

# Geospatial and MCDM tool mix for identification of potential groundwater prospects in a tropical river basin, Kerala

T. V. Swetha<sup>1</sup> · Girish Gopinath<sup>1</sup> · K. P. Thrivikramji<sup>2</sup> · N. P. Jesiya<sup>1</sup>

Received: 8 September 2016 / Accepted: 2 June 2017 / Published online: 21 June 2017  
© Springer-Verlag GmbH Germany 2017

**Abstract** The efficiency of GIS, RS and multi-criteria tools in isolating potential groundwater (GW) zones in the Kuttiyadi River basin (KRB), Kerala, has been robustly demonstrated by analysis of relevant data. To infer geohydrological makeup and consequent behavior of the KRB in respect of GW potential, firstly, various thematic layers viz. geomorphology, geology, slope, soil, lineament density and drainage density, were created. Secondly, thematic layers and their features were assigned suitable weights on the Saaty's scale according to their relative significance for the presence and potential of GW. The assigned weights of the layers and their features were normalized using analytic network process method, and then the selected thematic maps were integrated in GIS using weighted overlay method to create the final groundwater prospect zone map. From the outcomes, the groundwater prospect zones of the KRB basin was found to be very good (166.21 km<sup>2</sup>), good (92.01 km<sup>2</sup>), moderate (180.33 km<sup>2</sup>), poor (237.25 km<sup>2</sup>), which constitute 24, 15, 26 and 35% of the study area, respectively. The GW prospect zone map was finally validated using geohydrology of area and GW level data from 43 phreatic wells in the study area. This study showed that groundwater prospect zone demarcation along with multi-criteria decision making is a powerful tool for proper utilization, planning and management of the precious groundwater resource.

**Keywords** ANP · Groundwater prospect zones · Multi-criteria decision making · Remote sensing and GIS

## Introduction

The chief objective of sustainable development and management of groundwater (GW) is the identification and demarcation of prospective GW zones enabling their development for societal, agricultural and industrial uses. Currently, a kind of hybrid water is the national policy of governments, whereby a mix of GW and surface water is relied upon. The National Water Policy of India (National Water Policy 2012) emphasizes the need for regulating the development and utilization of GW equitably in the country and suggests periodic scientific reassessment of the GW status of the different regions of the country based on the quality, quantity and economic viability. A scientific approach for GW development, using special inputs (RS data) and techniques (GIS) along with analytic network process (ANP) modeling, is an excellent algorithm for understanding the complexities of GW sources, extents and viabilities.

Many researchers have used the mix of RS and GIS techniques in delineating GW prospect (Jha et al. 2007; Chowdhury et al. 2010; Eastman 1999). A blend of these two techniques amply proved its efficiency in GW zonation reported from various parts of the world (Jhariya et al. 2016). Agarwal et al. (2013) observed that moderately high-resolution data and GIS techniques are very reliable in identification of GW prospects. Ubiquitous thematic layers such as geomorphology, slope, drainage density, geology, lineament density and soil act as indicators of occurrence of GW (Todd 1980; Jha and Peiffer 2006). The normalized weight and rank for each feature and sub-feature have been used to identify groundwater potential zones in coastal groundwater basins

✉ Girish Gopinath  
gg@cwrmdm.org

<sup>1</sup> Centre for Water Resources Development and Management, Kozhikode, Kerala 673571, India

<sup>2</sup> Center for Environment and Development, Thiruvananthapuram, Kerala 695013, India

using the multi-criteria decision technique—AHP (Mandal et al. 2016). Though RS data cannot directly indicate GW, its presence can be inferred by integrating aforesaid thematic layers. Assigning suitable weights for thematic layers in a spatial domain will enable identification of GW prospects.

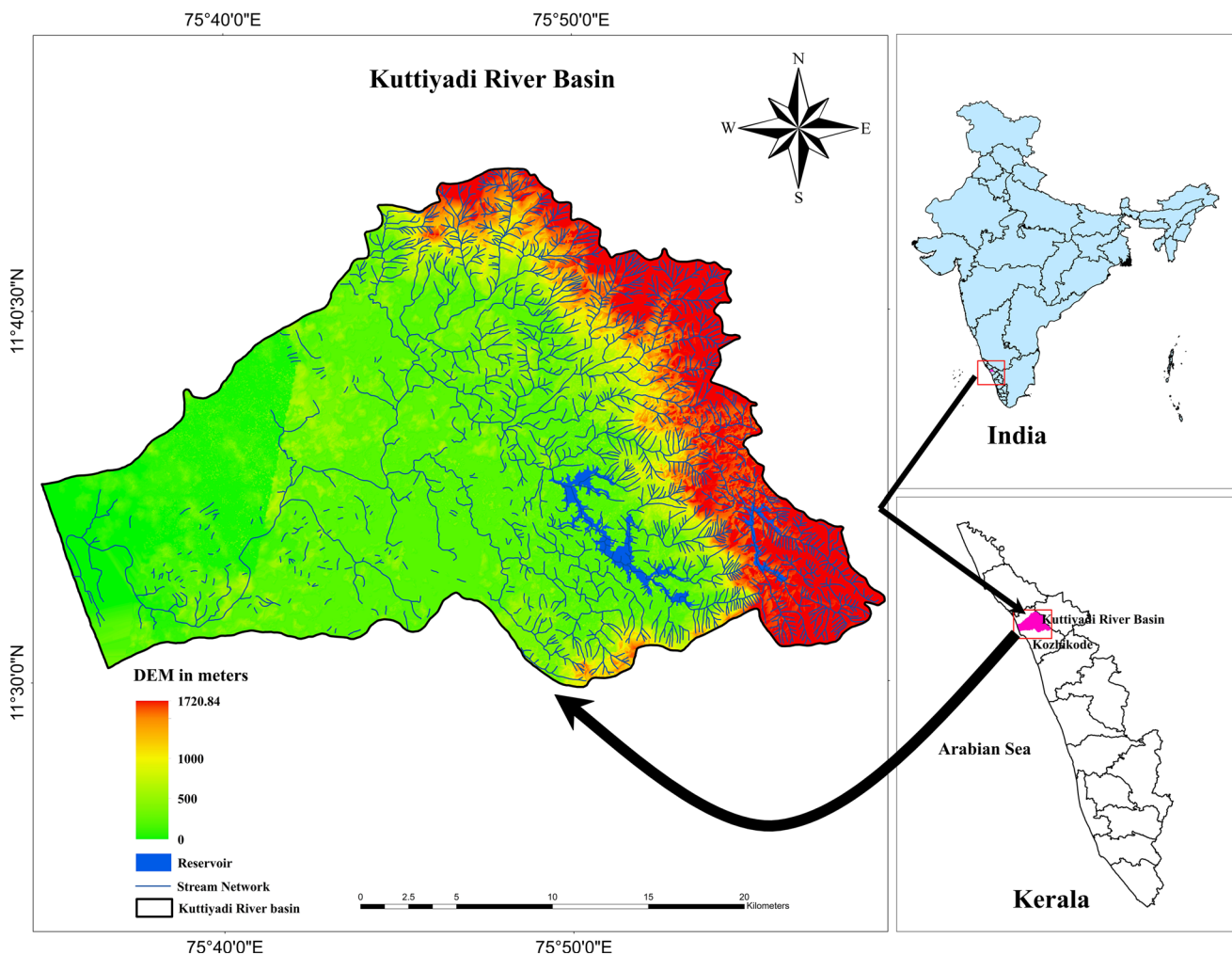
In order to account for the varying significance of each criterion, the ANP is the chosen MCDM (multi-criteria decision making) tool along with RS and GIS techniques. So far, MCDM has proved itself to be a precise predictor when expert knowledge was used with it to predict economic down turns in business, social and political events, and sports outcomes and so on. ANP, one of the most important methods in MCDM, solves the problem of dependency among alternatives or criteria.

ANP, a context-specific multi-criteria evaluation method, allows for the measurement of one unique alternative in the face of general criteria (Saaty 1999; Ghayoumian et al. 2007). A few but notable contributions on integrating GIS and multi-criteria evaluation can be found in the studies by Machiwal et al. (2011) and Nagaraju et al. (2012). The multi-

parameter analysis to explore the prospect zone/s for choosing GW recharge sites has been carried out by GIS-based MCDM technique (Kaliraj et al. 2014). Delineation of GW prospects using RS and GIS eliminates or minimizes the tedium, time and money and enables quick decision making in respect of sustainable water development and management (Kumar et al. 2014). Gopinath et al. (2016) demonstrated how benefits accrue by integrating GIS and MCDM tool set in watershed planning with the input of morphometric data. The network model in ANP describes the interdependencies between thematic layers in delineating GW prospects in Kuttiyadi River basin, Kerala, in a better way.

## Regional settings

Focus of this research is delineation of GW prospects in KRB (area = 676 km<sup>2</sup>; location = 11°0'N and 11°44'N 34'E), Kerala. Kuttiyadi River (Fig. 1) rising at an elevation of 1220 m in the Narikota Ranges of Western Ghats



**Fig. 1** Stream network of Kuttiyadi River basin (KRB)

flows westerly before draining into the Lakshadweep Sea. The main stream, ~74 km long, receives the chief tributaries such as Onipuzha, Thottilpalampuzha, Kadiyanganadupuzha, Mannathilpuzha and Madappalipuzha at different locations along its seaward course. The KRB enjoys typical tropical humid climate. The mean annual rainfall over the highlands and lowlands of the KRB is ~5170 and ~3070 mm, respectively. Average annual discharge of Kuttiyadi River is ~1273 mm<sup>3</sup>. About 60% of the rainfall is received during SW monsoon and 30% during the NE monsoon. The average temperature in KRB is in the range of 34° to 20 °C. Kuttiyadi River drains a large swath of the agricultural belt of northern Kerala. Major crops cultivated are rice, cashew, rubber and coconut. Two dams are located in the river: one at Peruvannamuzhi and the other at Kakkayam. These reservoirs satisfy the water demand, to a large extent, in the agricultural sector as well as the domestic needs of rural and urban settlements.

**Materials and methods**

Multiple parameters such as geomorphology, slope, geology, lineament density, drainage density and soil texture were analyzed by ANP approach using normalized weights to explore the prospects of GW. The input data, i.e., thematic maps of the parameters analyzed, were aggregated from secondary sources and SOI Toposheets (1:50,000 scale).

