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Hydrogeophysical investigation for groundwater potential through Electrical Resistivity Survey in Islamabad, Pakistan

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ABSTRACT

Background: The hydrological cycle has been disturbed because of global climate change. The rising global ocean level due to melting of ice with substantial increment in temperature led to climate warming. These circumstances have a negative influence on water resources, especially groundwater. The groundwater is one of the extraordinary natural resources used in maintaining life on the earth. It has a direct relationship with the population. The population growth, along with climate factor, has raised the demand for freshwater. Hence, there is an ultimate need to search for the location of new wells that can be utilized to fulfil population needs.

Objectives: The primary purpose of research is to carry out an electrical resistivity survey to determine potential aquifer capacity, properties and propose the location of the new wells in sector G-14/3, Islamabad.

Methods: Vertical Electrical Sounding (VES) was used with the Schlumberger configuration. ABEM Terameter SAS4000 was employed to perform 2D geoelectrical resistivity imaging surveys to obtain resistivity values. IX1D software was utilized for the data interpretation and the development of different geological layers.

Results: Results from the VES models shows that the subsurface is divided into different lithological layers. The depth and thickness of these layers vary due to tectonic activities and depositional environments. Clay is the dominant lithology along with sandy gravel layers. The Dar-Zarrouk parameters result specifies that VES-3 and VES-5 have an excellent protective capacity, moderate transmissivity, and a high coefficient of anisotropy

Conclusions: Due to variations in lithology and thickness, a single layer cannot be described as an aquifer. At depth >35 meters, only two points, i.e., VES-3 and VES-5, are marked as the zone of probable exploitable well locations. The higher values of the anisotropy coefficient indicate that the groundwater is highly polluted.

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1. INTRODUCTION

There would be no life without water is a well-known fact as being the most extraordinary gift bestowed upon us by nature in many forms, i.e., subsurface aquifers, precipitation, and snow. Water holds a special place as a vital ingredient for life and a vibrant research component (Adagunodo et al., 2018). One can

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argue whether life's origins are outside of earth or from the world, but none can say that life developed without water (Velzeboer et al., 2018; Westall & Brack, 2018).

Surface and underground water are the two primary sources used in maintaining life on a blue planet. Still, an exponential increase in population and constant human advancements have polluted these sources to a concerning degree (Roselló et al., 2009; Soomro et al., 2019). It is predicted that in the future, water shortage may arise mainly due to a large number of contaminations and an overwhelming intake by the existing supplies (Adagunodo et al., 2013). Apart from the above two factors, global drought in the current climatic scenario has also contributed mainly to the shortage of water and its availability in industrial and domestic use (Ayolabi et al., 2017; Famiglietti, 2014). It puts intense pressure on groundwater, which is an essential part of the earth's ecosystem: it supports us in our daily lives ranging from irrigation to household and other groundwater-dependent ecosystems (Kløve et al., 2014; Selvarani et al., 2016). Also, the groundwater has many advantages as it does not demand so-called treatment processes; however, some problems with the groundwater are also common like salinity issue which gets worst with the depth (Sikandar et al., 2010). According to the statistics, the groundwater consists of 96.3% of the unfrozen global freshwater resources and is a source of one-third of all freshwater withdrawals worldwide (Taylor et al., 2013; Zaveri et al., 2016). Aspects like economic development, population growth, and land changes lead to a forcible increase in water demand (Murray et al., 2012; Wang et al., 2016). Due to climate change, extreme conditions have started to rise faster and more aggressively, like droughts and floods. Because of their direct impact on groundwater, living beings that thrive on groundwater, such as plants, are immensely affected, impacting both humans and animals, as plants are a significant food source for both domains (Tabari, 2020; Taylor et al., 2013).

With regards to developing countries in Asia, groundwater-based irrigation has grown up to 500% and this type of irrigation has caused excessive abstraction of groundwater in countries like China, India and Bangladesh at an alarming rate (Wang et al., 2016). The growing scarcity of groundwater and ever-widening consumption for food production could weaken the agriculture-dependent economies (Mancosu et al., 2015; Schneider et al., 2011). Similarly, like the most developing world, Pakistan is also affected by acute groundwater shortage due to climate change and overexploitation (Iqbal et al., 2016; van Steenbergen et al., 2015). Since Pakistan's economy is also mostly based on agriculture and the biggest consumer of groundwater in Pakistan is also this sector, groundwater plays a massive role in socio-economic development in Pakistan (Ali et al., 2017; Iqbal et al., 2017).

Groundwater exploration has been accomplished using various hydro-geophysical techniques, including the electrical resistivity method (ERM), gravity method, magnetic method, an electromagnetic method, etc. (Adagunodo et al., 2018; Arefayne Shishaye & Abdi, 2015). The geoelectric survey, which incorporates the Vertical Electrical Sounding (VES), is being used globally and has been proven to be cost-effective, simple, fast, and efficient for groundwater investigations (Case et al., 2017; Stampolidis et al., 2005).

The purpose of the electrical resistivity survey is to lay bare the surface effects generated by the earth's current flow (Abdullahi, 2015). In this study, the authors used the most popular configuration in the VES, "Schlumberger array," having the symmetrical layout of electrodes on both sides of the array (Mohamaden et al., 2016; Oladunjoye & Jekayinfa, 2015; Shishaye & Abdi, 2016).

In Rawalpindi and Islamabad, the groundwater water is mainly used for drinking and agriculture purpose. The local public was used to collect water for drinking purpose from the large number of wells which have been abandoned because the groundwater level dropped to its extreme limits (Shabbir & Ahmad, 2016). So, the main beneficiaries of this study are the general public. In this research, sector G-14/3 was chosen to investigate and present the digitized groundwater table model. This paper aims to examine the aquifer properties, aquifer potential capacity and propose potential new wells site localities to fulfil the ever-increasing demand for water supply.

1.1 Geological and hydrogeological framework

Islamabad is located at the Himalayas foothills, one of the tectonically active zones between Indo-Pak and Eurasian tectonic plates. The dominant tectonic forces are due to the formation of series of thrust faults formed after the collision of the Indian and Eurasian plates that began nearly 50 million years ago, and these faults brought the older rocks to the surface, which are depicted in Margala Hills (Sheikh et al., 2008). The city lies in Hazara-Kashmir syntaxis (Main Boundary Thrust), which experiences moderate to strong earthquakes (Waseem et al., 2020).

The lithology exposed in Islamabad and its surrounding areas comprises Jurassic to the Pleistocene, having clastic and carbonate inputs in older and younger ages, respectively. The depositional environment of the oldest rocks of the area is shallow marine, while, due to considerable fluctuation, the younger rocks are deposited in deltaic to fluvial environments (Shah, 2009). The Samana Suk, Chichali, Lumshiwal, Hangu, Lockhart, Patatla, Maragala Hill Limestone, and Chorgali formations are deposited in the marine environment which are 675 meters thick in the study area, and Murree, Kamlial, Chinji, Nagri, Dhok Pathan, Soan Formations and Lei conglomerate are deposited in the non-marine fluvial environment with more than 7000-meter thickness (Figure 2) (Khattak et al., 2017; Shah, 2009). Moreover, it is important to mention that the Kudana Formation comprises marine and non-marine facies (Cooper et al., 2009).

