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Evaluation of Heterogeneous Aquifers in Crystalline Rocks from Resistivity Sounding Data In and Around Kanigiri, Prakasam District, Andhra Pradesh, India

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ABSTRACT
Interpretation of vertical electrical sounding (VES) data coupled with the estimation of coefficient of anisotropy (λ) in three profiles around Kanigiri, Prakasam district, Andhra pradesh, India. The coefficient of anisotropy estimated at 130 sites from VES data has shown variation between 1 and2.5 along AA^1profile, 1 and 14 along BB^1 profile, 1 and 12 along CC^1profile, which in turn reveals the anisotropic character of the crystalline granitic gneiss aquifers.

***Keywords**: Anisotropy, crystalline aquifers , vertical electrical sounding, fracture*

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I. INTRODUCTION

Water is most important for any type of land development and conservation of groundwater is economically important. Geophysical methods has been used for a number of applications particularly groundwater potential zone identification. Accurate and reliable results has been obtained when these methods are proposed with thoroughly understanding of geological, geomorphological and hydrogeological environments, water table conditions and topography in a specific location. The electrical resistivity method plays a key role for solving groundwater problems through its highest subsurface resolving power and economical viability. Electrical resistivity methods are used to investigate the different lithological formations, bed rock dispositions, the depth to water table or zone of saturated formations, thickness of weathered zones, detection of fissures, fractures, fault zones, establishment of their depths, thickness and lateral extent of aquifers, groundwater flow directions, valley fills, depth to basement in hard rocks, fresh and salt water intrusions, groundwater prospective zones, for locating ore deposits and archaeological studies. In this study area electrical resistivity method has been used to analyse geoelectrical parameter identification.

II. GEOLOGY AND GROUNDWATER FLOW SYSTEM:

CRYSTALLINE AQUIFER SYSTEM:

This system, is represented by granite – gneiss, hornblende biotite- gneiss, charnockites, khondalites and schistose group of rocks. This system lacks primary porosity and the occurrence and movement of groundwater in these rocks depends on the thickness of weathered zone available and degree of fracturing or jointing in those rocks. The fracturing in this area may be attributed to prevailing seismic activity in the area as discussed by earlier workers.

CUDDAPAH AQUIFER SYSTEM:

This system, comprises of quartzites, shales and limestones. The occurrence and movement of groundwater in these rocks depending on the extent of weathering, degree of compaction, presence of solution channels in the limestones.

UPPER GONDWANA SYSTEM:

In this system, sandstone and shale formations occur in certain mandals in the district.

ALLUVIUM SYSTEM:

This constitutes sand, gravel, kankar as coastal alluvium, river alluvium and wind blown sands. As this system nearer to the Bay of Bengal coast.

GEOLOGY:

The area is divided as 3 east west segments shown in figure 1 and the geology follows. The study area is close to the eastern margin of the proterozoic cuddapah basin and to south of Vinukonda. A foliated alkali granite pluton occupying an area of 10sq.Km is emplaced within the metavolcano metasedimentary sequence of the Archean Nellore schist belt. In its western part the 'Podili alkali granite pluton' exhibits sharp contracts with NS to NNE-SSW trending quartz – chlorite schist and quartzite of Nellore schist Belt. The Podili pluton is traversed by a semi-elliptical syenite, dykes of alkali feldspar granite and tourmaline bearing quartz vein. Astrophyllite arfvedsonite bearing alkali granite is localized along the western part of the Podili pluton. The occurrence of the Podili alkali granite and Kanigiri-biotite granite to the south of Podili were reported by Geological Survey of India.

The petrological studies of Kanigiri- Podili granites indicated the occurrence of fluorite, zircon, sphene, garnet, apatite, topaz and columbite as accessory minerals along with molybdenite, arsenopyrite, pyrite and discrete grains of samarskite, fergusonite and monazite in the Kanigiri granite. The location map of the study area is shown in the figure2.