Slope map is created out of Cartosat-1 DEM, and IRS 1D (LISS III) is the basis for deriving lineament map, lineament density map and land use/land cover map. Software platforms, viz. ArcGIS 10 and ERDAS IMAGE 2011, were used for creating various thematic maps and estimations. Figure 2 is the workflow diagram illustrating the methodology for demarcating the GW prospects in KRB.

**Criteria vis-a-vis GW prospects**

GW is under the influence of landscape attributes such as geomorphology, drainage density, the lineament density, slope, geological makeup and soil texture in addition to climate variations. Appropriate weights are assigned to each of these attributes in proportion to their degree of influence on the GW regime. Representative weight of a factor of the prospect is the sum of all weights from each factor. A factor of a higher weight obviously is deemed to have a larger impact, and a factor with a lower weight would have a lower influence on GW prospect. Integration of these attributes with their respective weights is computed through weighted overlay analysis in a GIS platform. Kumar et al. (2014) put forward an equation to get total

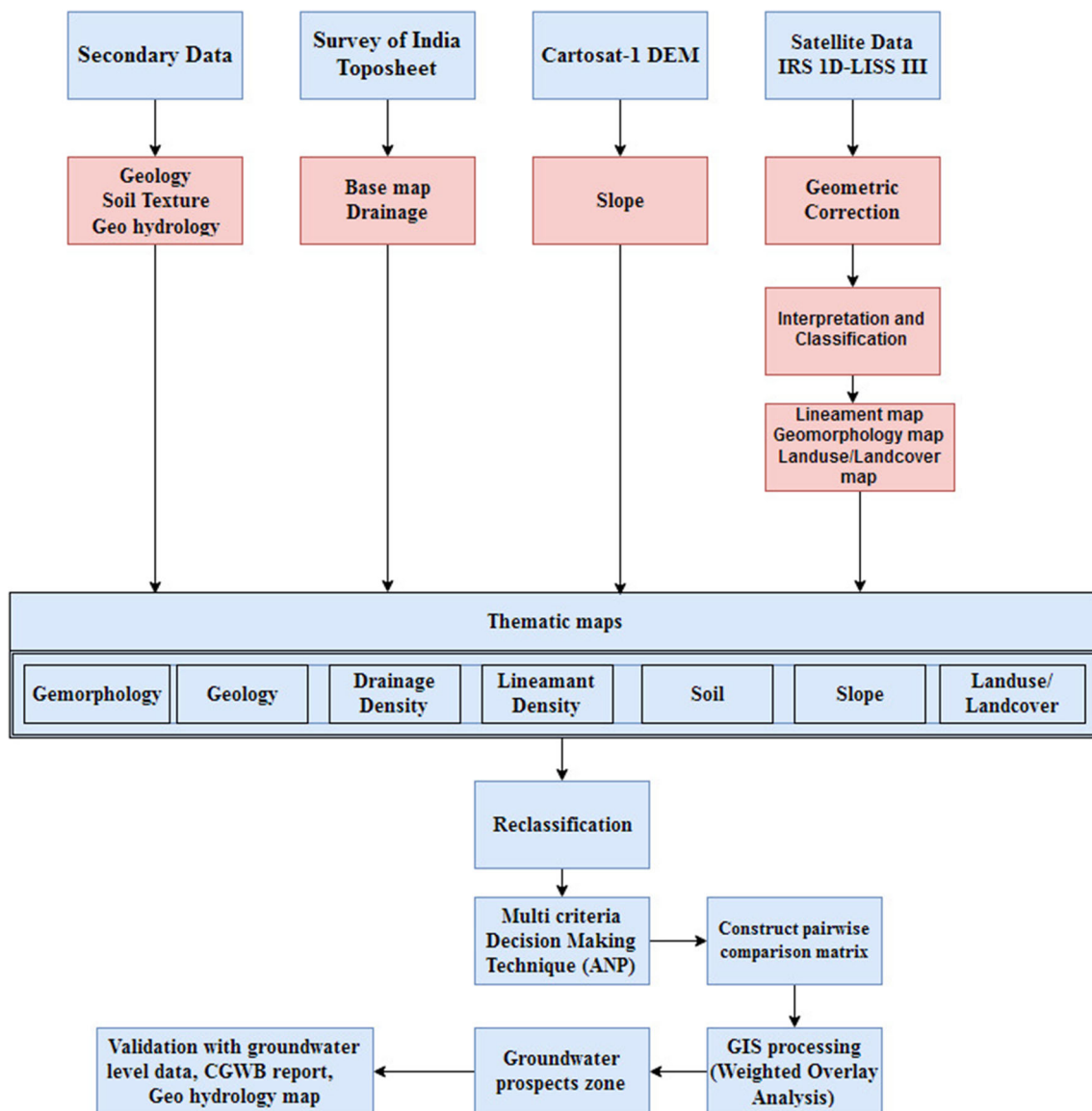
normalized weights of different polygons in the integrated layer to calculate GW potential index in ArcGIS environment. In this study, Eq. 1 is used to estimate Groundwater Potential Index (GWPI).

$$GWPI = (GM_w GM_{wi} + SL_w SL_{wi} + DD_w DD_{wi} + LD_w LD_{wi} + LU_w LU_{wi} + SO_w SO_{wi} + GG_w GG_{wi}) \tag{1}$$

where GWPI Groundwater Potential Index, GM = geomorphology, SL = slope, DD = drainage density, LD = lineament density, LU = land use and land cover, SO = soil, GG = geology, ‘w’ = normalized weight of a theme, ‘wi’ = normalized weight of the individual features of a theme.

**Analytical network process (ANP)**

Based on the normalized weights obtained from pair-wise comparison of each of the factors, the GW prospect delineation is carried out. Ranking of each factor for conservation activities is carried out by applying MCDM, followed by ANP. ANP is the generalization of analytic hierarchy process (AHP), developed by Saaty (2005), which relies on a structural hierarchy ical to explain the decision problem and does a pair-wise comparison between criteria to arrive at the weights used in the prospect identification. However, AHP assumes various criteria to be independent of each other, which is seldom true in respect of environmental variables. Hence, Saaty (2005) chose ANP where interdependence among different criteria is the rule rather than an exception. Inner dependence considering interaction and feedback within clusters of elements and outer dependence considering those among clusters are reflected in the constructed network (Liu and Jiang 2011). The ANP is implemented in the software *Super Decisions* and has been applied to various problems dealing with decisions and illustrating the uses of the new theory ([www.superdecisions.com](http://www.superdecisions.com)). *Super Decisions* software was developed by Adams in 1999–2003 (Baby 2013), with support from the Creative Decisions Foundation. This software is widely used in multi-criteria decision making, using AHP and ANP (Gardašević-Filipović and Saletić 2010; Liu and Jiang 2011; Baby 2013; Azizi and Maleki 2014). This software builds the model as clusters of elements, which are connected on the basis of their dependence to one another (Rostamnejad and Keimnasi 2011). The ANP is a general approach for any kind of decision problem. It is considered as an ideal tool to gain deeper understanding of specific goal and its relation to related factors. The use of ratio scale helps to confine all kinds of interactions and enables accurate predictions. Versatility, consistency in evaluation and simplicity in pair-wise



**Fig. 2** Workflow diagram of steps in data aggregation, analysis and representation in groundwater potential zone mapping

comparison, makes it a reliable and easy tool for decision makers. The major disadvantage of the method is in selecting a suitable important criterion over an alternative than other by the decision maker. Thorough brainstorming is needed to find important criteria and significant factors and interconnection between nodes, hence calling for systematic investigations.

The goal of this work is identification of GW prospects, criteria cluster and criteria clusters with feature nodes. Criteria cluster consists of six nodes, and these nodes are connected to feature nodes coming under each parameter. The network model created goal node is connected to criteria nodes, and each criterion node is connected to each other and to the related feature nodes (Fig. 3). Feedback dependencies are depicted as reciprocal arrows. Pair-wise comparisons can

be select from Graphic, Verbal, Matrix, and Questionnaire methods. The normalized weight obtained from ANP, in a scale of 1–9 (Table 1), uses questionnaire method (Fig. 4). The score of 1 represents equal importance, and 9 represents extreme importance of one element over the other (Saaty 2005). Comparisons are done by answering the question “How important is one criterion than the other, with respect to the specified goal”, i.e., GW prospect in this study (Fig. 6). The measure of consistency or Consistency Index (C.I) is calculated using Eq. 2 (Saaty 1999)

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

where  $n$  = number of factors (i.e., 7 in this study),  $\lambda_{\max}$  = average of consistency vector; Eq. 3 is used to



