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Evaluation of Groundwater Potential Index (GWPI) using Geophysical Survey in Kallar Watershed, Tamil Nadu, India

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Abstract: The increasing demand for water has brought immense pressure on groundwater resources in the regions where groundwater is prime source. In the present study an attempt has been made to evaluate groundwater potential index (GWPI) for understanding the hydro geological condition of Kallar Watershed, South India. Vertical Electrical Sounding (VES) was carried out at 17 locations within and around the study area. The interpretation of the data obtained from the VES revealed that three non-aquifer geo - electrical layers overlie the un-fractured basement. The first layer has an average thickness of about 0.5 m and resistivity of 83 Ohm-m. The thickness of the second layer is about 0.7 m and resistivity of 438 Ohm-m. The third layer is about 3.4 m thick and has resistivity of about 63 Ohm-m. Aquifer resistivity and thickness interpreted from VES data is used to generate the corresponding thematic maps. Weights are assigned to different ranges of resistivity and thickness values based on their position on geological map. Finally the weighted maps are integrated using a GIS based aggregation method to evaluate the groundwater potential index of the area.

***Keywords:** Geology, Electrical resistivity, GIS, GWPI, Thematic maps, Geological map, aggregation method*

1. Introduction

In the arid and semi-arid regions across the globe, water scarcity is a major problem. In these regions, due to deficit rainfall, immense pressure is brought on groundwater. The study area is located in the semi-arid climate zone, within granitic terrain. Hard rock terrains develop complex hydrogeology over long period of geological time due to heterogeneous nature of the weathering. Groundwater in hard rock aquifers is essentially confined to fractured and weathered horizons. 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). The hydro geologic characteristics of basement rocks are only enhanced when the rocks are fractured and/or when they are weathered. The conditions are better enhanced when the rocks are overlain by thick overburden. Groundwater potential of a basement complex area is often determined by using geophysical inputs, as geophysical investigations help in determining the thickness of the overburden and the network of fractures that may exist in the area. Geophysical surveys are also important for groundwater investigation in basement areas in view of the discontinuous (localized) nature of basement aquifers (Satpaty and Kanugo, 1976). Gustafsson (1993) used a GIS for the analysis of lineament data derived from SPOT imagery for ground water potential mapping. The VES data are interpreted by using Evolutionary Programming (EP) technique, based on global optimization (Shahid et al., 1999). The use of the vertical electrical sounding method is popular for groundwater investigation in both soft rock (sedimentary) and hard rock (igneous and metamorphic) terrains (Shemang, 1993). To meet the main objective of present study, GIS is used for spatial modeling of hydro geological condition of hard rock terrain of Kallar Watershed, Tamil Nadu, India. The GIS application has been carried out through the integration of geological and geophysical thematic maps and VES results, respectively.

2. Study Area

Kallar watershed is one of the sub-watersheds in the Cauvery River; it is categorized under semi critical area based on existing groundwater development condition. Kallar watershed is located in Salem district, west, central, southern and eastern parts of Perambalur and Cuddalore districts and small portion of northern part of Viluppuram district. It is well connected by roads and railways with rest of the cities in Tamil Nadu. It is lying in between 780 38’ 58” to 790 20’ 19” Eastern longitudes and 110 20’ 38” to 110 32’ 10” Northern latitudes (Fig.1). The total area is 545 sq. km. For present study the study area is subdivided in to eight blocks. The Kallar is known for aggressive agricultural practices, such as tapioca cultivation and sago industry. Semi-arid climatic condition is prevailing in the watershed, without much variation. The annual average rainfall in the study area is about 842 mm, which is much lower than the state average. The Kallar watershed is mostly covered by pediments and pediplain with extensive coverage of black cotton soil, which normally has low infiltration. At present, the agricultural practices are mostly dependant on the availability of groundwater in the watershed. Charnockite and hornblende biotitic gneiss are the major rock types present mostly in the northern and southern parts of the Kallar watershed. The metamorphosed gneissic rocks are foliated and weathered compared to charnockitic rocks. However, lineaments associated with joints and fractures control high weathered condition, irrespective of rock types. Both dug wells and bore wells are catering groundwater requirements in the gneissic terrain.