In the hydrogeological context, Islamabad has a profound presence of a shallow aquifer and deep aquifers. The shallow aquifer is composed of the Holocene and upper Pleistocene alluvium deposits; on the other hand, the deeper aquifer consists of Lei Conglomerate of Pleistocene age. The Lei conglomerate is uncemented, which amounts to the most significant groundwater aquifer in the Potwar Plateau. Nevertheless, the alluvium deposits overlying the Lei Conglomerate pose a shallow water table and are most frequently used by municipal and private wells (Figure 2) (Sheikh et al., 2008). The most important thing is that such aquifers' presence is demarked by the intercalation of large clayey lenses, causing dissection and an insignificant link in some sectors that are not located precisely. The study of Hydro-Geophysical and Environmental Science Consultants (HESC) in 2014 also indicates five aquifer levels in the region. Due to the lithological heterogeneity of the study area, this aquifer structure does not necessarily exist in all parts.

1.2 Local climate and hydrology

Regarding climate, Islamabad has four different seasons, i.e., summer (rainy monsoonal), dry and cold winter, dry autumn, and spring. The city's average temperature varies from 38°C in summer to 2°C in winter (Shah & Shaheen, 2008). The main stream draining the area is the Soan river, whose primary tributaries are Korang, Ling, Gumrah Kas, and Lei Nullah. The Rawal lake is constructed on the Korang river; however, the Soan River is dammed at Simly dam. Few small tributaries in the form of Lei Nullah that originates from Margalla hills also end on the Soan River. Lei Nullah also carries wastewater from Islamabad and Rawalpindi, contributing significantly to the Soan River's water pollution, having tremendous implications on groundwater reserves quality (Shabbir & Ahmad, 2016).

2. METHODS

Fieldwork was conducted for collecting data, which was subjected to various experiments to generate results.

2.1 Study design

The research data is presented as a qualitative and quantitative interpretation. The quantitative explanation includes the number of layers, resistivity differences, and Dar-Zarrouk parameters. Based on these quantitative examinations, qualitative results are also generated, i.e., the VES curves, lithological composition, and probable exploitable well locations.

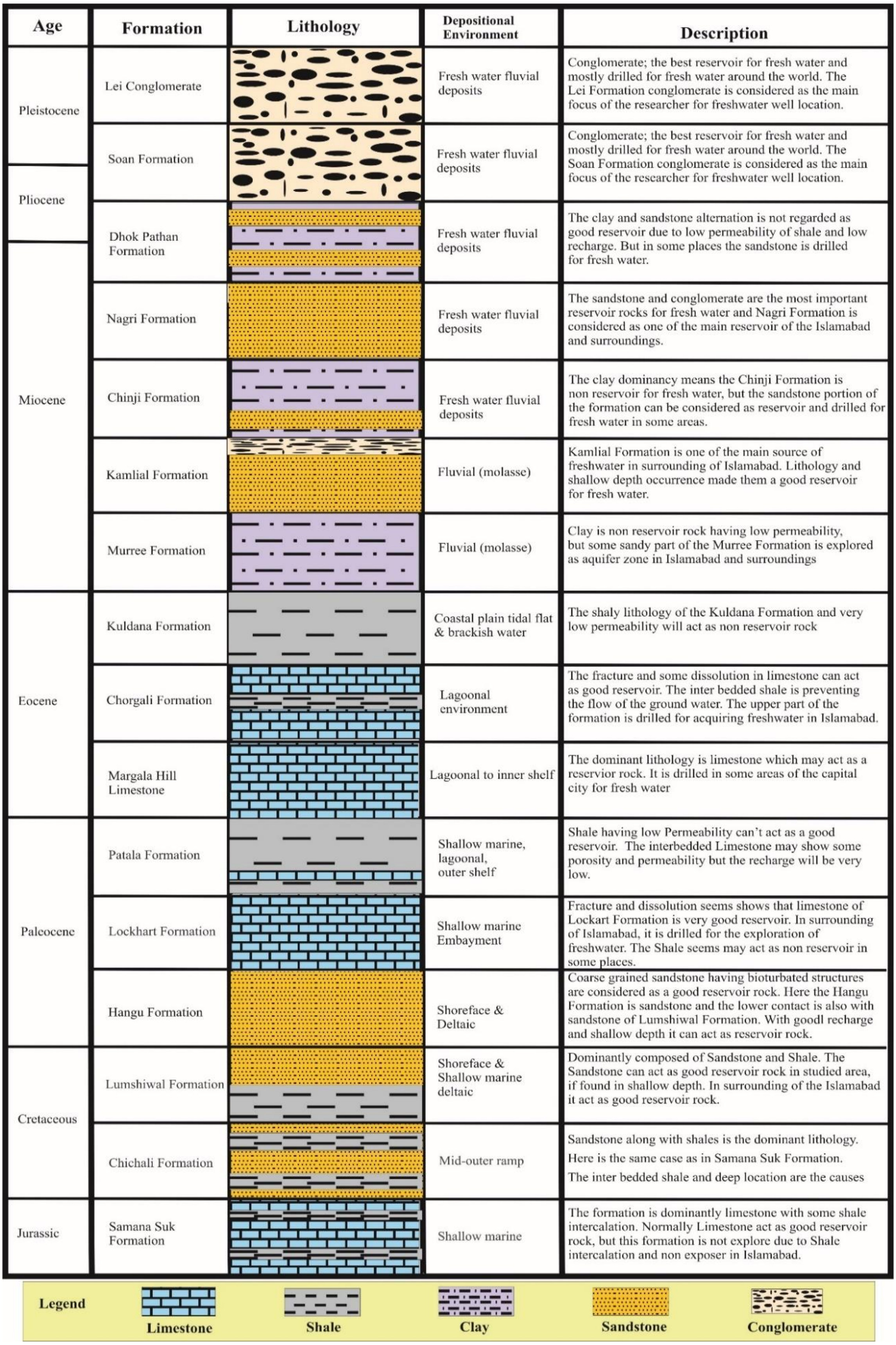

Figure 1 The lithological log and reservoir characteristics of the Islamabad rocks exposed and drilled in surrounding of the Islamabad and Rawalpindi. The Soan formation, Lei Conglomerates and recent alluvial deposits are more explored for the fresh water in study area (modified after Williams et al., 1999).