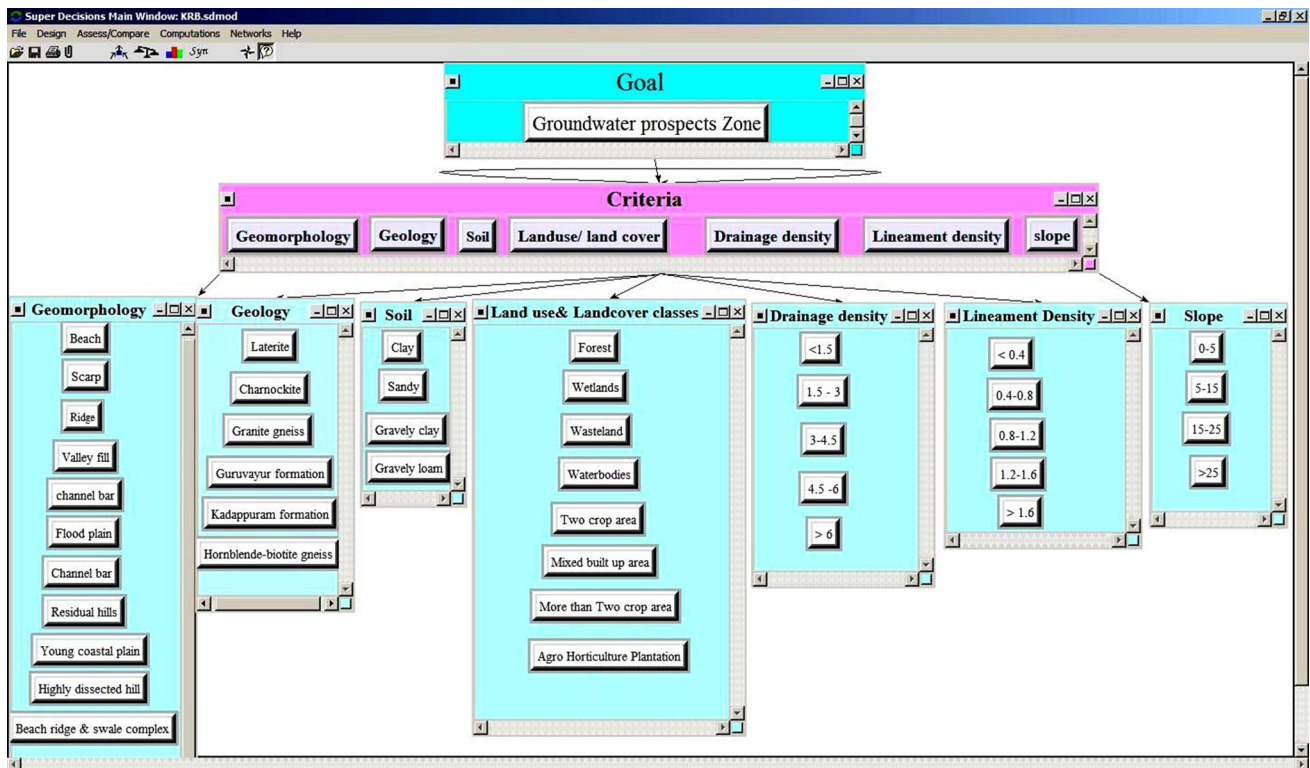


Fig. 3 Decision network design for delineating GW prospects, KRB

Table 1 Saaty’s 1–9 scale of relative importance

Scaling	Numerical rating
Extreme importance	9
Very to extremely strong importance	8
Very strong importance	7
Strong to very strong importance	6
Strong importance	5
Moderate to strong importance	4
Moderate importance	3
Equal to moderate importance	2
Equal importance	1

calculate the consistency ratio, a measure of consistency from pair-wise comparison

$$C.R = \frac{C.I}{R.I} < 0.1 \tag{3}$$

If R.I is ratio index for different values of ‘n’ (Table 6), then C.I value obtained is 0.0421 and C.R is 0.031 (i.e., <0.1).

**Data integration using GIS modeling**

The final integrated map is generated by applying the weighted sum analysis of Spatial Analyst tool in ArcGIS

3. Results		
Inconsistency: 0.01417		
Beach	0.12666	0.12666
Beach ridge	0.12666	0.12666
Channel bar	0.12666	0.12666
Dam and Ridge	0.12666	0.12666
Flood plain	0.12666	0.12666
Highly dissected hill	0.01656	0.01656
Low drainage density	0.01656	0.01656
Residual hills	0.01656	0.01656
Ridge	0.01656	0.01656
River	0.12666	0.12666
Rolling plain	0.03058	0.03058
Scarp	0.01656	0.01656
Valley fill	0.12666	0.12666

Fig. 4 Geomorphic domains, inconsistency values and normalized weights

9.1, which is a better method for combining multiple thematic layers of common measurement scale of values to each raster, weighting each according to its importance, and adding them together to create an integrated map (Gopinath and Seralathan 2004). Weights for each theme and ranks for features were assigned based on their capacity to hold GW. It is learned from previous study that

(Dinesh Kumar et al. 2007) geomorphology plays a vital role for groundwater storage followed by slope, geology, lineament density, drainage density, land use and soil in the study area.

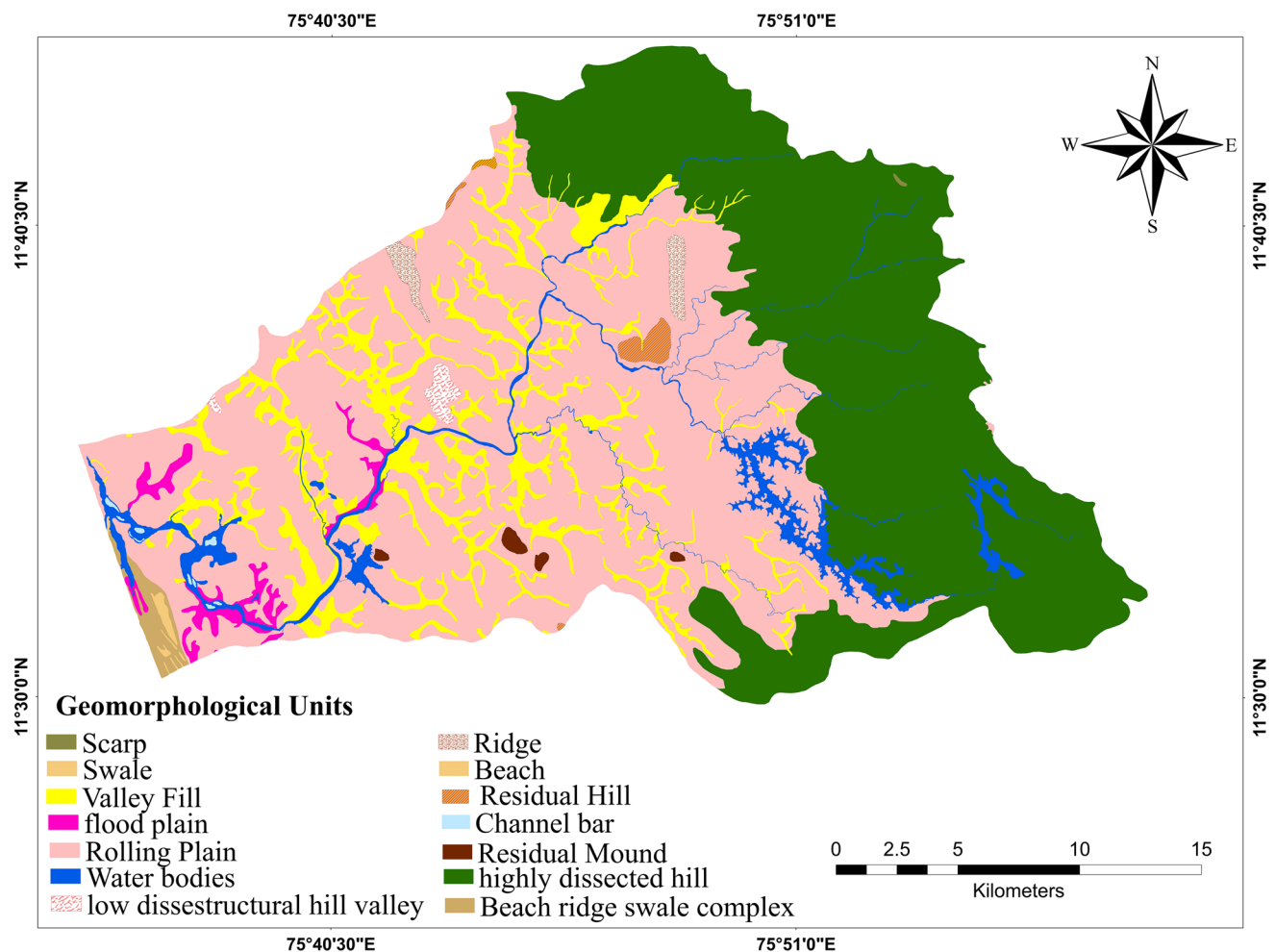
## Results and discussion

The thematic maps were integrated in the GIS to identify the promising GW prospects. Ranking implies the ranges of GW prospects within each factor. Ranks were assigned to each theme according to the order of influence of the theme on its importance with respect to GW reserve. The normalized weight obtained from ANP, in a scale of 1–9, represents poor, moderate, good and very good chance of GW prospect. Normalized weights of various classified thematic layers (Figs. 5, 6, 7, 8, 9, 10) in GIS-based overlay analysis represented poor, moderate, good and very good GW storage prospect.

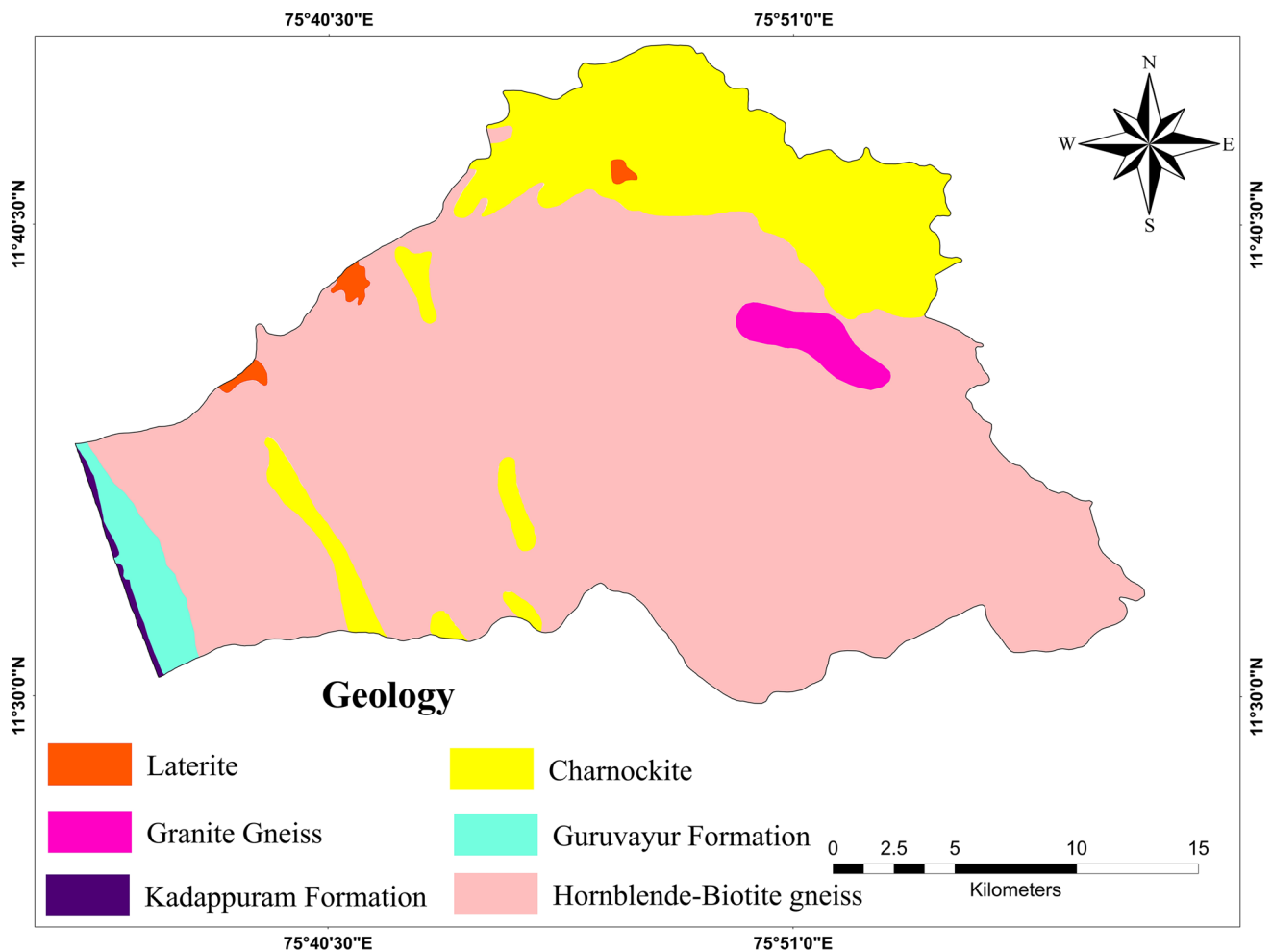
## Multi-influencers of groundwater prospects