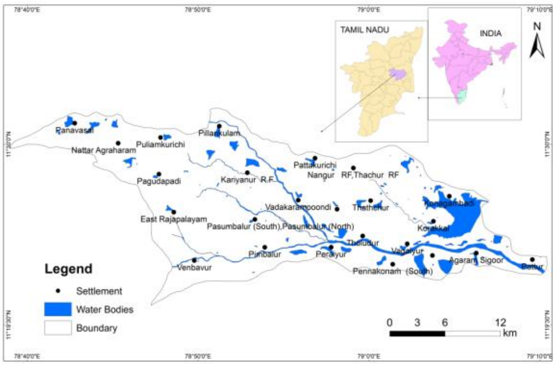

Figure 1 *Location map of the study area*

3. Data and Methodology

Survey of India Toposheets (SOI) of 1:50,000 scale were used for preparation of base map and for delineating watershed boundaries. District resource map published by Geological Survey of India was used for extracting litho-logical units of Kallar watershed (KWS). Geophysical data greatly help in locating the groundwater potential in any hydro geological setup. Venkateswara Rao and Briz-Kishore (1991) proposed a method for the interpretation of geophysical data and estimation of groundwater potential index (GWPI) at various survey locations. Edet and Okereke (1997) used a similar approach for Oban massif, Nigeria and calculated the ground water potential. In both the cases researchers used VES data for the estimation of layer parameters, namely, aquifer resistivity and thickness at different points. As the GWPI obtained in this process is derived from the physical properties of the subsurface layers, they showed that it gives an accurate measurement of groundwater potential. In this investigation, for the estimation of hydro geological condition, data obtained from VES surveys are interpreted for the estimation of the subsurface parameters viz. electrical resistivity of the aquifer and aquifer thickness.

In the present study, feature of an individual geophysical theme has been scored in the 1-10 scale in the ascending order of hydro geologic significance. The raw score for each feature is then normalized using the following relation to ensure that no layer exerts an influence over the other,

$$X_j = \frac{R_j - R_{min}}{\mathrm{R_{max}} - \mathrm{R_{min}}} \dots \quad 1$$

Where

Xj is the normalized score
Rj is the raw score
Rmin is the minimum score and
Rmax is the maximum score of a layer

The groundwater condition of the study area is then estimated as

Groundwater Potential Index = Rs + Ts … 2

Where, Rs represents score of aquifer resistivity and Ts represents score of aquifer thickness.

4. Results and Discussion

4.1 Geology

It is well established that geology plays a vital role in the distribution, occurrence and movement of ground water flow. The district resource map published by Geological Survey of India has been used to study and preparation of geological map for KWS (1995). The entire water shed (WS) is covered by the hard crystalline rocks of Archaean formations. Gnessic and charnockite groups are the major rock types in the WS (Fig.2). Granotoid gneiss, biotite gneiss and granitic gneiss belong to the oldest group of gneissic formations. The major portion of the WS is covered by gneissic formation with the northern and southern part of the WS. These groups of rocks are well exposed at Veeraganoor, Laduvadi and Kavarpanai villages in the south. In the north, it is exposed at Thalaivasal, Siruvachur and Puthur. The gneissic group of rocks approximately covered an area of about 300 sq.km. The charnockite group of rocks occupied an area of about 107 sq.km in the central part of the WS.

