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ORIGINAL ARTICLE

Groundwater recharge potential zones mapping in upper Manimuktha Sub basin Vellar river Tamil Nadu India using GIS and remote sensing techniques

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Abstract An attempt has been made to assess the groundwater recharge potential zones in Upper Manimuktha sub basin, Vellar river, Tamil Nadu. Groundwater recharge denotes to the entry of water from the unsaturated zone into the saturated zone below the water table surface, together with the associated movement away from the water table within the saturated zone. This study mainly focus the many factors that control the occurrence and movement of groundwater in a hardrock region including topography, Geology, lineament, drainage patterns, land use/land cover, slope and soil. Using remote sensing and Geographic Information System it is possible to take number of different thematic maps of the area and overlay form a new integrated layer. The integrated map reveals about the groundwater recharge potential zones of the area and classified into five categories which represents very low to Very good Groundwater Recharge Potential Zones (GWRPZ). Downstream areas as well as waterbodies fall in the very high GWRPZ (12.4 km^2) indicates high infiltration and low runoff. Then followed by high GWRPZ (115.74 km^2) indicate these area maximum covered by agricultural land (57.99 km^2) as well as fallow land (85.41 km^2), so the infiltration high. In the poor (125.28 km^2) and very low GWRPZ (82.61 km^2) mainly fall in the hilly terrain as well as in the waste, barren and buildup land of the study area. Based on the GWRPZ study indicate 34.4 % of the rainwater infiltrate in the ground of the entire study area.

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Keywords Geographic Information System (GIS) · Geology · GWRPZ

Introduction

In hard rock terrain availability of groundwater is of limited extent and its occurrence is essentially confined to fractured and weathered zones (Saraf and Choudhary 1998). Unfortunately, water scarcity and over exploitation of groundwater resources are common in several parts of India (Rodell et al. 2009; Tiwari et al. 2009). Groundwater is a main resource for water and it occur only limited quantity under the ground. The occurrence and movement of groundwater in a watershed of a hard rock terrain are mainly controlled by secondary porosity caused by fracturing of the underlying rocks (Srivastava and Bhattacharya 2006). In India, about 65 % of the country is underlain by hard rocks (Saraf and Choudhury 1998). A number of attempts on delineation for groundwater potential zones using remote sensing data have been made by Murthy (2000), Jaiswal et al. (2003), Anbazhagan et al. (2005), Sener et al. (2005), Dinesh Kumar et al. (2007), Kumar et al. (2008), Chowdhury et al. (2009), Yeh et al. (2009, 2014, 2016), Adham et al. 2010, Dar et al. (2011), Venkateswaran and Ayyandurai (2015) and Prasanta Kumar Ghosh et al. (2016). Geographic Information System (GIS) techniques facilitate integration and analysis of large volumes of data, whereas field studies help to further validate results Solomon and Quiel (2006), Kannan et al. (2016) Satheeshkumar et al. (2016) and Vijay Prabhu et al. 2016. Geology, geomorphology, lineaments, soil, land use, drainage and slope all play an important role in groundwater location (Srivastava and Bhattacharya 2006).

Study area

The study area lies between 78°42′–78°59′E longitude and 11°42′–11°59′N covering a total area of 497.11 km^2 in which hilly area occupies 187.19 km^2. Western side the study area covered by Kalvarayan hills which divide the Salem and Villupuram districts are seen to the extreme west of Kallakurichi Taluk. The average annual rainfall of the study area is 1115 mm bring the groundwater recharge in the area. The study area chiefly consists of hard crystalline rocks of Archean age. The depth of dug wells and water table ranges from 15 to 20 m and 8 to 18 m, respectively (Venkateswaran and Deepa 2016). The flow of water in the river is reduced during the period from February to June, and as a result, in the region depends on groundwater for their use. A major part of the study area fall in the agricultural activities, where sugarcane, paddy, and groundnut are being cultivated. The upper reaches of the river basin comprises the precambrian peninsular Gneiss and its retrograded products (Krishna Kumar et al. 2008) the area mainly underlain by chornockites, fissile hornblende gneiss, hornblende biotite gneiss, pink granite and ultrabasic rocks. The depth of bore holes in upper ranges of Manimuktha basin from 90 to 150 ft (Krishna Kumar et al. 2008). The study area map is shown in Fig. 1.

Methodology

The base map of the study area was prepared using Survey of India topographic sheets (58E 9 and 13) having scale of 1:50000 and digitized using ArcGIS 9.3 software. Survey of India toposheets, satellite imageries and some other collateral data is used for the preparation of thematic layers like geology, geomorphology, percent slope, drainage density, lineament density and land use/land cover of the study area. Multi-criteria evaluation technique is used to integrate all the thematic layers. Individual themes and their corresponding categories are assigned a knowledge base weightages given depending on their suitability to hold groundwater and their weightage are calculated. The process of visually interpreting digitally enhanced imagery attempts to optimize the complementary abilities of the human mind and the computer. The mind is excellent at interpreting spatial attributes on an image and is capable of identifying obscure or subtle features (Lillesand and Kiefer 1999). ERDAS Imagine 2014, image processing software was used for the image registration then the preparation of land use and land cover. Figure 2 shows the detailed Flowchart of methodology. These factors influencing groundwater recharge, and their relative importance, were compiled from previous literature (Shaban et al. 2006; Yeh et al. 2009, 2014, 2016).