Figure1. Geology map of the study area (after GSI)

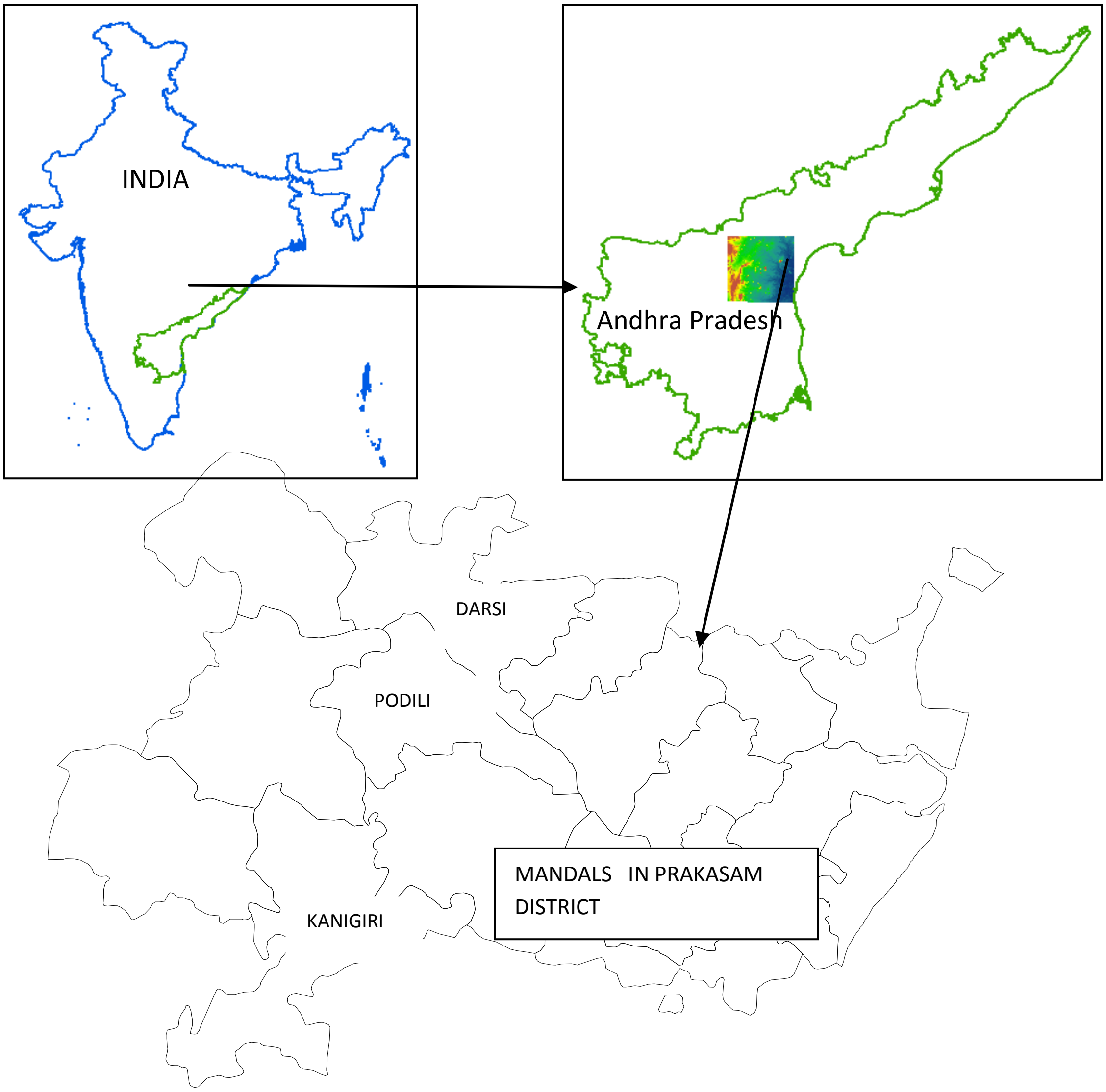


Figure2. Location map of the study area

GROUNDWATER FLOW SYSTEM:

WATER LEVELS & FLUCTUATIONS:

The ground water level, maps prepared varied due to undulatory nature of terrain and different geological settings with complex types of hydrogeomorphological structure present in the area. Shallow water levels along the coast and most of the central parts of the area. The water levels are deeper in the North eastern and western hilly areas. The shallow areas posses less than 4.0 m bgl water level whereas in western central undulatory areas of Donakonda, Dornala posses 6m bgl water level. The water table elevation in the district ranges from 5.0 m AMSL near the coast and 200 m AMSL in the western hilly area regions. The general groundwater gradient is 1.12 to 1.6 meters during pre-monsoon to 0.55m to 1.8 m during the post monsoon. The rise and fall of groundwater levels are due to the draft of water for various agricultural practices in this area. The main crop pattern in the area is chilly and tobacco apart from paddy.

