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GROUNDWATER POTENTIAL IN THE HARD ROCK TERRAIN OF WESTERN GHATS: A CASE STUDY FROM KOTTAYAM DISTRICT, KERALA USING RESOURCESAT (IRS-P6) DATA AND GIS TECHNIQUES

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ABSTRACT

The present study was aimed to identify and delineate the groundwater potential areas in parts of Western Ghats, Kottayam, covering the upper catchment of Meenachil river. The study area is composed rocks of Archaean age and Charnockite dominated over others. The information on lithology, geomorphology, lineaments, slope and land use/land cover was generated using the Resourcesat (IRS P6 LISS III) data and Survey of India (SoI) toposheets of scale 1:50,000 (surveyed in 1969) and integrated them with raster based Geographical Information System (GIS) to identify the groundwater potential of the study area. Thus, a GIS-based model which takes account of local condition/variations has been developed specifically for mapping groundwater potential. On the basis of hydrogeomorphology, three categories of groundwater potential zones namely good, moderate and poor were identified, and delineated. The high potential zones correspond to the fracture valleys, valley fills, pediments and denudational slope, which coincide with the low slope and high lineaments density areas. The low zone mainly comprise structural hills and escarpments and these act as run-off zones. The derived panchayath-wise groundwater potentiality information could be used for effective identification of suitable locations for extraction of potable water for rural populations.

Introduction

Groundwater is a dynamic and replenishable natural resource, but in hard rock terrain availability of groundwater is of limited extent and its occurrence is essentially confined to fractured and weathered zones. The occurrence, origin, movement and chemical constituents of groundwater are

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dependent on the geologic framework i.e., lithology, thickness, structures and permeability of the rocks through which it moves. Exploration and utilisation of groundwater especially in hard rock terrains, requires thorough understanding of geology, geomorphology and lineaments of the area, which directly or indirectly control the terrain characteristics.

There are several methodologies to locate and map the occurrence and distribution of groundwater. Recent studies have focused on the utility of high resolution satellite imagery to identify and delineate the surface features more accurately. Remote sensing method provides the efficient way of mapping of natural resources economically than those of the conventional methods and yields better results. Krishanmurthy and Srinivas (1996); Ravindran and Jayaram (1997); Jagadeeswara Rao *et al.* (2004), used the satellite remote sensing data to define the spatial distribution of different groundwater prospect classes on the basis of geomorphology and other associated parameters. Analysis of remotely sensed data along the SoI topographical sheets and collateral information with necessary ground truth verifications help in generating the baseline information for groundwater targeting. Sankar (2002); Basudeo Rai *et al.* (2005); Lokesha *et al.* (2005), in their studies found that, identification of groundwater occurrence location using remote sensing data is based on indirect analysis of some directly observable terrain features like geological structures, geomorphology and their hydrologic characteristics. Bahuguna *et al.* (2003), in their studies found that lineaments play significant role in groundwater exploration particularly in hard rock terrain. Groundwater prospecting based on mapping of landforms and lineaments is now very common using remote sensing data. Remote sensing serves as the preliminary inventory method to understand the groundwater prospects/conditions and helps in delineating areas where further explorations need to be taken up through hydrogeological and geophysical methods. In addition, the advantage of using remote sensing techniques together GPS in a single platform and integration of GIS techniques facilitated better data analysis and their interpretations. Murthy *et al.* (2003); Khan *et al.* (2006), reported that, temporal data from the remote sensing enables identification of groundwater aquifers and assessment of their change, where as, GIS enables user specific management and integration of multi-thematic data.

The present study focus on the identification of groundwater potential areas in the hard rock terrain of Western Ghats, the upland sub-watershed of Meenachil river in Kottayam, Kerala using the advanced technology of remote sensing and raster based GIS. The high degree of terrain slope, presence of hard crystalline rocks and increased land encroachment in the headwater region, availability of water (groundwater) throughout the year is a major problem and hence, it is necessary to identify the new groundwater potential areas for the sustenance of life. In the study area, no previous studies were conducted to find out the groundwater potential areas and also the relationship between groundwater potential and geological units. The present study, Multi-Criteria Evaluation (MCE) techniques were used to systematically assess the importance of each terrain factors in the occurrence of groundwater.

