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Evaluating Groundwater Potential of a Hard-rock Aquifer Using Remote Sensing and Geophysics

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Abstract

Water constitutes one of the sensitive environmental parameters of the hydrological processes. Therefore, the study of water resources exploitation sustainable to the environment is important. Water resources development in hard rock terrain in many parts of Kerala state poses a key issue in the management strategy. The sustainable aspect of the water resources exploration in this state necessitates the need for a better water resources management. Usefulness of remote sensing techniques in conjunction with geophysical investigation and yield analysis were attempted in understanding the groundwater resources potential of diverse land cover classes around Kasaragod, located in the northern tip of Kerala state. This work provides a methodological approach for an evaluation of the water resources in hard rock terrain and enables an opening of the scope for further development and management practices.

Keywords: Groundwater; remote sensing; geophysics; well-yield

Introduction

Water resources development occupies a key place in India because of its role in stabilizing the Indian agro-economy. With about 700 million people sustaining their livelihood through agriculture in India, dependence on groundwater has recently increased due to the introduction of high yielding varieties of crops and adoption of multi-cropping patterns, both of which require a timely, assured water supply (Naik and Awasthi, 2003). Therefore, the development of the water resources in India needs an effective management of resources. The development of water resources and the regime of its activity largely depend on the porosity and permeability of water bearing formations. The porosity of rock is a measure of the amount of interstitial space that is capable of holding water and the hydraulic conductivity of a rock is a quantitative measure of the case with which it will permit the passage of water through it under a hydraulic gradient.

Remote sensing tools and methods are increasingly becoming popular for mapping land features with the advent of improved satellites sensors; where images can be acquired with fine resolution and image interpretation is faster and less expensive than the ground survey. Remote sensing techniques provide us opportunity to study the surface resources of the Earth in a systematic repetitive manner. Categories of land cover and land use are mapped at different scales and resolutions ranging from global to local. Land use and land cover describe appearance of land on the surface of earth (Sabins, 1997). The weathered and fractured rocks present a good resistivity contrast with compact basement crystalline, and the structures, such as joint, fault, dyke, etc., in a

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geological terrain impose marked anomalies on the resistivity profiles (Majumdar et.al., 2000). A reliable procedure for the assessment of dynamic water resources potential is necessary to delineate the water potential areas. As a part of ground survey, geoelectric resistivity studies have wide applications in hydrogeological and related field investigations (Ilkisik et al., 1997; Monteiro Santos et al., 1997; Raju and Reddy, 1998; Yadav and Abolfazli, 1998; Mohammed-Aslam and Balasubramanian, 2002).

Characterizing water resources potential is highly helpful in generating the strategy of targeting water resources. The present study provides a methodological approach in the water resources exploration by conducting a study at a northern district of Kerala state.

Description of Study Area

The study area is located near Kasaragod district head quarter in Kerala state, India. This area is occupied between the north latitudes of 12° 30′ and 12° 38′, and East longitudes of 75° and 75° 8′ (Figure 1). The mean annual rainfall observed in the study area is 3581mm. Dry weather lasts from December to February, and March to May is noticed for hot season. The south west monsoon starts towards the end of May or the beginning of June, and continues till September. The north-east monsoon is witnessed during October and November. Geologically, the area of study comprises of charnockites. At places laterite covers are noticed.