### Geomorphology

Geomorphologic map depicts important geomorphic units, landforms and reflects underlying geology so as to provide an understanding of the processes, materials/lithology, structures and geologic controls relating to aquifers as well as GW prospects. The geomorphologic units identified in the KRB in the increasing order of GW prospect are: Water bodies, Valley fills, Flood plain, Channel bar, Rolling Plain, Beach and swale complex, Residual mounds, Residual mound complex, Linear ridges, Residual hills, Structural hills and Scarps (Fig. 5). These classes represented as nodes in ANP, and after node comparison, the inconsistency obtained is 0.01417 (Fig. 4). Structural hills are prominently found in the northeastern parts of KRB, where the major rocks are hornblende-biotite gneisses and charnockite. A tract with structural hills is normally considered as poor source of GW; hence, chances of



**Fig. 5** Geomorphology of KRB



**Fig. 6** Geologic map of KRB (Source: Geological map of Kerala, GSI-1995)

occurrence of GW depend on the geologic structures in this tract. The geomorphologic features such as residual hills, residual mounds and linear ridges are also ‘poor’ in respect of GW storativity (Rao et al. 2001). On the other hand, valley fills are considered as good prospects for GW exploration. Auden (1933) and Kumar and Srivatsava (1991) investigated hydrogeomorphologic domains using RS data in Agnigundala mineralized belt, Andhra Pradesh, and reported that valley fills have better prospects for GW over granites and granite gneiss.

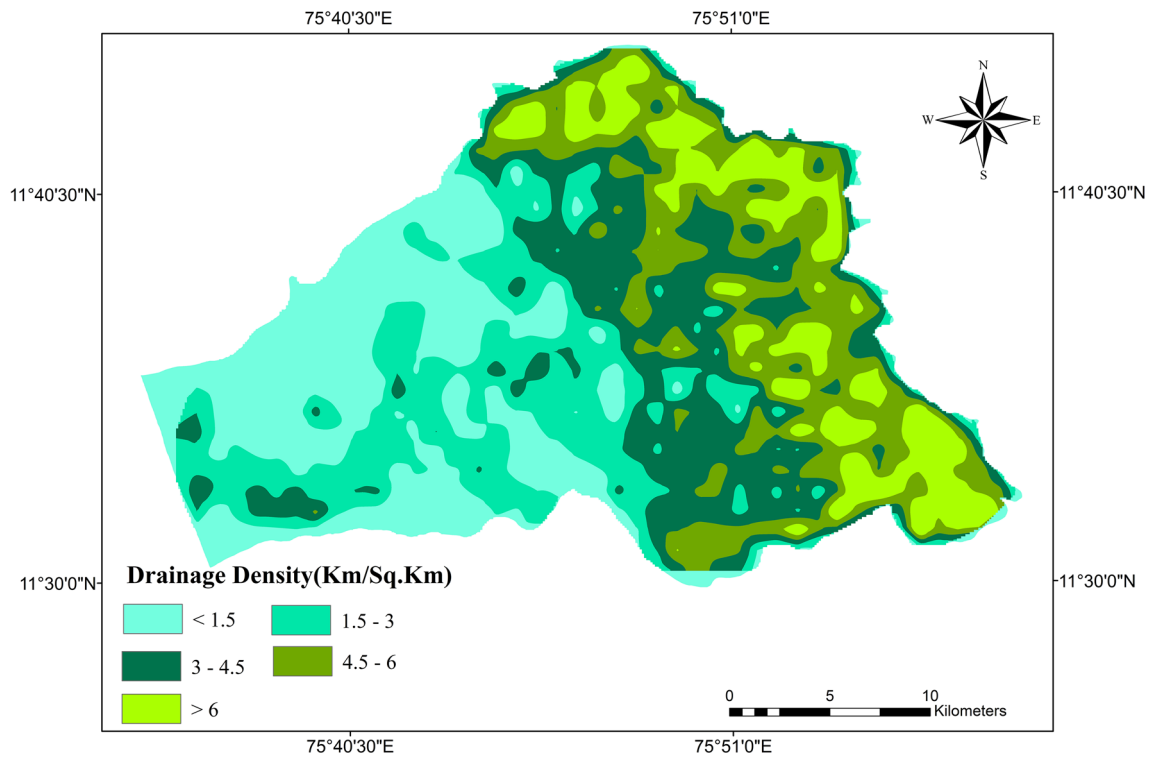
*Geology*

Three distinct rock types in KRB are (1) crystalline rocks of Archean age, (2) laterite capping over the crystallines and tertiary sedimentary rocks and (3) recent and sub-recent sediments in low-lying valleys and plains. These rocks can be further classified as (Fig. 6) charnockite, hornblende-biotite gneisses and other unclassified gneisses covering a major portion (94%). Granite gneiss and

charnockite have low permeability. But the thick laterite layers are porous and slightly permeable and so are ‘good’ aquifers. Guruvayur formation of late Pleistocene is a strand line deposit of (areal cover = 2.09%) paleo-marine origin, mostly comprised of medium to fine sand, while Kadappuram formation (areal extent = 0.29%) is contemporary marine deposit of beach and barrier beach sediments. NE–SW trending dolerite dykes are the chief intrusives occurring in the area.

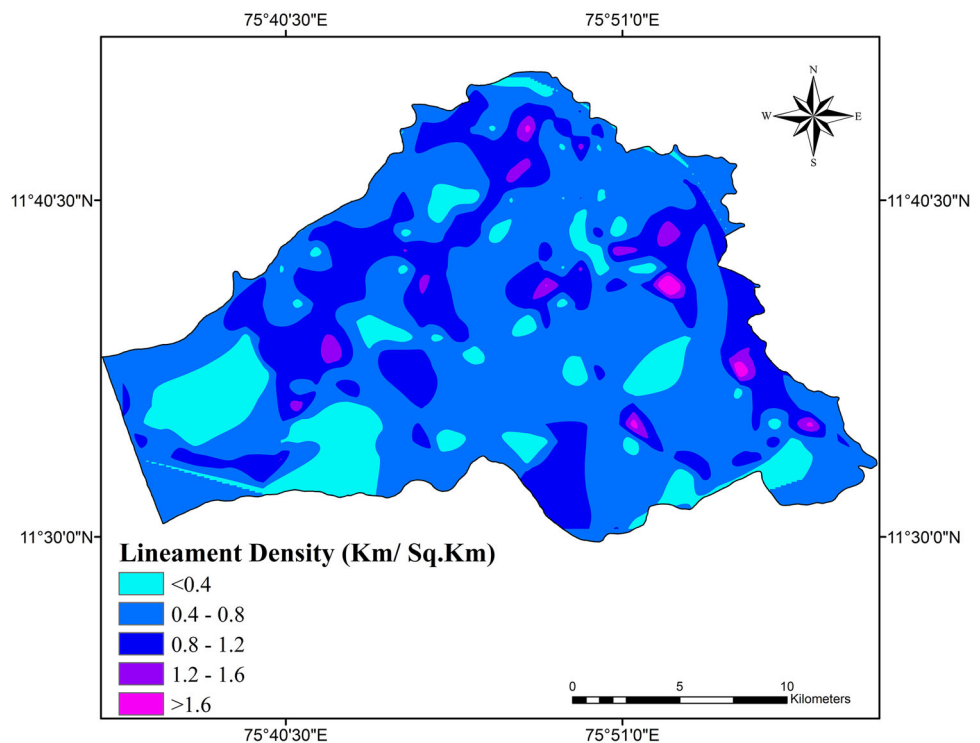
**Drainage density and lineament density**

Drainage density, Dd, is a useful quantitative measure of degree of landscape dissection, runoff and infiltration capacity of surface cover, vegetation cover and climatic conditions (Chorley 1969; Parker 1977; Patton 1988; Macka 2001). Dd is defined as the total length of streams of all orders per unit drainage area (km/km<sup>2</sup>) and is a measure of proximity of channels (Horton 1932). In the KRB, a sixth-order basin, drainage density is reclassified into four