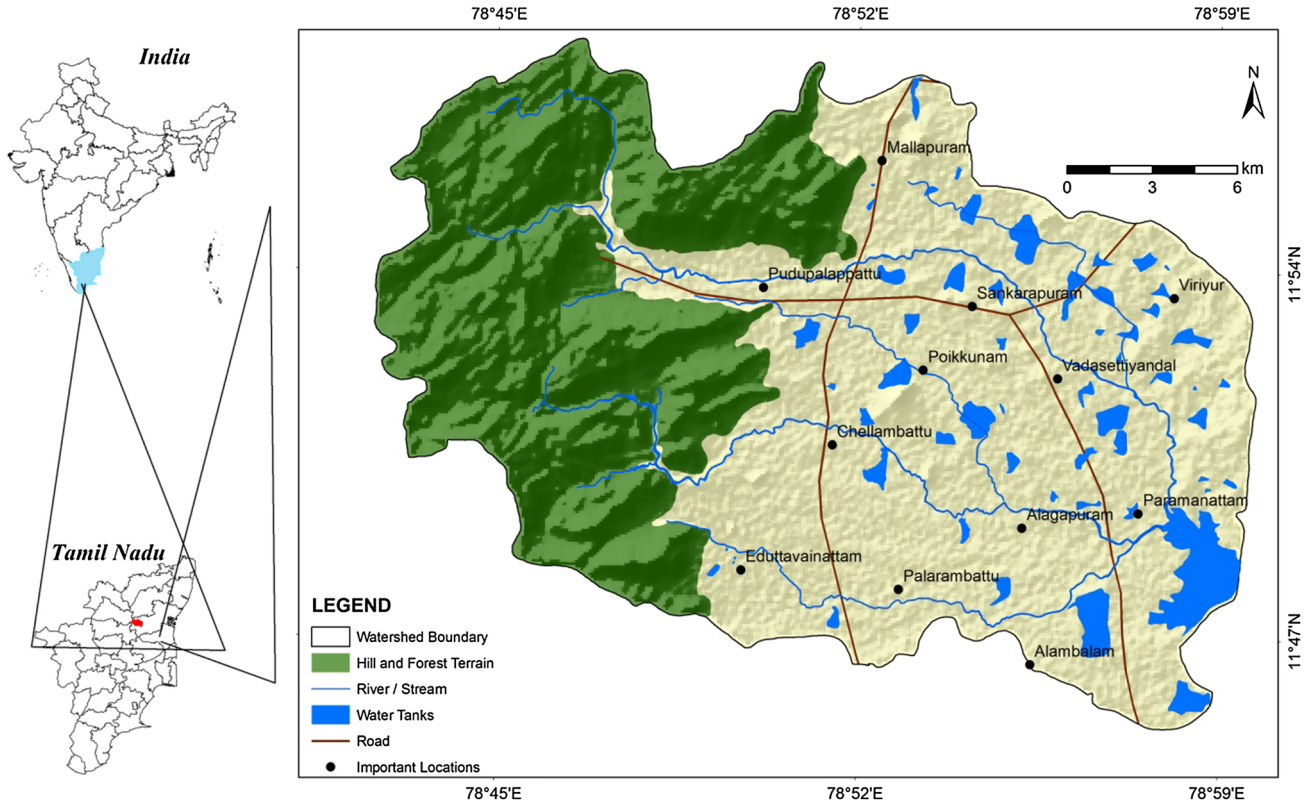

Fig. 1 Study area map

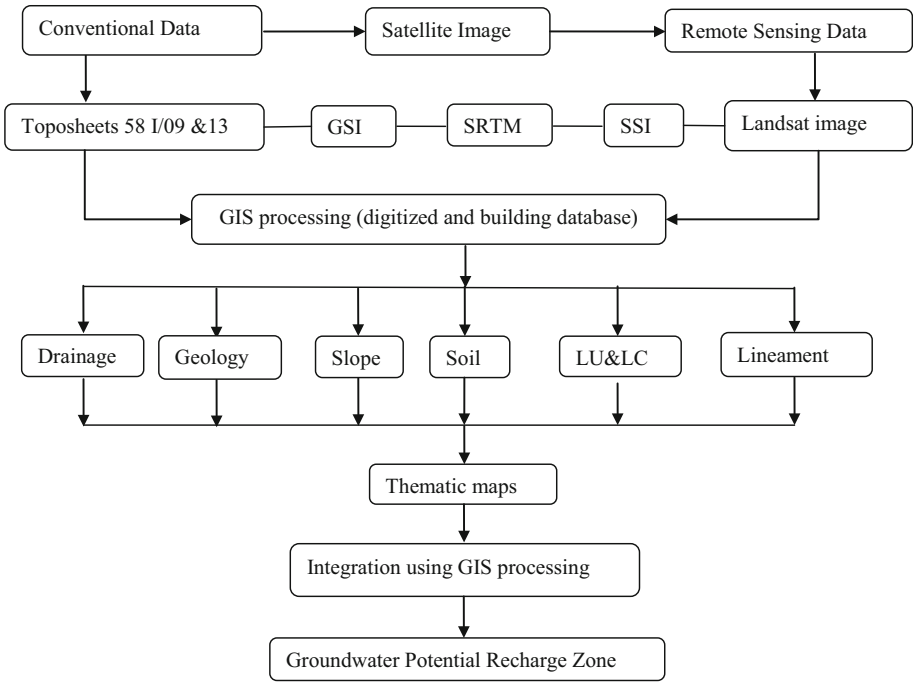

Fig. 2 Flow chart for methodology of groundwater recharge potential zone

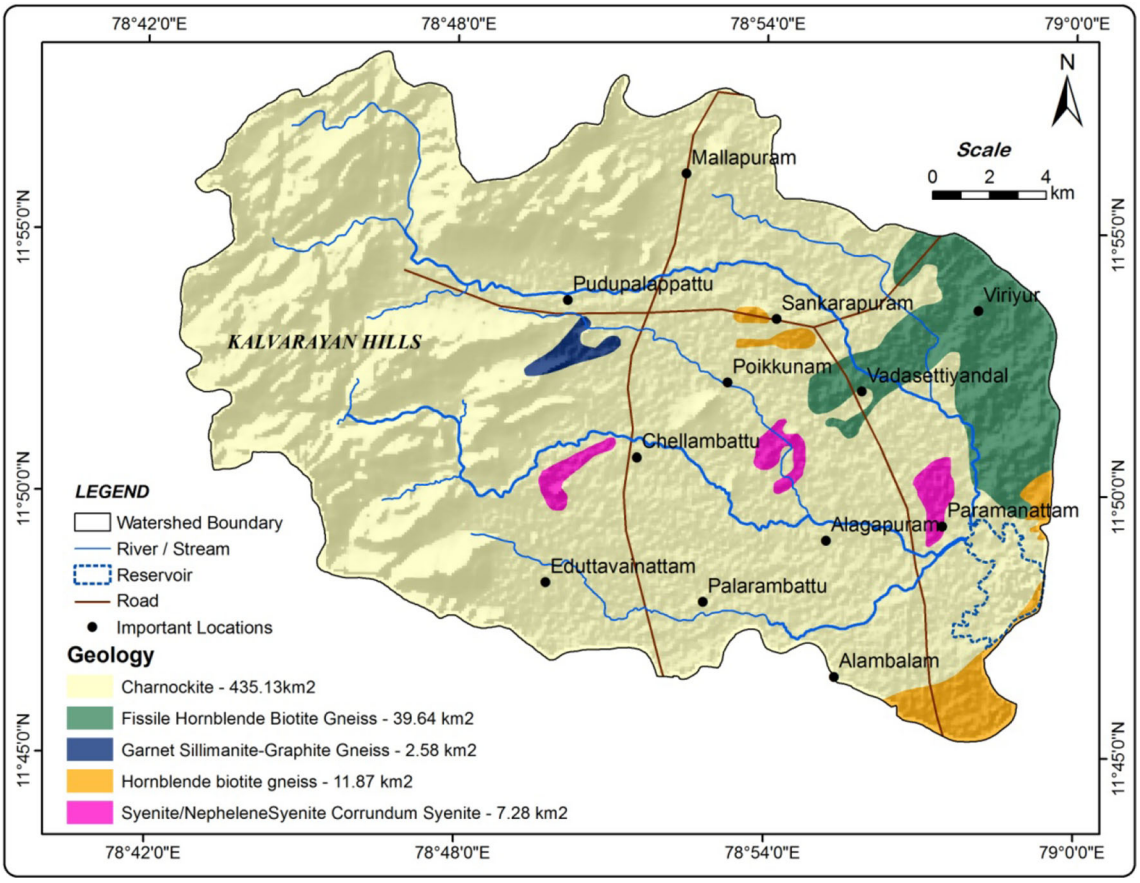

Fig. 3 Geology map of the study area

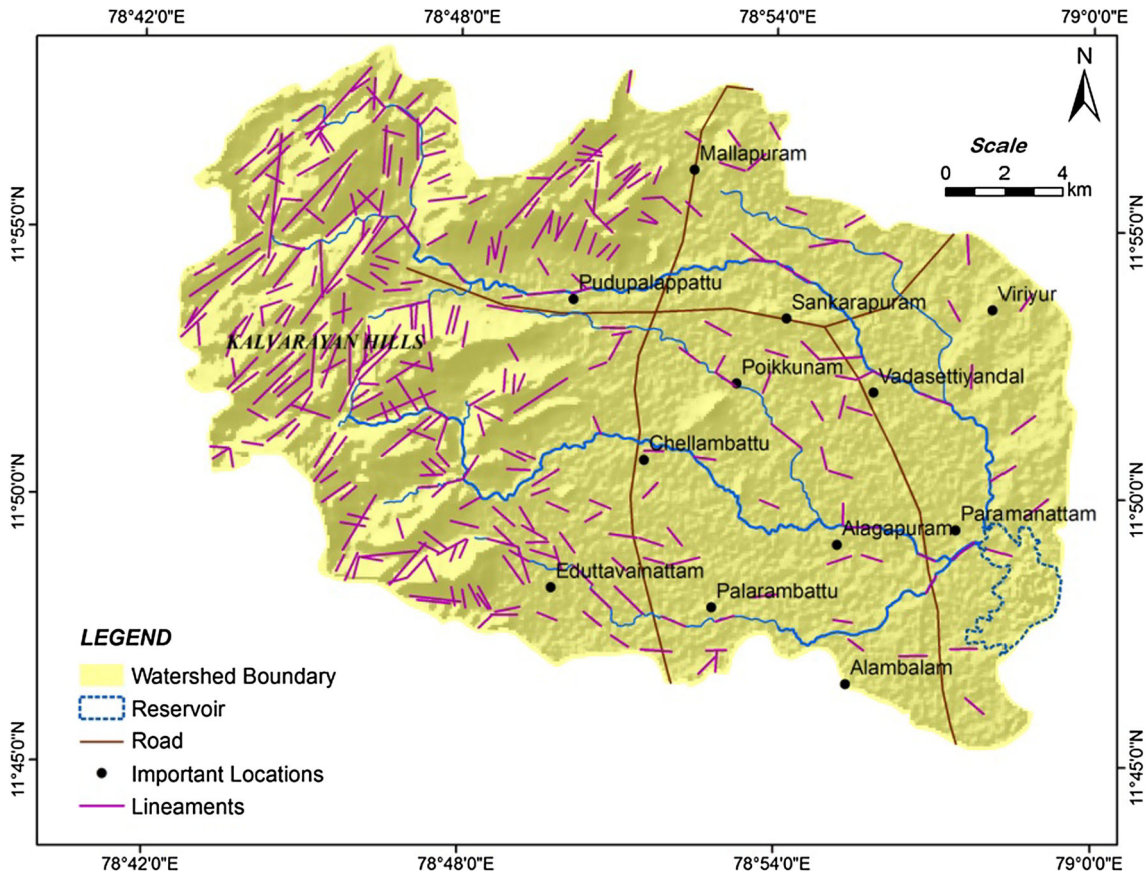

Fig. 4 Lineament map of the study area

Geology

Occurrence of groundwater mainly depending by the underlined rocks. Because the properties of porosity and permeability varied by rocks to rocks. According to Shaban et al. 2006 pointed out that the type of rock exposed to the surface significantly affects groundwater recharge. The geology map was obtained from Geological Survey of India (GSI). The map was traced, scanned and taken into GIS environment. Upper Mamimuktha basin mainly composed charnockite and then followed by fissile hornblende biotite gneiss and then other gneissic rocks are spread some other part of the study area (Fig. 3). In the study area mainly underlain by hardrock whereas groundwater occurrence mainly depending secondary porosity. Groundwater movement also depending secondary porosity of the rocks in the study area. Gnessic rocks are more favorable regions for GWRPZ. Fissile hornblende biotite is more favor for GWRPZ covering an areal extend of 39.64 km^2. Then followed by Hornblende biotite gneiss and Garnet sillimanite graphite gneiss also favorable zone for GWRPZ. Charnockite moderate category for GWRPZ and Syenite is unfavorable for GWRPZ.

Lineament

In the 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 (Dinesh Kumar et al. 2007, Selvam et al. 2014, 2015a, b). The Remote Sensing data, which offer synoptic view of large area, help in understanding and mapping the lineaments both on regional scale and local scale. Use of Remote Sensing technique is quite easy to analyze the lineament with different spectral bands. The lineaments control the movement and storage of groundwater. Lineament and around lineaments may take part in an important role in support recharge of water into the groundwater regime. Major lineaments presents in NE to SW and NW–SE are shown in Fig. 4.