III. MATERIALS AND METHODS

RESISTIVITY DATA ANALYSIS AND INTERPRETATION

The electrical resistivity measurements were carried out using DC resistivity meter (DDR3 of IGIS make of India) and its accessories. At the field site VES method employing Schlumberger configuration was deployed to obtain the field resistivity data. The current electrode spread (*AB*/2) length used varied between 1.5 m and 130 m depending on the accessibility in the area.

The measured apparent resistivity (ρa) field data are plotted on a double log graph paper with a modulus of 62.5 mm on an ordinate versus abscissa coordinate system as measured apparent resistivity (ρa) against the half current electrode separation (AB/2). The sounding curve so plotted shows the qualitative nature of the sounding for a given sounding position. This sounding curve reveals important subsurface information, viz. hydro geological scenario, resistive basement, thickness of resistive layers and anisotropic condition. The initial layer parameters/model from the field VES curve can be derived by full and partial curve matching techniques. As there is a chance of error in interpretation and judgments of manual curve matching procedures, several numerical computer programs for automated fit of resistivity data have been developed. In the present study the quantitative interpretation of the field data has been carried out with the help of the computer inversion program IPI2WIN, has been used to compute the geoelectrical parameters of the study area.

IV. GEOELECTRICAL PARAMETERS

A geoelectrical layer is characterized by two essential parameters like resistivity 'ρ' and thickness 'h'. The other geoelectrical parameters could be obtained from these variables:

1. Total longitudinal unit conductance (S)
2. Total transverse unit resistance (T)
3. Longitudinal resistivity (ρ_L)
4. Transverse resistivity (ρ_t)
5. Aquifer anisotropy (λ)

1. The total longitudinal unit conductance (S) is calculated by using the formula.
For 'n' layers, the total longitudinal conductance is

$$S=\sum_{i=1}^{n}\frac{h_i}{\rho_i}=\frac{h_1}{\rho_1}+\frac{h_2}{\rho_2}+\cdots+\frac{h_n}{\rho_n} \qquad \text{…………..} (1)$$

The total transverse unit resistance (T) of a VES can be observed by using the equation.
The total transverse unit resistance is

$$T=\sum_{i=1}^{n}h_i\rho_i=h_1\rho_1+h_2\rho_2+\cdots+h_n\rho_n \qquad \text{…………..} (2)$$

The average longitudinal resistivity for a given VES curve is given by using the equation
The longitudinal resistivity is

$$\rho_L=\frac{H}{S}=\frac{\sum_{i=1}^{n}h_i}{\sum_{i=1}^{n}\frac{h_i}{\rho_i}} \qquad \text{…………..} (3)$$

The average transverse resistivity for a given VES curve is given by using the equation
The transverse resistivity is

$$\rho_t=\frac{T}{H}=\frac{\sum_{i=1}^{n}h_i\rho_i}{\sum_{i=1}^{n}h_i} \qquad \text{…………..} (4)$$

The coefficient of anisotropy (λ) of a formation could be observed by using the formation.
The coefficient of anisotropy is

$$\lambda=\sqrt{\frac{\rho_t}{\rho_L}}=\frac{\sqrt{ST}}{H} \qquad \text{…………..} (5)$$

The parameters *T* and *S* (defined as transverse resistance and longitudinal conductance respectively) play an important role in the interpretation of sounding data. These are called the Dar Zarrouk parameters.
The result presented as coefficient of anisotropy is commonly higher than 1.00 but does not often exceed 2.00 (Zohdy et. al., Op. cit). It could be measure of carryout the extent of anisotropies in an area of interest. It accounts to 1.02-1.10 for alluvium, 1.05-1.15 for sandstones and shales 1.40-2.25 for slates and 2.0-0.8 for graphite schist. As the hardness and compaction of rocks increase, the coefficient of anisotropy also increases (Keller et. al., 1966) and hence such areas can be associated with low porosity and permeability. It can be used as a measure of finding out the extent of anisotropism prevailing in an area of interest.