**Fig. 7** Drainage density of KRB

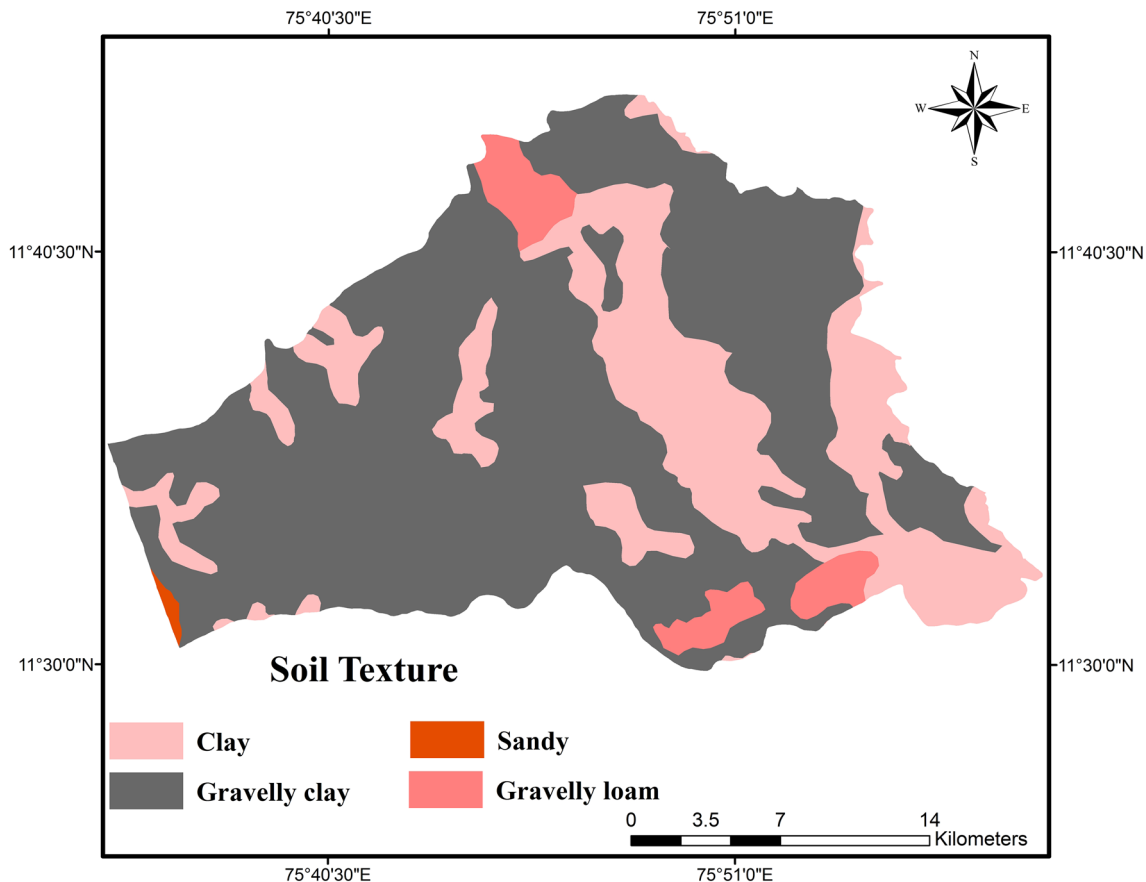
**Fig. 8** Lineament density of KRB



categories, viz. >6, very high; 4.5–6, high; 3–4.5, medium; 1.5–3, low and <1.5, very low for this study. Higher rating is assigned to areas of very low Dd, whereas areas of higher Dd are assigned low rating considering aspect of recharge

(Fig. 7). Areas having high density are not suitable for GW prospect because of the greater surface runoff. The extreme upstream part of the study area shows a high drainage density (3.67–6.48 km/km<sup>2</sup>) with annual mean rainfall of





**Fig. 9** Soil types of KRB (Source: National Bureau of Soil Survey and Land Use Planning (NBSS & LUP))

4522 mm. In KRB, tract of low drainage density (<1.5) occurs mostly toward west, covering an area of 293 km<sup>2</sup> (Table 2). Similarly, lineament density of a terrain is an indirect signature of the GW prospect, as the lineaments usually denote permeability. Areas of high lineament density go with good aquifers (Haridas et al. 1994, 1998). The highest lineament density, >1.6, occurs only on an area of 1.34 km<sup>2</sup> in KRB, while the lowest of <0.4 on the area 142.85 km<sup>2</sup> (Table 3; Fig. 8).

**Soil**

The chief soil types of KRB are alluvial soil, lateritic soil and forest loam. Alluvial soils (viz. coastal alluvial soil and river alluvial soil) reported mostly along the coastal plain and valleys and are excessively to moderately drained and are of sandy to clayey textures. Majority of the area under riverine alluvium was once used for paddy cultivation, but are currently utilized for cultivation of various annual crops and especially plantain. Lateritic soil, derived from the laterite under tropical climate with alternate wet and dry conditions, is reddish in color and well drained gravelly to clayey types. Forest loam is deep or very deep and is well drained loamy to clayey in texture (Fig. 9). In other words,

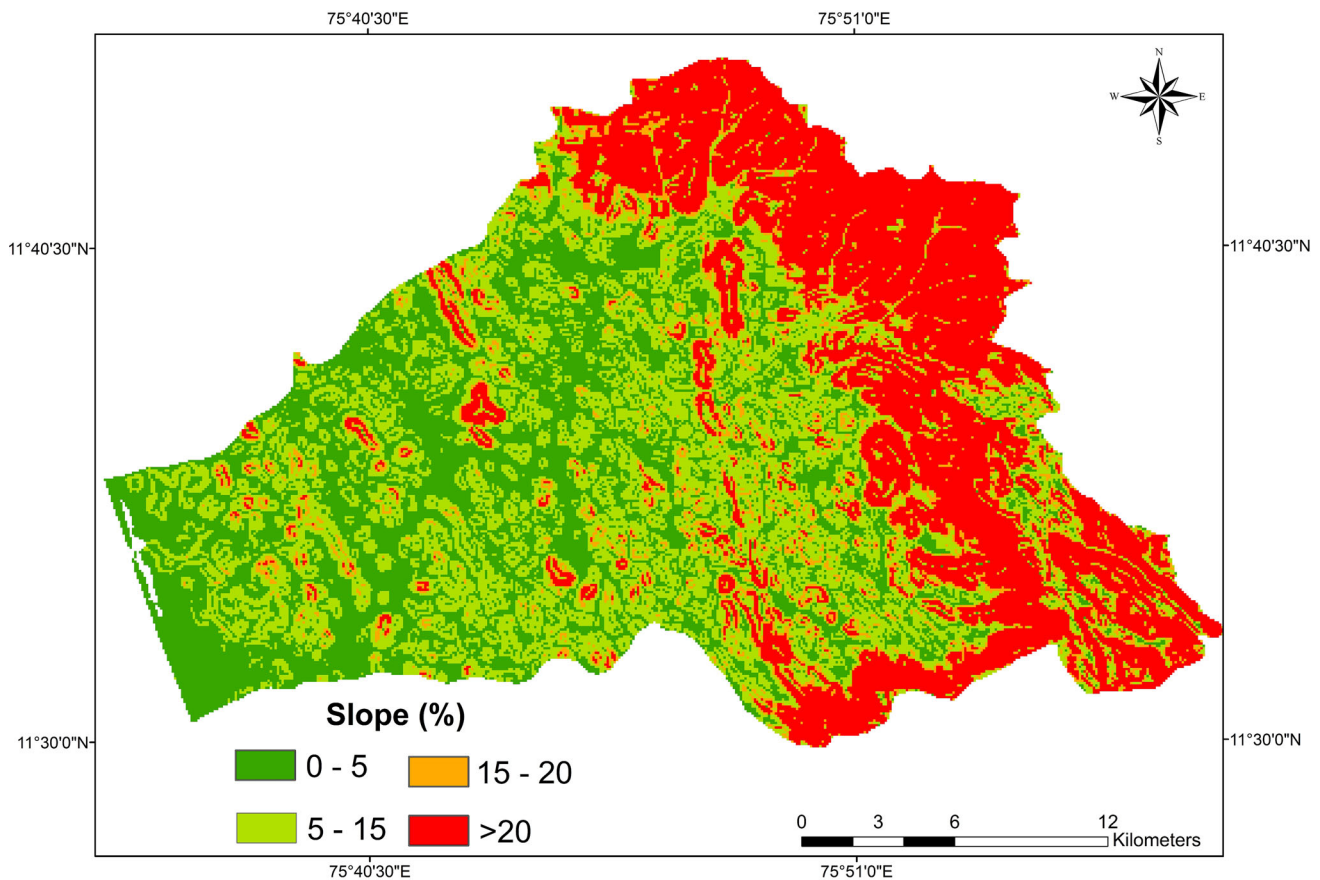
the soils of KRB fall under the five main soil texture classes, viz. clay, gravelly clay, gravelly loam and sandy. Ranks for soil types have been assigned based on infiltration rate. Sandy soil has high infiltration.

**Slope**

Cartosat-1 high-resolution stereo data are used to extract DEM and slope map of the KRB. The highly undulating eastern part of KRB is associated with denudational hills and valleys, while denudational plateaus are in the eastern region. Sarkar et al. (2001) evaluated GW prospect of Shamri micro-watershed in Himachal Pradesh using RS and GIS and concluded that lineaments and slope played a key role in GW occurrence. Slope class of low value, i.e., 0–5%, is assigned higher rank (almost flat terrain), while the class of maximum value (>20%) is placed under a lower rank due to relatively high runoff (Fig. 10).

