydraulic connection with the back water, (ii) acute water scarcity seen along the eastern hilly areas and also along Laterite hillocks and (iii) water logging along the western border of the district bordering the back water lagoons during the rainy season.

## Materials and Methods

The details of the materials and data sources for thematic layer preparation are Survey of India Toposheets for delineation of streams, Shuttle Radar Topographic Mission (SRTM) 30-m resolution data source (for digital elevation model, slope, topographic position index, topographic wetness index, roughness, curvature and dissection index), LISS III image (for geomorphology, land use/land cover and lineament), Geological Survey of India map (for geology), NBSS and LUP soil map (for soil) and Central Ground Water Board (for water level). ArcGIS 10.1 and ERDAS 9.2 software were used for performing GIS and remote sensing applications. Drainage density and lineament density were prepared using the line density function of spatial analyst extension in GIS platform. Inverse distance weighted (IDW) interpolation technique was used for spatial modelling of groundwater level data. In IDW interpolation method, it is assumed that things that are close to one another are more alike than those are farther apart (Burrough and McDonnell 1998).

Geomorphometry and Gradient Metrics Toolbox which is an ArcGIS Toolbox for Surface Gradient and Geomorphometric Modelling developed by Evans et al. (2014) is used for deriving dissection index, roughness and topographic wetness index. The topographic position index is derived based on Jenness algorithm (Jenness 2006). Curvature is derived using DEM Surface tools developed by Jenness (2013).

The thematic maps of all the layers were prepared using natural breaks (Jenks) classification method and then by assigning weights for each class in GIS platform. After plotting the maps, the rank of each factor was given on the basis of its significance in groundwater potentiality. The groundwater potential zones were obtained by integrating all the thematic maps in a linear combination model using the Raster Calculator tool in spatial analyst extension of GIS software. Weighted overlay analysis is one method of modelling
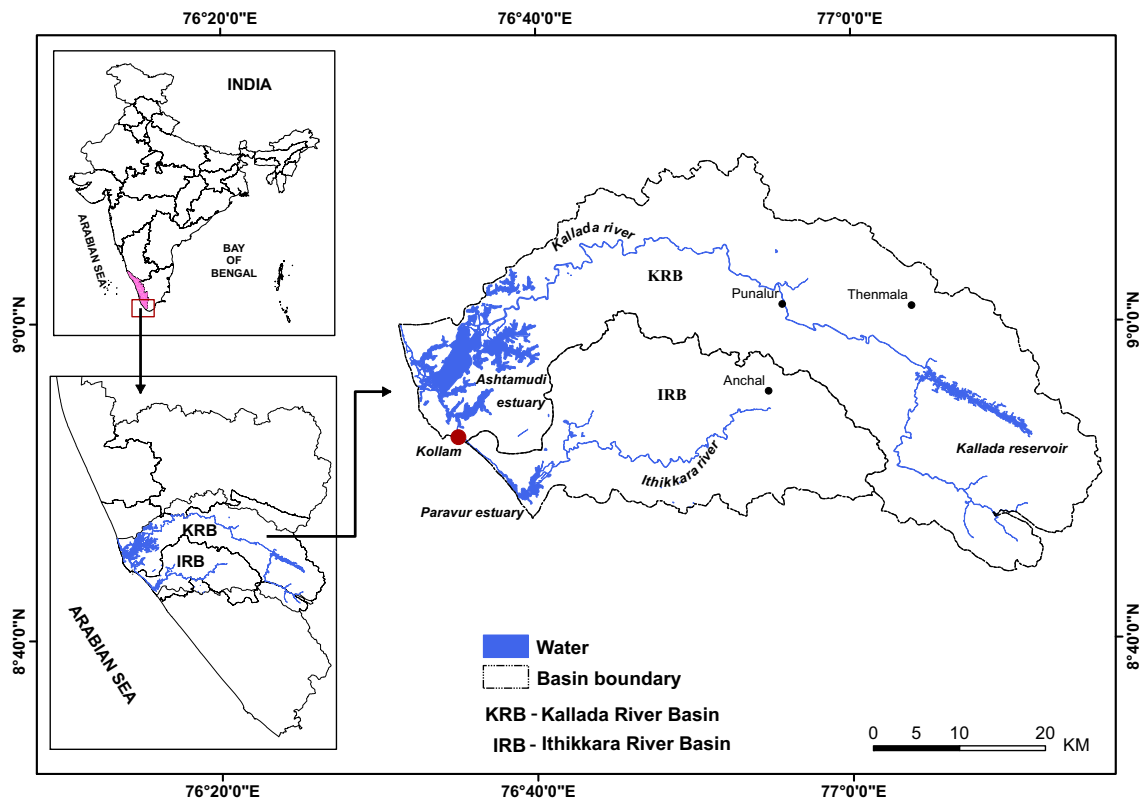
**Fig. 1** Location map of the Ithikkara (IRB) and Kallada (KRB) river basins selected for the present study

suitability. Each thematic layer which will be in a raster layer is assigned a weight depending upon their influence in groundwater potentiality. Values in the raster are then reclassified to a common suitability scale. Raster layers are overlayed, multiplying each raster cell's suitability value by its layer weight and totalling the values to derive a best suitable value. These values are written to new cells in an output layer. The symbology in the output layer is based on these values. Figure 2 depicts the methodology flowchart that is followed in delineating the groundwater potential zones. Validation of the groundwater potential zone with field was done by ground truthing. The GPS (Gramin eTrex 20) was used to locate high-yield wells and springs of the study area. These locations were overlaid onto the groundwater potential zone map for validating the results.

## Results and Discussion

### Geomorphology

Groundwater and geomorphology have much to offer each other in several fields such as river-groundwater interactions, location and evolution of aquifers and landform evolution (Brown 1995). Thomas et al. (2009) reported that geomorphology has a dominant role in the movement and storage of

groundwater in an area. The relief, slope, depth of weathering, type of weathered material, thickness of alluvium, nature of the deposited material and the overall grouping of different landforms play an important role in defining the groundwater regime, especially in the hard rock terrain (Reddy et al. 2000). The geomorphology of the study area includes coastal plain, floodplain, pediplain, denudational hills, denudational structural hills, piedmont zone, plateau and residual hill (Hema et al. 2015). More promising groundwater can be seen in floodplains, alluvial fans, sand bars, etc., that are linked with thick alluvial and weathered materials to give high porosity and permeability. Hills, ridges, etc., are generally not favourable for groundwater storage.

### Slope

The slope of a topographic landform refers to the amount of inclination of that surface to horizontal. Topography relates to the local and regional relief and gives an idea about the general direction of groundwater flow and also its influence on groundwater recharge (Gupta and Srivastava 2010). Slope plays significant role in infiltration. Infiltration is inversely related to slope; i.e. the more gentle the slope is, infiltration would be more and runoff would be less and vice versa (Rais and Javed 2014). Digital elevation model (SRTM) at 30-m resolution (Fig. 3) is used for generating slope map of the
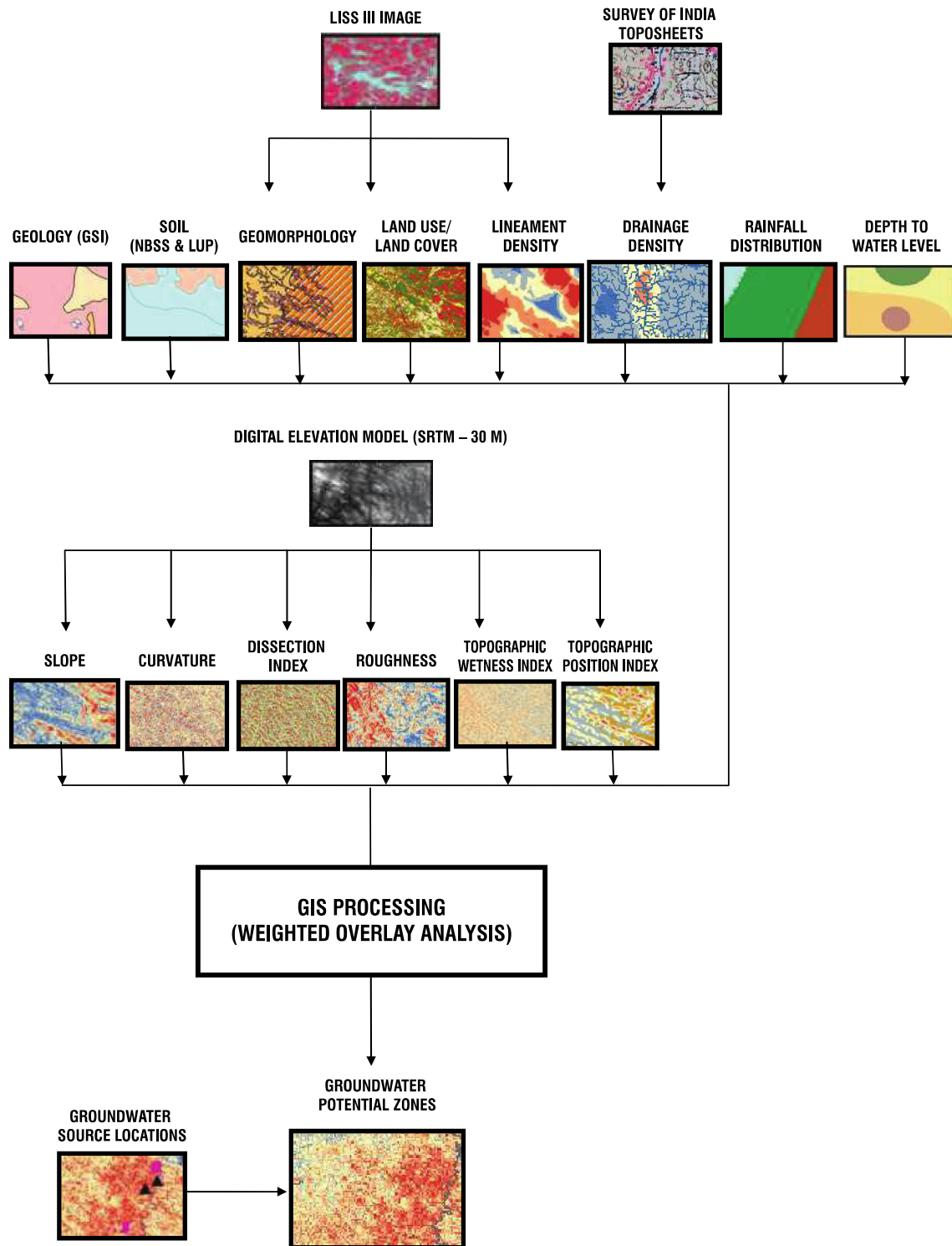
**Fig. 2** Methodology flowchart used in determination of groundwater potential zones

