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ORIGINAL ARTICLE

Mapping of groundwater potential zones in Killinochi area, Sri Lanka, using GIS and remote sensing techniques

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Abstract Groundwater is a vital natural capital for the consistent and economic provision of potable water supply for both rural and urban environments. There is now a strong consensus that climate change poses a fundamental challenge to the well-being of all countries, with potential of being the harshest on countries already suffering from water scarcity. Dry zone of Killinochi basin in Northern Sri Lanka, which was devastated by civil war for last 25 years, is again being revitalized by human settlement and urbanization in last couple of years. However, the decreasing trend in the rainfall regime of the dry zones and the increase in population size (temporary inflow) and, hence, the demand for water for irrigation and other livelihood requirements, calls for a sustainable exploitation of the groundwater resources in the region. The development of a reasonable model for groundwater potential is need for the present time. This work strives to generate groundwater potential zonation map using integrated use of remote sensing and geographic information system (GIS) for Killinochi area, Northern Sri Lanka. Five different themes of information, such as geomorphology, geology, soil type (extracted from existing topo sheet); slope [generated from shuttle radar topography mission (SRTM) digital elevation model (DEM)]; and land use/land cover (extracted from digital processing of AVNIR satellite data) were integrated with weighted overlay in GIS to generate groundwater potential zonation map of the area. The final map of the area was demarcated by four different zones of groundwater prospects, viz., good (5.32 % of the area), moderate (61.90 % of the area) poor (26.61 % of the area), and very poor (6.17 % of area). The hydrogeomorphological units, such as alluvial plain, low slope area, and land occupied by forest, are prospective zones for groundwater occurrence in the study area.

Keywords Killinochi · Groundwater potential zonation · GIS · Remote sensing

Introduction

Water is one of the most essential commodities for mankind and the largest available source of fresh water lays underground. It is one of the most significant natural resources which support both human needs and economic development. The arid and semi-arid areas characterized by short periods of heavy rainfall and prolonged dry periods, the continual replenishment of groundwater storage and its sustainable utilization is indispensable to address the water needs of the community. Human activities cause changes in groundwater by change in land use/land cover, soil cover, and reduction in groundwater recharge. Although best methods to estimate aquifer thickness and preferable location of borehole are groundwater pumping test/drilling test and stratigraphy analysis, they are cost and time intensive as well as often require skilled manpower (Moss and Moss 1990; Fetter 1994; Madan et al. 2010; Mukherjee et al. 2012; Mallick et al. 2015). On the other hand, the integrated use of remote sensing, GIS, and satellite data is time and cost effective means to assess and manage groundwater resources (Adiat et al. 2012; Verma and Singh 2013). This method that has a significant potential to monitor the information about

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various phenomenon and changes on the earth surface, such as soil type, geomorphology, land use/land cover, elevation, slope, etc., based on spectral reflectance on earth surface is widely accepted (Avtar et al. 2010; Verbesselt et al. 2006; Scanlon et al. 2005). Several scientific communities have already reported the importance of different hydrogeological factors, viz., geomorphology, geology, land use/land cover, slope, soil cover, drainage density, surface temperature, etc., controlling groundwater potential of any areas, however, the extent to which they affect it may differ from place and time (Sener et al. 2005; Sreedhar et al. 2009; Avtar et al. 2010; Gaur et al. 2011; Adiat et al. 2012). It is important to consider these factors very precisely with inputs from different scientific experts and field observation. Sri Lankan economy depends on agricultural production. Water availability and demand in Sri Lanka show a highly spatial variability and temporal variability. The water scarcity is prominent especially in the dry areas of the country, where there is a high demand of usable water to irrigate 85 % of the land, which is aimed at increasing agricultural productivity (Hettiarachchi 2008). Groundwater is the major source of fresh water, especially among the rural communities in the dry parts of Sri Lanka. The groundwater flow dynamics is highly dependent on the hydrogeological formations through which the flow takes place (Freeze and Cherry 1979). For the dry zones of the Killinochi basin in Northern Sri Lanka, the monsoon and inter-monsoonal periods play the major role in replenishing these ground water resources. This area was devastated by civil war for last 25 years, and is again being revitalized by human settlement and urbanization in last couple of years. The long civil war between Sri Lankan Government and the Liberation Tigers of Tamil Eelam (LTTE) has caused significant hardships for the population, social and physical aspects, and the economy of the country (Gunawardena 2011). After having been displaced by war, residents return to their villages and started their livelihood. According to the census report by department of census and statistics in Sri Lanka, the population size has jumped from 23,625 in 2009 to 112,875 in 2012 in Killinochi district (Population and Housing data 2012).

The decreasing trend in the rainfall regime of the dry zones and the increase in population size, and hence the demand for water for irrigation and other livelihood requirements, calls for a sustainable exploitation of the groundwater resources in the region. The task of estimating the volume of groundwater entering the aquifer system and its spatial and temporal distribution over the domain is very difficult (Gupta 2008). It is highly demanding, both in terms of manpower and resources, to get reliable information on its availability. The previous studies have shown that the seasonal available water resource per unit area in the Killinochi district is less than 0.1 m for both the maha and yala seasons. The per capita water withdrawal is among the highest in Sri Lanka for the Killinochi district. According to a projection by the same study considering the current level of irrigation efficiency, it is expected that by 2025, more regions will fall into water-scarce category (Amarasinghe et al. 1999). Sustainable development of the groundwater resources can be considered as the only viable alternative to support the community in the dry areas without depleting the groundwater reserve, mainly to improve their livelihood by maximizing agricultural output. With aforementioned background information, present work attempts to generate groundwater potential zonation map based on five thematic layers, viz., geomorphology, geology, soil cover, slope, and land use/land cover using remote sensing and GIS technique for the better planning, utilization, and management of groundwater resources. These five thematic layers are taken into consideration after deep literature review and because of only available data along with field expert advice. The result is validated with observed seasonal hydraulic head map.