**Land use/land cover**

Land use/land cover (LULC) classes of KRB, derived from interpretation of IRS-1D (LISS III) satellite imagery, primarily include agricultural land, wetland, wasteland, built-



**Fig. 10** Slope variability of KRB

**Table 2** Drainage density and areal extent

Class name	Area (Km <sup>2</sup> )
<1.5	293.25
1.5–3	223.55
3–4.5	144.5
4.5–6	14.4
>6	0.161
<b>Total</b>	<b>675.80</b>

**Table 3** Lineament density and areal extent

Class name	Area (Km <sup>2</sup> )
<0.4	142.85
0.4–0.8	322.41
0.8–1.2	195.85
1.2–1.6	13.35
>1.6	1.34
<b>Total</b>	<b>675.80</b>

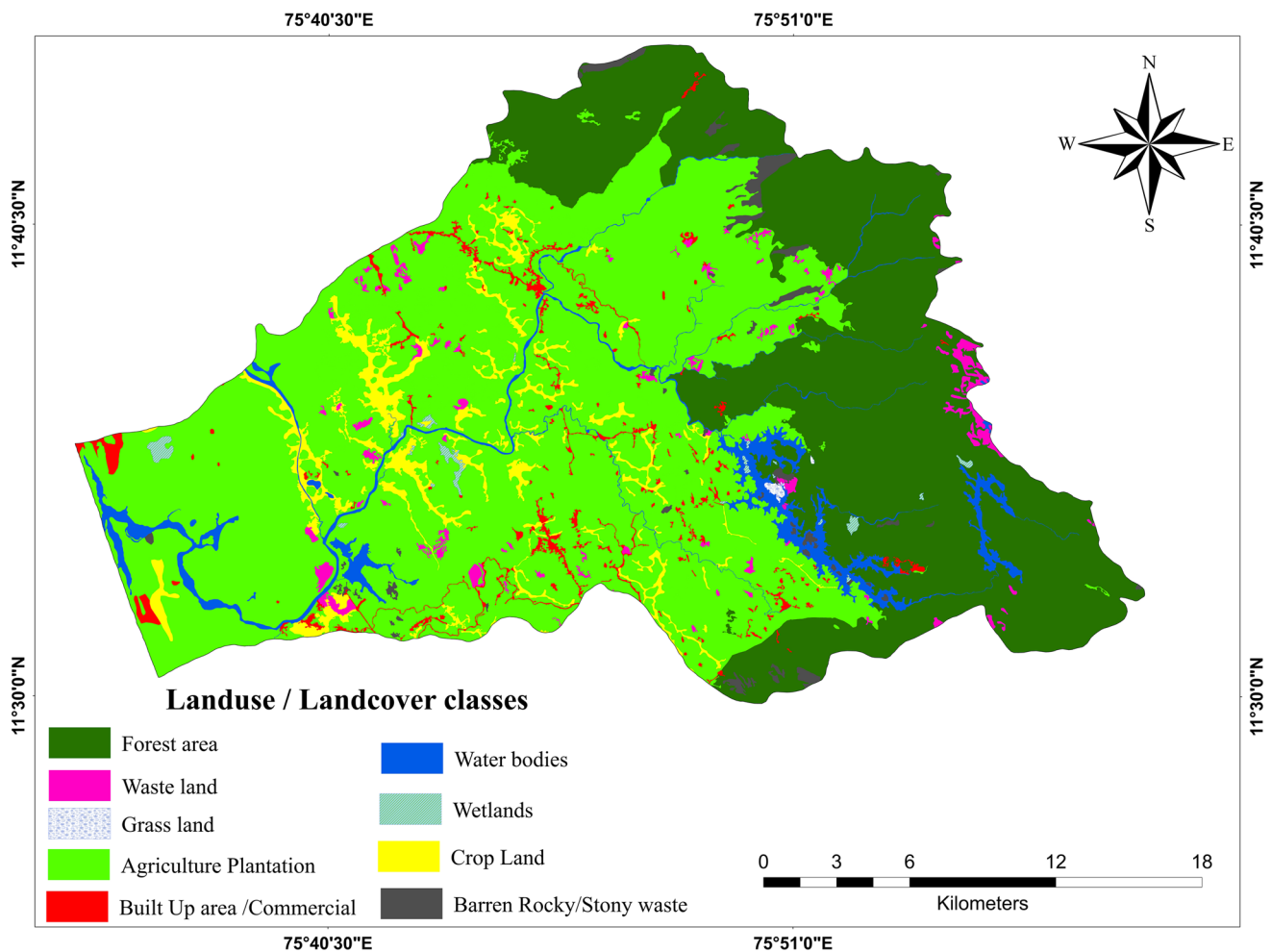
up area, forest and water bodies. The LULC data, important indicators of the extent of groundwater requirement and groundwater utilization (Kumar et al. 2014), are a proxy of infiltration and runoff characteristics. Hence, it is

an important parameter in the assessment of ground water potential zone. In KRB, the agricultural land (400 km<sup>2</sup>) is predominant viz. rubber, coconut and cashew plantations, two or more cropped farm land, etc. The crop land with vegetation can be given high rank due to its high potential for GW storage. The forest cover of 218 km<sup>2</sup> in KRB occurs chiefly on eastern part. The wetlands, wastelands and built-up area occur as isolated patches across the basin and water bodies cover a total of 25.0 km<sup>2</sup> (Fig. 11). Table 4 is the normalized weights obtained for each subclass of ANP in a scale of 1–9.

**Normalized weights for thematic layers**

In order to assign weights to each thematic layer of KRB, questionnaires of comparison ratings on the Saaty’s scale are designed. Then, all the thematic layers are compared against each other in a pair-wise comparison matrix (Fig. 12). GWPZ map generated using normalized weights of individual themes and different features are obtained from ANP (see Table 4).

The consistency ratio (C.R) of 0.031 (i.e., <0.1) indicates sensible level of consistency in the pair-wise comparison, and hence, the following weights are assigned to



**Fig. 11** Land use/land cover classes of KRB

all seven factors viz. geomorphology (0.331), geology (0.0669), slope (0.304), soil (0.023), drainage density (0.062), lineament density (0.066), land use/land cover (0.154). The average value of consistency vector is 7.25 (Table 5). Inconsistency index is obtained from software for each parameter and subclasses to check possible conflicts in different pair-wise comparisons. As the inconsistency values are <0.1 for all parameters, no reconsideration of the matrix is warranted (Table 5). The output map represents poor, moderate, good and very good GWP in KRB (Fig. 15; Table 6).

**Demarcation of Groundwater prospect Zones**

A systematic analysis using ANP on weighted parameters produced a useful groundwater prospect (GWP) zone map in raster format using overlay tools in spatial analyst extension in ArcGIS platform. In KRB, the GWP group under very good, good, moderate and poor is determined by their physical makeup to store GW (Fig. 15). A closer

look at Fig. 13 reveals that the very good zone is spread over the southwestern part of the study area—a tract of coastal plain sediment, valley fill and flood plain—all with a low slope. Small patches of good zone occur in the highland, lowland and most of the midland of KRB with an aerial coverage of 92.01 km<sup>2</sup> (Table 7). Eastern tracts of KRB with dissected hills (slope > 20%) and with high drainage density fall under poor prospect. Residual mounds, residual hills and ridges occurring as isolated patches in KRB also fall under poor prospect.

**Data validation**

It is now clear that GW prospects with higher recharge are located in the southwestern part of the KRB. Mandal et al. (2016), utilizing well yield data to validate the GWPZ map, pointed out that almost all wells came under good and very good categories. But in our study, a cross-validation has been added to ensure the recharge prospect of GW by factoring in field data (i.e., depth in meters below ground

**Table 4** Relative weights of various thematic layers and their corresponding classes

No	Layers	Normalized weight (from ANP)	Sub-domains/map units	Normalized weight (from ANP)
1	Geomorphology	0.3311	Beach	0.1266
			Beach ridge and swale complex	0.1266
			Channel bar	0.1266
			Dam and reservoir	0.1266
			Flood plain	0.1266
			River	0.0165
			Valley fill	0.0165
			Rolling plain	0.0165
			Highly dissected Hill	0.0165
			Low dissected structural Hill valley	0.1266
			Residual Hill	0.0305
			Ridge	0.0165
2	Geology	0.0669	Scarp	0.1266
			Charnockite	0.0617
			Granite gneiss	0.0632
			Guruvayur formation	0.3554
			Hornblende-biotite gneiss	0.0316
			Kadappuram formation	0.3554
3	Slope	0.304	Laterite	0.1322
			0–5%	0.6669
			5–15%	0.2072
			15–20%	0.0791
4	Soil	0.023	>20	0.0466
			Clay	0.0466
			Gravelly clay	0.0791
			Gravelly loam	0.2072
5	Drainage density	0.062	Sandy	0.6669
			<1.5	0.6067
			1.5–3	0.2152
			9–4.5	0.0880
			4.5–6	0.0449
6	Lineament density	0.066	>6	0.0449
			<0.4	0.0449
			0.4–0.8	0.0449
			0.8–1.2	0.0880
			1.2–1.6	0.2152
7	Land use/land cover	0.154	>1.6	0.6067
			Agro horticulture plantation	0.1643
			Forest	0.0440
			Mixed built-up area	0.016
			More than two crop area	0.2582
			Two crop area	0.2565
			Wasteland	0.0204
			Water bodies	0.1457
Wetlands	0.0945			