region. Slope map is categorised into five classes (in degrees), i.e. 0–5.35, 5.35–10.94, 10.94–18.05, 18.05–27.14 and 27.14–67.43 (Fig. 4). Classes having less value are assigned higher rank due to almost flat topography, whilst the class having utmost value is characterised as lower rank due to relatively high runoff.

## Lithology

One of the most important requirements for groundwater occurrence and flow is that the geological horizon must be porous and permeable, so that it may store and permit easy movement of water. Geologically, area forms part of Pre-
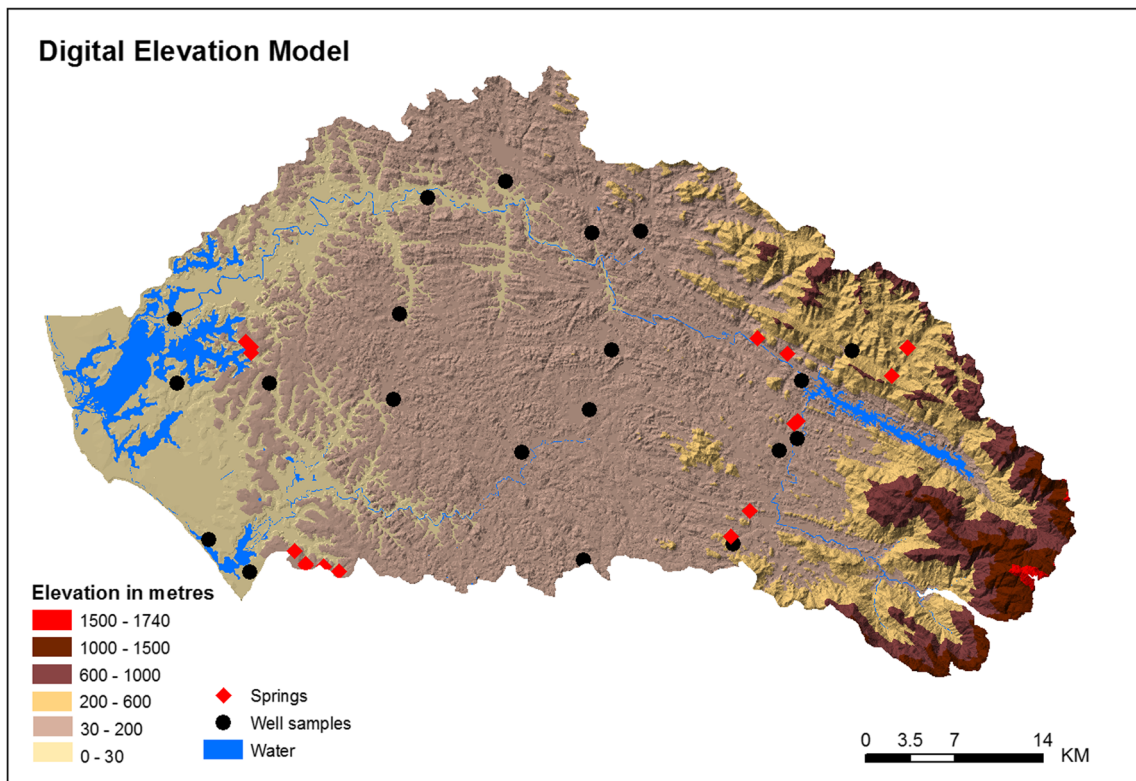
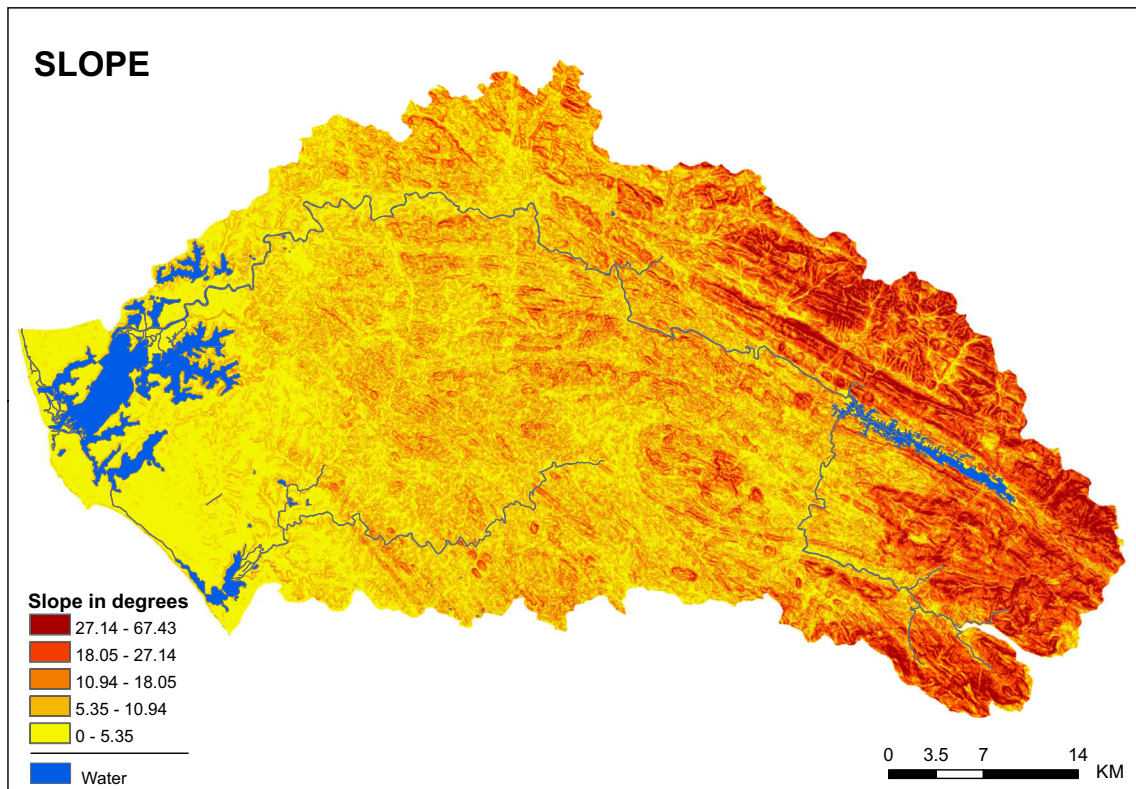**Fig. 3** Digital elevation model (DEM) of the Ithikkara and Kallada river basins