2.2 Setting

The rapid development of twin cities (Islamabad and Rawalpindi) combined with the population, which is estimated at 1.3 million, exerted an increase in demand for freshwater (Shabbir & Ahmad, 2016). Hence, there is an utmost need to search for new water wells locality to fulfil population needs. The problem of prospecting new well locations can be solved using geophysical investigation, as the application of geophysics has been widely applied for subsurface characterization (Coker, 2012; Metwaly et al., 2012; Riwayat et al., 2018). Capital development authority (CDA) authorized the development of new sectors in Islamabad in 2010. The selection of the study area was one of the crucial steps. Finally, a G-14/3 sector with latitudes 33°38'36.69″N and 33°38'53.67″N and longitudes 72°56'48.516″E and 72°57'10.67″E was selected to highlight the spots for freshwater (Figure 2).

2.3 Instrumentation

The ABEM Terameter SAS4000, portable, lightweight equipment, was utilized to perform 2D geoelectrical resistivity imaging surveys at the selected localities. One dimensional resistivity software (IX1D) was used for the interpretation of data. The Corel draw, Click Chart, and ESRI ArcGIS software were used to enhance the presentation of graphs and figures in this paper.

2.4 Data measurement

The VES survey is very sensitive to noise; therefore, the early morning time and calm locality were selected to obtain VES field data. The Google Earth Engine spotted areas were fielded for confirmation. The G-14/3 Sector in Islamabad was found better for this type of survey. The resistivity values were obtained in the field by using current electrodes (AB) to induce a current in the ground, and the potential was obtained with the help of potential electrodes (MN) (Khaki et al., 2014).

2.5 Data analysis methods

The data was collected using a standard Schlumberger configuration. The sounding mechanism in Schlumberger configuration is far better than other methods because of high resolution, greater probing depth, and less time-consuming field deployment (Khan et al., 2013). Space controls the depth of sounding in the Schlumberger array among current electrodes A and B. With the increase in distance between A and B electrodes, the depth of sounding also surged (Pomposiello et al., 2012). The current electrodes separation (AB/2) in the study area was from 1 to 160 meters, and this spread aimed to trace deep aquifers.

Similarly, the separation of the potential electrodes (MN/2) was between 0.2 to 20 meters. At each step of the AB spacing, the resistivity meter signals became weaker. So, the data was mostly taken in overlapping segments. Therefore, MN spacing was enlarged in two values for the same AB/2 (Sikandar et al., 2010). Multiple iterations were applied to the data obtained from the field. By plotting the apparent resistivity values against the depth, the curves were generated in the IX1D software (Odeyemi, 2014). The sub surface’s apparent resistivity values were plotted in the software, and then by the curve matching technique, the apparent resistivity values were converted into true resistivity values. Hence, the subsurface is divided into different geological layers (Qadir et al., 2018).

3. RESULTS

3.1 Multilayer resistivity interpretative models

The data was acquired from eight different sites for the VES survey. The number of layers detected during this survey is unique from spot VES-1 to VES-8. The distinguishable subsurface lithological layers of the VES-1, VES-2, VES-3, and VES-6 are five, VES-5, and VES-7 comprise eight, and lastly, VES-8 encompasses seven layers (Figure 3). The differences in resistivity values of the subsurface depend on the lithology and morphological subsurface structures. A detailed description of the VES points and the number of layers for each point and their respective resistivities, the thickness of layers, and the RMS error are shown in Table 1. The range of RMS error for the VES survey ranges from 1.5 to 2.8 %. Moreover, the depth, thickness, and relative position of the layers are correlated in Figure 4.

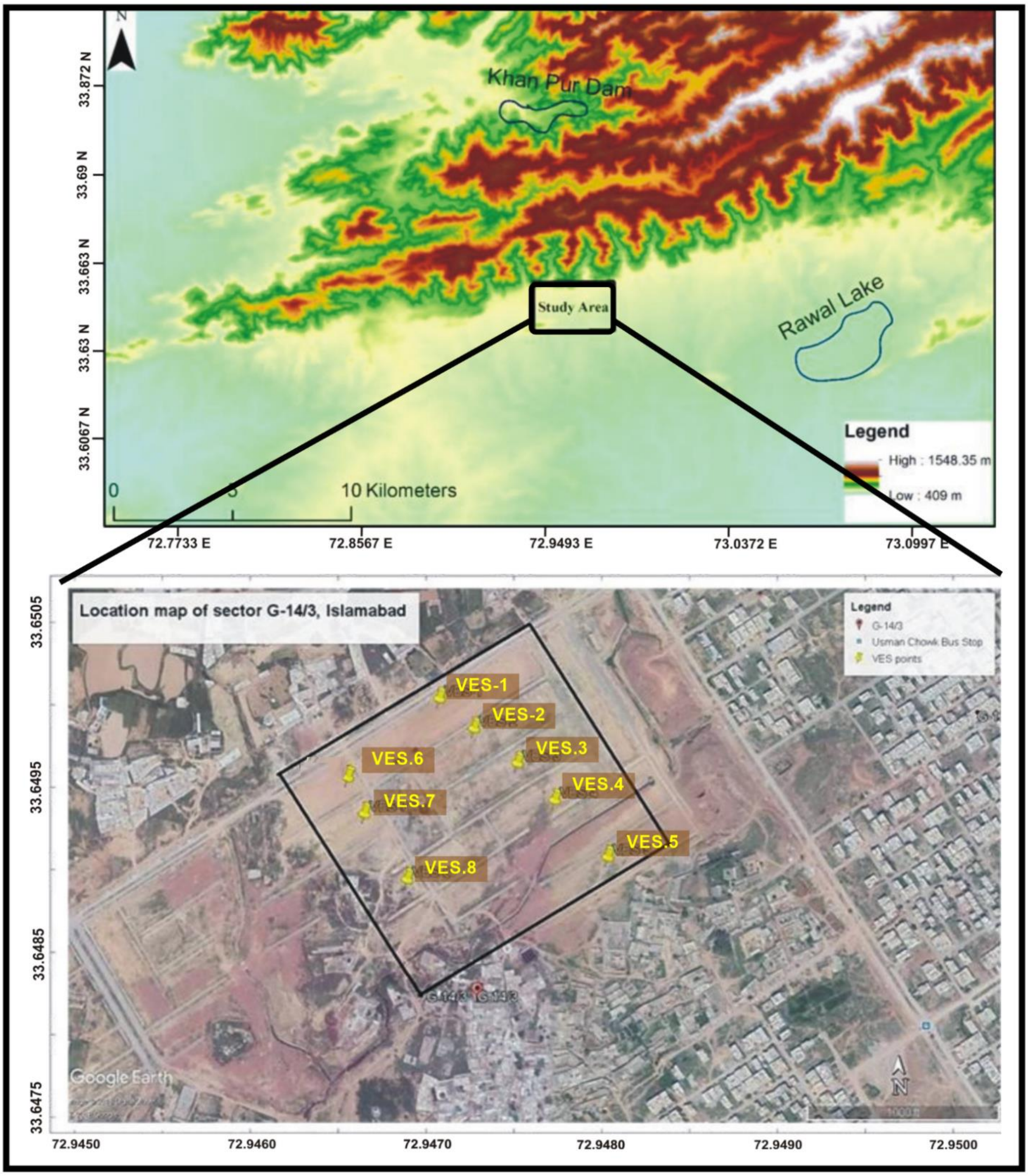

Figure 2 The Digital Elevation Map of Islamabad and the location of the study area, along with zoom map of the data collected spots.