Study area

The Killinochi area is situated in the dry zones of Northern Sri Lanka on 9°22′39.54″N and 80°22′33.54″E coordinates with an annual average temperature of 28 °C (Fig. 1). There are two distinct seasons: wet and dry. January and May are the coolest and hottest months, respectively. The average annual rainfall in dry zone is 1,300 mm per year. Most of the rainfall occur during the Maha season, which occur from October to January and bring rain to the northern and eastern regions of Sri Lanka. The dry season (Yala season) varies from May to September (Bandara 2003). The total land area is approximately 1205 Km^2. Although rainfall amount is quite enough for this small area, because of temporal asymmetry and poor water resource management policies, there is water scarcity especially in the dry period. The poverty level in this area is as high as 64 %, which is more than double for the national average (Asian Development Bank 2011). The Killinochi area, being at the center of the 26 years long devastating civil war (1983–2009), has seen major destruction of its irrigation facilities and water reservoirs. Hence, the poverty in the area can be mainly attributed to the war that resulted in the destruction of most of the infrastructure in the district. As the war displaced residents return to their villages, competition for the already scarce water resource is expected to grow sharply. According to the national census data, the population has quadrupled from 23,625 in 2009 to 112,875 in 2012 (Wikipedia. http://en.wikipedia.org/wiki/Kilinochchi_District).

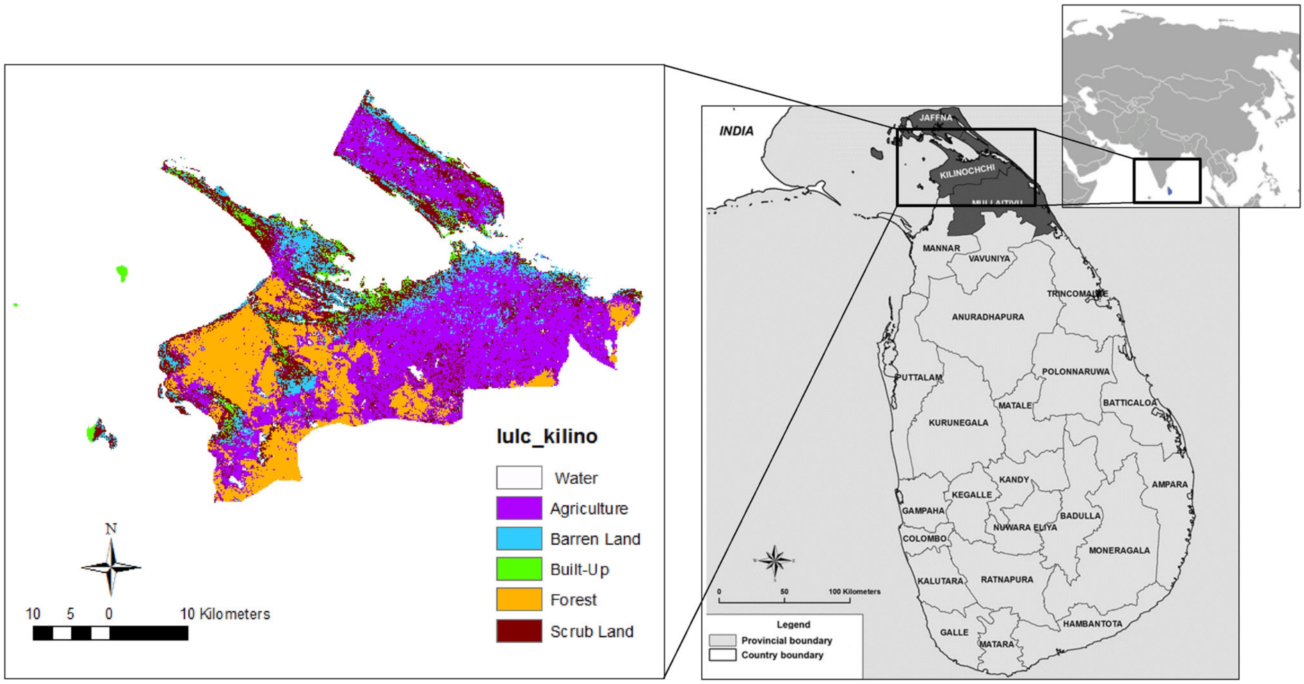


Fig. 1 Study area map

Material and methodology

To generate groundwater potential zonation map, a multi-parametric data set comprising remote sensing data and conventional maps, including topographic sheets, provided by survey of Sri Lanka were used. In the first step, all the data have been converted to digital format, by scanning in TIFF format and geo-referenced into Universal Transverse Mercator (UTM), spheroid, and datum WGS-1984. Remote sensing data were used directly for thematic map generation, as they are already in digital format. Five different themes of information, viz., geomorphology, geology, soil type, slope, and land use/land cover, were prepared and used. Map of geomorphology, geology, and soil type were extracted from existing topo sheet and maps with a scale of 1:250000, developed in 2013 (Thomas et al. 2009). These maps were further updated using satellite data. Slope map was generated from shuttle radar topography mission (SRTM) digital elevation model (DEM) data. Map of land use/land cover was extracted from digital processing of AVNIR satellite data. All satellite images to generate slope and land use/land cover were captured during March to June, 2013 with less than ten percent of cloud cover. A standard false color composite (FCC) was prepared from bands-4,-3,-2 coded in red, green, and blue colors' scheme which highlights the geomorphic features, land use, vegetation cover, and soil types. The AVNIR 2 image and ArcGIS 10.2 software were used for the data processing.

To generate groundwater potential zonation map of the area, all five different thematic layers were integrated with weighted overlay in GIS. Each thematic map was assigned a weight on a scale of 1 to 5 depending on its influence on the groundwater development (both storage and movement of groundwater). The weight for respective thematic maps was calculated based on weight normalization using the principal component analysis followed by pair-wise comparison matrix using Saaty's analytical hierarchy process (Saaty 1994). Different features of each theme were assigned rank on a scale of 0 to 9 according to their relative influence on the groundwater development. Based on this scale, a qualitative evaluation of different features of a given theme was performed with very poor (weight = 0–1.5), poor (weight = 1.5–3.0); moderate (weight = 3.0–4.5); good (weight = 4.5–6.0); very good (weight = 6.0–7.5); and excellent (weight = 7.5–9). The weight and rank of each thematic layer are given in Table 1. To differentiate groundwater potential zone, scored maps of all the five thematic layers after assigning weights were integrated (overlaid) step by step using spatial analyst tool of ArcGIS. The total weights of different polygons in the integrated layer were derived from the following equation to obtain groundwater potential index (Rao and Briz-Kishore 1991):

$$\mathrm{GWPI} = ((\mathrm{GM_w})(\mathrm{GM_{wi}}) + (\mathrm{GG_w})(\mathrm{GG_{wi}}) + (\mathrm{SL_w})(\mathrm{SL_{wi}}) + (\mathrm{ST_w})(\mathrm{ST_{wi}}) + (\mathrm{LC_w})(\mathrm{LC_{wi}})), \quad (1)$$