Lineament-length density (Ld); the total length of all recorded lineaments divided by the area under study (Greenbaum 1985):

$$\text{Lineament density} = \sum_{i=1}^{n} \text{Li} \,/\text{A}\,(m^{-1}) \quad (1)$$

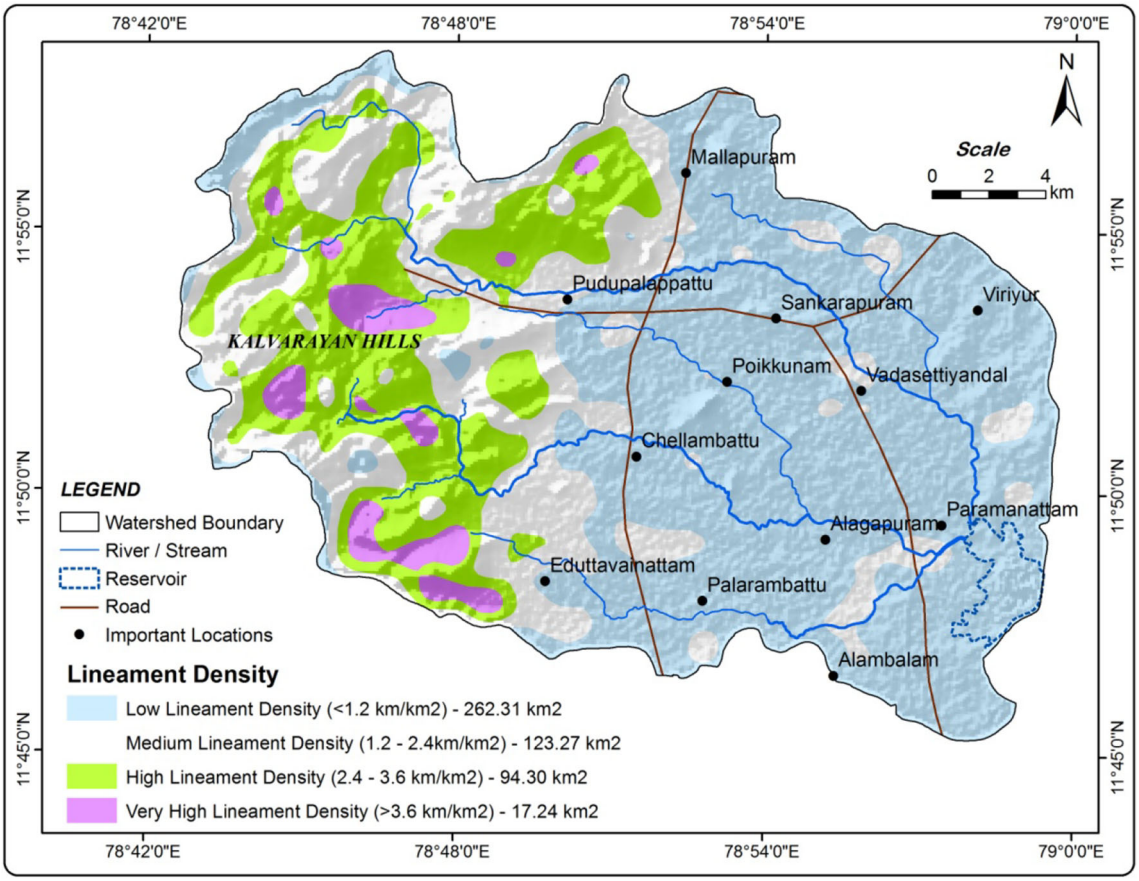

Fig. 5 Lineament density map of the study area

where $\sum_{i=1}^{n} \mathrm{Li}$ denotes the total length of lineaments (L) and A denotes the unit area (L^2). Lineament are extracted and then getting lineament density map. Groundwater potential is high near lineament intersection zones. The lineament density in the study area as shown in Fig. 5 revealed low lineament density of <1.2 km/km^2 present in the maximum part of study area in the eastern side. Followed by medium (1.2–2.4 km/km^2) and high lineament density (2.4–3.6 km/km^2) present in 123.27 km^2 and 94.30 km^2, respectively. The very high lineament density areas which constitute about higher than 3.6 km/km^2 (17.24 km^2). Lineament is the indication of some obstruction for groundwater. Therefore very high and high lineament densities are more favor for GWRPZ.

Drainage density

Drainage pattern depict history of the evolution of the earth crust. The density of the drainage network as well as the occurrence of lineaments, faults, fractures, major or minor joints can have a major influence on groundwater recharge and movement, also provides path ways for groundwater movement and is hydraulically very important (Dinesh Kumar et al. 2007). Another input to evaluate the recharge property can be realized by detailed morphometric analysis of the drainage network. This character is determined fundamentally by the underlying lithology, and thus provides an important indication of water percolation rate (Shaban et al. 2006). It is well known that the denser the drainage network, the less recharge rate. The extraction and analysis of the drainage network was prepared from topographic maps, field data and satellite images. Many studies have integrated lineaments and drainage maps to infer the groundwater recharge potential zone (Edet et al. 1998; Shaban et al. 2006). Drainage densities (DD) were calculated in each of the grid square using following equation (Murthy 2000):

$$\text{Drainage density} = \frac{\text{LWS}}{AWS} \tag{2}$$

where LWS = total length of streams in watershed and AWS = area of the watershed. Most of the drainage originates from the Charnockite hills and inselbergs in the western part of the study area and the drainage pattern is generally dendritic, typical of crystalline basement terrain. The estimated drainage density in the study area as