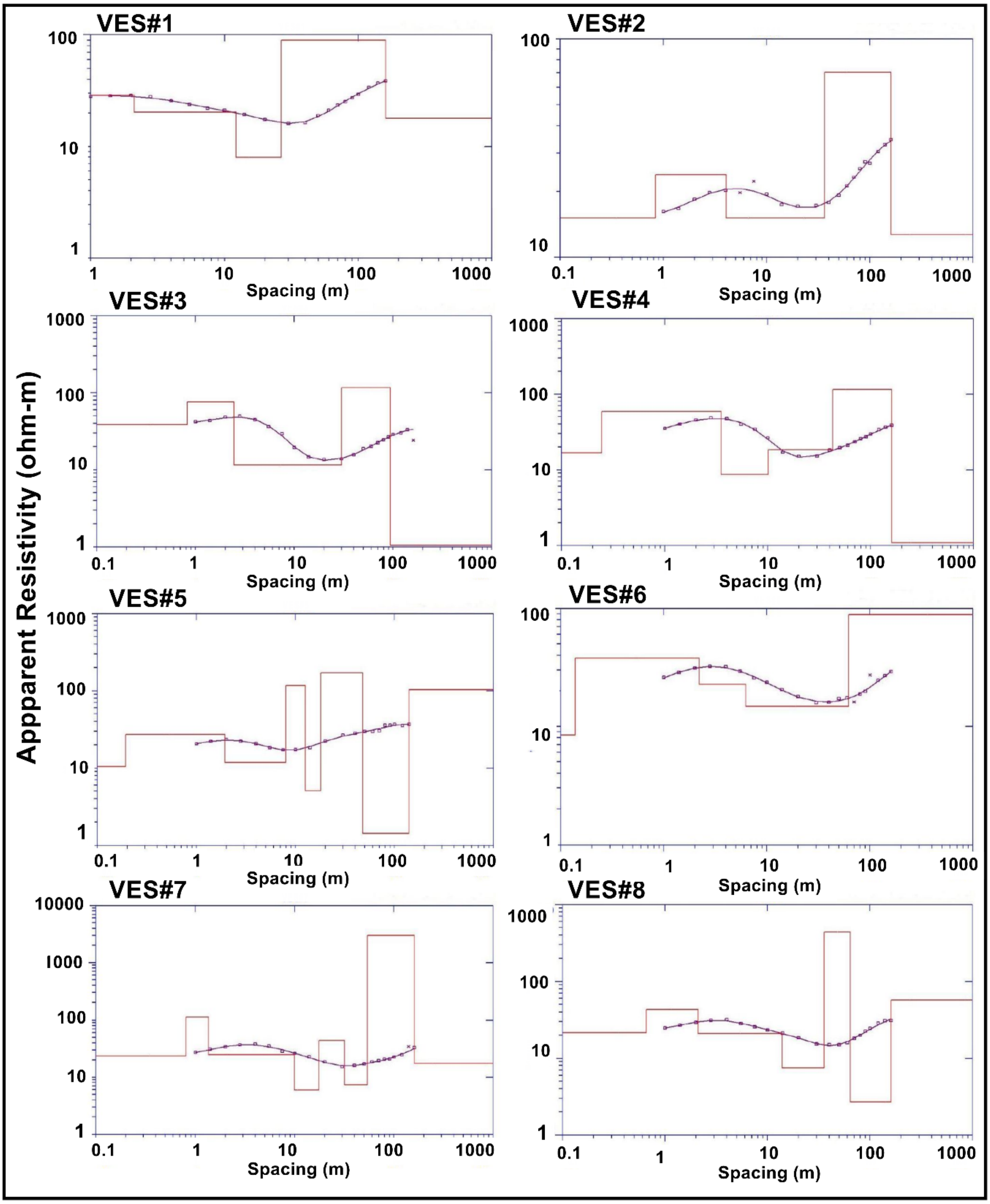

Figure 3 The resistivity variation curves from VES-1 to VES-8.

Table 1 The summation of the VES model resistivity values and their thickness

Name of VES	Longitude	Latitude	No. of layers	The resistivity of the layers (Ω-m)								The thickness of layer (m)							RMS Error
				ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	ρ7	ρ8	T1	T2	T3	T4	T5	T6	T7	
VES 1	72.951	33.642	5	29	20.4	7.97	89.72	17.8	-	-	-	2.118	10.03	14.3	134	-	-	-	1.5
VES 2	72.947	33.65	5	15.1	23.9	15.1	70.33	12.7	-	-	-	0.835	3.222	32.3	124	-	-	-	1.8
VES 3	72.948	33.649	5	38.4	75.6	11.4	116.4	1.04	-	-	-	0.827	1.619	27.5	63.5	-	-	-	2.2
VES 4	72.948	33.649	6	16.7	58.8	8.57	18.3	116	1.08	-	-	0.245	3.268	6.57	32.7	117	-	-	2.3
VES 5	72.950	33.648	8	10.5	27.3	11.8	115.6	5.06	171	1.42	103	0.193	1.743	6.05	4.56	5.39	29.8	92..322	2.8
VES 6	72.945	33.649	5	8.39	37.9	22.6	14.71	88.3	-	-	-	0.138	2.062	4.04	56	-	-	-	1.8
VES 7	72.942	33.646	8	23.4	113	24.6	5.946	43.7	7.28	30	17.4	0.811	0.54	8.54	7.57	14.3	22.1	106.15	2.5
VES 8	72.946	33.648	7	21.4	42.8	20.9	7.427	441	2.68	57.2	-	0.653	1.444	11.8	21.4	28.5	95.9	-	2.3