Table 1 Weight and ranking for different themes and features, respectively, for groundwater potential zonation

Theme	Weight	Features	Rank
Geomophology	5	Beach ridges, bars, and splits	8
		Low planta. Surfaces with inselbergs and thin soil	4
		Plateau of miocene limestones	9
		River plains and adjacent coastal lowlands	7
		Undifferentiated	2
		Upwarped pleistocene coastal plain	6
Geology	4	Alluvial and lagoonal clay, silt, and sand	6
		Chamockitic biotic gneiss	4
		Jaffna limestone	8
		Red earth and brown sand	6
		Undifferentiated Vijayan gneiss with trend lines	5
Slope	3	0–1	5
		1–2	4
		2–5	3
		5–9	2
		9–30	1
Soil type	2	Immature brown loams (dry zone)	2
		Reddish brown earths	5
		Regosolic alluvial soil	8
		Solodised solonetz and solonchaks	6
Land use/land cover	1	Water	9
		Agriculture	6
		Barren land	4
		Built up	1
		Forest	7
		Scrub land	5

where GWPI = groundwater potential index, GM = geomorphology, GG = geology, SL = slope, ST = soil type, and LC = land use/land cover, and the subscripts ‘w’ and ‘wi’ refer to the normalized weight of a theme and the normalized weight of the individual features of a theme, respectively. Here, GWPI is a dimensionless quantity that helps in indexing probable groundwater potential zones in the area. The resultant map was classified into good, moderate, and poor zones. The results were validated using hydraulic head maps (groundwater depth) of the area using observed field data. Hydraulic head map is generated by the inverse distance weighting method. Flow chart for the methodology adopted in this work is shown in Fig. 2.

Result and discussion

Description of all five thematic layers (geomorphology, geology, slope, soil type, and land use/land cover) with their spatial distribution in the study area is presented in following section.

Geomorphology map

Visual interpretation of digitally enhanced images enables identification of the geomorphologic features. Geomorphology of an area gives the information about description and genesis of its landforms, which depends upon the structural evolution of geological formation (Gupta 2003). In other way, geomorphologically, the area depicts both its erosional and depositional landforms. Among five different thematic layers, geomorphology was assigned highest weight, because it plays dominant role in the movement and storage of groundwater at any place (Thomas et al. 2009). In this study area, geomorphological map is composed of five major units, as shown in Fig. 3. Geomorphologically, the study consists of structures formed in both coastal and continental environments.

- Beach ridges, bars, and splits: Beach ridges, bars, and splits are morphological signature of coastal environment typically found in the north and west parts of the study area. Here, beach ridges are the coastal barriers

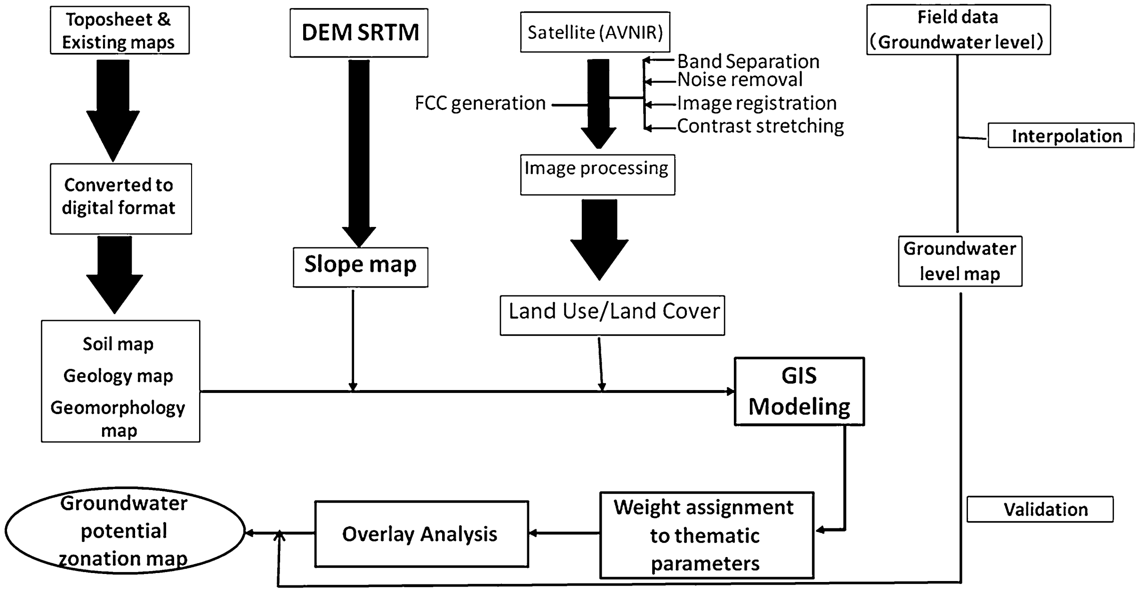
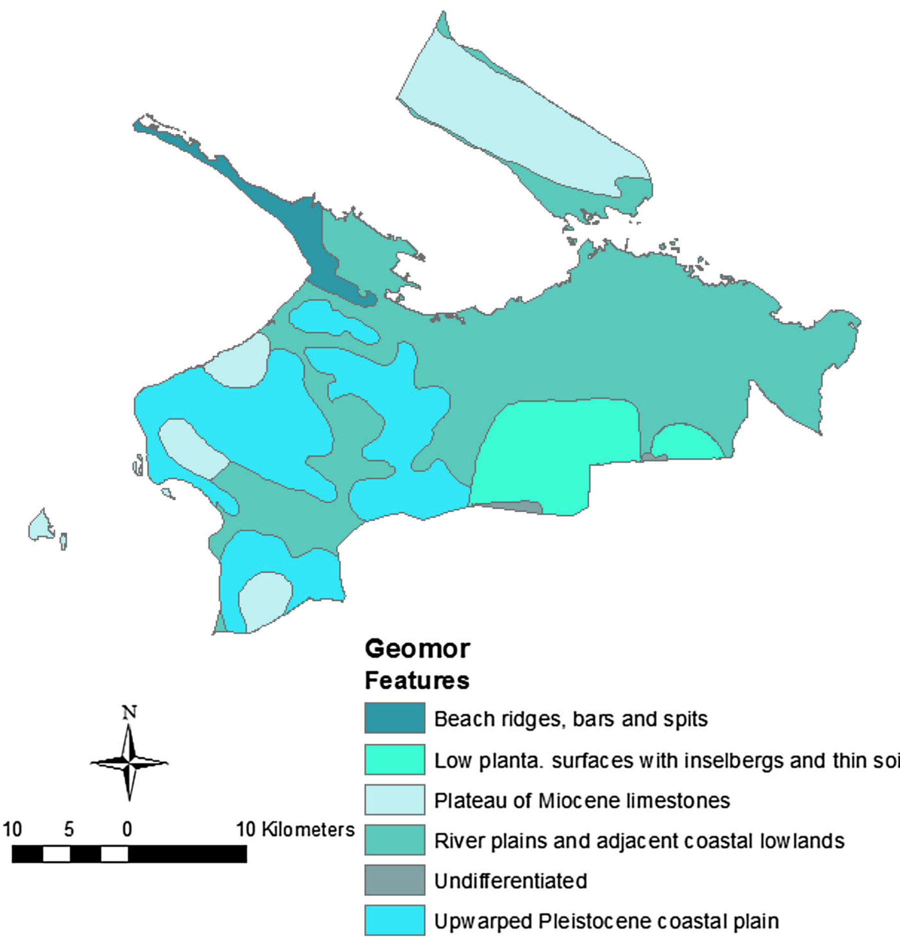