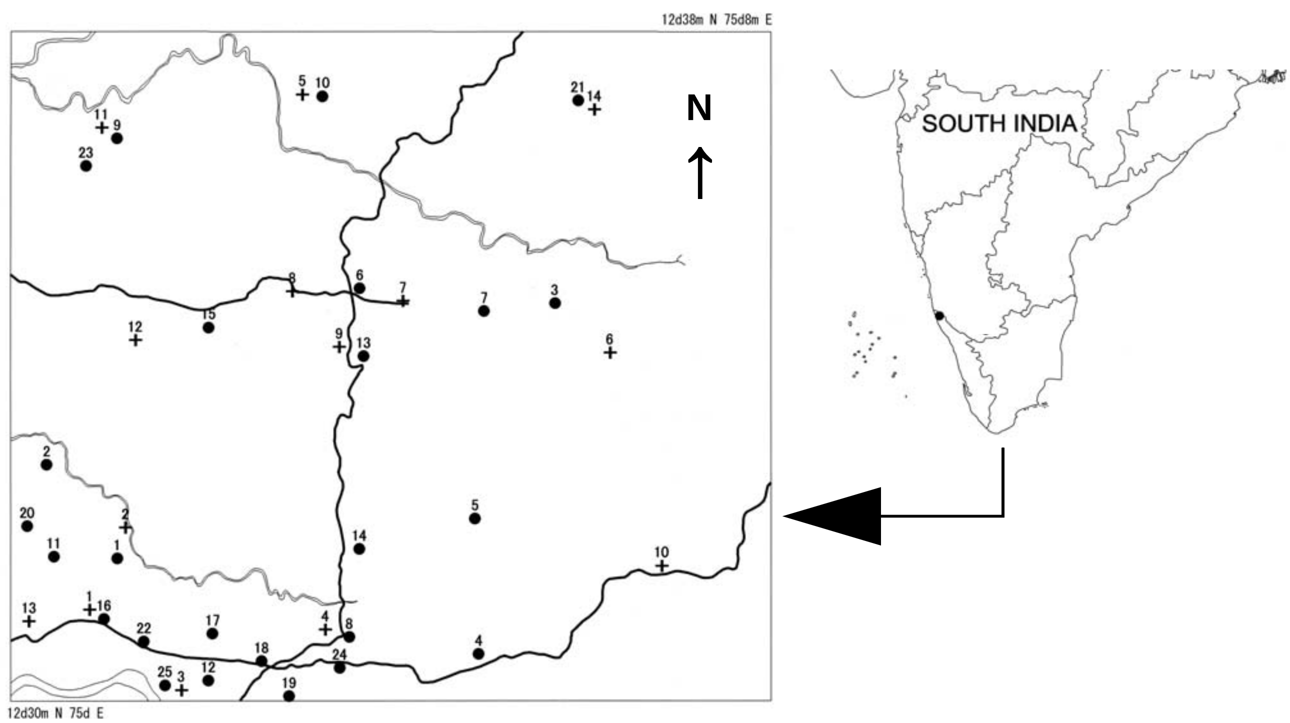

Figure 1. Location Map of Study Area (+ indicates locations of Geoelectrical surveys; Filled circle indicates the locations of yield analysis)

Methodology

The methodology incorporates the integrated approach of remote sensing, geophysics and yield analysis of aquifers. A remote sensing method has been employed for classifying the land-cover/use categories of the area of study. Geophysical investigations have been conducted at different locations encompassing the diverse land cover exists in the area of study in evaluating the groundwater resources of the terrain. Finally, yield analysis of the wells has been carried out in support of the remote sensing and geophysical analysis for estimating water resources potential of the aquifer.

Remote Sensing Analysis

Land Cover Classification

Classification of satellite image can be considered as the process of pattern recognition or identification of the pattern associated with each pixel position in an image in terms of the characteristics of the objects or materials those are present at the corresponding point on the Earth's surface (Mather, 1999). Land cover is a spatial description of the ecosystem interface that responds to regional climate, determining major fluxes in the biogeochemical activities. The land cover and use changes can be accomplished reasonably by using Landsat TM imagery owing to the high resolution and continuity in temporal series. Supervised and unsupervised classifications are used for land cover change detection (White et al., 1995). In order to obtain a better classification result, supervised classification is preferred over unsupervised classification, especially when there are many number end-members with similar reflectance (Thomson et.al., 1998). The specific classification of vegetated land must be discernible with high accuracy from remotely sensed data, and should be directly related to physical characteristics of the surface. Supervised classification clusters pixels in a data set into classes corresponding to user-defined training classes. Here we selected the maximum likelihood classification method. Image classification is a method of the identifying features using digital records. In the Supervised classification, the training sites that describe the typical spectral pattern of the land cover classes are defined. Pixels in the image are compared numerically to the training samples and are labeled to the land-cover class that has similar characteristics.

Landsat-TM image having, path 145 and row 51 acquired on 2nd, January 1991, georeferenced to UTM map projection (Zone 43, North) and WGS84 ellipsoid, was used for the image analysis. Supervised classification has been followed in discriminating the various land cover units of the study area. The supervised classification involves three basic steps: (1) training stage, (2) classification stage, and (3) accuracy assessment stage.