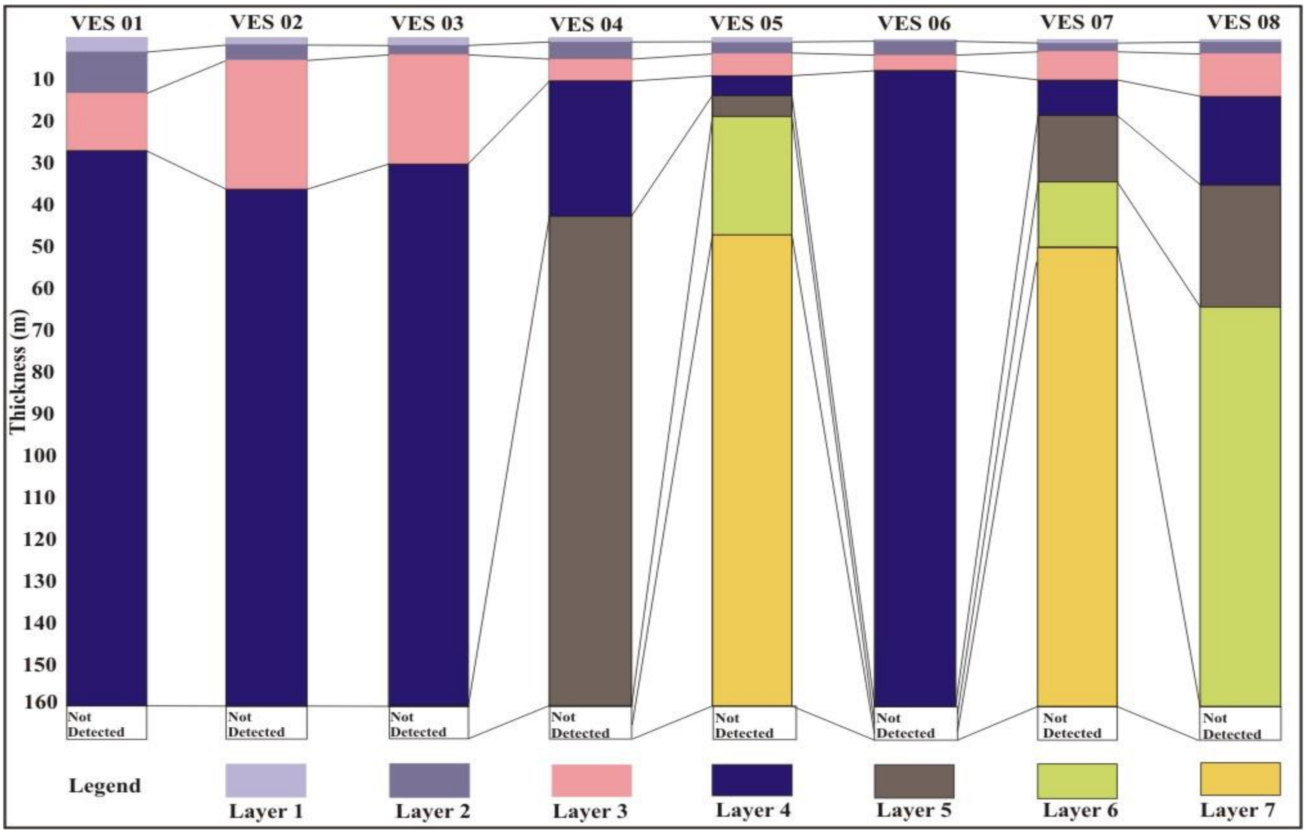

Figure 4 The cross-sectional correlation of the layer detected in VES-1 to VEs-8 the length of the column shows the depth and thickness of the detected layers.

3.2 Examination of Dar-Zarrouk Parameters

The Dar Zarrouk parameter includes longitudinal conductance (S), transverse resistance (T), and coefficient of the electrical anisotropy (λ) obtained from the layer resistivity and their thickness. These parameters are beneficial in interpreting groundwater (Okonkwo Gabriel & Ugwu, 2015). The coefficient of anisotropy (λ) is derived from transverse resistivity and longitudinal conductance. With an increase in compaction of rock, anisotropy also increases, and hence the porosity and permeability decrease (Yeboah-Forson & Whitman, 2014).

3.3 Longitudinal conductance (S)

The longitudinal conductance (S) has a direct relationship with groundwater potential. The higher the S in any locality, the greater the probability for groundwater potential and protective capacity rating (Abiola et al., 2009). It is the product of the thickness and average conductivity of a particular layer. VES points (1-8) are shown on the contour map in Fig. 5. Based on the S values, the VES is categorized into four ranges. The first range is between 0.4 to 4.9 Ω-1 (moderate to good protective capacity), comprising the VES-1, VES-6, VES-7, and VES-8 points. VES-2 lies in the second range (4.9 to 13.6 Ω-1), having good to excellent protective capacity. The third and fourth longitudinal conductance ranges are from 13.5 to 41.6 Ω-1 and 41.6 to 74.9 Ω-1 (excellent protective capacity) consisting of VES-04, VES-03 & VES-05.

The longitudinal conductance (S) contour map of saturated zone (greater than 35m) is computed to differentiate between excellent, good, and poor protective capacity zones. The VES points are marked on four distinctive S ranges (Figure 6). The VES-1, VES-6, and VES-7 points are present in the S range from 0.7 to 5.5 Ω-1 (good to very good protective capacity). The VES-2 and VES-4 lie in the range between 5.5 to 20.1 Ω-1 (very good to excellent protective capacity), and VES-8 lies in the range of 20.1 to 43.5 Ω-1 (excellent protective capacity). Lastly, the VES-3 and VES-5 points occupy the S range of 20.1 to 71.9 Ω-1 (excellent protective capacity).