**Fig. 4** Map showing various slope categories in the Ithikkara and Kallada river basins
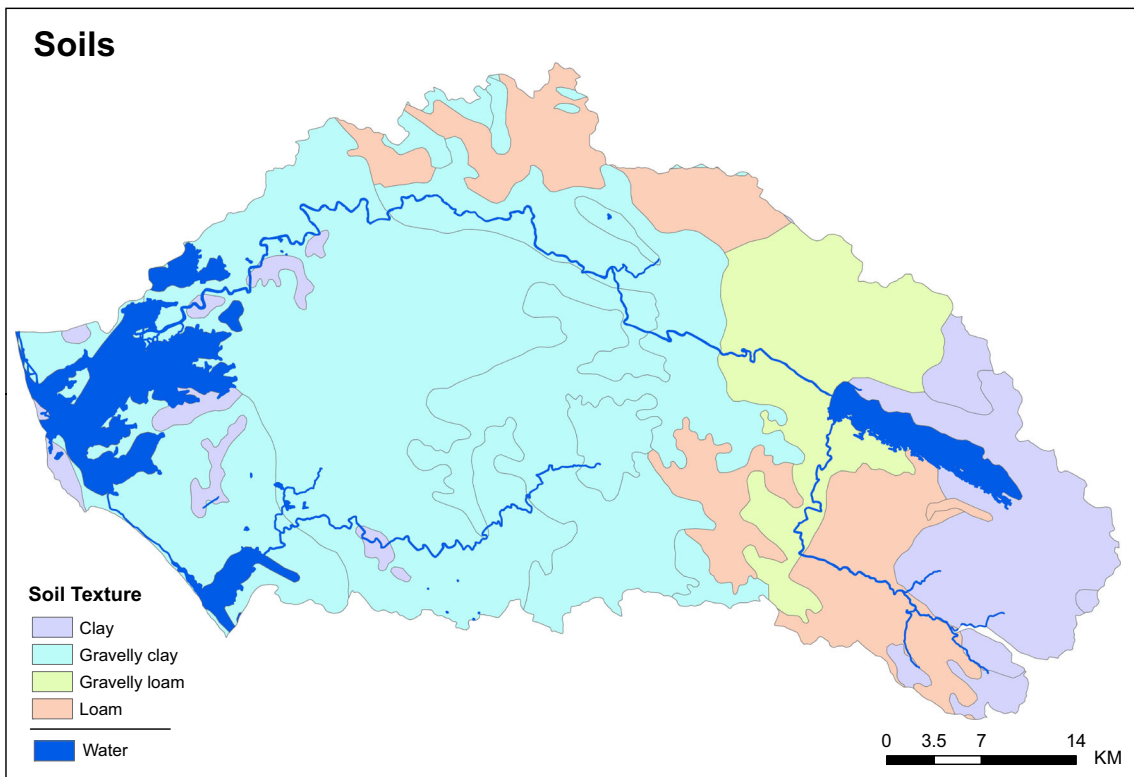
**Fig. 5** Map of the study area (Ithikkara and Kallada river basins) showing different soil categories. *Source*: NBSS and LUP (2005)
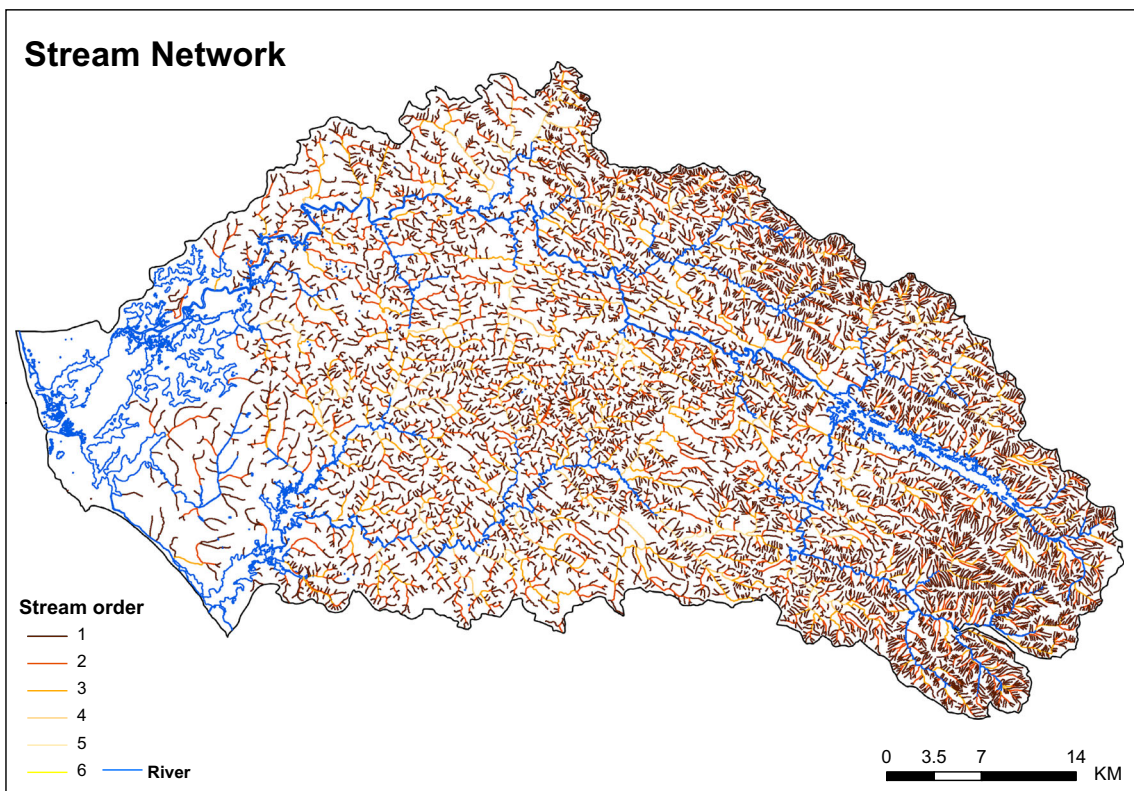


**Fig. 6** Stream network of the study area. Note the structurally controlled drainage characteristics in the uplands of Kallada river basin
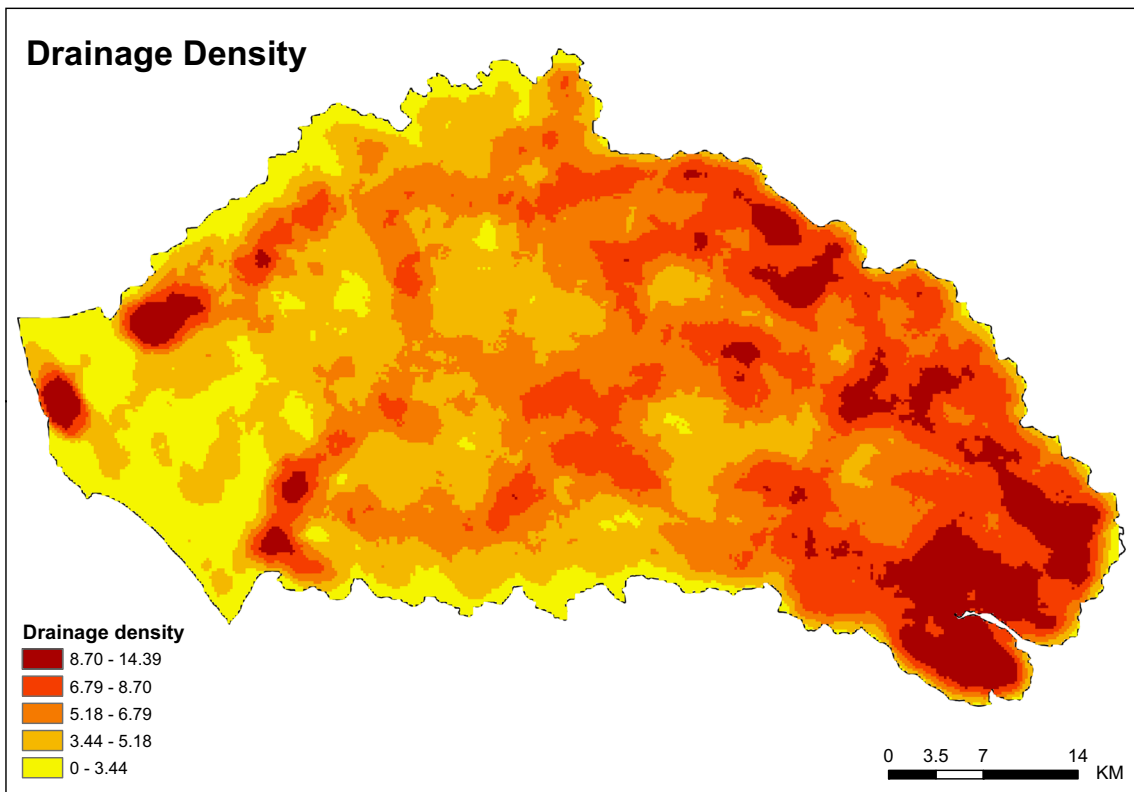
## Drainage Density

**Drainage density**
- 8.70 - 14.39
- 6.79 - 8.70
- 5.18 - 6.79
- 3.44 - 5.18
- 0 - 3.44

0   3.5   7        14   KM

**Fig. 7** Map showing drainage density of the Ithikkara and Kallada river basins

## Landuse / Landcover

- Waterbody
- Forest
- Built up
- Plantation
- Mixed vegetation
- Agricultural field