From eqs (1) to (5), the coefficient of anisotropy is estimated along with the secondary geoelectric parameters. The estimation shows that the total longitudinal conductance along profile AA^1 varies from 0.04 to 7.11 Ω^{-1}, along BB^1 varies from 0.03 to 7.11 Ω^{-1} and along profile CC^1 varies from 0.05 to 2.6 Ω^{-1} in the area. The qualitative use of this parameter is to demarcate changes in total thickness of low resistivity materials. The total transverse resistance ranges along profile AA' from 29to 125924.8 $\Omega.m^2$, along profile BB' varies from 8.5 to 125924.5 $\Omega.m^2$ and along profile CC' varies from 26 to 115584.38$\Omega.m^2$, which gives information both about the thickness and resistivity of the area.

Based on these estimates it was found that the coefficient of anisotropy λ along profile AA^1 ranges from 1.0027 to 2.5, along profile BB^1 ranges from 1.011 to 14, along profile CC^1 ranges from 1.1 to 12 which depicts the true variation of the anisotropic character of rock formations. The area with high values of λ suggests that the fracture system as shown in figure3 must have extended in all the directions with different degrees of fracturing, which had greater water-holding capacity from different directions of the fractures within the rock resulting in higher porosity. At the same time, unidirectional fracture may not produce good yield of water and such areas show low values of λ. Consequently, it indicates the presence of macro-anisotropy in the present geoelectric strata in the area, which is clear to distinguish the individual layers for a given VES earth model.