4.2 Geophysical Survey through vertical electrical sounding

In the present investigation, a total of 17 VES data are collected using Schlumberger electrode configuration with an electrode spacing varying between 50 and 100 m. The sounding locations are shown in Figure 3. All the VES data are interpreted using evolutionary programming (EP) techniques based on global optimization (Shahid et al., 1999). In D.C. resistivity sounding we are concerned with the parameters like r1, r2, ..., rn and h1, h2, ...,hn-1. For each parameter we have a pair of bounds i.e., the upper and lower limits. The layer parameters derived from VES using EP at different points are used for the generation of geophysical thematic maps. Semi-variograms are used to estimate the spatial correlation between different points relating to aquifer resistivity and its thickness. For better spatial correlation nearest eight points are clustered. The thematic maps of aquifer resistivity and its thickness are displayed in Figures 4.

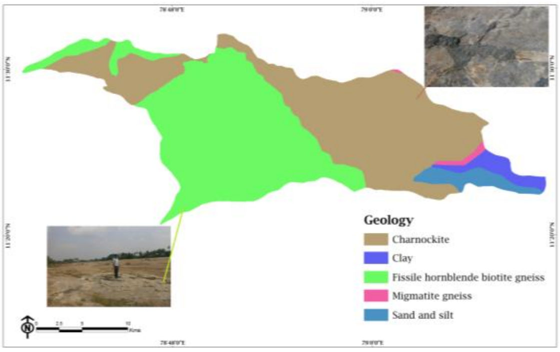

Figure 2 *Geology of study area*

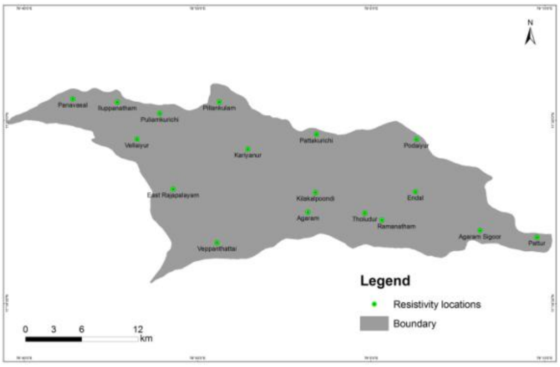

Figure 3 *Sounding locations of the present study*

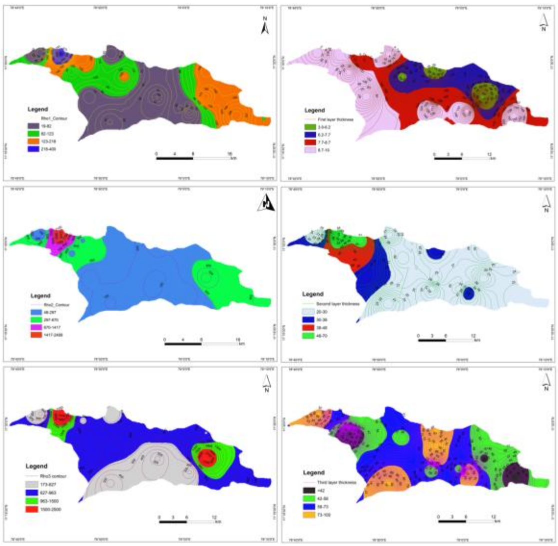

Figure 4 *Aquifer resistivity and its thickness*

4.3 Assignment of ratings to different geophysical features and layer integration

Resistivity of water bearing formation: Resistivity of aquifer in the study area varies from 23.1 to 327 ohm m. This has been selected by comparing with litholog information. The lithological variation from the nearby borehole logs in the survey area, when superimposed on the resistivity-depth section, is found to reveal resistivity variations of different formations, including good quality aquifers. Water bearing formations have moderate resistivity compared to saline water, having resistivity around10 to 20 ohm.m. However, when resistivity reaches values beyond 150 to 200 ohm.m, conductivity becomes lower indicating absence of water bearing formations. In the present case it has been decided (using combined litholog and VES results) to consider resistivity values ranging between 75 to 150 as favourable and values below 35 ohm m as unfavourable. A higher rating is, therefore, assigned to the resistivity range of 75 and above(but less than 150 ohm m) and least to the lowest (in the present case 35 to 55 ohm.m).It is essential to note that resistivity range for good aquifers vary, in different granitic terrains based on structure, texture and mineral composition. And as such before assigning ratings one should have area specific calibration for different sub surface layers, including good quality water bearing aquifers.