Study Area

The upland sub-watersheds chosen for the study is located in the Meenachil river basin, which forms the western slopes of the Western Ghats, Kottayam district, Kerala, India. The study area is enclosed between 9° 37′ to 9° 52′ North latitudes and 76° 44′ to 76° 56′ East longitudes, covering an area of 218.15 km^2 (Fig. 1). The two major rivers flowing through the area are Kalathukadavu and Poonjar and these two confluence in Irattupettah to form the river Meenchil, flowing through the rolling plains of Kottayam and finally debouches into the Vembanad estuary. The elevation varies between 100 m in the west to 1100 m above mean sea level in the east. The area experiences good to high rainfall during the southwest monsoon (June-August) and northeast monsoon (October-December) seasons. The measured rainfall varies from 350 mm – 900 mm / day. Temperature of the area varies from 20° – 34° and the maximum in the summer seasons. In general the climate of the area is good and is influenced by the high land regions and the monsoons.

Methodology

In the present study Resourcesat (IRS P6 LISS III) data acquired on 19th February 2004 (P100/R67), Survey of India toposheets 58 C/13 and 14 of scale 1:50,000 of year 1969 and geological map published by Geological Survey of India (scale 1:2,50,000 of year 1987) were used. The technical guidelines prepared by National Remote Sensing Agency (NRSA, 1995 & 2000) formed the basis of methodology for the preparation of various thematic maps and final groundwater potential map. Various thematic maps like basemap, lithology, geomorphology, and land use/ land cover were prepared and verified in the field. Slope, lineament and lineament density map were also prepared. The weightages of individual themes and feature score were fixed and added to the layers depending upon their suitability to hold groundwater (Table 1). This process is most commonly known as Multi-Criteria Evaluation. Of several methods available for determining interclass/ inter-map dependency, a probability weighted approach has been adopted that allows a linear combination of probability weights of each thematic map (*Wt*) and different categories of derived thematic maps have been

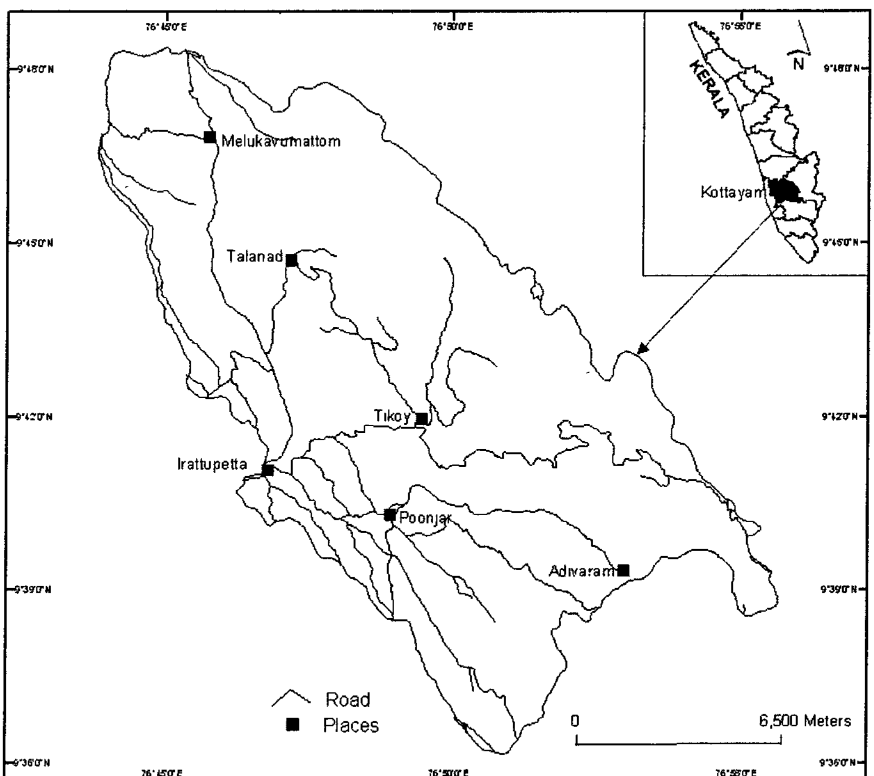

Fig. 1. Study area location map.

Table 1: Identified features in each theme and weighted factors.