Fig. 2 Methodology adopted for the generation of groundwater potential map in Killinochi area, Sri Lanka

Fig. 3 Geomorphological map of the study area



which migrate landward in response to changes in sea level, changes in sediment supply, and changes in coastal erosion that result from tectonic uplift or subsidence. They are the transitional zone from terrestrial to marine processes with bi-directional flows. Bar-like structure form here, because of high seasonality in

the area. High energy storms during winter cause beach erosion, while beach construction occurs during fair weather conditions summer months.

- Low plantation surfaces with inselbergs and thin soil: These structures found in south of the study area and represent erosional remnants of oldest plain surface marked by domes of Vijayan gneiss and quartzite. Because of high slope and relief, they are not suitable for groundwater exploration.
- Plateau of Miocene limestone: Extensive belt of Miocene (5–20 million years ago) limestone is found along the northwest coast, overlain in some areas by Pleistocene (1 million years ago) deposits. They consist of relatively flat terrain that is raised significantly above the surrounding area with some steep slopes. They exhibit characteristic island karst features. Because of high hydraulic conductivity, they are considered as very good sites for groundwater exploration.
- River plains and adjacent coastal lowlands: Natural stream of fresh water fed by its tributaries flows along a definite course into the sea. Because of the flat topography, this region has high groundwater potential.

Geology

Geology also plays major role in groundwater occurrence in any area. Here, the study area is occupied by five major features (Fig. 4).

- Alluvial and lagoonal clay, silt, and sand: Alluvial is the depositional structure formed by running water from all different basins in Killinochi area. Lagoons are bodies of water on the landward side of barrier islands near the coastal region. Both of these places contain finer sediments with grain size varying from clay to sand and poor sorting order. Area is considered moderately well for groundwater exploration.
- Chamockitic biotic gneiss: Here, charnockite represents a conformable intrusive igneous rock which with biotite gneiss was subjected to high-grade metamorphism. Charnockite and surrounding gneiss have layer structure composed of melanocratic and leucocratic parts. Mineralogically, melanocratic parts consist of hornblende and biotite in gneiss, and orthopyroxene added in charnockite. Leucocratic parts are composed of