The classification scheme defined the land cover classes to be used for the classification of the image. In the initial step of classification of the present study, training data extraction was done as it the critical step in a supervised image classification process. Accurate delineation of the training data controls the success of classification. Detailed field investigations have been done to ensure the quality of those training data and were selected from the locations representative of the land cover classes under analysis. Care has been taken to gather information from relatively homogeneous areas consisting of those classes. The collection of training data was a time consuming and tedious process involved a strenuous field surveys. The number of pixels composing the training data was sufficiently enough to precisely distinguish the land cover classes. Fifteen to twenty-five sample plots were selected for each class. The number of training set for each class (Table 1) was selected in proportion to the area occupied by the respective classes on the ground. The classification scheme followed in the study comprises of 5 classes (Table 1). The spectral responses of selected model plots for each class were evaluated to make sure that they have comparable reflectance characteristics within the class and separate response patterns between the classes. After the refining of the training data set, the classification algorithm was applied to classify the image.

Table 1. Land cover classification scheme

Land cover class	Description
Crop land	Crop fields and agricultural land including plantations and agricultural fields of smaller extents
Sparsely vegetated	Low vegetation density with exposed ground; vegetation cover which are mostly natural and not dense
water	Rivers and permanent open water
Bare land	exposed rock without vegetation; land without vegetation
settlements	Mixed towns and villages (mainly of low to medium density residential lands); residential and commercial built-up land

Figure 2 illustrates the classified image of the study area where detailed studies have been carried out. Land cover includes vegetation and non-vegetation types (human settlements and non-vegetated area like water body and bare land). Vegetation abundance is one of the most influential factors in controlling the availability of the water resources. The characterization of land-cover types and their distribution is required to monitor hydrological condition and for the study of hydrological processes. Classification procedure is normally incomplete until its accuracy has been assessed. The percentage of accuracy is evaluated from the confusion matrix of classification. The supervised classification has shown an overall accuracy of 90.64%. In this context, "accuracy" means the level of agreement between labels assigned by the classifier and the class allocations on the ground collected by the user as test data. The land cover classes that were considered for the present study include cropland, water bodies, mixed land (sparsely vegetated), bare land and settlements/buildings.

NDVI analysis

Vegetation Index is composed from data on visible and near infra-red radiation of the remote sensing data. The parameters derived from remotely sensed observations are being directly used in various studies relating NDVI (Normalized Difference Vegetation Index) and hydrological processes (Sellers, 1987; Gamon et al., 1995; Kondoh and Higuchi, 2001). NDVI is a sensitive biophysical parameter that correlates with photosynthetic activity of vegetation and provides an indication of the 'greenness' of the vegetation (Sellers, 1985). The vegetation index is a very sensitive factor in studying the hydrological processes. The Digital Numbers (DNs) of bands 3 (R) and 4 (NIR) were used to calculate the TM based normalized vegetation index (TM-NDVI) according to the Equation 1:

$$\text{TM-NDVI} = (NIR - R) / (NIR + R) \quad (1)$$

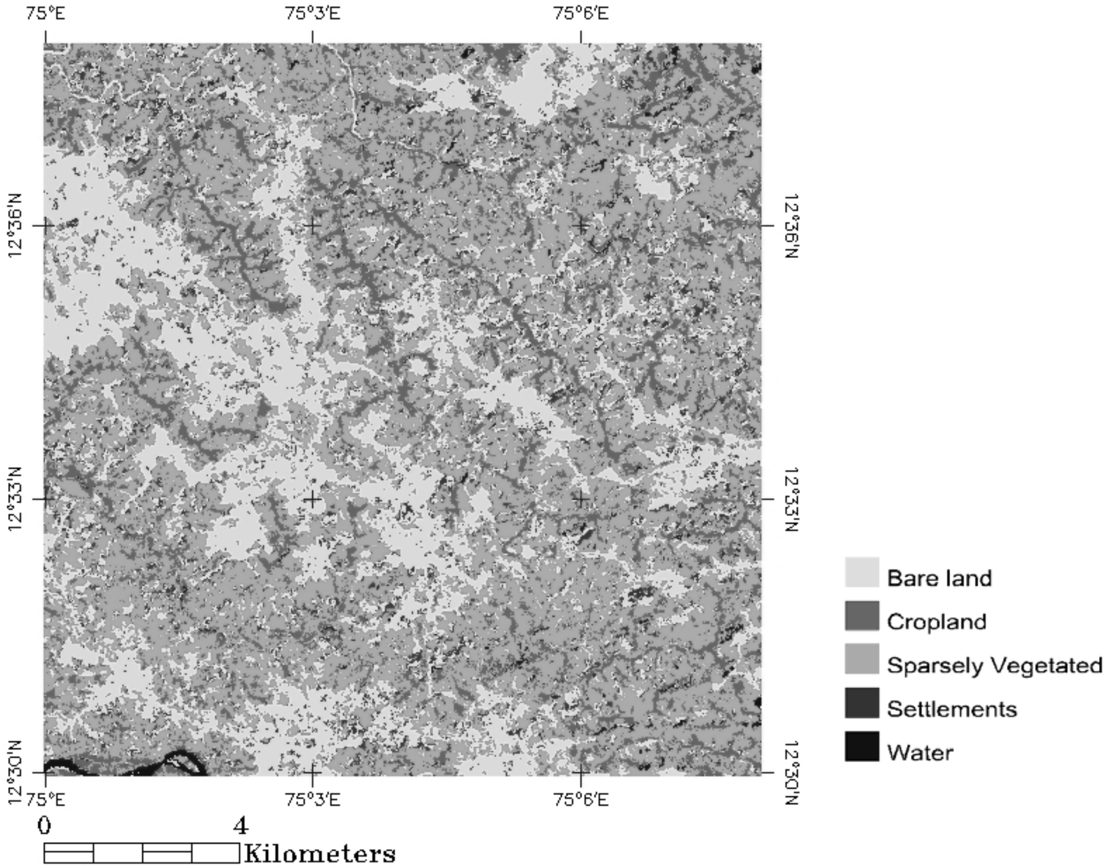

Figure 2. Landcover classification in Kasaragod area; Landsat TM, 2-1-1991

The NDVI distribution map (Figure 3) showed the vegetation vigour according to availability of water resources in the region. Higher pixel values have been shown by the land cover classes occupied by the crop lands. The maximum and minimum values of NDVI are 0.644 and -0.405 respectively. The crop lands showed the maximum value of NDVI. The minimum is exhibited by the water bodies which are occupied by smaller river draining over the area.

NDVI was generated in the analysis was found to be correlated well with water availability due to the good water content in the soil covers and weathered zones. Field investigations showed that the NDVI was controlled by shallow groundwater levels around topographic low, which forms the pathways for surface runoff during monsoon form the good zones of groundwater. Thus, the vegetation index in this area is a response of the green vegetation condition to environmental factors including soil moisture and water availability. Higher NDVI values implied availability of sufficient shallow groundwater and surface to stimulate vegetation growth and to support local water needs.