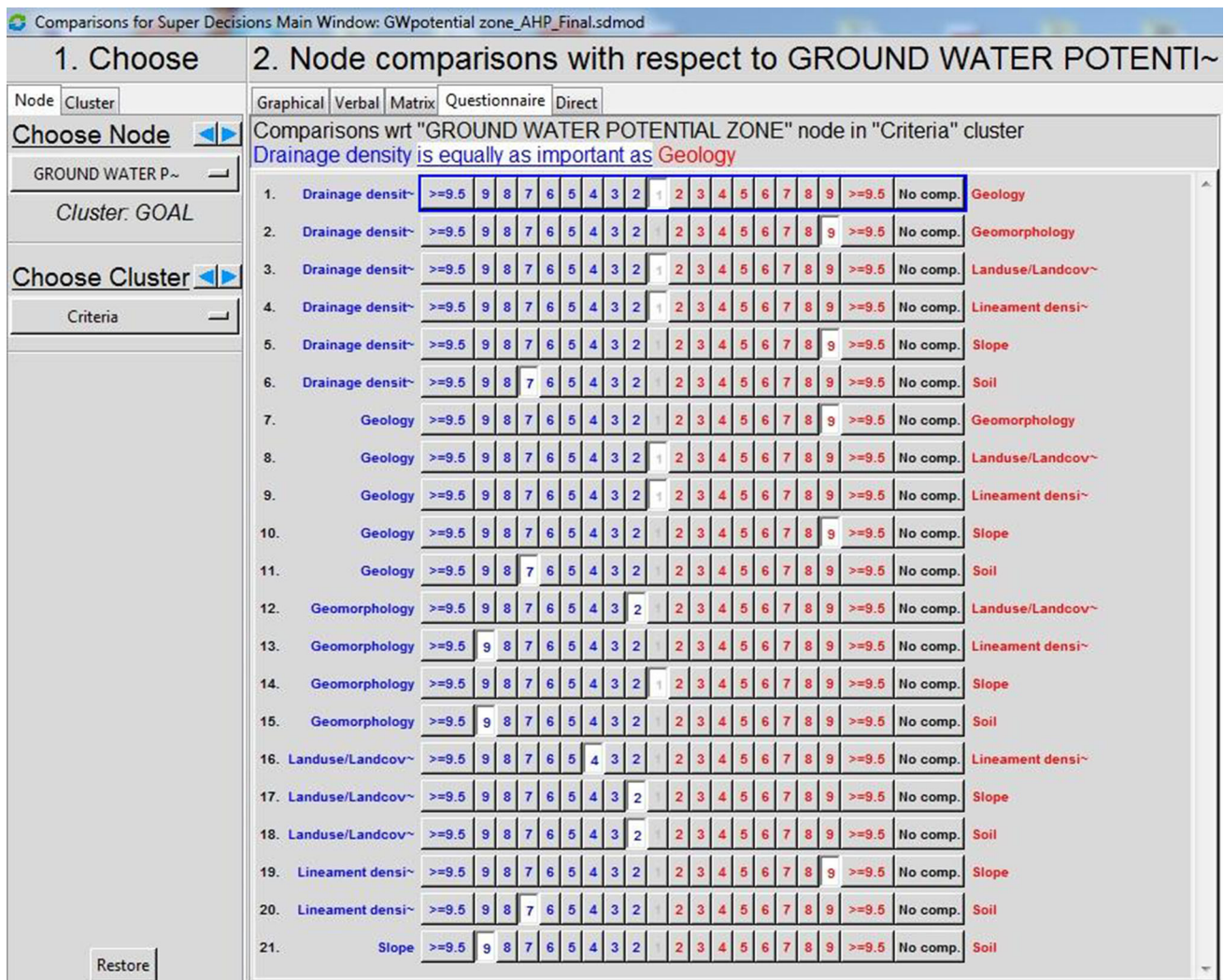


Fig. 12 Questionnaire of criteria set for comparing nodes

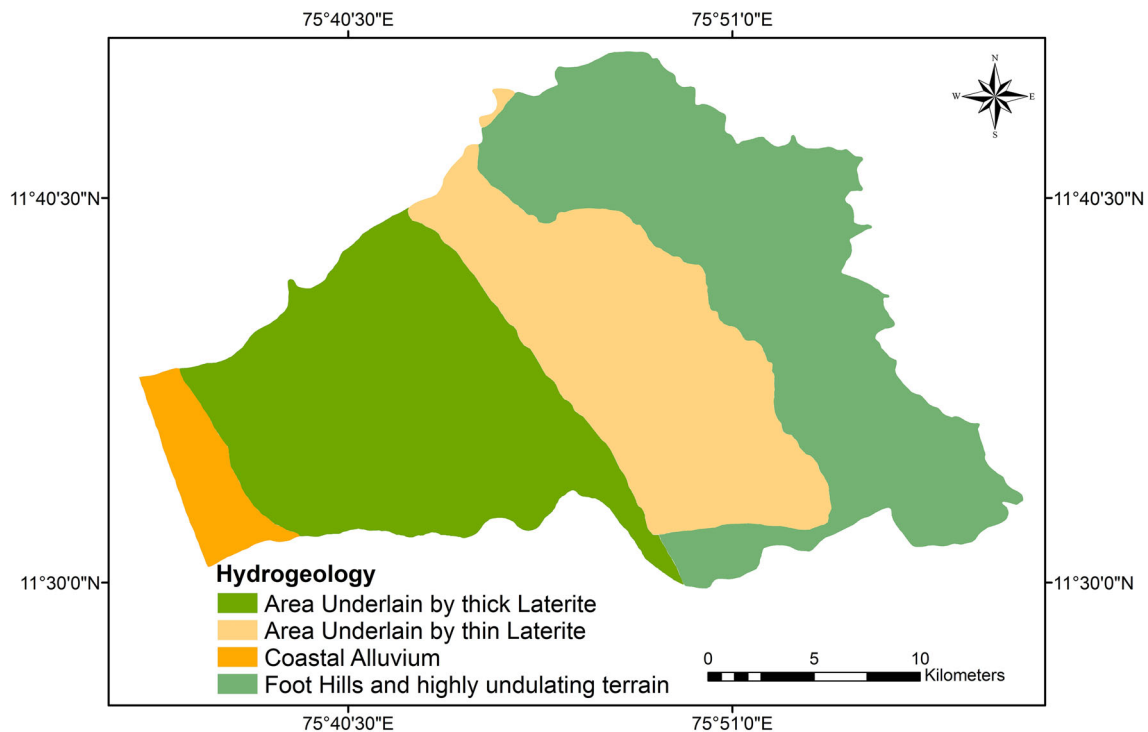
Table 5 Inconsistency index and consistency vector of each criteria

Si. no	Layers	Inconsistency index	Consistency vector
1	Geomorphology	0.01417	6.8552
2	Geology	0.08541	7.7652
3	Drainage density	0.04197	8.3789
4	Lineament density	0.11993	6.0952
5	Slope	0.04381	6.6768
6	Soil	0.18561	8.0491
7	Land use/land cover	0.17924	6.9924
			Average = 7.25

level or mbgl), CGWB (2013) report and geohydrology of KRB. Based on the depth to water level, the river basin is classified into three zones such as 1–5, 5–10 and >10 mbgl (meter below ground level), shown in Fig. 14. Hydrogeologically, the river basin is categorized into foot hills and highly undulating terrain, area underlain by thin laterite,

area underlain by thick laterite and coastal alluvium based on geohydrology (Fig. 13). The narrow coastal belt, with alluvial deposit, is a potential aquifer with depth to water level is at 1–5 mbgl, and well yield of 50 lps is suitable for filter point wells. The midland region has a thick laterite cover with depth to water varying from 5 to 10 mbgl is





**Fig. 13** Hydrogeology map of KRB

**Table 6** Ratio index for different values of *n*

<i>N</i>	1	2	3	4	5	6	7
R.I	0	0	0.52	0.89	1.11	1.25	1.35

**Table 7** Classification of groundwater prospect zone and areal extent

Ground water potential	Extent (km <sup>2</sup> )
Very good	190.81
Good	235.43
Moderate	113.63
Poor	135.93
Total	675.80

found suitable for open wells. With foot hills of highly undulating terrain in the east, with thin soil cover, yield of ground water is poor but the fracture planes are potential zones in this region. Validating the water level data with groundwater prospect zones reveals that very good zones were characterized by the depth to water level of 1–5 mbgl and good and moderate zones were at the depth to water level of 5–10 mbgl, which was concurring with the findings of the study. Eastern tract is occupied with poor potential zone having depth to water level at >10 mbgl. Most of the pumping wells are coming under very good

and good groundwater potential zones of Kuttiyadi River basin (Fig. 15).

**Conclusions**

This research on GW prospects of KRB, Kerala, using RS-GIS technology in combination with MCDM elegantly demonstrated the efficacy of approach and reliability of the outcome. Several thematic maps, the corresponding features along with assigned weights (on a 1–9 scale) based on their relative importance in hosting GW prospects, and the normalized weights obtained using Saaty’s Analytical Network Process (ANP) can be an eye-opener to practicing hydrogeologists as well as researchers. In order to represent the output or results of ANP as a map, the map layers are integrated in a GIS platform using weighted overlay method in Spatial Analyst Extension. This approach enabled division of the KRB into four groundwater prospects, viz. very good, good, moderate and poor, respectively, covering 28, 34, 16 and 22% of the KRB.

Most of the wells with depth to water level between 1 and 10 mbgl (meter below ground level) come under very good to good category. The southwestern part of KRB, covering the coastal belt and vast agricultural lands, falls under very good to good, while the eastern tract of highly dissected hills with slopes exceeding 20%, higher drainage