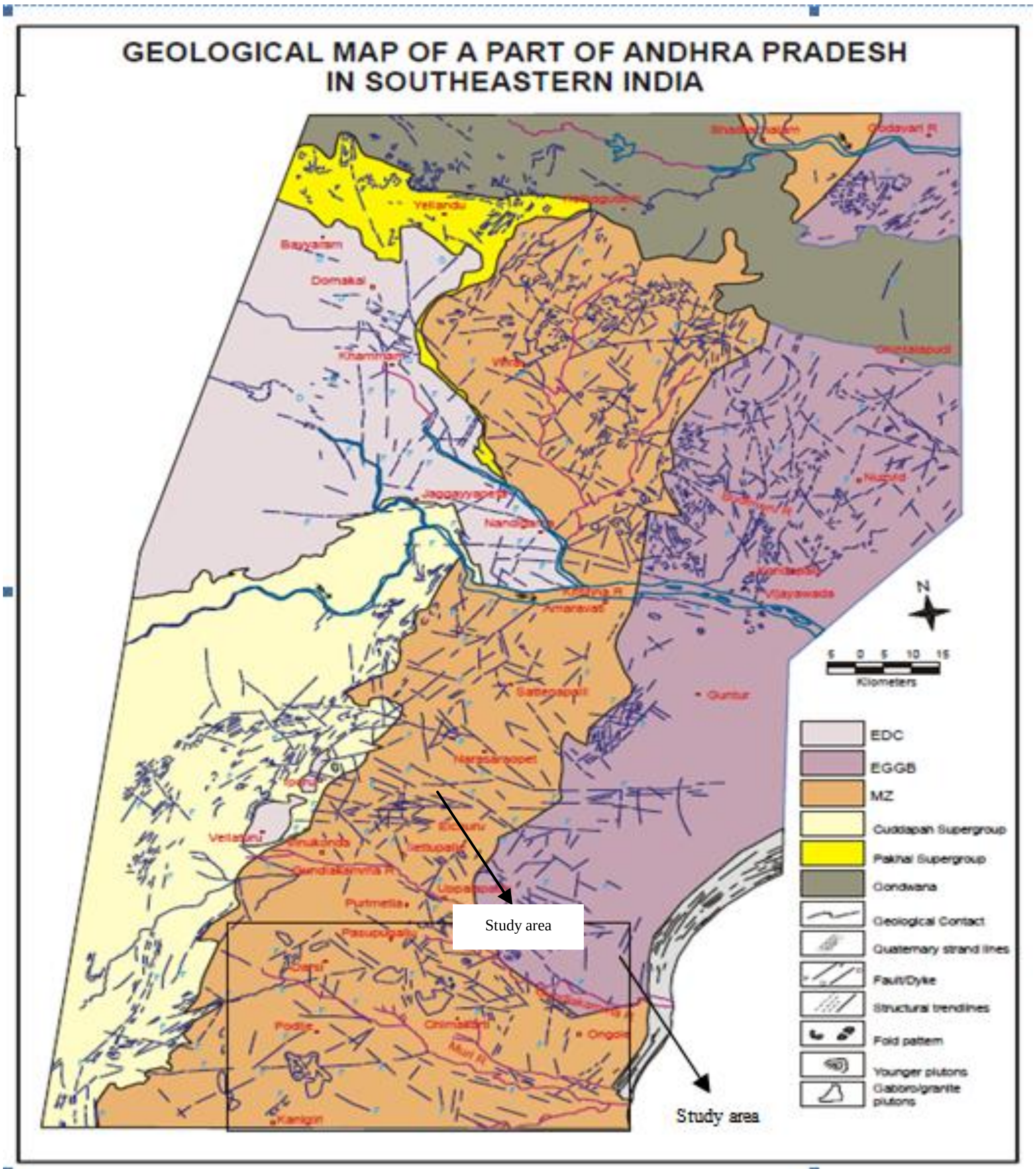
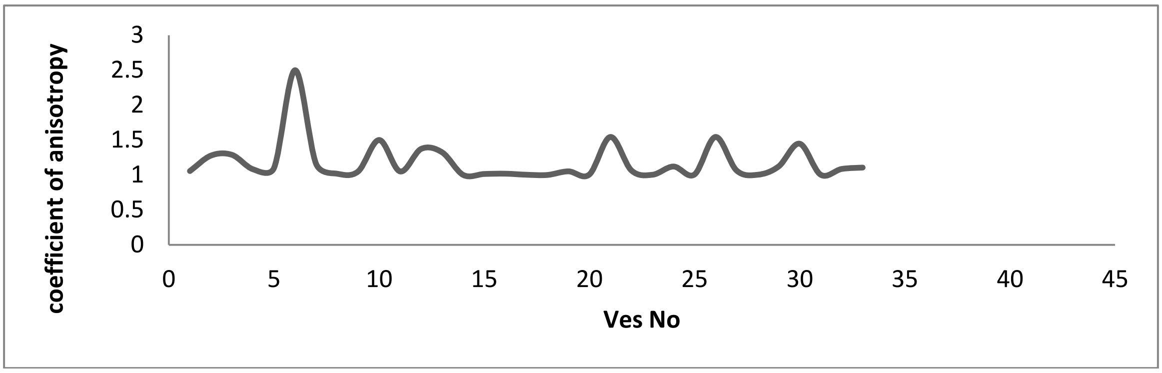


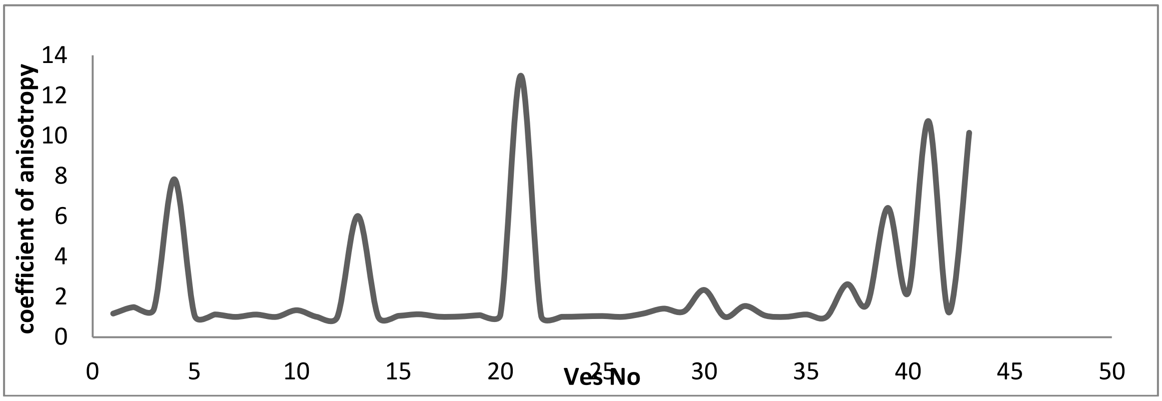
Figure3. Fracture system map of the study area (after GSI)