0   3.5   7        14   KM
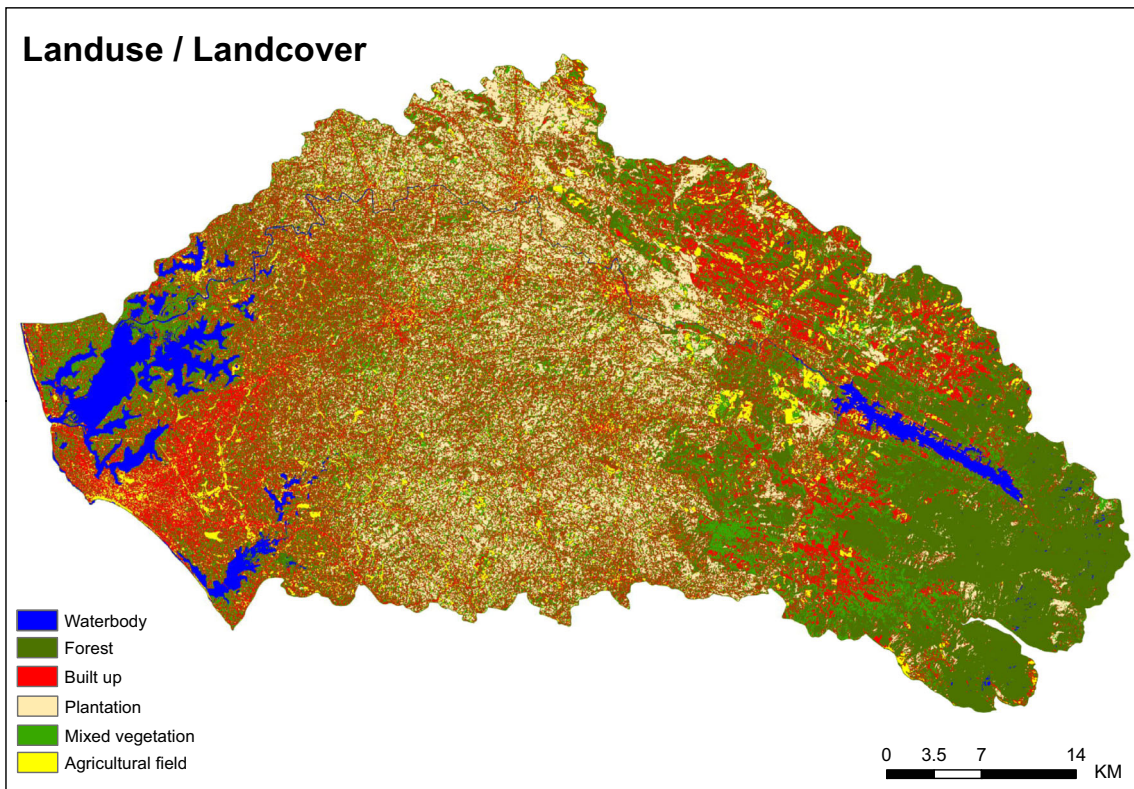
**Fig. 8** Map showing land use/land cover details of the Ithikkara and Kallada river basins

**Lineament Density**

Lineament density
- 1.99 - 4.08
- 1.24 - 1.99
- 0.69 - 1.24
- 0.26 - 0.69
- 0 - 0.26

0    3.5    7         14
                              KM
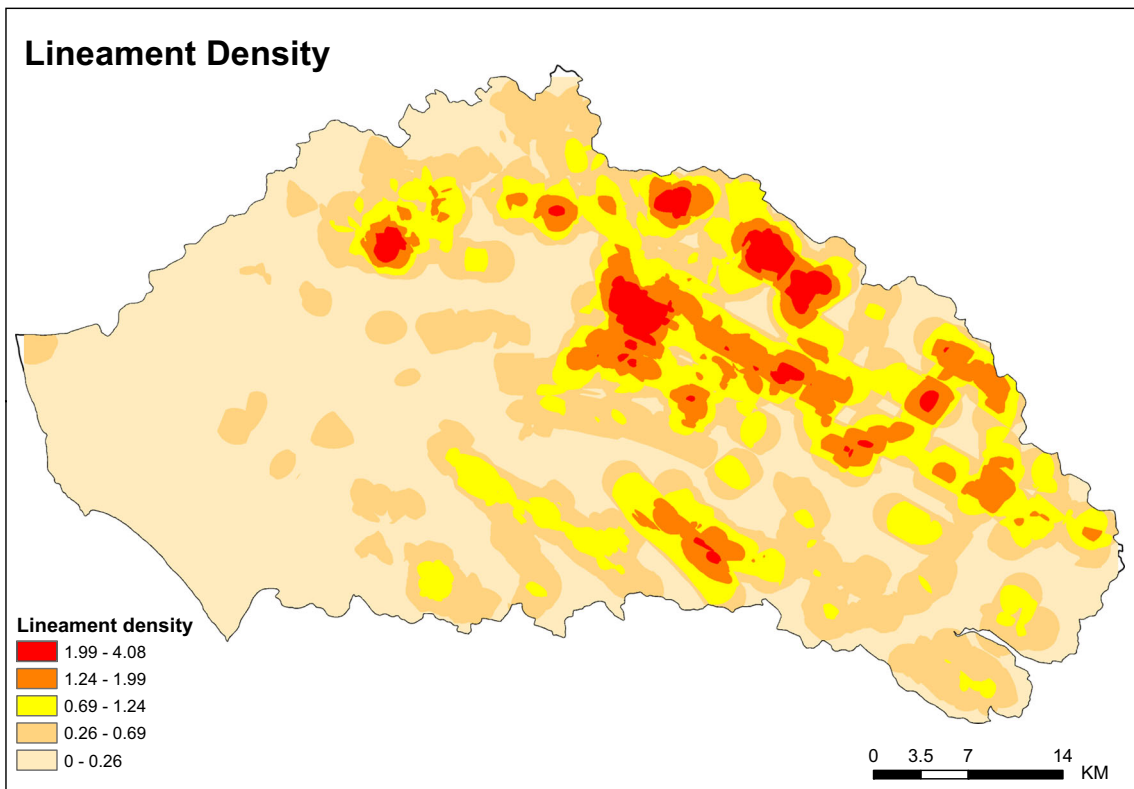
**Fig. 9**  Lineament density map of the Ithikkara and Kallada river basins

**Topographic Wetness Index**

TWI
- 11.56 - 21.17
- 8.85 - 11.56
- 7.05 - 8.85
- 5.76 - 7.05
- 2.52 - 5.76
- Water

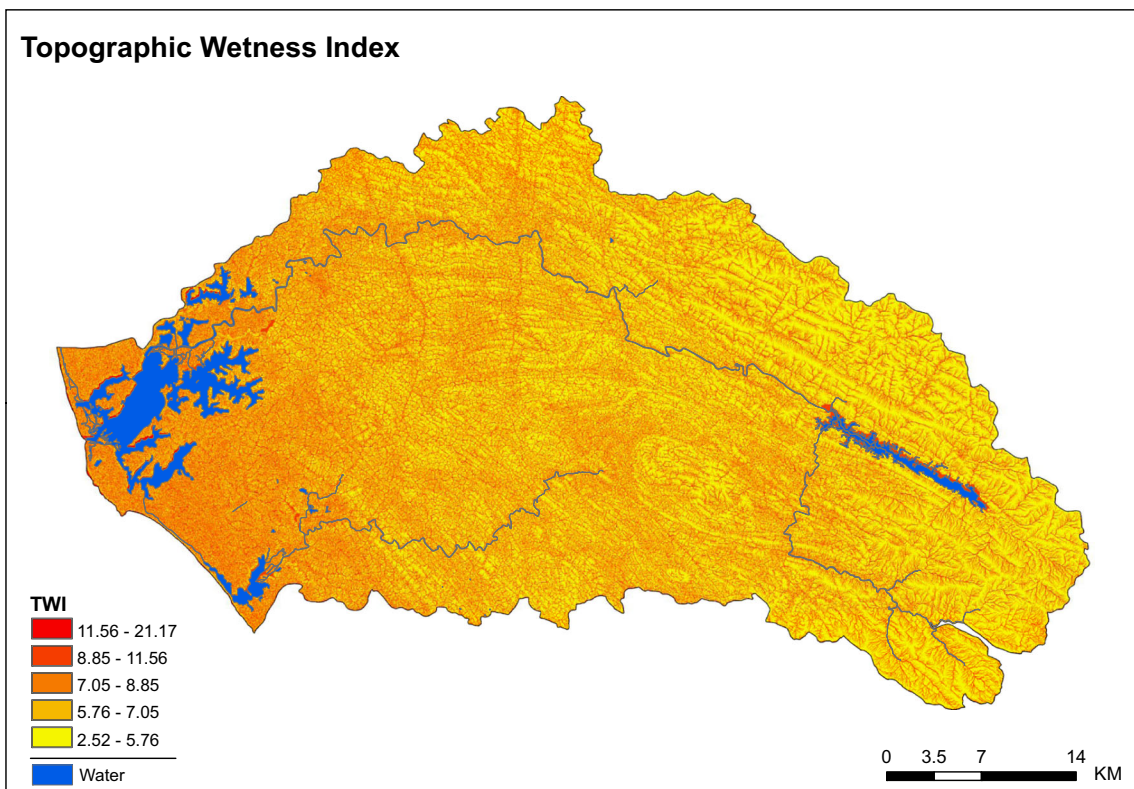0    3.5    7         14
                              KM