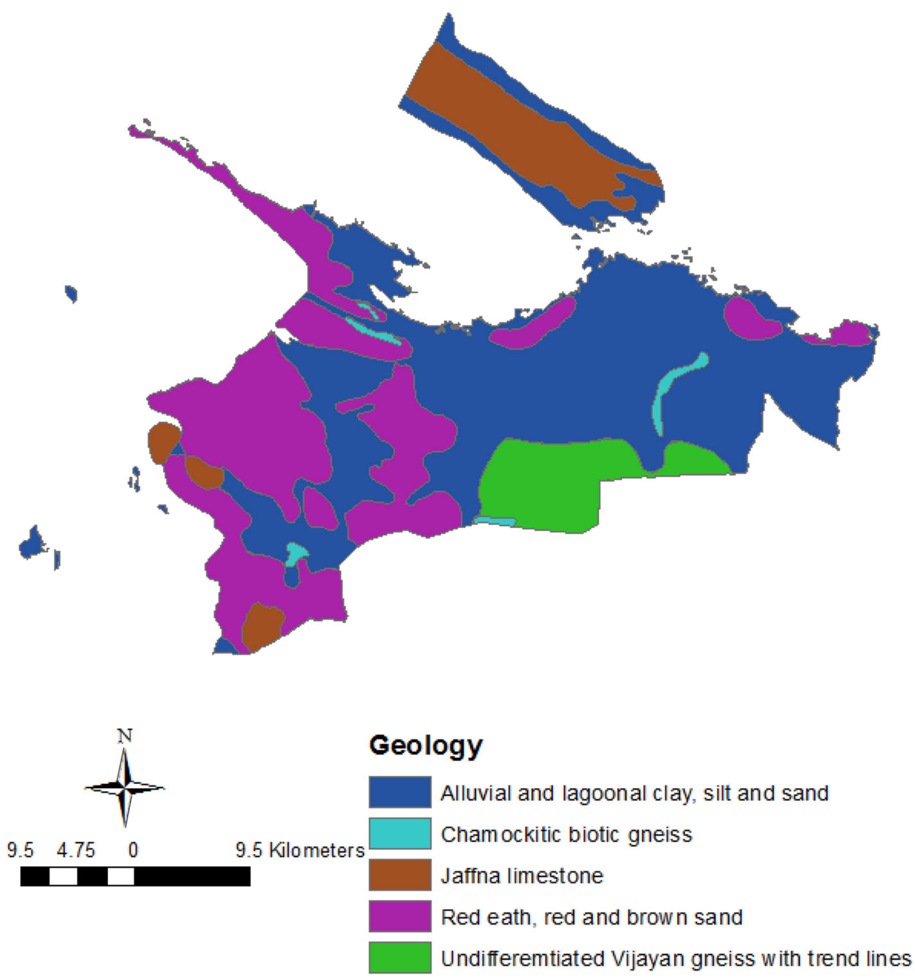


Fig. 4 Geological map of the study area

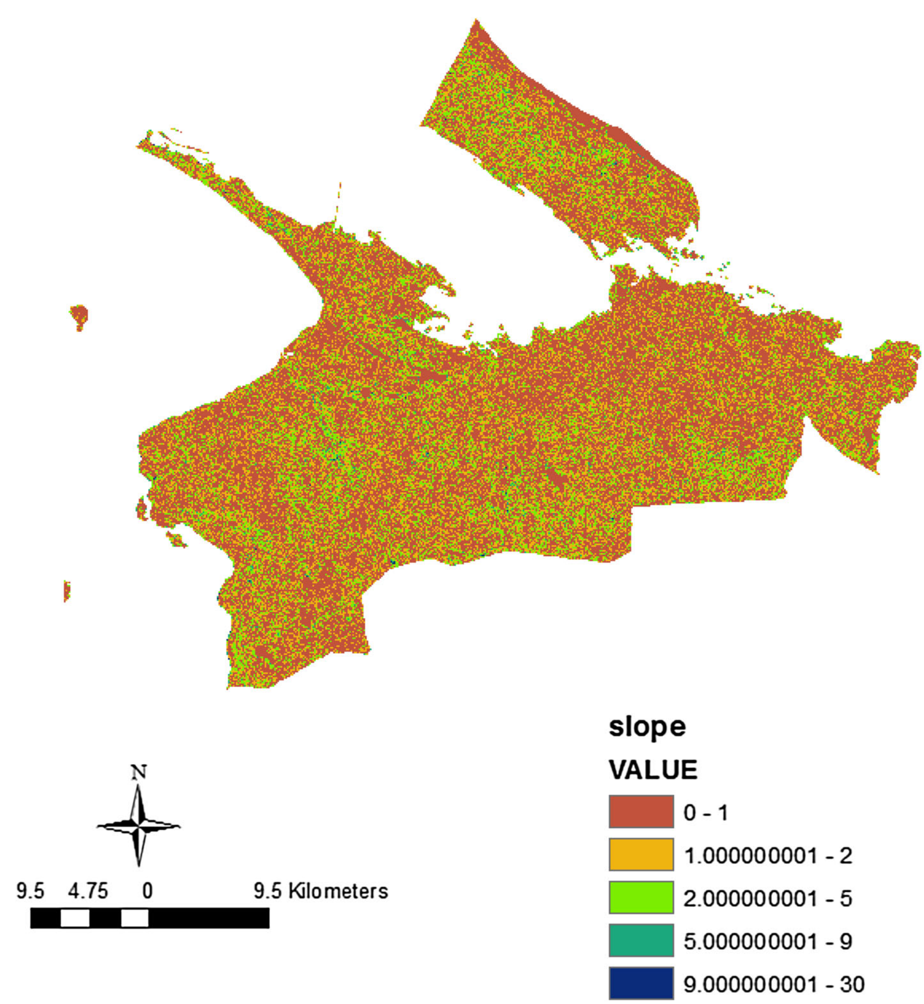
biotite and colorless minerals in gneiss, while biotite is absent in charnockite.

- Jaffna limestone: Jaffna limestone is typically a compact, hard, partly crystalline rock formed in the early Miocene age. The limestone is a creamy colored hard compact, indistinctly bedded, and partly crystallized rock. It is massive in parts, but some layers are richly fossiliferous into a honeycombed mass. Easily, soluble limestone gives rise to a number of underground solution caverns. The limestone is an important aquifer, and, together with thin sand layers, forms an extensive cover providing a source of drinking water and irrigation across the area.
- Red earth, red, and brown sand: They are the sandstone with the mineral composition of quartz and/or feldspar. In the study area, it is of red and brown colored. These rock formations usually allow easy percolation of water and other fluids and are porous enough to store large quantities, making them valuable aquifers.
- Undifferentiated Vijayan gneiss with trend lines: They are mainly granitic rocks composed of garnet and feldspar with very low porosity. They are considered as poor aquifers zones.

Slope

Slope is one of the important terrain parameters expressing the steepness from the ground surface which provide important information on the nature of geologic and geodynamic processes operating at that regional scale. In the elevation raster, slope is calculated by the identification of maximum rate of change in value from each cell to its neighboring cells. Higher value of slope resembles to steeper terrain, whereas the lower slope values indicate the flatter terrain or surface. The slope map was generated from the digital elevation model (DEM) using the Arc GIS 10.2 spatial analysis tool. Result shows that although slope angle of the study area varies from 0° to 30°, most of the part lie within slope angle between 0° and 5° (Fig. 5). The result shows that elevation decreases from the south to north and east to west parts to the study area. The area with

Fig. 5 Slope map of the study area



slope angle (0°–2°), surface is flat and mountainous resulting into slow runoff allowing rain water more time to percolate and, therefore, considered as good groundwater potential zone.

Soil type

Soil is an important factor for delineating the groundwater potential zones. The climate, physiography, and geology characterize soil and play an important role in groundwater recharge and runoff. The water holding capacity of the area depends upon the soil types and their permeability. The analysis of the soil type reveals that the study area is predominantly covered by four main soil types, namely, soil classes Immature brown loams (dry zone); reddish brown earths; regosolic alluvial soil; and solodised solonetz and solonchaks (Fig. 6). According to their influence on groundwater occurrence, regosolic alluvial soil is considered as very good, whereas reddish brown earths are being considered as moderately better than other soil types.

Land use/land cover

The land-use/land-cover map was generated using the unsupervised classification of AVNIR satellite data through image classification. Land-use/land-cover study is useful in assessing impacts of different land uses on water infiltration capacity. On this basis, the whole area was classified into six categories, viz., water, agricultural land, barren land, built up, dense forest, and scrub land (Fig. 7). Waterlogged area and forest area are good, whereas build up area is poor for groundwater percolation and, hence, groundwater potential (Chowdary et al. 2008).