The coefficient of anisotropy shows that it increases from west to east in all three profiles and the eastern directions and profile AA^1 reaches a maximum value close to 2.5, profile BB^1reaches a maximum value close to

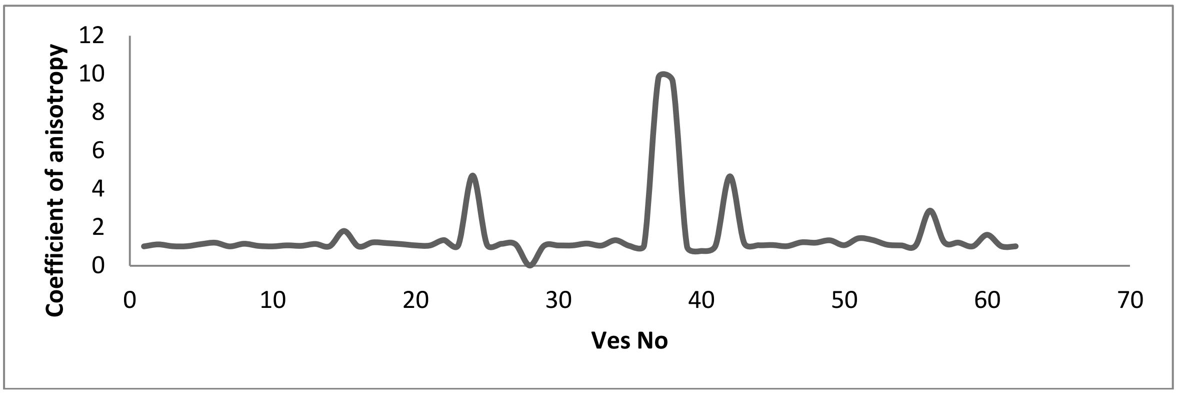
14, profile CC[1] reaches a maximum value close to 12 in the eastern direction, as shown in anisotropy map (Figure 4). It indicates that this physical property is not uniform in all directions and anisotropy plays a major role in fracturing. Here it indicates more fracturing towards the eastern direction and thus suggests comparatively more potential groundwater zone and hence better prospect for groundwater availability.



Profile AA'



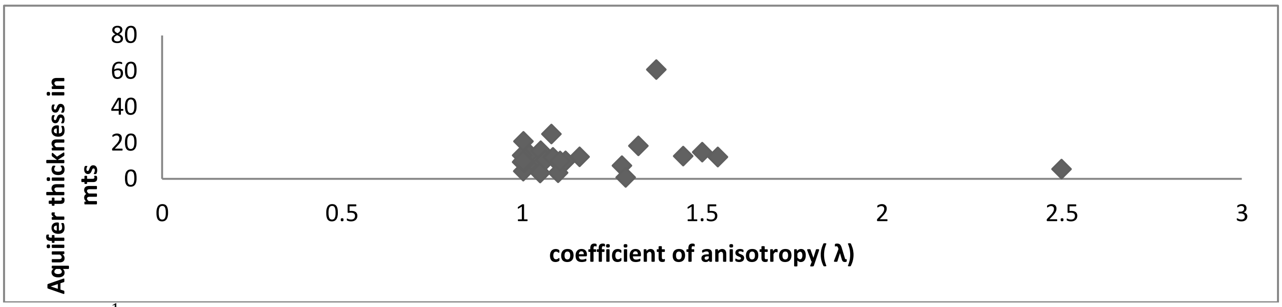
Profile BB'