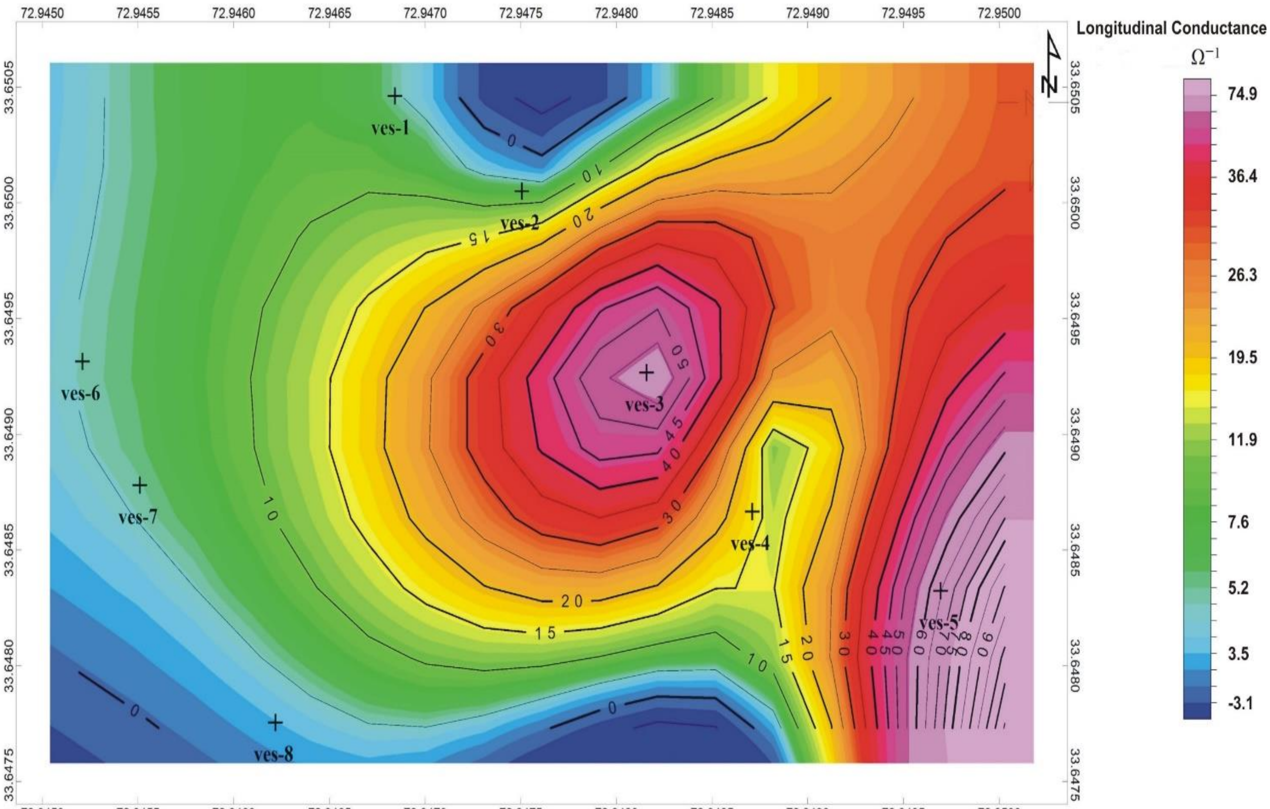

Figure 5 The contour map of (overall) the longitudinal conductance.

3.4 Interpretation of Transverse Resistance (T)

The transverse resistance (T) is exercised to detect good groundwater potential zones. It is related to transmissivity, so high T values represent the highest transmissivity values in the aquifer (Okonkwo Gabriel & Ugwu, 2015). The results are VES-2, VES-3, VES-5, and VES-6 are located in the 6854.3-9111.1 Ωm2 range in this survey. The VES-7 and VES-1 are present in the interval between 9111.1-10898.6 Ωm2 and 10898.6-13238.1 Ωm2, respectively. The VES-4 and VES-8 are in T domain 13238.1-14279.4 Ωm2 (Figure 7).

The transverse resistance value of the saturated zone (>35m) is in the range of 6187.5 and 13935.8 Ωm2, as in Fig. 8. The VES-3, and VES-5, VES-6, encompasses the range of 6187.5-8929.0 Ωm2, and VES-2 lies in 8929.0 and 10576.8 Ωm2. In the contour map, the VES-1 and VES-8 are spotted in the range of 10576.8-12822.7 Ωm2. The VES-3 and VES-5 mark off the transverse resistance below the 8929.00 Ωm2 and the VES-4 mark off the highest value, i.e.,>13935.8 Ωm2.