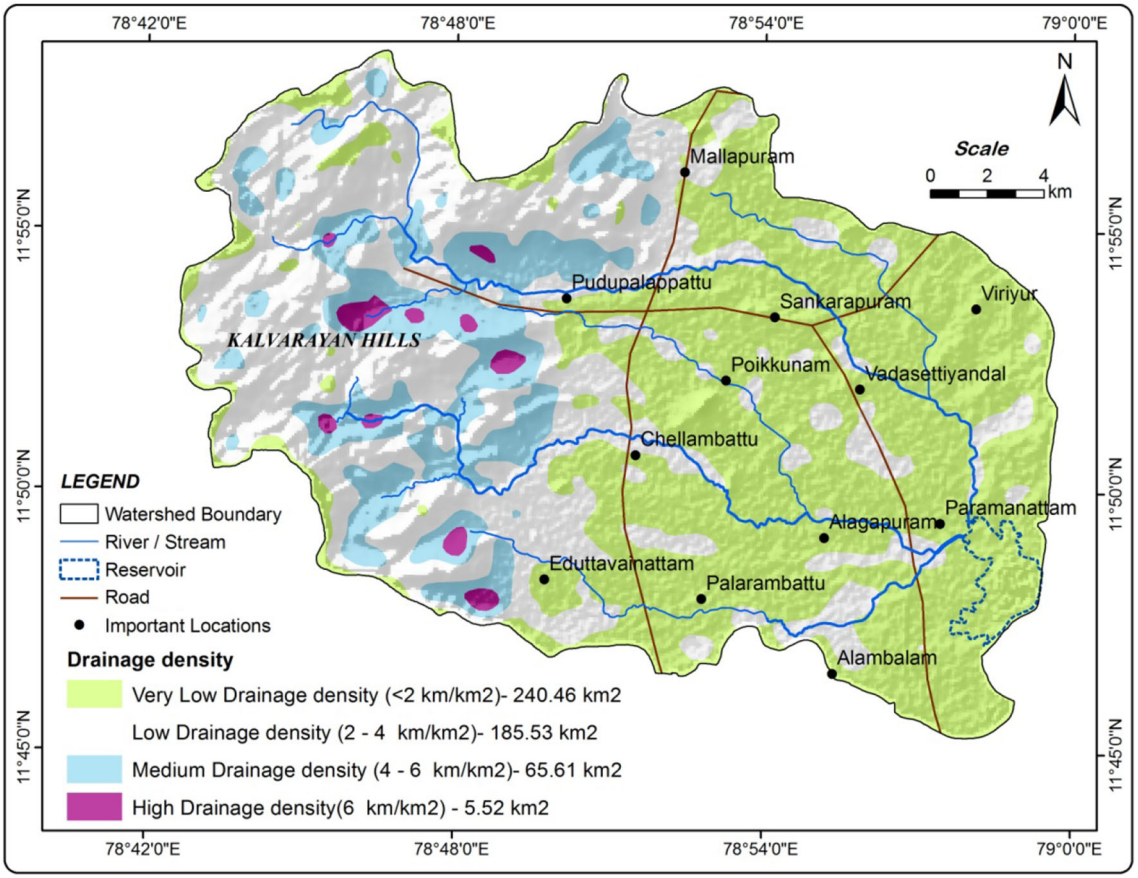

Fig. 6 Drainage density map of the study area

presented in Fig. 6 revealed very low drainage density of <2 km/km^2 present in the maximum part of study area in the eastern side and this is more favorable for GWRPZ. Followed by low (2–4 km/km^2) is areal extend of 185.53 km^2 is favor for GWRPZ. Medium drainage density (4–6 km/km^2) present in 65.61 km^2. The high drainage density areas which constitute about higher than 6 km/km^2 (5.52 km^2). However, the generally moderate to high drainage density implies low or moderate infiltration and recharge potentials of the study area.

Land use and Land cover

Leduc et al. (2001) estimated the difference in the amount of groundwater recharge due to changes of land utilization and vegetation from changes in the groundwater level. Remote sensing and GIS technique provide reliable information for land use/land cover mapping (Selvam and Sivasubramanian 2012; Selvam et al. 2015a). Land use and Land cover mainly illustrate the nature characteristic and coverage of land it gives more information about land. Based on the characteristic wise it used for many purpose and give the valuable information such as water bodies is landcover and agricultural, buildup lands are the Land uses etc… Vegetation has also a major role in groundwater recharge as it affects many processes, (Shaban et al. 2006). Based on the water holding capacity weightages assigned for each subfactors in LULC (Fig. 7) and weightages given in Table 1.

Slope gradient

The gradient of slope is one of the factors that directly influence the infiltration of rainfall (Selvam et al. 2014). Slope determines the rate of infiltration and runoff of surface water, the flat surface areas can hold and drain the water inside of the ground, which can increase the ground water recharge whereas the steep slopes increase the runoff and decrease the infiltration of surface water into ground. The slope of the study area has been calculated in percentage based on the DEM model which was based on the SRTM data. The slope has been classified into five classes (Fig. 8). Slope varied between less than 4 % to more than 16 %. Maximum part of area in the flat

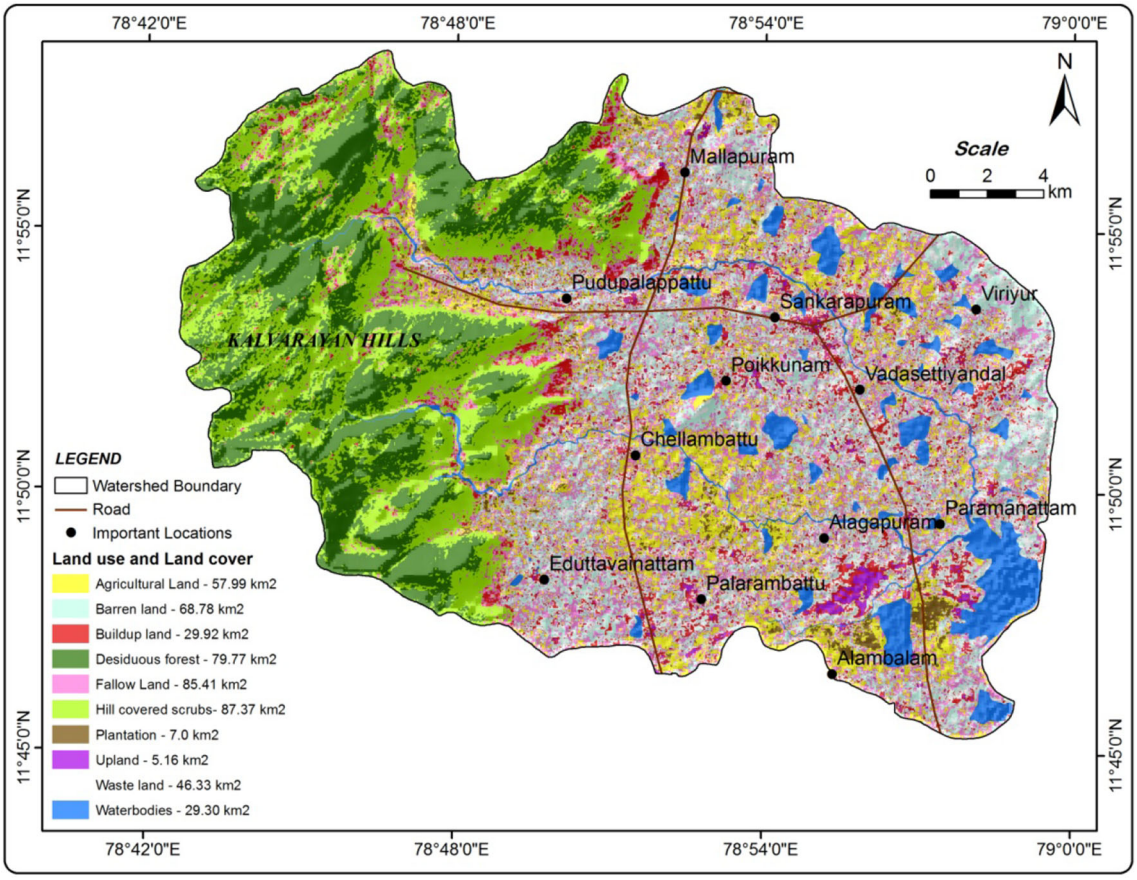

Fig. 7 Land use and Land cover map of the study area

Table 1 Relative rates and score for each potential factor

Factors	Major effects (A)	Minor effects (B)	(A + B)	Proposed score of each influencing factor $\frac{(A+B)\times 100}{\sum 16}$
Geology	1 + 1 + 1 + 1 + 1	0	5	31.3
Lineaments	1 + 1	0	2	12.5
Drainage	1	0.5 + 0.5	2	12.5
Land use and Land cover	1 + 1	0.5 + 0.5	3	18.8
Slope	1 + 1	0.5	2.5	15.6
Soil	1	0.5	2.5	9.4
			Σ16	100