Delineation of groundwater potential zone

The groundwater potential zonation was prepared by overlaying cumulative weight assigned to all the five thematic layers, viz., geomorphology, geology, slope, soil, and land-use/land-cover maps, using the weighted overlay

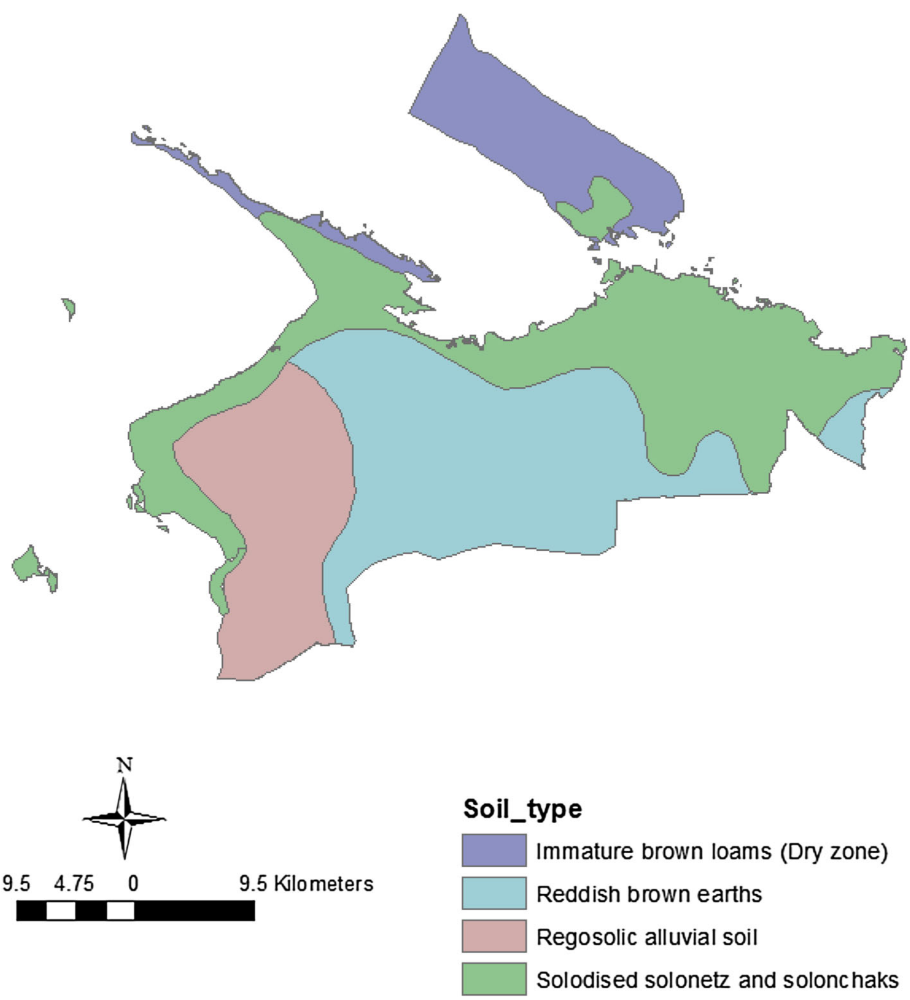


Fig. 6 Soil type map of the study area

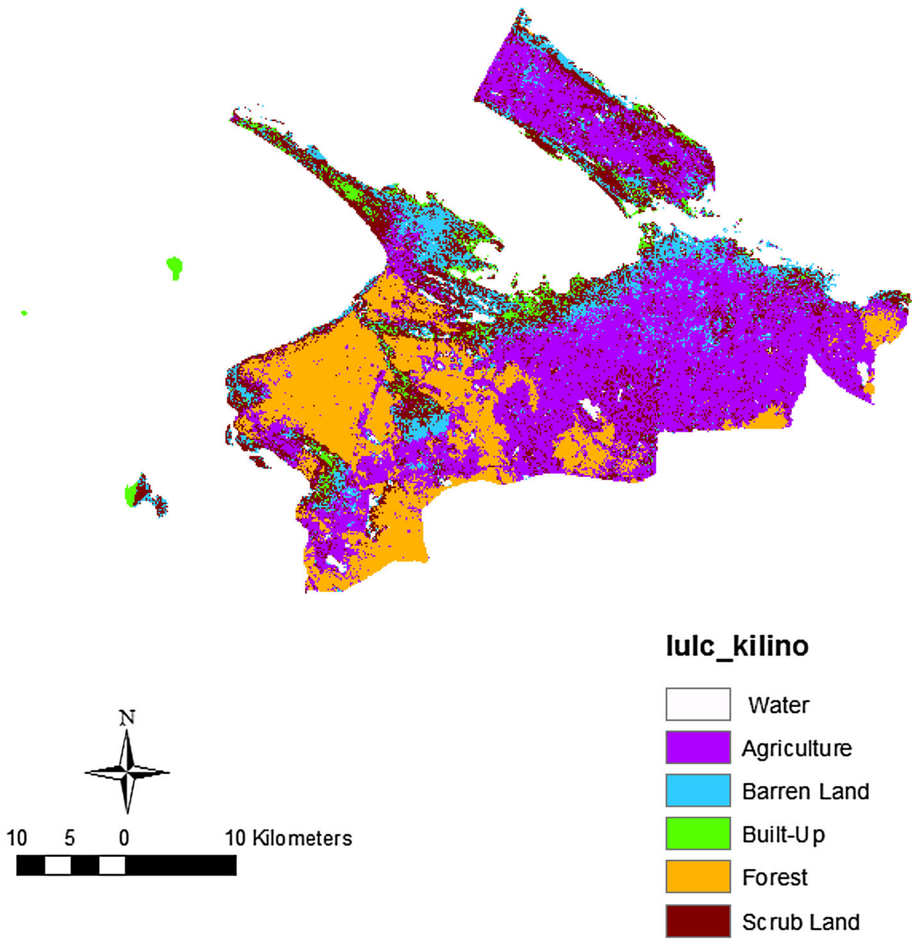


Fig. 7 Land-use/land-cover map of the study area

Table 2 Classification of study area with groundwater potential zonation and index

S. no.	Groundwater potential zone	Groundwater potential index	Percentage of total area
1	Good	0.24–0.30	5.32
2	Moderate	0.18–0.24	61.90
3	Poor	0.12–0.18	26.61
4	Very poor	0.06–0.12	6.17

methods in spatial analysis tool of Arc GIS 10.2. Through the weighted overlay analysis process, knowledge-based ranking and weightage of different class for each thematic layer has been given based on their contribution toward groundwater potentiality/development. Based on calculation, groundwater potential index for the study area ranges from 0.06 to 0.30 with a standard deviation of 0.04. Then, natural-break classification scheme using Jenk's optimization method was applied for mapping (Jenks 1967). The GWPI was grouped into four classes: good, moderate, poor, and very poor (Table 2). All the thematic layers were converted into raster format and overlaid in Arc/Info; and the resultant composite coverage was classified into four groundwater potential zones, such as good (5.32 % of the area), moderate (61.90 % of the area), poor (26.61 % of the area), and very poor (6.17 % of area) (Fig. 8). The maximum area (61.90 % of the total area) is characterized by moderate groundwater potential zone. Looking into the study area terrain, geomorphology plays most vital role for groundwater occurrence followed by geology, slope, soil type, and land use/land cover. Result shows that the excellent groundwater potential zone is concentrated in the south–western and north–western regions of the study area due to its almost flat terrain nature like alluvial plains with the distribution of limestone and dense forest land with high infiltration ability.