Thematic layers	Map weight (*Wt*)	Individual features	Feature score (*Wi*)
Lithology	10	Biotite gneiss	6
		Dolorire	1
		Pink / gray granite	4
		Charnockite	7
		Quartzite	1
Geomorphology	20	Structural hill	2
		Escarpment/ cliff	1
		Residual mound	3
		Valley fill	8
		Fracture valley	10
		Denudational slope	4
		Pediment	6
		Water body	0
Lineament density	30	Very low	5
		Low	7
		Moderate	9
		High	10
Slope	35	1- 8°	10
		9- 15°	8
		16- 25°	6
		26- 35°	2
		> 45°	1
Land use / land cover	5	Built up land	1
		Barren land	3
		Barren rock	1
		Cleared area	3
		Crop land	5
		Grass land	8
		Natural vegetation	9
		Rubber plantation	4
		Tea plantation	4
		Water body	0

assigned scores (*Wi*), depending upon their suitability to hold groundwater. The maximum value is given to the feature with highest groundwater potentiality and the minimum being to the lowest potential feature. The procedure of weighted linear combination dominates in raster based GIS software systems. Spatial analyst extension of ArcGIS 8.3 was used for converting the features to raster and also for final analysis. In this method, the total weights of the final integrated map were derived as sum or product of the weights assigned to the different layers according to their suitability. Finally, the panchayath -wise groundwater condition has been assessed by superimposing the panchayath map over the groundwater potential zone map.

Lithology and Geomorphology

The study area consists Precambrian metamorphic rocks and forms hilly ground. The major rock types are Quartzite (0.99%), Charnockite (94.81%), Biotite gneiss (2.55%), Pink/ Gray granite (0.65%). Numerous dolerites dykes (1.01%) trending NW-SE traverses the older rocks. The major part of the area is covered by Charnockite.

The study area has a dominant rocky terrain, which is manifested by hills and undulating surfaces. Seven distinct geomorphologic units have been identified and delineated from the study area, include structural hills, escarpment/cliff, residual mounds, denudational slope, pediment, fracture valley and valley fill. These distinct geomorphic features are resulted from the complexity of geomorphic evolution. The distribution and extent of these geomorphic zones are varying from place to place.

Lineament

In hard rock terrain the storage and movement of groundwater is controlled by the secondary porosity i.e., presence of lineaments and fractures. Lineament study of the area from remotely sensed data provides important information on sub-surface fractures that may control the movement and storage of the groundwater. Subsurface permeability is a function of fracture density of rocks (Pradeep, 1998). Hence the identification of lineaments in the hard rock terrain from the satellite data possesses more importance. Most of the lineaments are identified with the anomalies associated with features like straight drainage course, vegetation pattern, topography etc. The study area is criss-crossed by major and minor lineaments. They vary in length from few meters to kilometers in dimension. General trend shown by the lineaments present in the study area are NNE - SSW and NE - SW.

Classified lineament density map

The study area was divided into grids of 1 km^2 and the total lengths of all lineaments in each grid were calculated in order to determine the lineament density values per sq. km. These values were regrouped to produce a lineament density map that was classified into four categories, i.e., high (>800 m), medium (400 m–800 m) and low (200 m–400 m) and very low (1 m–200 m) in the study area. A major portion (>75%) of the region has low lineament density (<400 m/km^2).

Slope

Steeper the slope, greater will be the runoff and thus, lesser is the groundwater recharge. Digital Elevation Model (DEM) is derived using contour information from the topographical map for estimation of slope in degrees. The identified slope category varies from 1° to $>35^\circ$ degree in the study area and are classified into five classes like, 0°-8° (gentle), 9°-15° (moderate), 16°-25° (high), 26°-35° (very high) and $>35^\circ$ (steep).

Land use/land cover

For the identification and interpretation of land use pattern of the area, the standard methods of visual interpretation were adopted and the various land use classes delineated includes barren land, barren rock, built-up land, cleared area, cropland, grassland, natural vegetation, rubber and tea (plantations), and water body. Out of the total area, >76 % is falling under rubber plantation.