category (>4 %), it cover the eastern and central part of area and areal cover of 314.36 km^2 is more favor for GWRPZ. Sloping (4–8 %) is indicate less amount of infiltration, strongly sloping (8–12 %) and moderately steep (12–16 %) are groundwater runoff is more. Mountainous Sloping (>16 %) cover in the western part of the area covered 65.78 km^2. The mountainous region indicating more runoff and no infiltration of groundwater.

Soils

Soils play an important role in encouraging or discouraging the recharge of groundwater and determining the quality parameters of groundwater. The term soil has specific implication to different groups involved with soil survey and mapping (Lillesand and Kiefer 1987). Study area mainly underlined by alfsols, entisols, hillsols, inceptisols, vertisols

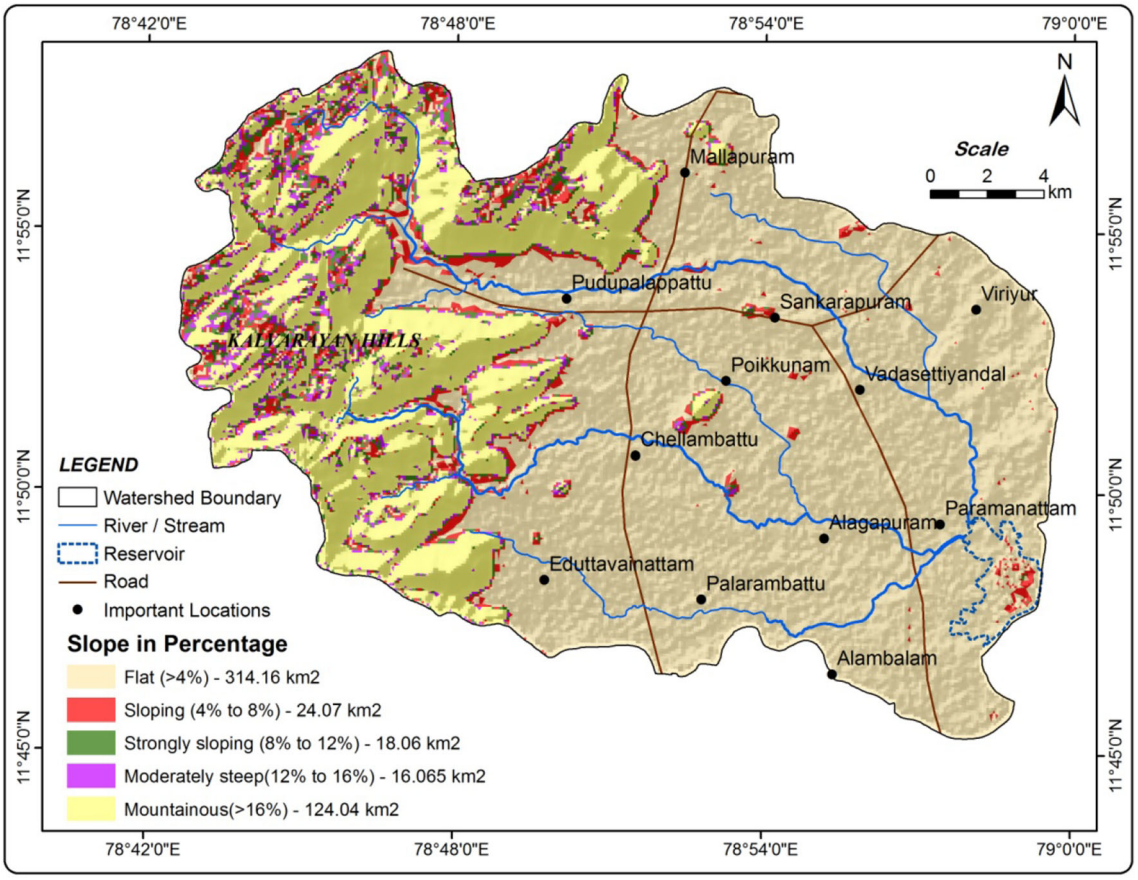

Fig. 8 Slope map of the study area

and reserve forest. The Fig. 9 shows major part of area covered by hillsols (166.43 km^2). groundwater recharge mainly depending of soil type of the study area. Because soil type indicates the groundwater holding capacity and infiltration. Based on the water holding capacity vertisols more favor for GWRPZ. Vertisols are very fine grains and to hold more groundwater. Alfisols favor for GWRPZ because this also fine grains and interconnected.

Results and discussion

Factors influencing recharge potential

The occurrence and movement of groundwater is influenced by geology, structure, geomorphology and drainage, soil, slope is further affected by land use. In this study, seven thematic layers viz. Geology, lineament, lineament and drainage density, Land use and Land cover, slope and soil have been generated for analysis and integration into a prospect map. The groundwater recharge potential zone has been assessed in many countries (Krishnamurthy et al. 1996; Saraf and Choudhury 1998; Shahid et al. 2000; Jaiswal et al. 2003; Sener et al. 2005; Shaban et al. 2006; Yeh et al. 2009, 2014, 2016; Adham et al. 2010); Selvam et al. 2014, 2015a, b, Samson and Elangovan, 2015 and Prasanta Kumar Ghosh et al. 2016.

Weightage calculation in influence factor (IF) techniques

This study bears similarities to studies performed in other regions (Shaban et al. 2006; Yeh et al. 2009 and Prasanta Kumar Ghosh et al. 2016) in terms of the approach used but is distinguishable by the larger spatial scale and finer resolution considered here.