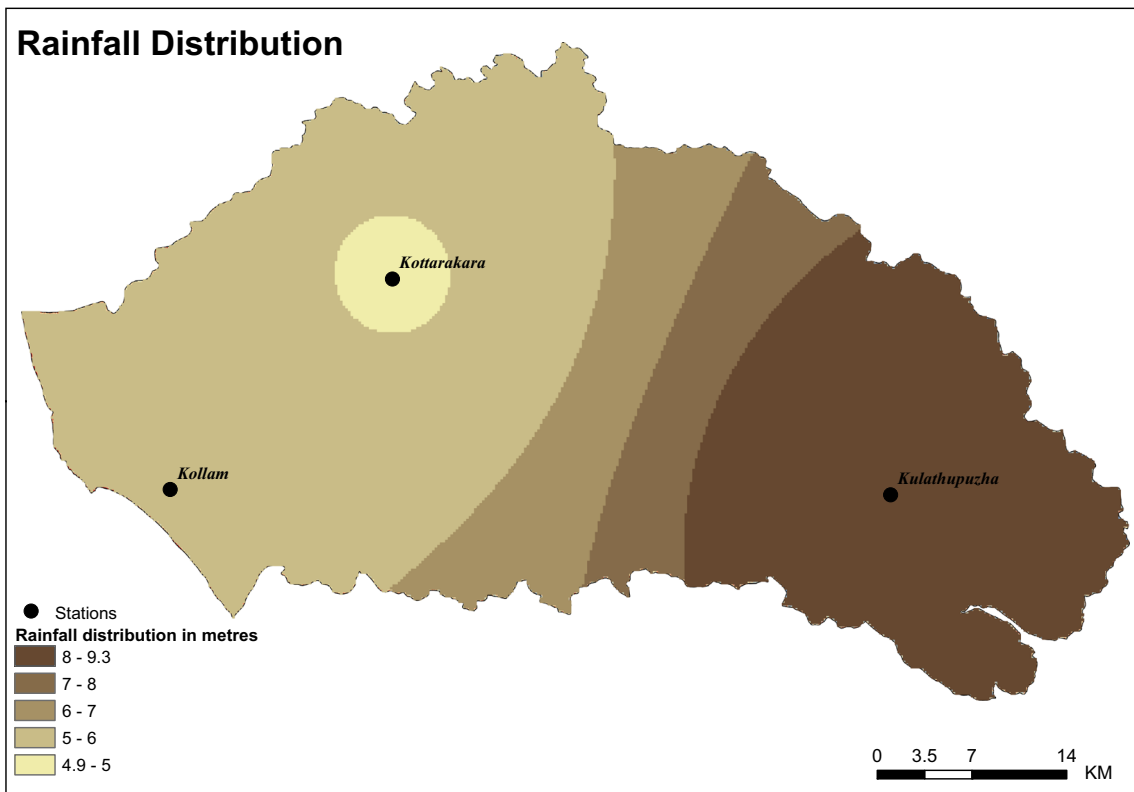**Fig. 10**  Map showing topographic wetness index of the Ithikkara and Kallada river basins

**Fig. 11** Rainfall distribution map prepared from the Kulathupuzha, Kottarakara and Kollam gauging stations of the study area
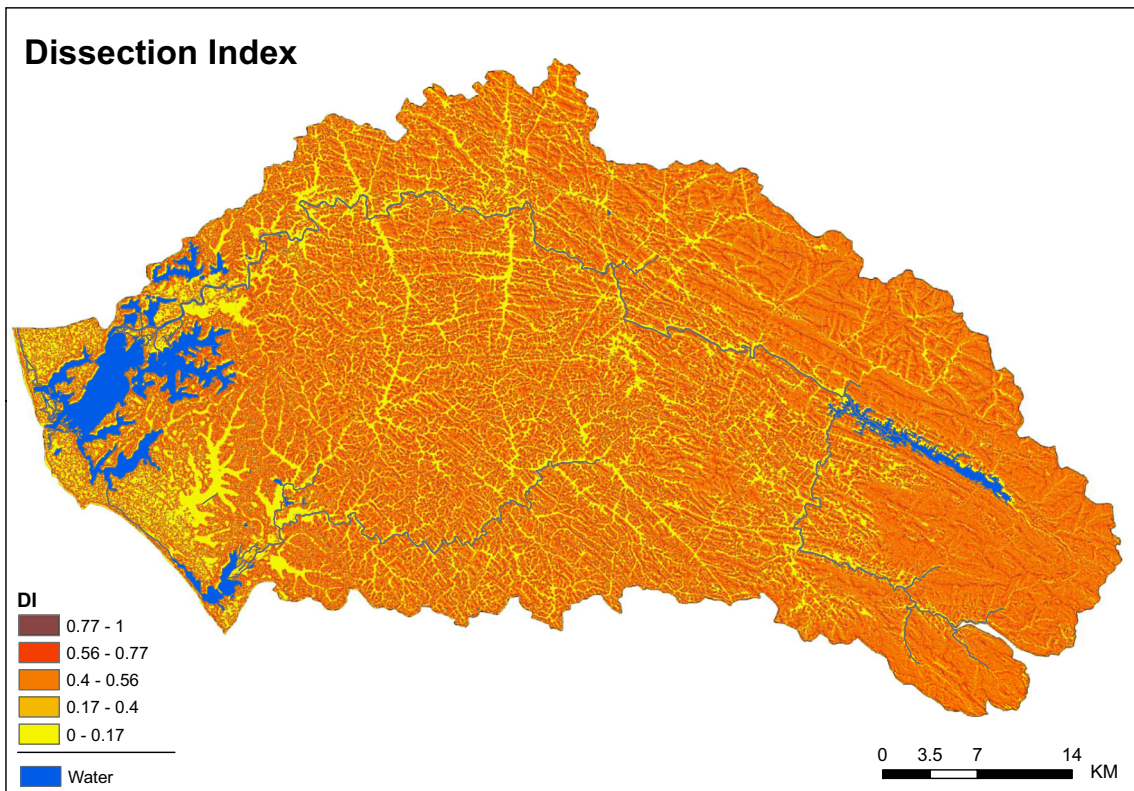


**Fig. 12** Map showing dissection index of the Ithikkara and Kallada river basins

**Roughness**

**Roughness**
- 3.11 - 7.63
- 2.24 - 3.11
- 1.53 - 2.24
- 0.61 - 1.53
- 0 - 0.61
- Water

0  3.5  7  14
KM
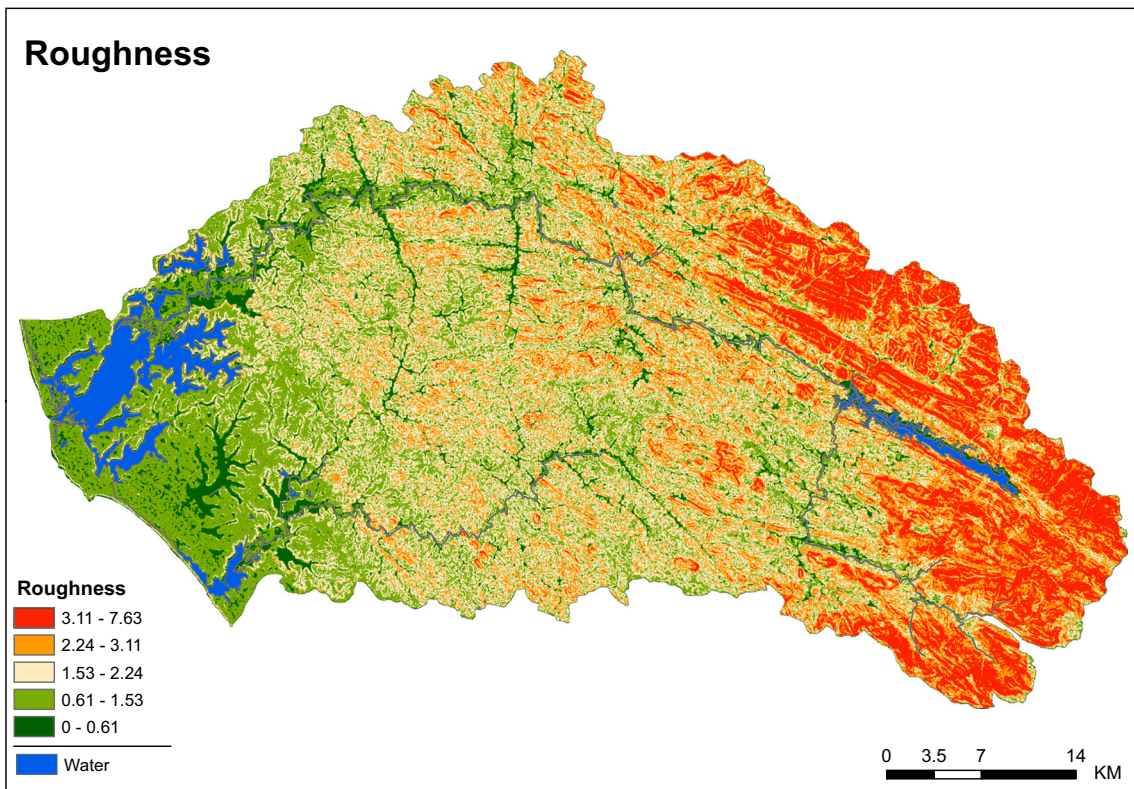
**Fig. 13** Map showing roughness of the Ithikkara and Kallada river basins