Validation

Depth to groundwater level below ground level from thirty-five observation sites was considered for seasonal variation and correspondence with precipitation received by the area. The study area receives an average rainfall of 1250 mm with maximum amount concentrated in monsoon period

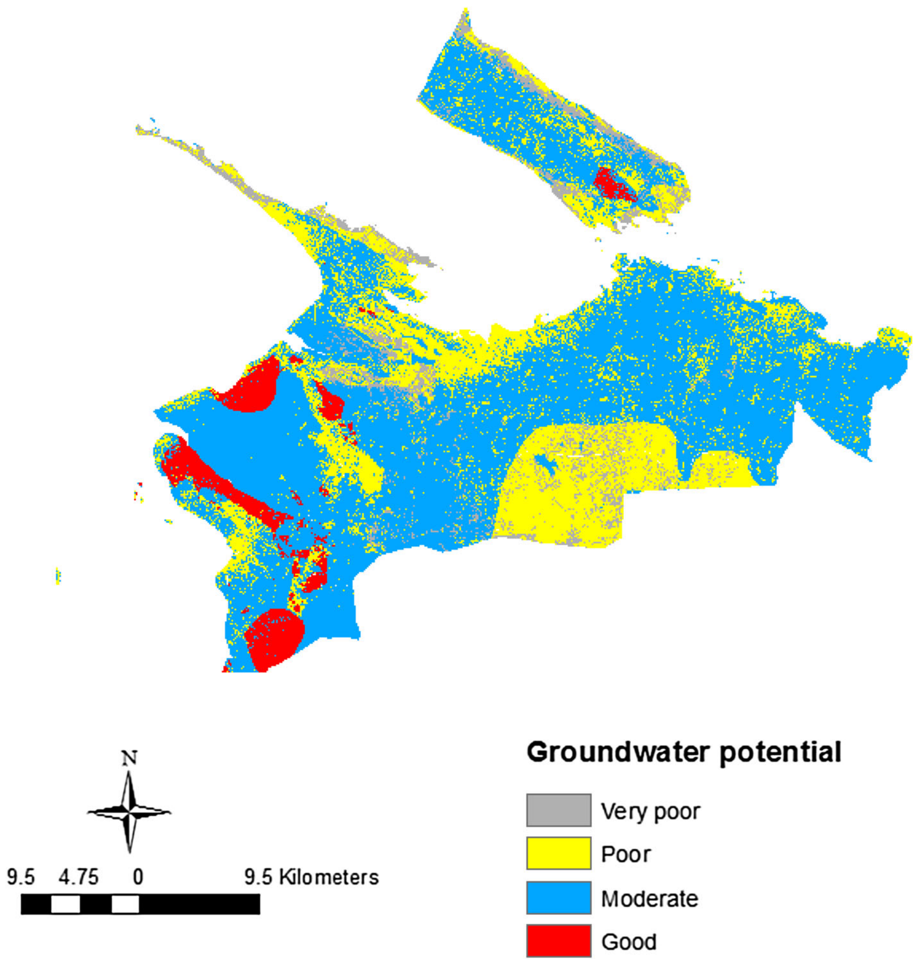


Fig. 8 Groundwater potential map of the study area

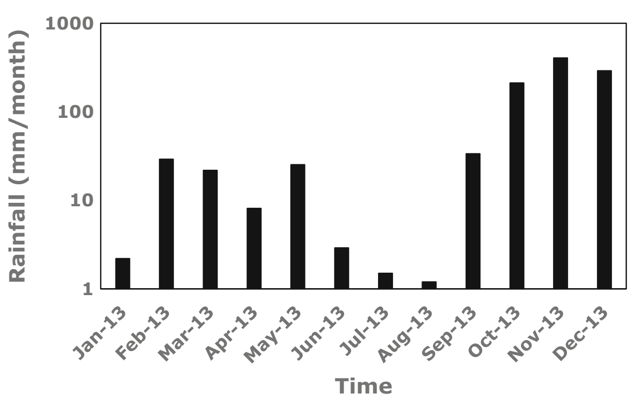


Fig. 9 Average monthly rainfall in the study area for year 2013

(also known as Maha period). Depth to groundwater is generally reduced during monsoon/post-monsoon (or wet period), whereas it gets deepened during pre-monsoon (or dry period), because discharge rates are greater than the recharge rates. Seasonal fluctuation of groundwater is significantly correlated with precipitation, as is found that recharge into the groundwater system is considered entirely to be from rainfall percolation. In addition, more or less flat topography inhibits the possibility of any significant contribution from lateral inflows quite evident from slope map. In this study, monthly, average rainfall of year 2013 (Fig. 9) is considered to observe seasonal groundwater fluctuation in the study area. Here, groundwater level from May and December is presented considering contrast in the amount of rainfall received by the study area (Fig. 10). Here, it is evident that groundwater level varies from 5 to 55 and 2 to 49 m below ground level during pre-monsoon and monsoon periods, respectively. The groundwater depths are maximum in the northern and central-southern parts of the study area, and are minimum in the south-western and north-east part of the study area. Result also corroborates the assumption that the groundwater fluctuation is synchronized with the fall and rise of the rainfall regime. The magnitude of seasonal fluctuation in water levels in response to monsoon recharge is related to geomorphological structure, topography, aquifer porosity, and storage. The range of seasonal fluctuation generally varied from region by region of the study area, reflecting the different hydrogeological conditions and possible spatial