During weighted overlay analysis, the weightage was given for each individual parameter of each thematic map, and weights were assigned according to the multi IF of that particular feature on the hydro-geological environment of the study area (Shaban et al. 2006; Yeh et al. 2009, 2014; Adham et al. 2010; Singh et al. 2011; Magesh et al. 2012; Gumma and Pavelic 2012; Selvam et al. 2014, 2015a, b; Samson and Elangovan, 2015; Prasanta Kumar Ghosh et al. 2016). For this study mainly focuses six factors such as Geology, Lineament density, drainage density, Land use

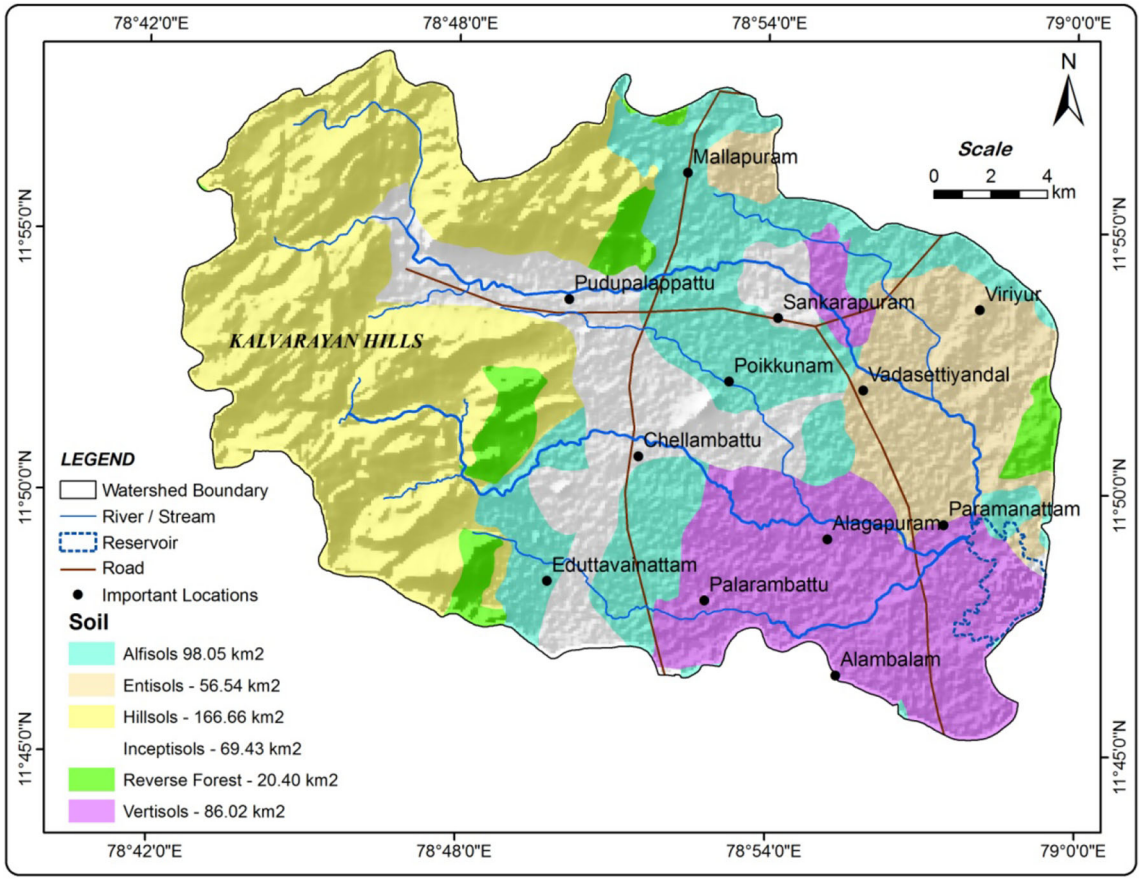

Fig. 9 Soils map of Manimuktha

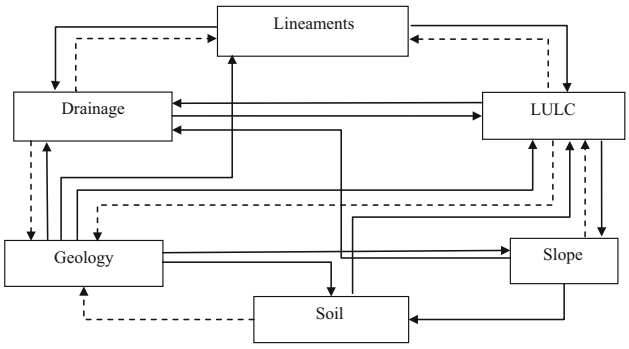

Fig. 10 Interactive influence of factors concerning recharge properly (modified from Shaban et al. 2006)

and Land cover, slope and soil were related to other factors and also some factors were interrelated. Figure 10 shows the primary and secondary relationship of the influence factors. Based on this relation weightages were examined and assigned for evaluated the groundwater potential recharge zone. A major interrelationship between two factors is assigned a weight of 1.0. A minor interrelationship between two factors is assigned a weight of 0.5 (Shaban et al. 2006 and Yeh et al. 2009). Finally, the total weight of each factor is the representing weight of the recharge potential. This high weight value means that the factor significantly influences the groundwater recharge. The process for determining the relative rate of each factor given in Table 1. The score of each recharge potential factor was calculated as 100 multiplied by the weight of the recharge potential divided by the total weight of each recharge potential factor (Yeh et al. 2009, Selvam et al. 2014 and Prasanta Kumar Ghosh et al. 2016). Table 1 shows the calculation approach.

The proposed score of every Influence factors reclassified and to put for subfactors (Table 2).

Integration analysis

Finally all the influence factors superimposed one over another get the final out map of groundwater recharge potential zone. Based on the score the groundwater recharge potential zone classified as five types such as very low, low, moderate, high and very high. Figure 11 shows the score and five types of GWRP. It show the water bodies and downstream areas fall in the very high GWRPZ (12.4 km^2) indicate high infiltration and low runoff. Then followed by high

Table 2 Assigning weightage of factors influencing recharge potential

Influence factor	Subfactors	Proposed score of each influencing factor	Weightages
Geology	Syenite/nephelenesyenite corrundum syenite	31.3	6.3
	Garnet sillimanite-graphite gneiss		12.5
	Hornblende biotite gneiss		18.8
	Fissile hornblende biotite gneiss		25
	Charnockite		31.3
Lineament density	Very high lineament density (>3.6 km/km^2)	12.5	3.1
	High lineament density (2.4–3.6 km/km^2)		6.3
	Medium lineament density (1.2–2.4 km/km^2)		9.4
	Low lineament density (<1.2 km/km^2)		12.5
Drainage density	Very low drainage density (<2 km/km^2)	12.5	12.5
	Low drainage density (2–4 km/km^2)		9.4
	Medium drainage density (4–6 km/km^2)		6.3
	High drainage density (6 km/km^2)		3.1
LULC	Hill covered scrubs	18.8	1.9
	Buildup land		3.8
	Upland		5.6
	Waste land		7.5
	Barren land		9.4
	Desiduous forest		11.3
	Fallow land		13.1
	Plantation		15
	Agricultural land		16.9
	Waterbodies		18.8
Slope	Mountainous (>16)	15.6	3.1
	Moderately steep (12–16)		6.3
	Strongly sloping (8–12)		9.4
	Sloping (4–8)		12.5
	Flat (<4)		15.6
Soil	Hillsols	9.4	1.6
	Inceptisols		3.1
	Reserve forest		4.7
	Entisols		6.3
	Alfsols		7.8
	Vertisols		9.4
		100	