**Curvature**

**Curvature**
- 0.77 - 14.08
- 0.21 - 0.77
- -0.19 - 0.21
- -0.71 - -0.19
- -13.68 - -0.71
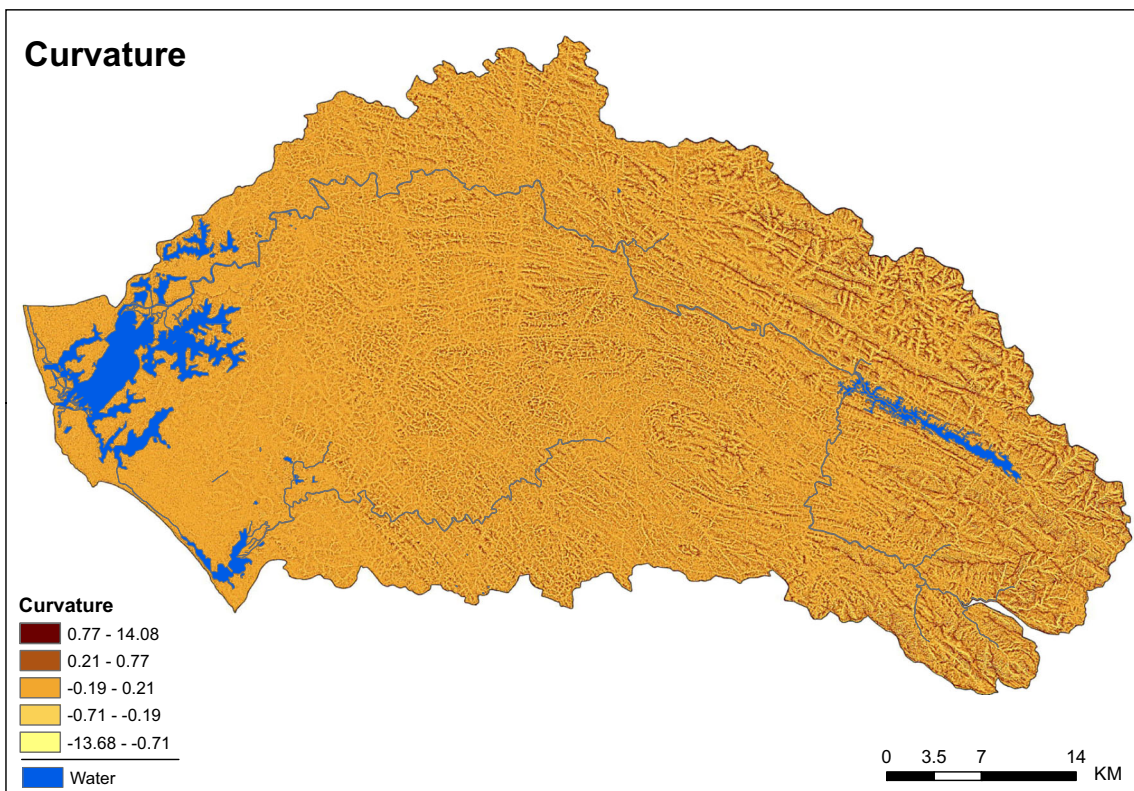- Water

0  3.5  7  14
KM

**Fig. 14** Map showing curvature categories of the Ithikkara and Kallada river basins

Cambrian crystalline rocks composed of mainly charnokite and khondalite, which have undergone weathering to form laterite at varying depths, and also, a part of the area is occupied by migmatite complex eg. Valley and low-lying areas are covered by fluvial sediments/materials like colluvium and alluvium composed of sand, silt and clays of varying proportions. Generally hard rocks are unable to hold or transmit water due to the absence of porosity unless otherwise traversed by intersecting features like fractures, joints or fault planes. The groundwater is occurring under water table condition in the pore spaces of the weathered material, viz., laterite. Therefore, the extent of laterite and its thickness is considered as one of the factors controlling groundwater under unconfined condition in a tropical crystalline terrain. The lithological unit, laterite, has been assigned a higher rank next to valley fill material which is composed of sandstone and clay (Hema et al. 2015).

### Soil

The soil (Fig. 5) of the study area exhibits four main textures, namely gravelly clay, clay, loam and gravelly loam. Weightage of soil has been assigned on the basis of their infiltration rate. Gravelly clay has high infiltration rate, hence given high priority, whilst the clayey soil has least infiltration rate, hence assigned low priority.

### Drainage Density

A drainage map (Fig. 6) of the area gives an idea about the permeability of rocks and also gives an indication of the yield of the basin (Wisler and Brater 1959). Drainage density is an inverse function of permeability, so it is an important parameter in evaluating the groundwater zone. High drainage density indicates less infiltration and hence acts as poor groundwater potential zone compared to low drainage density zones, implying an inverse relation between the two. Low network of drainage course indicates existence of highly resistant and permeable rock where as high drainage course indicates highly weak and impermeable rocks (Karanth 1999). For groundwater prospecting, higher rank was assigned to low drainage density zones and a lower rank was assigned to a high drainage density zones. The drainage density of entire study area varies from 3.44 to 14.39 km/km$^2$ (Fig. 7).

### Land Use/Land Cover

The land use/land cover (LULC) of the area (Fig. 8) provides important indications of the extent of groundwater requirement and utilisation. The synoptic viewing through remote sensing has provided the multi-spectral data, which has been utilised for classifying LULC (Sajjad et al. 2014). The major land use/land cover classes such as forest, plantation, barren land, agriculture and built-up were identified in the study area. From the point of view of land use, crop land with vegetation is an excellent site for groundwater exploration (Todd and Mays 2005). The area with water bodies is good for groundwater recharge and fallow land is poor for it (Chowdary et al. 2008). Basin area covered by forest, crop land and water bodies are favourable for groundwater storage and hence act as potential zones.

### Lineament Density

Lineaments are defined as naturally occurring linear or curvilinear features. Lineaments play an important role in groundwater recharge in hard rock terrains. These factors are hydrogeologically very important as they provide the pathways for groundwater movement. The groundwater potential is high near high-density lineament zones and vice versa (Srivastava and Bhattacharya 2006; Rashid et al. 2012). In hard rock terrains, lineaments represent areas and zones of faulting and fracturing, resulting in increased secondary porosity and permeability and are good indicators of groundwater potential (Kumar et al. 2007). Lineament density is the total length of all the lineaments present in the basin/watershed divided by the area of basin/watershed. The lineament density (Fig. 9) of the study area varies from 0.26 to 4.10.
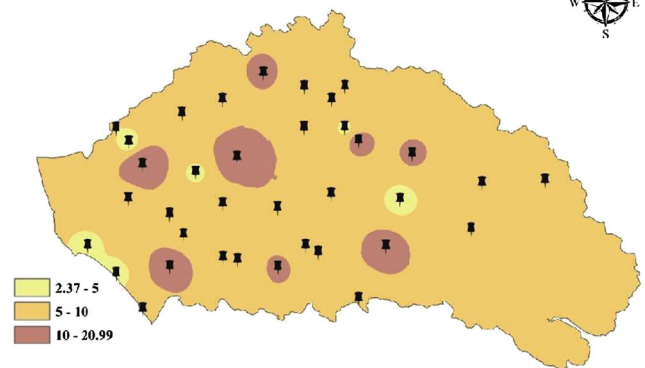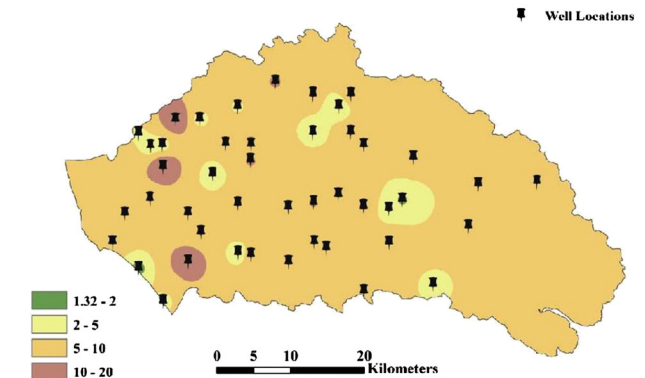


Fig. 15 Spatial distribution of groundwater levels during the period 2010–2015

## Topographic Wetness Index

The topographic wetness index (TWI) is commonly used to compute topographic control on hydrological processes and reflects the potential groundwater exfiltration caused by the effects of topography; thus, higher TWI value represented higher groundwater potential value. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. Its definition is as follows:

$$TWI = \ln{(\alpha)}/\tan{\beta}$$

where '$\alpha$' denotes the local upslope area draining through a certain point per unit contour length and $\beta$ denotes the slope angle. A higher TWI indicates a gentler slope and larger slope area. TWI (Fig. 10) of the study area ranges from 2.52 to 21.73.