Thickness of aquifer: The thickness of the aquifer in the area is found to vary between 3.1 and 17.1 m. It is well known that transmissivity increases with the thickness of the aquifer. In the present area, the transmissivity is higher for an aquifer of thickness more than 10 m, moderately high when the thickness is between 5 and 10 m, and poor when it is below 5 m. Accordingly, raw scores are assigned and normalized as tabulated in Table 1.

Table 1 *Score assigned to different features of geophysical thematic maps*

Parameter		Attribute	Raw score	Normalized
Resistivity of aquifer	Hornblende Biotite Gneiss	>35 W m	1	0
		36 - 55 W	2	0.25
		56 - 75 W	3	0.5
		76 - 90 W	4	0.75
		>90 W	5	1
	Charnockite	20- 40	1	0
		41-70	2	0.25
		71-200	1	0
		>200	1	0
Thickness of Aquifer		<5m	1	0
		5m-10m	2	0.5
		>10m	3	1

The two thematic maps are registered with one another through ground control points and integrated using the aggregation method in GIS. The fourteen polygons of aquifer resistivity are integrated with eleven polygons of aquifer thickness resulting in a layer of 55 polygons. The new score for each polygon of this layer is calculated using equation (2). Finally, the polygons are classified according to their score and the ground water potential index map of the area is prepared as shown in Figure 5. The figure ascertains that various regions have different ground water potential. The area having a score above 0.75 has a high aquifer transmissivity represents good zone for groundwater exploration. The area with a score between 0.5 and 0.75 represents moderate zone of groundwater potential and the area with a score below 0.5 represents poor zone for groundwater. The characteristics of different zones are given is Table 2. The resultant model is verified with pumping test data available in six test sites in the study area. A high transmissivity and storativity values are observed in the area where GWPI is greater than 0.75, and moderate transmissivity and storativity values in the zone where GWPI is between 0.5 and 0.75.

Table 2 *Groundwater prospect of various regions in study area*

Zone	Groundwater potential Index	Aquifer resistivity (ohm-m)	Aquifer Thickness (m)	Average transmissivity and hydraulic conductivity	Groundwater condition
1	0.75-1.0	75-150	>10	High	Good
2	0.5-0.75	55-75	5-10	Moderate	Moderate
3	<0.5	35-55 or >150	<5	Poor	Poor

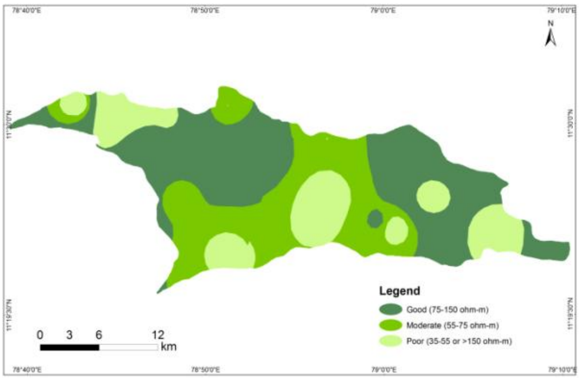

Figure 5 *Groundwater potential indexes for hydro geological condition.*

5. Conclusion

Integration of geophysical data using GIS is carried out for hydro geological study over an area of 545 km^2 in Kallar Watershed, Tamil Nadu. The geological study shows that the area is covered mainly by two types of rock formations. Charnockite and Hornblende biotitic Gneiss are found to be the predominating units all over the area. Geophysical survey using VES points to promising shallow groundwater resources in the area. Integration of the geophysical thematic maps (using GIS) revealed that 18.1% of the area has a score more than 0.75 representing highly prospective, 39% between 0.5 and 0.75 presenting moderately prospective, and the rest below 0.5 meaning poor for groundwater. The model is verified with available pumping test data and found to be in good agreement.

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