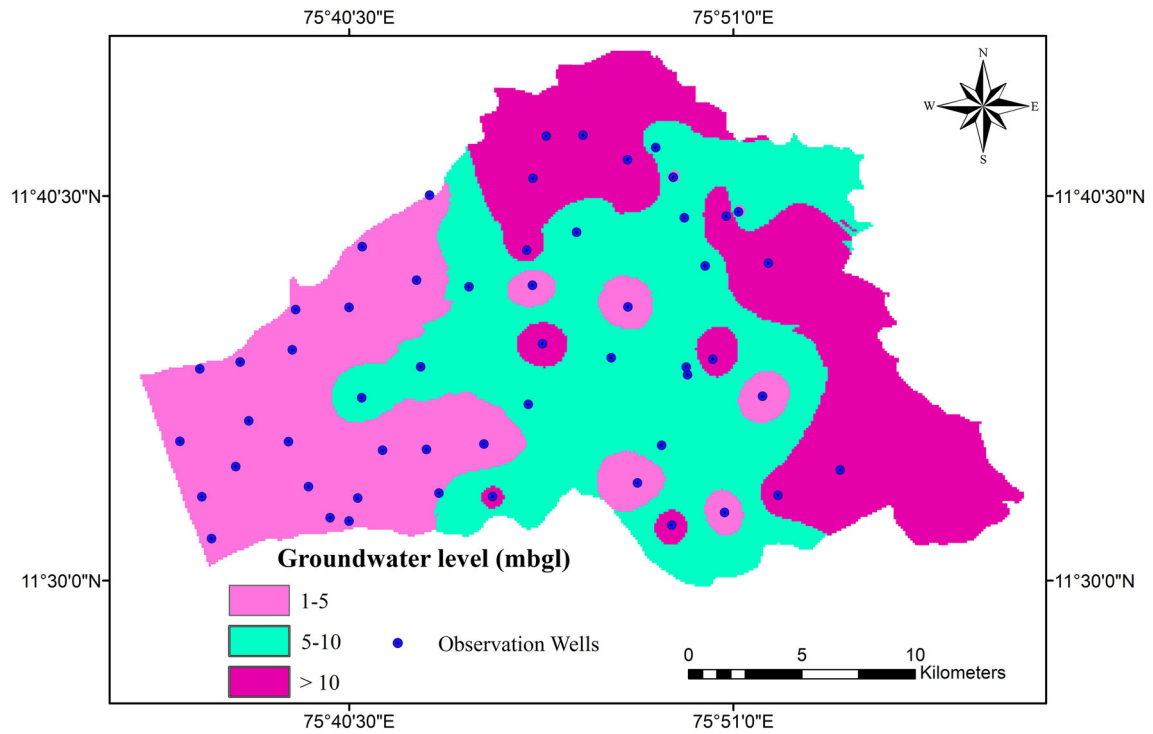


Fig. 14 Groundwater level map of KRB

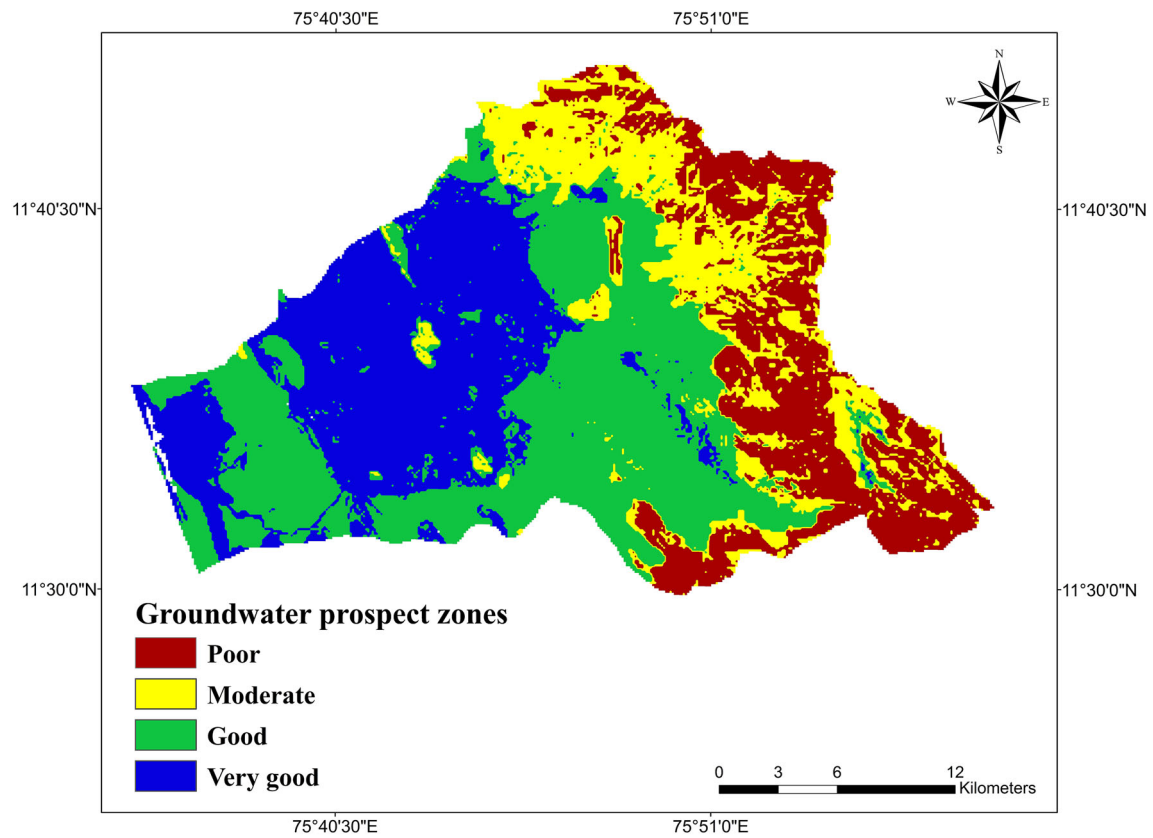


Fig. 15 Groundwater prospect map of KRB

density and mean annual rainfall of 4522 mm, is in the category of a zone of poor prospect and the remainder of the area goes under moderate prospect. This research also proved that the MCDM methodology, the proper assigning of weights through geostatistical modeling and its application in geospatial layers added more precise information on the current condition of the GW resources in the Kuttiyadi River basin and formulation of a long-term sustainable utilization plan.

**Acknowledgements** The authors are grateful to the Executive Director, Centre for Water Resources Development and Management (CWRDM), Kozhikode, Kerala, India, and for the guidance in the preparation of the manuscript.

## References

- Agarwal E, Agarwal R, Garg RD, Garg PK (2013) Delineation of groundwater potential zone: an AHP/ANP approach. *J Earth Syst Sci* 122(3):887–898
- Auden JB (1933) Vindhyan sedimentation in the Son Valley, Mirzapur district. *Geol Sur India* 62(2):141–250
- Azizi A, Maleki R (2014) Comparative study of AHP and ANP on multi-criteria suppliers with multi-criteria. In: Proceedings of the international multi conference of engineers and computer scientists 2014, vol II, IMECS 2014, March 12–14, 2014, Hong Kong
- Baby S (2013) AHP modeling for multicriteria decision-making and to optimise strategies for protecting coastal landscape resources. *Int J Innov Manag Technol* 4(2):218–227
- Central Ground Water Board (CGWB) (2013) Groundwater information report of Kerala
- Chorley RJ (1969) Introduction to physical hydrology. Methuen and Co., Ltd., Suffolk, p 211p
- Chowdhury A, Jha MK, Chowdary VM (2010) Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal using RS, GIS and MCDM techniques. *Environ Earth Sci* 59(6):1209–1222
- Dinesh Kumar PK, 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. *Int J Remote Sens* 28(24):5583–5601
- Eastman JR (1999) Multi-criteria evaluation and GIS. *Geogr Inf Syst* 1:493–502
- Gardašević-Filipović M, Saletić DZ (2010) Multicriteria optimization in a fuzzy environment: the fuzzy analytic hierarchy process. *Yugoslav J Oper Res* 20(1):71–85
- Ghayoumian J, Saravi MM, Feiznia S, Nouri B, Malekian A (2007) Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran. *J Asian Earth Sci* 30(2):364–374
- Gopinath G, Seralathan P (2004) Identification of groundwater prospective zones using IRS ID of LISS III and pump test methods from the Muvattupuzha river basin, Kerala. *Indian J Remote Sens* 32(4):329–342
- Gopinath G, Nair AG, Ambili GK, Swetha TV (2016) Watershed prioritization based on morphometric analysis coupled with multi criteria decision making. *Arab J Geosci* 9:129
- Haridas VR, Chandra Sekaran VA, Kumaraswamy K, Rajendran S, Unnikrishnan K (1994) Geomorphological and lineament studies of Kanjamalai using IRS-IA data with special reference to ground water potentiality. *Trans Inst Indian Geogr* 16(1):35–41
- Haridas VR, Aravindan S, Gopinath G (1998) Remote sensing and its applications for groundwater favourable area identification. *Q J GARC* 6(1):18–22
- Horton RE (1932) Drainage basin characteristics. *Am Geophys Union* 13:350–361
- Jha MK, Peiffer S (2006) Applications of remote sensing and GIS technologies in groundwater hydrology: past, present and future. BayCEER, Bayreuth
- Jha MK, Chowdhury A, Chowdary VM, Peiffer S (2007) Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. *Water Resour Manag* 21(2):427–467
- Jhariya DC, Kumar T, Gobinath M, Diwan P, Kishore N (2016) Assessment of groundwater potential zone using remote sensing, GIS and multi criteria decision analysis techniques. *J Geol Soc India* 88(4):481–492
- Kaliraj S, Chandrasekar N, Magesh NS (2014) Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. *Arab J Geosci* 7(4):1385–1401
- Kumar A, Srivatsava SK (1991) Geomorphological units, their geohydrological characteristics and vertical electrical sounding response near Munger, Bihar. *J Indian Soc Remote Sens* 19(3):205–212
- Kumar T, Gautam AK, Kumar T (2014) Appraising the accuracy of GIS-based multi-criteria decision making technique for delineation of groundwater potential zones. *Water Resour Manag* 28:4449
- Liu S, Jiang M (2011) Providing efficient decision support for green operations management an integrated perspective. In: Jao C (ed) *Efficient decision support systems—practice and challenges in multidisciplinary domains*. Intech Publishers, Croatia
- Machiwal D, Jha MK, Mal MC (2011) Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. *Water Resour Manag* 25:1359–1386
- Macka Z (2001) Determination of texture of topography from large scale contour maps. *Geografski Vestnik* 73(2):53–62
- Mandal U, Satiprasad S, Selva BM, Anirban D, Sudhindra NP, Amlanjyoti K, Prasanta KM (2016) Delineation of groundwater potential zones of coastal groundwater basin using multi-criteria decision making technique. *Water Resour Manag* 30:4293
- Nagaraju D, Nassery HR, Dinehvandi AR (2012) Determine suitable sites for artificial recharge using hierarchical analysis (AHP), remote sensing (RS) and geographic information systems (GIS). *Int J Earth Sci Eng* 05(01):1328–1335
- National Water Policy (2012) Government of India ministry of water resources. <http://wrmin.nic.in/writereaddata/NationalWaterPolicy/NWP2012Eng6495132651.pdf>. Accessed 1 Sep 2016
- Parker RS (1977) Experimental study of drainage basin evolution and its hydrological implications, hydro paper 90. Colorado State University, Fort Collins
- Patton PC (1988) Drainage basin morphometry and floods. In: Baker VR, Kochel RC, Patton PC (eds) *Flood geomorphology*. Wiley, New York, pp 51–64
- Rao NS, Chakradhar GKJ, Srinivas V (2001) Identification of groundwater potential zones using remote sensing techniques in and around Guntur Town, Andhra Pradesh, India. *J Indian Soc Rem Sens* 29(1&2):69–78
- Rostamnejad M, Keimnasi M (2011) Prioritizing marketing mixes of commercial vehicles by ANP method. In: Proceedings of the international symposium on the analytic hierarchy process, 2011
- Saaty TL (1999) Fundamentals of the analytic network process. In: *International symposium of the analytic hierarchy process (ISAHP)*, Kobe, Japan

- Saaty TL (2005) Theory and applications of the analytic network process. RWS Publications, Pittsburgh
- Sarkar BC, Deota BS, Raju PLN, Jugran DK (2001) A geographic information system approach to evaluation of groundwater potentiality of Shamri micro-watershed in the Shimla Taluk, Himachal Pradesh. *J Indian Soc Rem Sens* 29(3):151–164
- Todd DK (1980) Groundwater hydrology, vol 2. Wiley, New York, p 535