GWRPZ (115.74) indicate maximum part of area covered by agricultural land as well as fallow land, so the infiltration high. In the poor and very poor GWRPZ mainly fall in the hilly terrain as well as in the waste, barren and buildup land of the study area, indicating more runoff and less infiltration. In the moderate GWRPZ mainly fall in plantation, some of the charnockite rock of the study area.

In order to measure the quantity of recharged water to subsurface media, a simplified calculation for the proposed recharge rates (adapted from UN 1967) and areal extent of recharge potential zones obtained in this study (Table 3): as the average rainfall is 1115 mm/year, the volume of precipitated water of this Manimuktha subbasin will be around 554.2×10^6 m^3/year. This is applied for five recharge potential zones to estimate total recharged water (W) as follows:

$$W = \text{Precipitated volume} \times \text{recharge ratio} \times \%\ \text{of area} \quad (3)$$

$$= 555.4 \times 10^6 (0.45 \times 0.03 + 0.42 \times 0.23 + 0.37 \times 0.32 + 0.32 \times 0.25 + 0.21 \times 0.17)$$

$$= 555.4 \times 10^6 (0.355)$$

$$= 191.17 \times 10^6 \mathrm{m}^3/\mathrm{year}$$

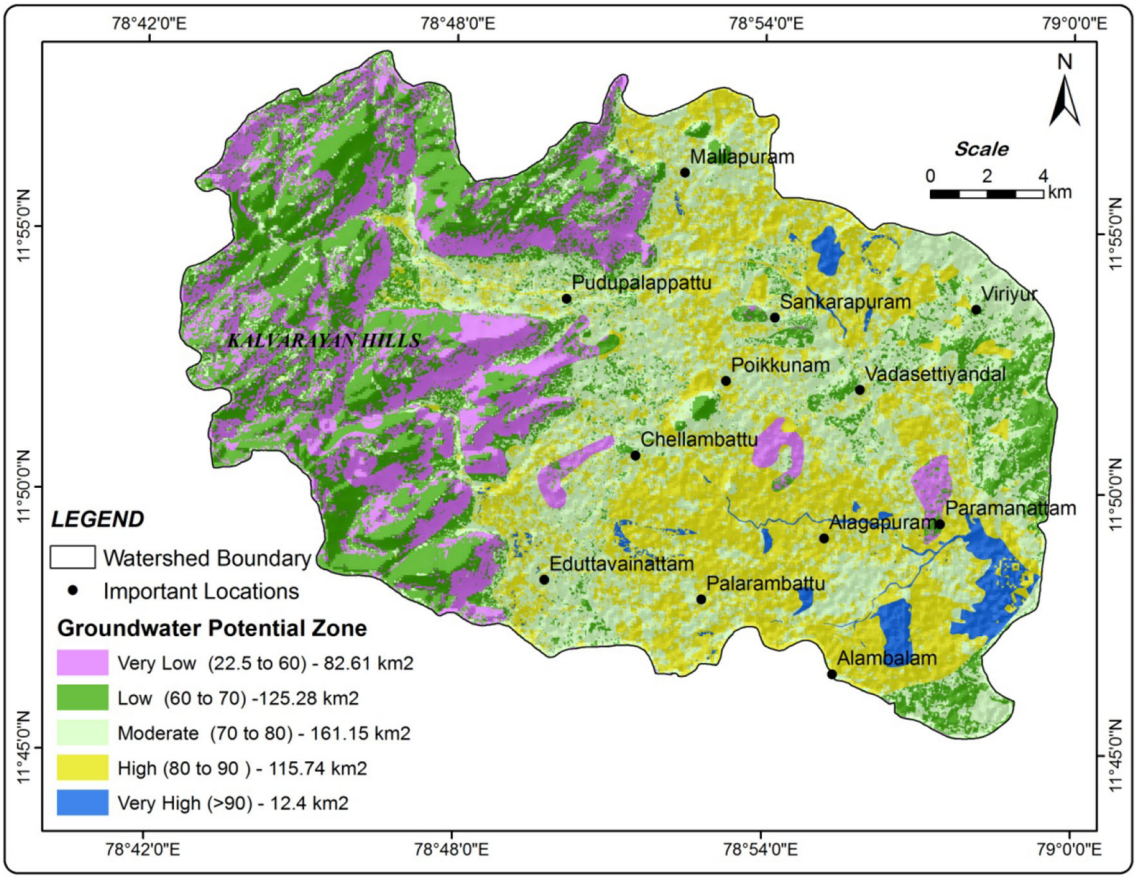

Fig. 11 Groundwater recharge potential map of Manimuktha

Table 3 Groundwater recharge potential zones and categorization

Recharge potentiality	Very high	High	Moderate	Low	Very low
Proposed score	90–93.4	80–90	70–80	60–70	22.8–60
Recharge potential score average	45.3	42.1	37.2	32.1	20.9
Occupying study area in km^2	12.4	115.74	161.15	125.28	82.61
Area in percentage	3	23	32	25	17

which indicates that only 191.17×10^6 m^3/year water that means 34.42 % of precipitated water in Upper Manimuktha subbasin is infiltrating downward to recharge the groundwater reservoirs and waterbodies etc… whilst the rest of precipitation either evapo-transpirates or flow out as surface run off. So proper prediction to need to maximum infiltration and obstruction of water for groundwater recharge.

Conclusion

This study mainly gives some idea about groundwater recharge potential of Upper Manimuktha subbasin, Vellar, Villupuram district of Tamil Nadu. The study indicates geoinformatic help to assess the GWRPZ. Based on the study the very high GWRPZ fall in the Manimuktha reservoir, waterbodies and surrounding of the downstream area. Then the lineament also obstructs the water to help the recharge of groundwater. Based on the GWRPZ study indicates 34.4 % of the rainwater infiltrate in the ground of the entire study area. So some additional sustainable developments need to recharge maximum of groundwater.

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