## Rainfall Distribution

The rainfall distribution map of the study area is prepared secondary data obtained from the Centre for Water Resources Development and Management (CWRDM) (Fig. 11). Rainfall distribution along with the slope gradient directly affects the infiltration rate of runoff water hence increases the possibility of groundwater potential zones.

## Dissection Index

Dissection index (DI) (Fig. 12) is a parameter referring to the degree of dissection or vertical erosion, and the stage of landform development in any given watershed (Singh and Dubey 1994). DI is the ratio between the total relief (relative relief) and absolute relief of the basin which always varies between 0.0 (complete absence of dissection and hence the dominance of flat topography) and 1 for infrequent cases such as vertical cliff topography at the seashore or vertical escarpment of hillslope (Farhan et al. 2015). The lower value of DI will have high influence in groundwater potential.

## Roughness

In an area of undulated terrain like that of Kerala, the degree of undulation can be expressed in terms of roughness. More the roughness means the area is more undulated and vice versa. Generally undulated topography is characteristic of a mountainous region where weathering and erosion process continuously modify the landscape of a rugged into a smooth and plane surface in long run. In the hard rock terrain, the roughness is associated with nature and thickness of weathered product retained on
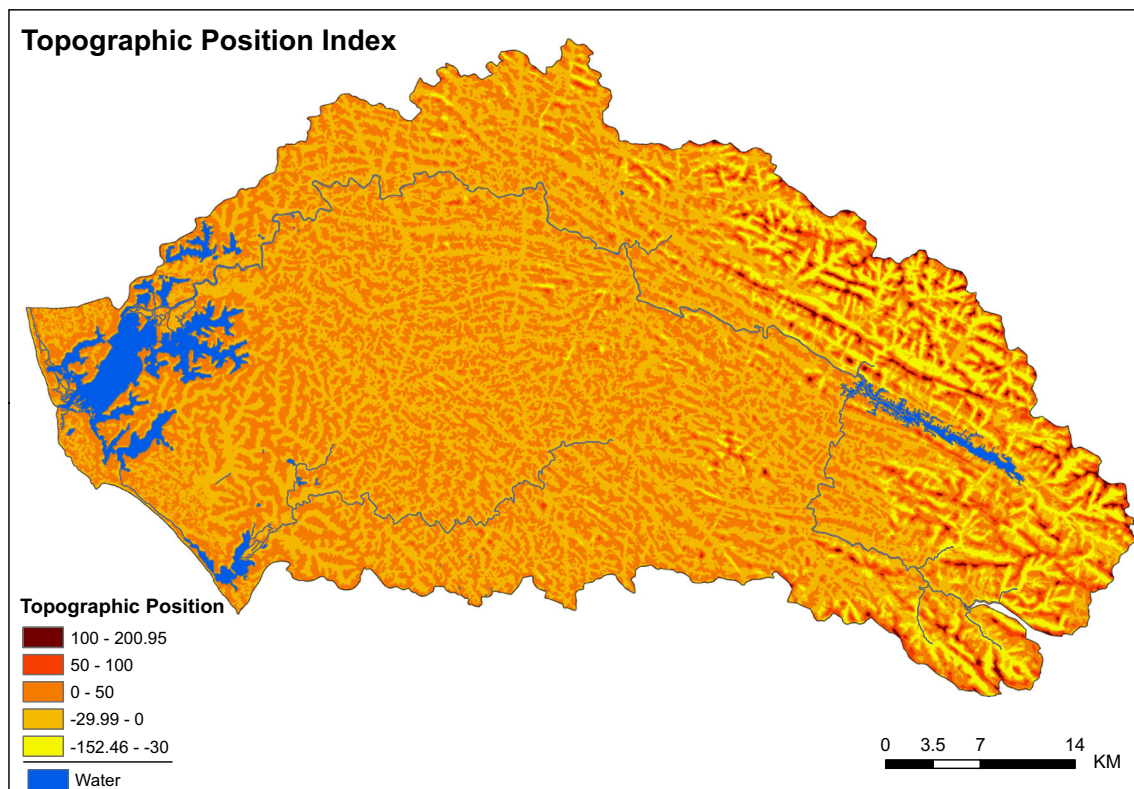


**Fig. 16** Map showing topographic position index of the Ithikkara and Kallada river basins

**Table 1** Weights assigned to different factors of thematic layers used in the study

| Factor | Class | Weight | Factor | Class | Weight |
|---|---|---|---|---|---|
| Slope (in degrees) | 0–5.35 | 10 | Lineament density | 0–0.26 | 2 |
| | 5.35–10.94 | 8 | | 0.26–0.69 | 4 |
| | 10.94–18.05 | 6 | | 0.69–1.24 | 6 |
| | 18.05–27.14 | 4 | | 1.24–1.98 | 8 |
| | 27.14–67.43 | 2 | | 1.98–4.10 | 10 |
| Geomorphology | Valley denudational hills | 6 | Rainfall distribution (in meters) | 5–5.7 | 2 |
| | Young coastal plain | 10 | | 6.6–7.5 | 4 |
| | Lower plateau (Lateritic) | 7 | | 7.5–8.3 | 6 |
| | Valley | 9 | | 8.3–9.2 | 8 |
| | denudational hills | 3 | | 8.3–9.2 | 10 |
| | Old coastal plain | 10 | Land use | Forest | 2 |
| | Terraces | 7 | | Plantation | 4 |
| | Canal | 10 | | Built-up | 6 |
| Geology | Coastal sand and alluvium | 7 | | Barren land | 8 |
| | Sandstone and clay | 8 | | Agriculture land | 1 |
| | Khondalite group of rocks | 1 | | Mixed vegetation | 7 |
| | Charnokite group of rocks | 1 | Soil | Clay | 2 |
| | Laterite | 5 | | Gravely clay | 4 |
| | Migmatite group of rocks | 1 | | Loam | 6 |
| Drainage density (km/km$^2$) | 0–3.44 | 10 | | Gravely loam | 8 |
| | 3.44–5.20 | 8 | | | |
| | 5.20–6.83 | 6 | | | |
| | 6.83–8.76 | 4 | | | |
| | 8.76–14.47 | 2 | | | |
| Topographic wetness index | 2.52–5.76 | 2 | Dissection index | 0–0.17 | 10 |
| | 5.76–7.05 | 4 | | 0.17–0.40 | 8 |
| | 7.05–8.83 | 6 | | 0.40–0.56 | 6 |
| | 8.83–11.56 | 8 | | 0.56–0.77 | 4 |
| | 11.56–21.17 | 10 | | 0.77–1 | 2 |
| Curvature | −13.68–−0.71 | 2 | Roughness | 0–0.61 | 10 |
| | −0.71–−0.19 | 4 | | 0.61–1.53 | 8 |
| | −0.19–−0.21 | 6 | | 1.53–2.24 | 6 |
| | 0.21–0.77 | 8 | | 2.24–3.11 | 4 |
| | 0.77–14.08 | 10 | | 3.11–7.63 | 2 |
| Depth water level (in meters) | 1.13–2 | 10 | Topographic position index | −152.6–0 | 8 |
| | 2–5 | 8 | | 0–50 | 6 |
| | 5–10 | 6 | | 50–100 | 4 |
| | 10–12.79 | 4 | | 100–200.95 | 4 |

the surface that controls the groundwater occurrence. If there is considerably thick weathered zone, such area can be treated as groundwater potential zone to a limited extent than a highly rugged terrain where normally only a thin layer of weathered zone exists and therefore no scope for groundwater occurrence. Roughness is synonymous to relief ratio. The roughness (Fig. 13) of the study area ranges from 0 to 7.8. The groundwater potential will be high in low roughness area.

**Curvature**

Curvature is quantitative expression of the nature of surface profile. It can be concave upward or convex upward profiles. Gentle slopes usually attain concave upward profile in platform. In the convex profile, water tends to decelerate, and in the concave, upward profile water tends to accumulate, which is true for groundwater also. The curvature (Fig. 14) of the study area ranges between −13.7 and 14.1.