Results and Discussion

The ultimate objective of the investigation is to find out the areas, which are promising groundwater in the hard rock terrain of the Western Ghats. In the present study, the choice among a set of zones for development of groundwater is based upon multiple criteria, which gives linear combination of probability weights for lithology, geomorphology, lineament density, slope and land use/ land cover. The composite map represents regions with weight factors as values. The integrated final map has generated a range of values from 1.65-9.65, which is reclassified into three zones, to represent the groundwater potentiality of the area. The groundwater potentiality is classified as good, moderate and poor. The good potential zones occupy the 33.98% of the total area. Moderate and poor potential zones occupy 38.41% and 27.61% of the study area respectively. Hydrogeomorphological units such as fracture valley, valley fill pediments and denudational slope are potential zones for groundwater exploration and development of the study area. Table 2 shows the predicted potentiality and identified earth features in the area.

In the study area, slope and lineaments play a significant role in groundwater potentiality. Lineaments, particularly joints, fracture and their intersection enhances the potential of hydrogeomorphic units. Areas with high lineament density are good for groundwater development. The lineaments mapped from the satellite images cut across slope categories and litho-units, thereby indicating the possibility of acting as major conduits for subsurface movement and linear aquifer for the storage of water. It has been observed in the field and from the groundwater potential map, the gentler slope has more potential for groundwater.

Panchayath-wise groundwater potential map

The present study attempted to generate a panchayath-wise groundwater potential map by overlaying the panchayath boundary map over the groundwater potential zone map. The spatial distribution of panchayath-wise groundwater potential zones is given at Fig. 2. The study area covers five panchayaths as whole and four panchayaths partly. The names of the panchayaths and the groundwater potentials within the

Table 2: Predictable potentiality and identified earth features in the area.

Predictable potentiality	Hydrogeomorphic units	Area (km^2)
Poor – nil	Structural hills	100.23
Nil	Escarpment / Cliff	3.36
Moderate	Residual mounds	3.43
Moderate	Denudational slope	58.73
Moderate	Pediment	14.66
Good	Fracture valley	5.03
Good	Valley fill	32.48
Good	Water body	0.23
	Total area	**218.15**

panchayaths are given in Table 3. This shows that most of the villages have moderate to good groundwater potential.

Conclusion

The study has focused on the utility of remote sensing and raster based GIS in the identification and delineation of groundwater potential zones in a hard rock terrain of the Western Ghats, Kottayam district, Kerala. The hydrogeomorphic units developed under various terrain conditions were mapped during the study. From the present study, the slope area of 0-8°, lineament density of >400m and fracture valley, valley fills, pediments and denudational slope is found to be good zone for groundwater exploration and development and it occupies 33.98% of the area. These zones should be concentrated for the future watershed development activities.

Thus the above study has demonstrated the capabilities of a remote sensing data and GIS technique for demarcation of groundwater potential zones in hard rock terrain. This vital information could be used effectively for identification of suitable locations for extraction of potable water for rural populations. The current multiparametric