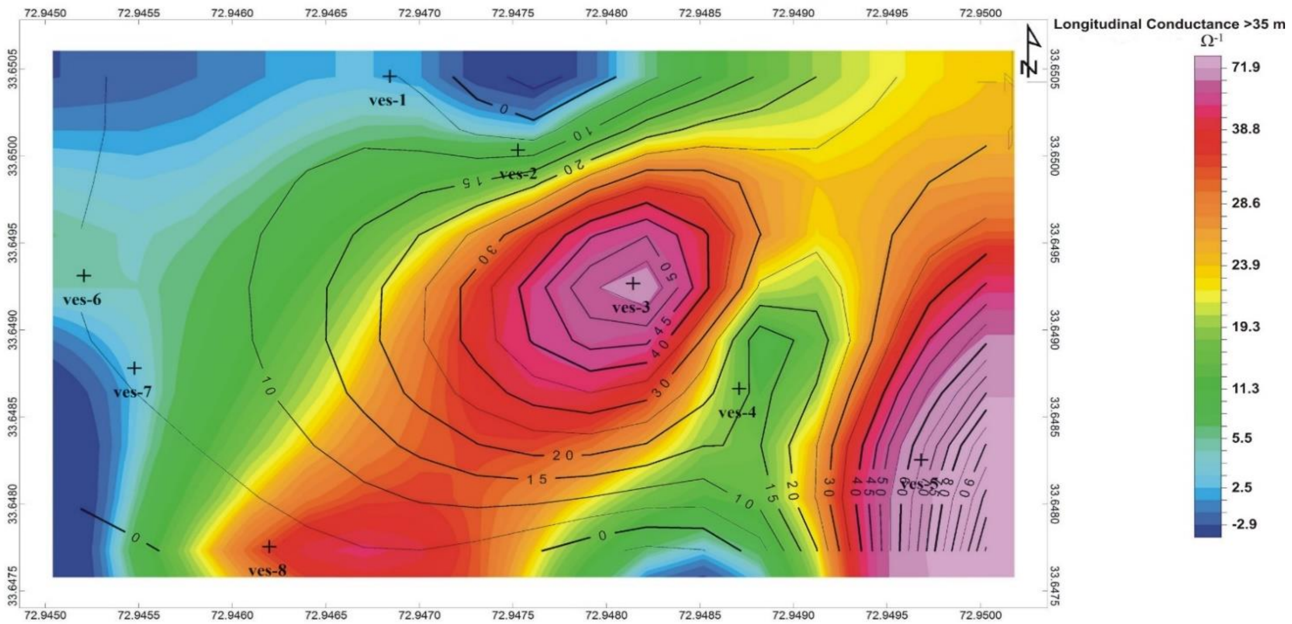

Figure 6 The longitudinal conductance contour map of depth >35m

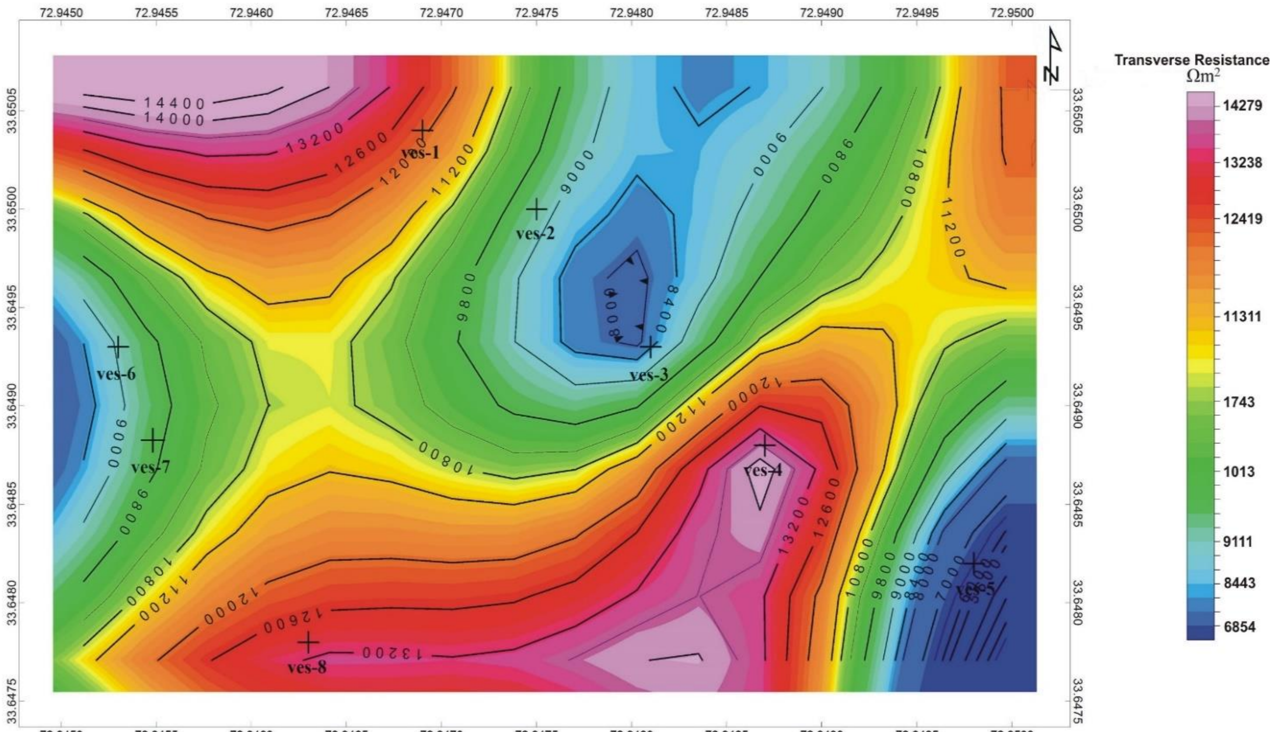

Figure 7 Graphical section of the transverse resistance (overall)

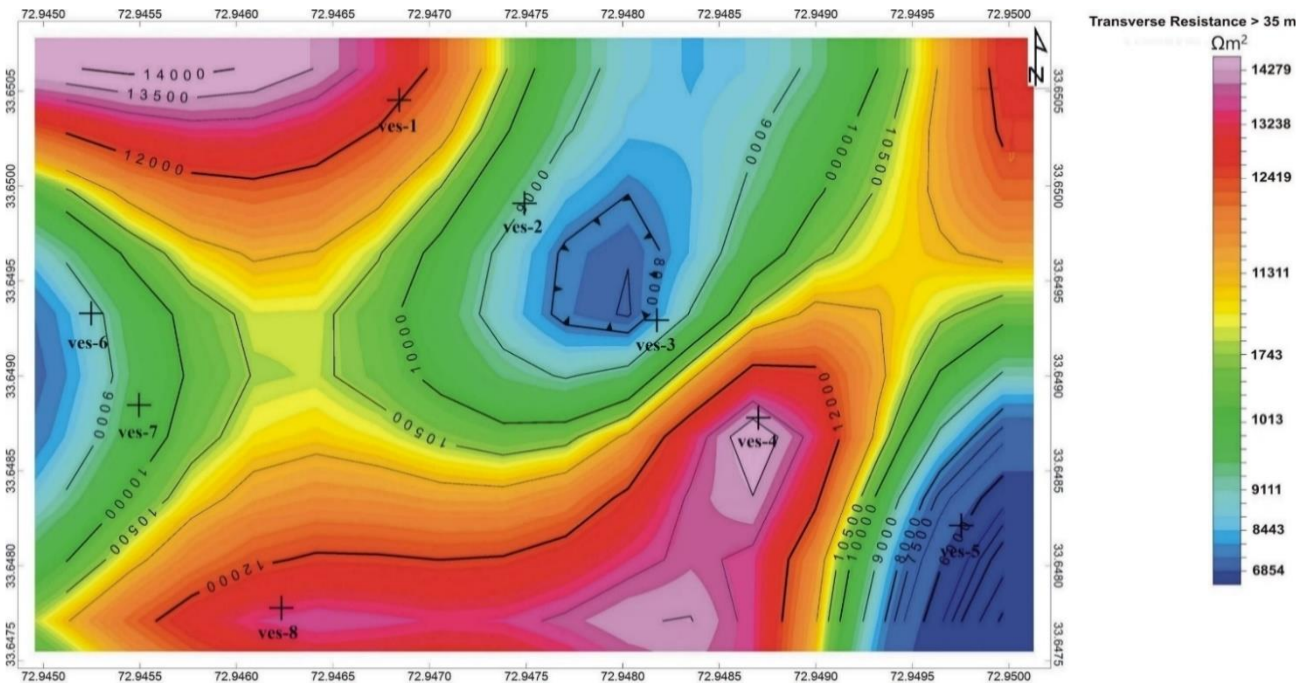

Figure 8 The transverse resistance map for the depth > 35m

3.5 Graphical interpretation of the Coefficient of Anisotropy (λ)

In sedimentary rocks, the anisotropy (λ) is affected by the alignment of the elongated grains, fracturing, and compositionally changed layers (Watson & Barker, 1999) and contamination in water (Niaz et al., 2019). The range of the anisotropy in the study area is from 1.0 to 2., and some unusual values, i.e., 3-4, are also encountered. The area's contour map shows four ranges of the anisotropy, including 0 to 1.0, 1.0 to 1.6, 1.6 to 2.0, and greater than 2.0 (Fig. 9). The first range having the lowest value consists of no VES point and the second range has VES-1, VES-2, VES-4, VES-6, and VES-8 points. The third anisotropy range spotted VES-3 and VES-5, while VES-7 is marked in greater than 5.6 anisotropy.

Figure 10 shows the contour map of anisotropy values at depth >35 meters. VES -1, VES-2, VES-4, and VES-6 have λ values between 0.6 to 1.9, and in the range between 1.9-2.7, VES-3, VES-5, VES-7, and VES-8 are present.

4. DISCUSSION

The lithological composition of the study area shows a variation in terms of thickness and composition. The dominant lithology of the area is clay, along with the lenses of sand and gravel. The water table in the study area and surrounding is marked by sandy and gravel layers. Due to tectonic distortion, weathering, and depositional environment, the variation in thickness of different layers in the study area is detected. In VES-1, VES-2, VES-3, and VES-6, five layers are detected, and in VES-4, six layers are sensed using resistivity and available well data. The stratigraphic column of the VES-5 and VES-7 is up to eight layers, and VES-8 is classified into seven layers.

The Dar-Zarrouk parameters (longitudinal conductance, transverse resistance, and coefficient of the electrical anisotropy) are used to obtain the probable exploitable water sources (Gupta et al., 2015; Mosuro et al., 2017). The longitudinal conductance in >35-meter depth is poorly protective in VES-1, VES-6, and VES-7, but VES-2, VES-4, and VES-8 show moderate protective capacity. The excellent protective capacity is detected in VES-3 and VES-5 points, where S value is greater than 20 Ω-1. The overall transmissivity of the aquifer (T) is highest in VES-4 and moderate in VES-1 and VES-7; however, T in > 35 meters contour map is moderate in VES-2, VES-3, and VES-5, and the highest T values are reported from VES-4 point. The high anisotropy and poor to moderate protective capacity indicate the contamination in urban aquifers and high salinity in coastal aquifers (Adeniji et al., 2014; Niaz et al., 2019; Shailaja et al., 2016; Singh et al., 2004). The dissolution seams and fractures are also indicated by the high coefficient of anisotropy and low average resistivity (Olateju O et al., 2014). In the present study, the overall and greater than 35 meters contour maps specify that the coefficient of anisotropy values is higher in VES-3, VES-5, VES-7, and VES-8. Protective capacity is weak in VES-1, VES-6, and VES-7, indicating sandy and gravel-sized grains, dissolution seams, and polluted water quality.