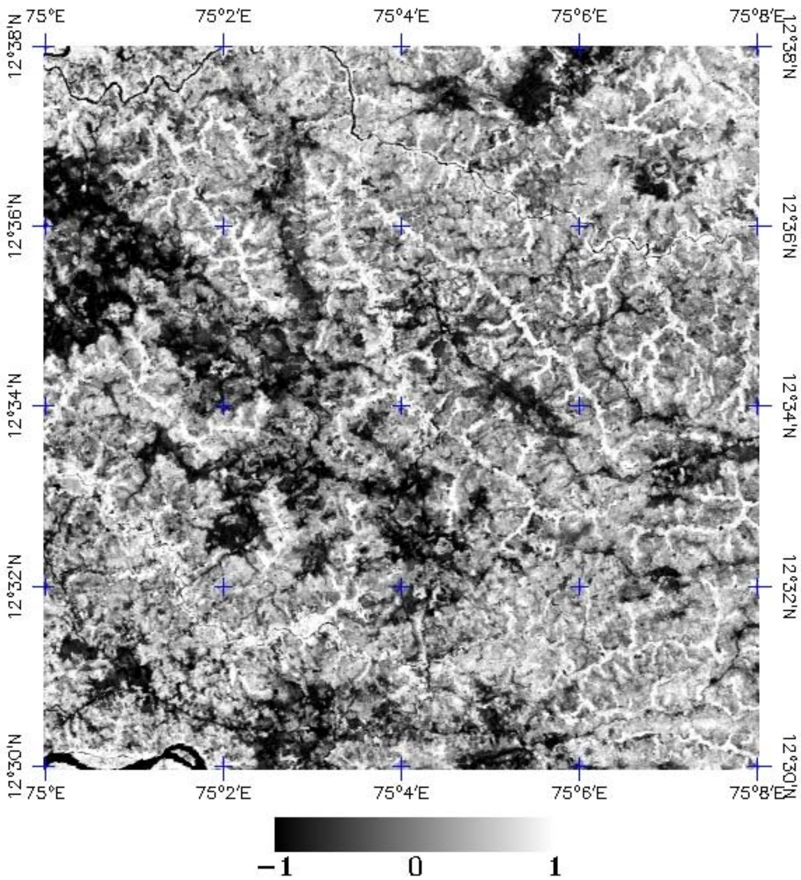

Figure 3. NDVI Image of the area in Kasaragod. Landsat TM, 2-1-1991

Geo-electrical Investigations

In the past, many investigators have tried to establish the empirical and semi-empirical relations between different aquifer parameters and the parameters obtained by geoelectrical soundings under varied geological conditions (Kosinski and Kelly, 1981; Ponzini et al., 1984; Niwas and Singhal, 1985; Mbonu et al., 1990; Yadav, 1995; and Frohlich et.al., 1996).

Geophysical studies involving Schlumberger sounding field configuration has been carried out in the study area to evaluate the geophysical characteristics of different land cover classes delineated from the satellite imagery. The studies involved geoelectrical soundings at 14 locations within the area of study. Depending on the availability of the area for electrode spread, the locations for VES (Vertical Electrical Sounding) were chosen and a maximum of 90m of AB/2 electrode spacing was made. The vertical electrical sounding using Schlumberger configuration has been adopted to delineate the aquifer geometry with varying half current electrode separation to relate geo-electric and hydraulic parameters.

The formula (Equation 2) for the computation of apparent resistivity (ρa) with Schlumberger electrode configuration is,

$$\rho a = \frac{(AB/2)^2 - (MN/2)^2}{MN} \cdot \frac{\pi \Delta V}{I} \qquad (2)$$

Where, AB and MN represent the current and potential electrode spread distances respectively.

Schlumberger electrode configuration has been followed for the geo-electrical investigation for characterizing the subsurface geo-electrical properties. Aquameter, the CRM-20, which is one of the modern digitized resistivity meters, has been used for carrying out field investigations.

VES data derived from field investigations were interpreted by partial curve matching technique to obtain the initial model parameters. This initial starter model was then used to obtain the final layer parameters through inversion technique. From the inversion technique, the best-fitting, lower bound minimum and upper bound maximum models were derived under 1% error level. The sounding curves end with higher resistivity layer indicating the basement formation. The preliminary interpretation of the VES curves was carried out by the curve matching technique (Orellana and Moony, 1966) in which the field curves are matched with the theoretical master curve. The theoretical curve that best fits the actual sounding curve specifies the thickness and resistivity of sub-surface layers of the respective VES station. The results thus obtained were used as a reference for the initial model for final interpretation by an inversion algorithm in which the layer parameters are adjusted automatically until a good match (minimum root mean square error) is obtained between the field and computed curves. The computer program VES1.30, developed by G.R.J.Cooper, for forward modelling and inversion of Schlumberger resistivity soundings, is used for this purpose. The sounding curves indicate that the area is composed of 3 geoelectric layers.

The resistivity variations in different land cover classes generated unique results. The VES investigations revealed the presence of three prominent geo-electric layers under prevailing hydro dynamic conditions. They correspond to the upper soil layer, weathered mantle and the basement rock.

Table 2 shows the thickness and the corresponding resistivity values of the layers. The intermediate weathered zone and the fractured rocks constitute a single aquifer system of varied hydraulic conductivity under water table condition. Lithology and groundwater conditions, as inferred from the VES, as well as hydrological studies, are in agreement with the nearby wells for which the yield tests were conducted. VES findings of these regions indicate that the occurrence and movement of groundwater take place mostly within the weathered and fractured rocks under unconfined condition. Figure 4 shows the graphical representation of the resistivity values of different locations corresponding to all the geo-electric layers.