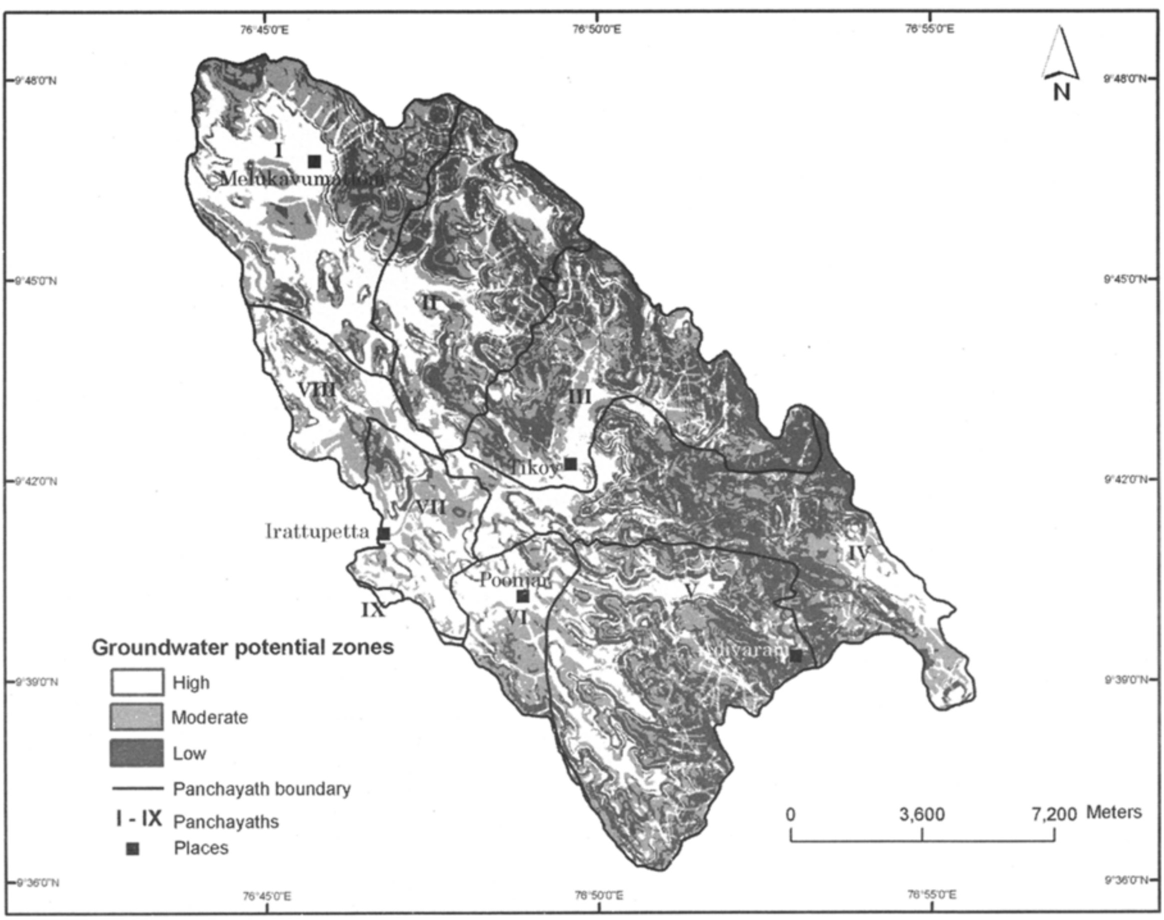

Fig. 2. Panchayath-wise groundwater potential zone map.

approach using GIS and remote sensing is holistic in nature and will minimize the time and cost especially for identifying groundwater-potential zones and suitable site-specific recharge structures, especially in hard rock terrain on a regional as well as local scale, thus enabling quick decision-making for water management.

Table 3: Panchayath-wise groundwater potentials and other related parameters.

Map symbol	Panchayath name	Potentiality score range	Area (%)	Groundwater potential category	Hydrogeomorphic units	Aquifer material
I	Melikavu	2.85 - 9.10	17.74	Mainly moderate and good, partly poor.	Structural hill, denudational slope, valley fill, residual mounds.	Weathered charnockite, laterite soil
II	Munnilavu	2.50 - 9.55	14.21	Dominated by moderate and good. Partly poor.	Structural hill, denudational slope, valley fill, fracture valley.	Weathered charnockite, laterite soil
III	Talanad	3.00 - 9.65	14.37	Dominated by moderate. Partly good and poor.	Structural hill, denudational slope, valley fill, escarpment/cliff.	Weathered charnockite, laterite soil
IV	Tikkoy	2.65 - 9.40	17.67	Mainly moderate. Partly good and poor.	Structural hill, denudational slope, valley fill, fracture valley, escarpment/ cliff, pediment	Weathered charnockite, laterite soil
V	Poonjar Thekkekara	1.65 - 9.10	20.18	Dominated by moderate and good. Partly poor.	Structural hill, denudational slope, valley fill, fracture valley, escarpment/ cliff, residual mounds, pediment.	Weathered charnockite, laterite soil
VI	Poonjar*	3.15 - 9.10	4.79	Mainly good and moderate. Partly poor.	Denudational slope, valley fill, fracture valley, residual mounds, pediment.	Weathered charnockite, laterite soil
VII	Erattupetta*	2.90 - 9.00	5.79	Mainly good and moderate. Partly poor.	Denudational slope, valley fill, residual mounds, pediment.	Lateritic soil
VIII	Talappalam*	3.35 - 9.10	5.05	Dominated by good and moderate.	Structural hill, denudational slope, valley fill.	Lateritic soil
IX	Tidanad*	5.10 - 8.10	0.20	Mainly good. Partly poor.	Denudational slope, valley fill, pediment.	Lateritic soil

* Panchayaths covered partly.

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