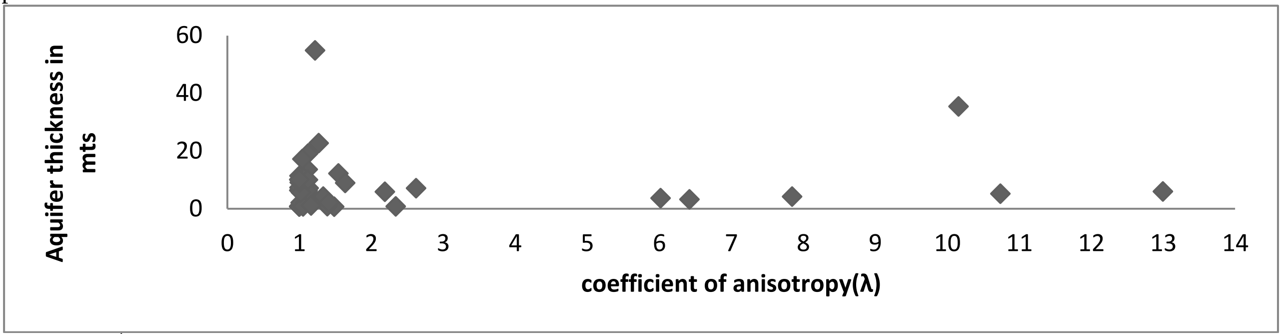
Profile CC'

Figure. 4 Plot of coefficient of anisotropy (*λ)* along Profiles

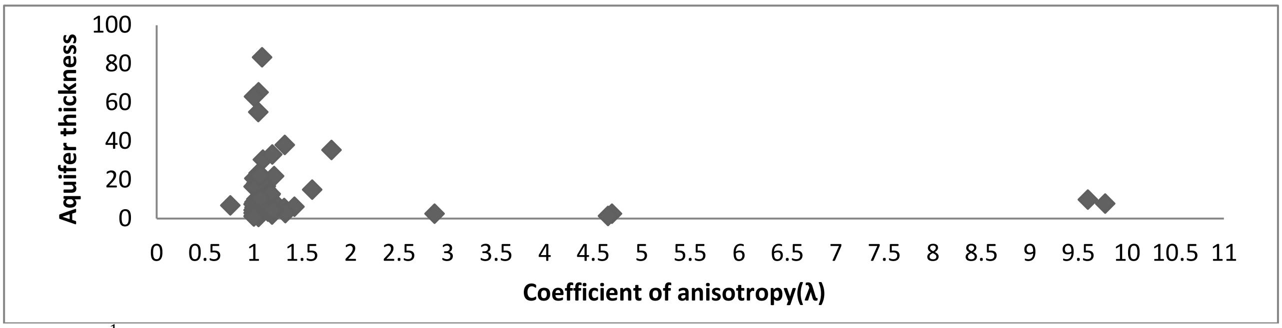
In other words, there is large variation in the transverse and longitudinal direction of the weathered/fractured granitic aquifer in the given study area. The high values of λ ($\lambda > 1$) signify more fracturing within the granitic gneiss rock formation, while values of $\lambda \approx 1$ obtained for granitic gneiss rocks could be explained on the basis of the relatively higher average value of the overburden thickness (*H*). This can be also witnessed from the plot of aquifer zone thickness and coefficient of anisotropy (Figure 5). Interestingly, λ values increase from west to east and in eastern directions with the maximum value concentrated around the eastern parts of the area.



profileAA1



Profile BB1



ProfileCC1

Figure 5. Plot of aquifer zone thickness and coefficient of anisotropy with maximum tendency of anisotropic behavior

V. CONCLUSIONS

The detailed characteristics of crystalline rock aquifers precisely delineated based on the complete VES resistivity data interpretation using both primary and secondary geo- electric parameters. The coefficient of anisotropy (λ) varies from 1 to 2.5 , along profile AA1 , and varies from 1 to close to 12 in profiles along BB1, CC1, which indicates large variation showing thereby more tendency towards anisotropy behavior of the geo-electric parameters of the study area.

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