Table 2. Thickness and Resistivity of different geo-electric layers for VES locations

Sl.No.	Location	Thickness (m)		Resistivity (Ohm.m)			Land cover
		Upper Layer	Middle Layer	Upper Layer	Middle Layer	Lower Layer	
1	Civil Station, Vidyanagar	2.4	2	1063	700	880.6	SV
2	Muttathody	2	0.9	2545	2762	691.4	St
3	Chengala	1.2	4.9	590	988	301.2	SV
4	Chengala - East	10	32.7	2145.5	180	95.3	SV
5	Cheni	4.6	22.9	1413	550.7	1130.3	SV
6	Kumbadaje	1.2	18.5	606.5	124.2	563.22	CL
7	Badiadka	2	9.1	500	112.3	696	CL
8	Badiadka - West	1.2	46.5	465.5	183.3	238.7	CL
9	Perdala	2.8	11.7	550.5	100.6	272	CL
10	Karadka	1.1	1	580	449	517.5	CL
11	Katib Nagar	4.9	25	1203	200	609.2	SV
12	Bela	2.9	3.1	1847	1152	408.6	BL
13	Near Nullipady	1.1	8.1	1752	79.6	255	St
14	Perla	2.9	13.8	972.5	271.3	324.7	BL

Note:- SV: at or near sparsely vegetated land cover; St: at or near Settlement; CL: at or near Crop Land cover; BL: at or near Bare Land cover

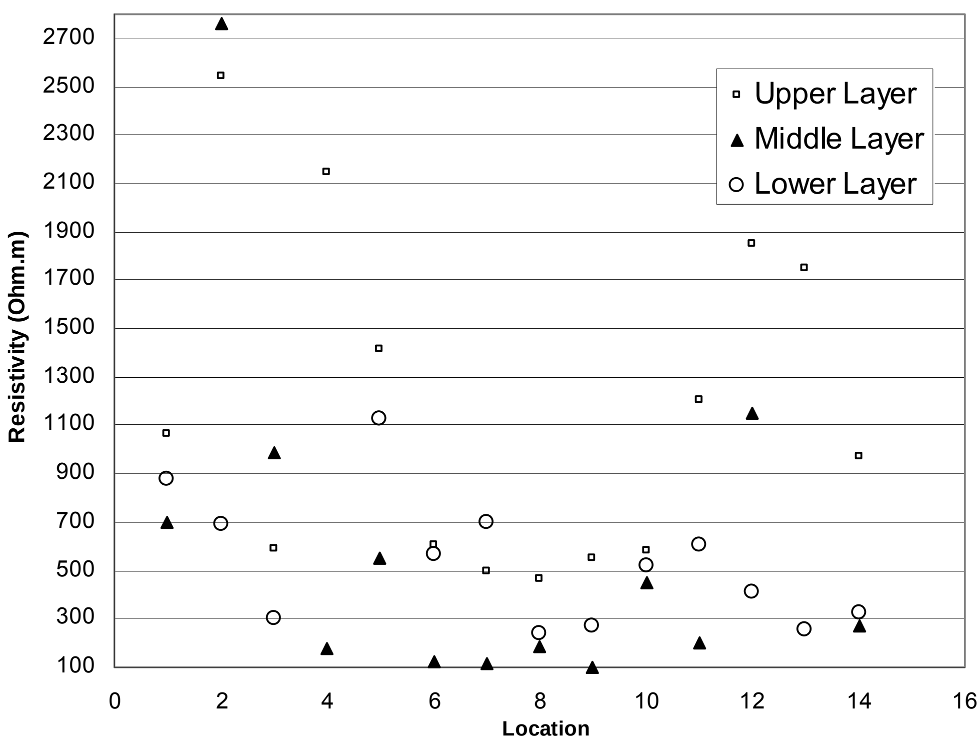

Figure 4. Resistivity values of the geo-electric layers in Kasaragod area.

Hydrogeologically, more water resources potential zones generally produce low-resistivity anomalies either by serving as active seepage conduits or because of the presence of weathering products. Preparation of geoelectrical sections by using VES results after calibrating with available geological information give the source of resistivity anomalies. Tables 3 and 4 show the characteristics of the thickness and resistivity values of the geo-electric layers.

Table 3. The characteristics of the thickness of geo-electric layers

Layer	Thickness (m)		
	Average	Maximum	Minimum
Upper	2.878571	10	1.1
Middle	14.3	46.5	0.9

Table 4 The Characteristics of the Resistivity of the geo-electric layers

Layer	Resistivity (Ohm.m)		
	Average	Maximum	Minimum
Upper	1159.536	2545	465.5
Middle	560.9286	2762	79.6
Lower	498.8371	1130.3	95.3

From the VES results, it is also inferred that the rock formations have undergone weathering/ fracturing up to an average depth of about 14m. Groundwater is being used mainly for drinking and other domestic purposes. Groundwater is mainly confined in the middle layer and fracture zones of fractured basement, forming an unconfined aquifer system.