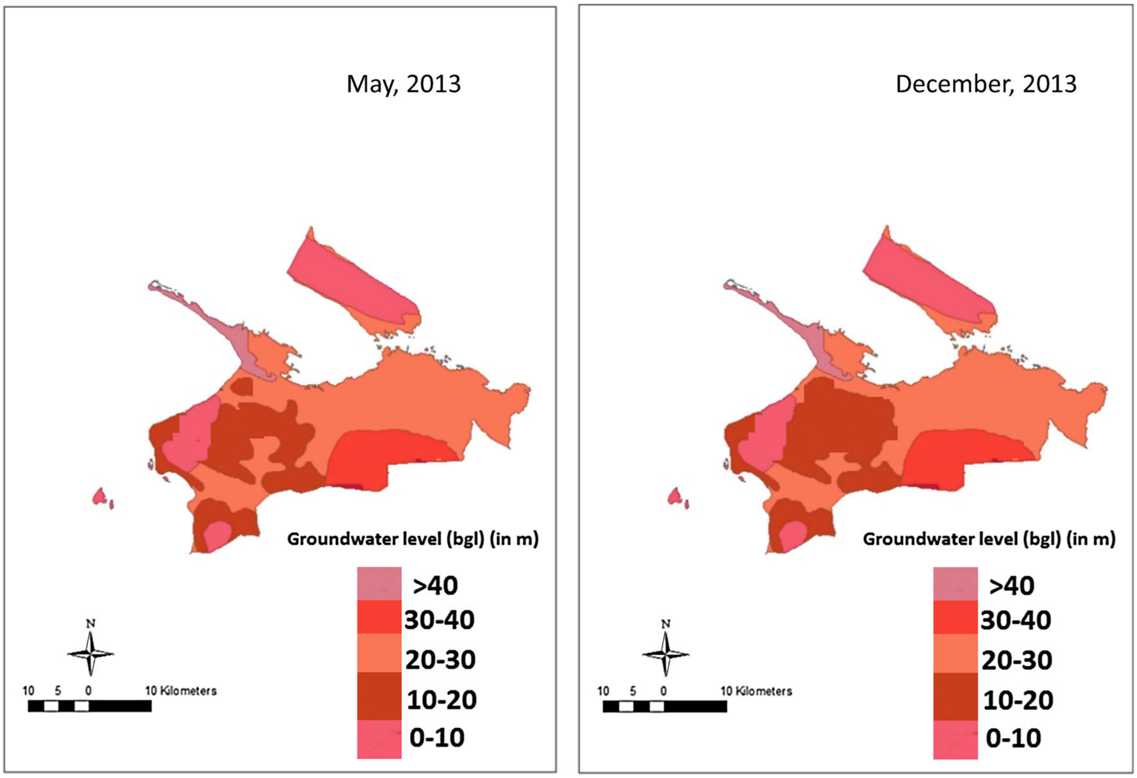


Fig. 10 Groundwater level in the study area for the months of May and December, 2013

variation in recharge rates or storage characteristics of the aquifer.

For validation, location for groundwater-level observation site was overlain on groundwater potential zone map. This was followed by drawing scatter plot between groundwater level below ground and its corresponding groundwater potential index for both dry and wet seasons (Fig. 11a, b, respectively). The linear regression coefficient for both the plots was 0.78 and 0.73, which confirms the reliability of this methodology. Maps generated from interpolation of groundwater-level data (Fig. 9) were superimposed on groundwater potential map to identify the area with water scarcity and it showed most of the area with low groundwater level lie into the poor groundwater potential zones. The area around the alluvial plain, low slope, flat topography near river plain is good in groundwater prospects. On the other hand, areas with high slope, high-drainage density, and ravenous, low lineaments are poor to very poor in groundwater prospects.

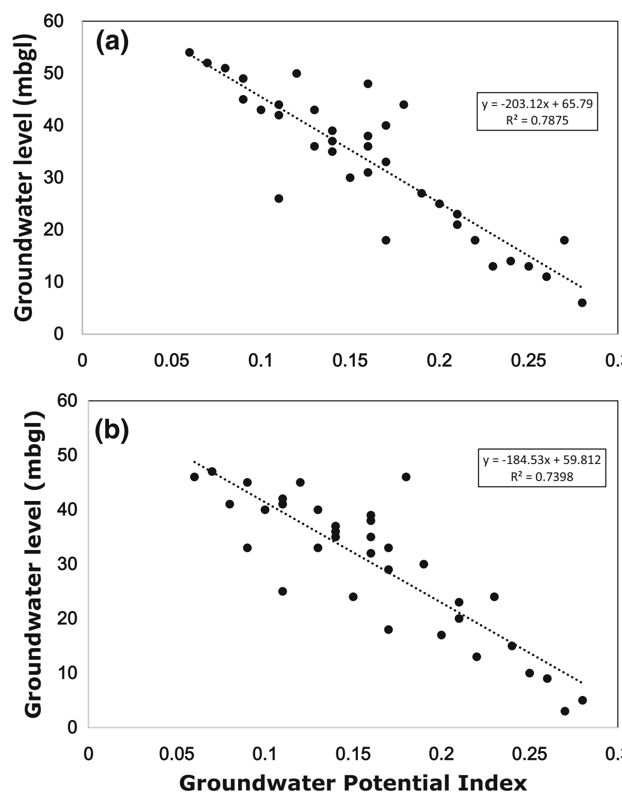


Fig. 11 Scatter plot between groundwater potential index and groundwater level for **a** Dry and **b** Wet seasons. (mbgl–meter *below* ground level)

Conclusion

Integrated use of remote sensing and GIS for delineation of the groundwater potential zones in this study proved efficient in terms of minimizing cost, time, and labor. Five different thematic layers, namely, geomorphology, geology,

soil type, slope, and land use/land cover, are prepared using satellite imageries, topographic maps, and secondary data set, and integrated with weighted overlay in GIS to generate groundwater potential zonation map of the area. The result shows that whole study area is divided into four groundwater potential zones, such as good (5.32 % of the area), moderate (61.90 % of the area), poor (26.61 % of the area), and very poor (6.17 % of area). The best groundwater potential zone is concentrated in the south-western and north-western regions of the study area due to its almost flat terrain nature with high limestone and dense forest land having high infiltration ability. Rain water is chiefly accountable for the groundwater recharge in the study area. The results of this study can serve as guidelines for planning future artificial recharge projects in the study area to ensure sustainable groundwater utilization. In a developing country like Sri Lanka with weak infrastructure as well as scarce information/data, finding from this study is a good tool which enables policy makers for quick decision-making in sustainable water resources management.

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