**Table 2**  Contributing factors and rank in identifying groundwater potential zones

| Serial no. | Contributing factor | Rank |
|---|---|---|
| 1 | Geomorphology | 10 |
| 2 | Land use | 9 |
| 3 | Geology | 8 |
| 4 | Soil | 5 |
| 5 | Slope | 6 |
| 6 | Drainage density | 4 |
| 7 | Lineament density | 7 |
| 8 | Rainfall distribution | 6 |
| 9 | Topographic wetness index | 6 |
| 10 | Depth water level | 6 |
| 11 | Curvature | 4 |
| 12 | Dissection index | 4 |
| 13 | Roughness | 3 |
| 14 | Topographic position index | 2 |

## Depth to Water Level

Groundwater level indicates the elevation of atmospheric pressure of the aquifer. Any phenomenon that produces a change in pressure on groundwater will cause a variation in groundwater level. Spatial distribution of depth to water level of dug wells in the study area for the pre-monsoon and post-monsoon period (2010–2015) is shown in Fig. 15 (Source: CGWB).

## Topographic Position Index

Topographic position index (TPI) is a topographic position classification identifying upper, middle and lower parts of the landscape. TPI compares the elevation of each cell in a DEM to the mean elevation of a specified neighbourhood around that cell. Mean elevation is subtracted from the elevation value at centre.

$$\mathrm{TPI}_i = M_0 - \sum_{n-1} M_n / n$$

where $M_0$ is the elevation of the model point under evaluation, $M_n$ is the elevation of grid, and $n$ is the the total number of surrounding points employed in the evaluation (Guisan et al. 1999; Weiss 2001; Jenness 2006). High TPI values would be found near the tops of hills, whilst low TPI values would be found in valley bottoms (Fig. 16). TPI values near zero would be found on either flat ground or somewhere in midslope. High ranking was given to
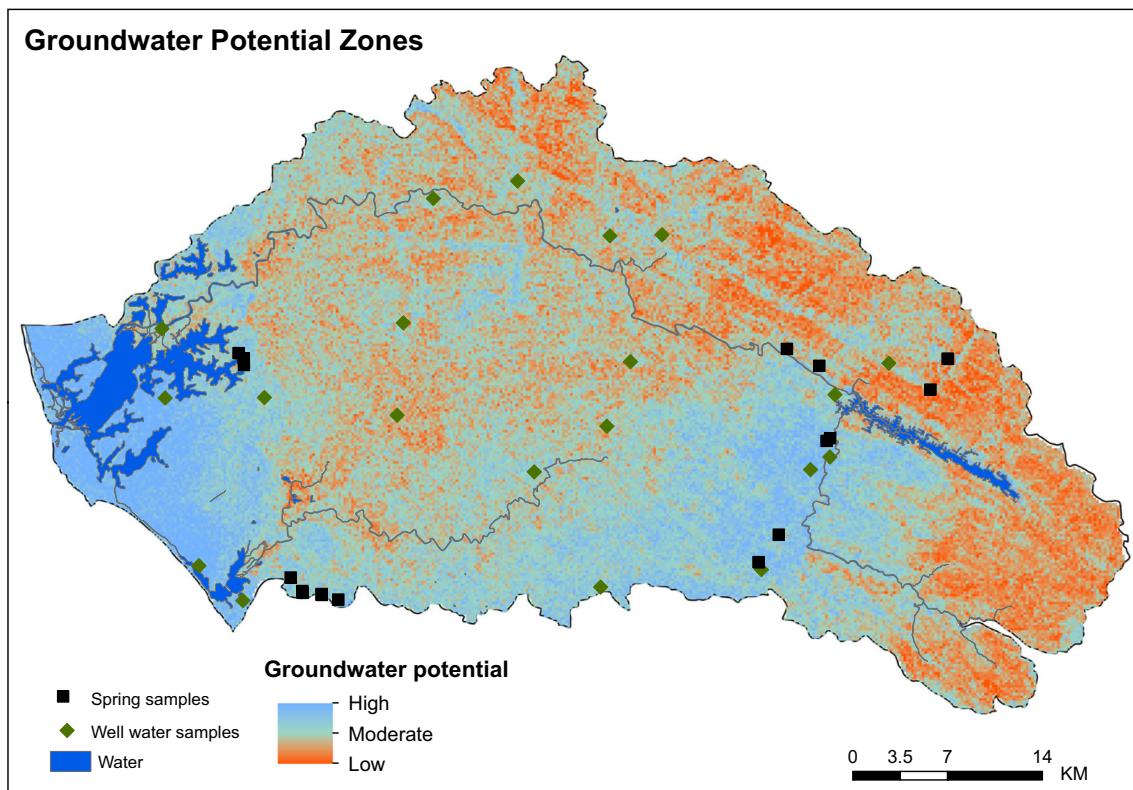


**Fig. 17**  Map showing groundwater potential zones of the study area. Note the high water potential zones in the highland (coincides with the structurally controlled drainage networks) and lowland (coincides with Tertiary aquifers)

area with low TPI values for its chances of groundwater potentiality.

## Groundwater Potential Zones in the Study Area

The groundwater potential zones are obtained by integrating all the thematic maps in a linear combination model in GIS platform. A weighted overlay analysis (WOA) method was adopted, and the ranking value (Table 1) is assigned for each class of individual thematic maps according to the influence of the different parameters on groundwater potentiality. WOA is a simple and straightforward method for a combined analysis of multi-class maps. WOA method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis are defined and each parameter is assigned importance (Saraf and Choudhury 1998). Determination of weightage of each class is the most crucial in integrated analysis, as the output largely depends on the assignment of appropriate weightage (Nag and Ghosh 2012) given to each thematic layer as shown in Table 2. The groundwater potential map of the study area prepared following the above method is shown in Fig. 17.

Based on the present study, the groundwater potential zones of the study area can be classified into three categories—low, moderate and high. About 37% of the study area (845.17 km$^2$) falls in low-category zone, 42% in moderate-category zone (960.29 km$^2$) and 21% of the area is in high-category zone (460.73 km$^2$). A study carried out earlier by Preeja et al. (2011) in a similar environmental and ecological condition states that the spatial variation of groundwater potential indicates that the

groundwater occurrence is controlled by the geology, lineaments, slope and geomorphology which justifies the resultant groundwater potential zones. Figure 18 shows a 3D perspective view of wells and springs overlaid to the groundwater potential zone map. This clearly indicates that the groundwater potential zone delineated using the present method is in good agreement with data of high yielding springs and dug wells of study area. Validation using the available secondary data of wells in the study area reveals that the overlay of this method using GIS and remote sensing gives an accuracy of 95%.

## Conclusion

The mapping of groundwater resources has assumed importance in recent years because of increased demand for freshwater for various purposes. The present study reveals that remote sensing and GIS are important tools for groundwater resource assessments. It is an essential tool for ecological monitoring, climatic situation, geographical, geomorphologic mapping, vulnerability management, resource estimation, urban planning and to study the farming practices. In the present study, 14 thematic layers have been utilised for identifying the potential zones for groundwater. From the analysis, the groundwater potential zones in terms of high, moderate and low have been delineated. In this study, major part (42.3%) of the area falls under moderate zone and 20.5% of the area under high groundwater potential zone. The groundwater potentiality map derived from the present study is validated using the available secondary data of springs and wells, and it was found that the overlay method using GIS and remote sensing used in the present study yields 95% accuracy.
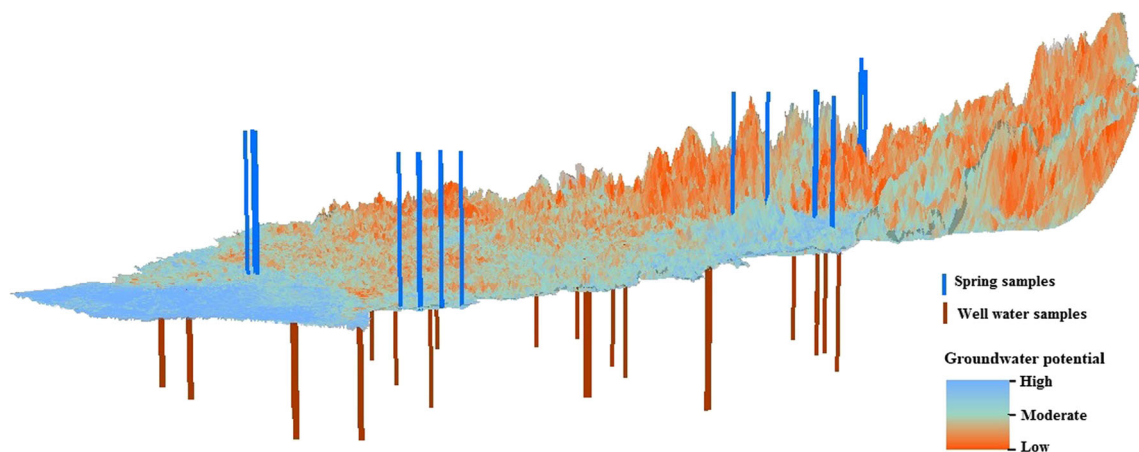


**Fig. 18** The 3D view of groundwater potential zone. Note that 95% of high-yield wells and springs of the study area perfectly overlap in the high potential zones

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