Well Yield Analysis

Properly and correctly interpreted data from pumping test are among the most useful information which can be used to plan groundwater development programmes. In a highly permeable formation or in the formation at significant depth below land surface where there is a long water column in the well casing, rapid changes in the momentum of the water column caused by changes in pumping test rate can result in oscillatory water level responses (Shapiro and Oki, 2000). Several methods have been developed for interpreting, the hydraulic responses in pumped wells, making it possible to interpret water-level responses and estimate formation properties from single-well tests (for example, Jacob, 1947; Van Everdingen, 1953; Rorabaugh, 1953; Ramey and Agarwal, 1972; Kruseman and de Ridder, 1991). Other Conceptual models, which consider heterogeneous formation properties, are seen in the models of Barker and Herbert (1982) and Butler (1988).

Yield test data have been available for 25 tube wells in the study area. Yield data for the tube wells have been procured from Groundwater Department, Kasaragod district, Government of Kerala.

The thickness of weathered zone, the compactness of rock, fracture/joint patterns and weathering patterns etc determine the yield of the well. Table 5 presents the results of the yield of wells. Greater thickness indicates the possibility of better recharge, as well as suitability for groundwater localisation and movement. The thickness of the fractured zone depends on the nature of rock, its compactness, degree of weathering and the presence of fracture/joint patterns. Higher well yields indicate relatively greater groundwater availability than areas with low well yields.

Table 5. Yield Test results of tube wells.

Sl.No.	Location	Yield in Liters per hour	Land cover
1	South Muttathody, Chengala	250	BL
2	Udayagiri, Madhur	2000	SV
3	Marapanadka, Kumbadaje	4000	CL
4	Povval Akkara, Muliyar	500	BL
5	Mallam Meethal, Muliyar	300	BL
6	Chedikkana, Badiadka	2500	CL
7	Karuvalthadka	2500	CL
8	Cherkala East	1000	BL
9	Kattatadka	1000	BL
10	Maniyan Para, Badiyadka	3000	BL
11	Chettam Kuzhi, Madhur	2000	St
12	Rehmath Nagar, Chengala	3000	CL
13	Badiyadka	6000	CL
14	Edaneer	2500	SV
15	Neerchal	1500	BL
16	Vidyanagar	6000	St
17	Chengala	3500	SV
18	Rahmath Nagar-2, Chengala	2500	SV
19	Tekkil side, Chengala	3000	SV
20	Ramdas Nagar	2500	SV
21	Perla- north	3000	SV
22	Naimarmoola	5000	SV
23	Puthighe	2000	BL
24	Chengala	5000	CL
25	Cherkala	2000	SV

Note:- SV: at or near sparsely vegetated land cover; St: at or near Settlement; CL: at or near Crop Land cover; BL: at or near Bare Land cover

The Yield pattern of wells also bears a strong correlation with the observation made from remote sensing data analysis and geo-electrical survey regarding the aquifer characteristics of the study area which occur in varied water resources potential zones.

Summary and Conclusions

Investigation of nature and dynamics of surface and groundwater in different water resources potential zone has both practical and research applications.

The hydrogeological assessment and evaluation of groundwater resources can be improved by integrating the analysis of land cover classification of satellite data and resistivity surveys in areas having varied groundwater resources. A good relationship among the land cover and NDVI from remotely sensed data, ground measured resistivity value, field tested well yield are observed for the identification of water resources potential zones. The results can be effectively applied for assessing and drafting a plan for groundwater resources exploitation particularly in regions encompassing crop-lands, sparsely vegetated areas in hard rock terrains. Remote sensing provided an easy means for land cover classification. Electrical resistivity surveys have proven successful in identifying the water resource potential zones, which are responsible for aquifer characteristics. The VES method has delineated the various subsurface geological formations and hydroegeological environment with associated land cover units demarcated by classified land cover using remote sensing data. Yield performance of the tube wells in different land cover confirmed the correlation exists among the respective land covers, resistivity values and groundwater potential. Crop lands and sparsely vegetated land cover showed good and bare lands showed low groundwater potentials respectively.

Groundwater occurs in the fractures, joints, fissures and weathered zone of the basement rocks under water table and semi-confined conditions.

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