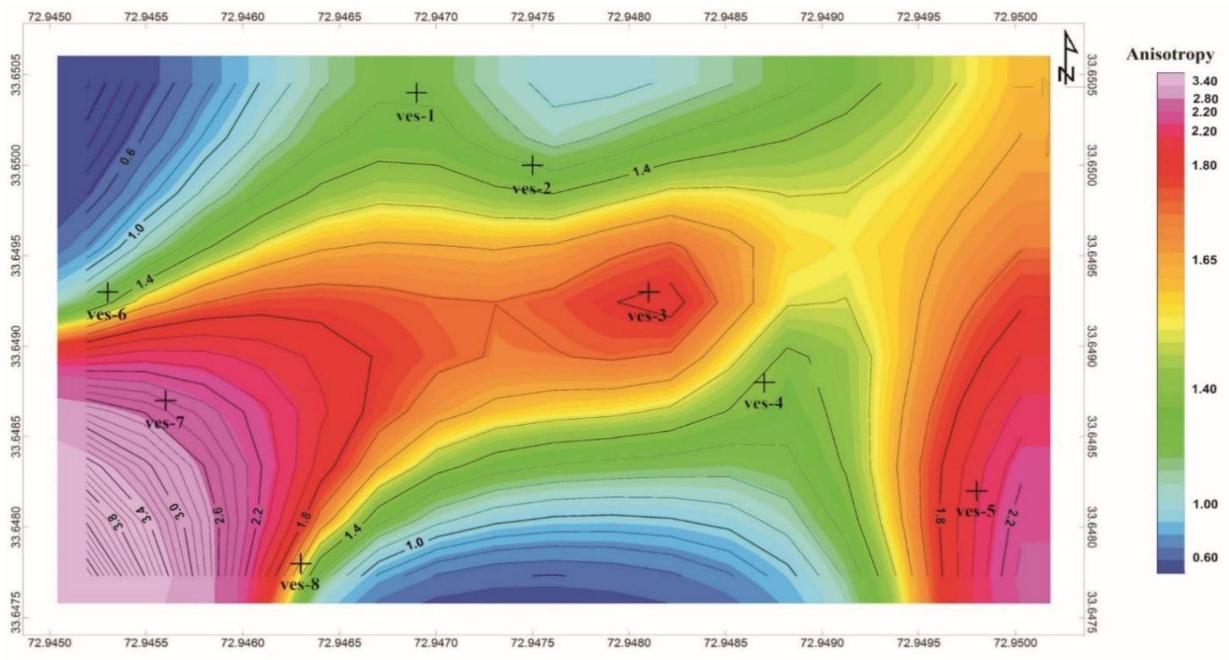

Figure 9 The anisotropy map of the study area (overall)

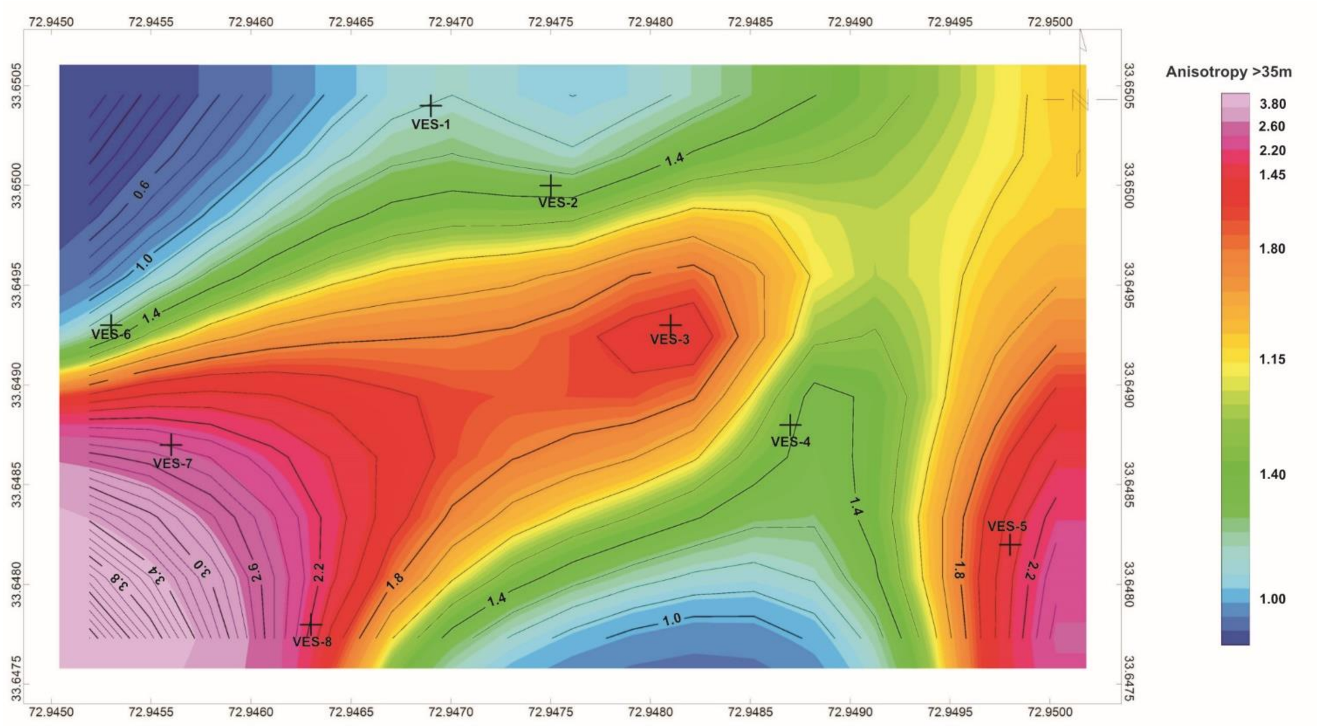

Figure 10 The graphical representation of anisotropy for depth >35m

The data obtained from VES points, and by interpretation and processing of models, along with Dar-Zarrouk parameters' results, the probable exploitable well locations are shown in Figure 11. Based on the high longitudinal conductance (excellent protective capacity), low transverse resistance, and a high coefficient of anisotropy (probably dissolution seams) (Olateju O et al., 2014), the probable well locations can be given at VES-3 and VES-5.

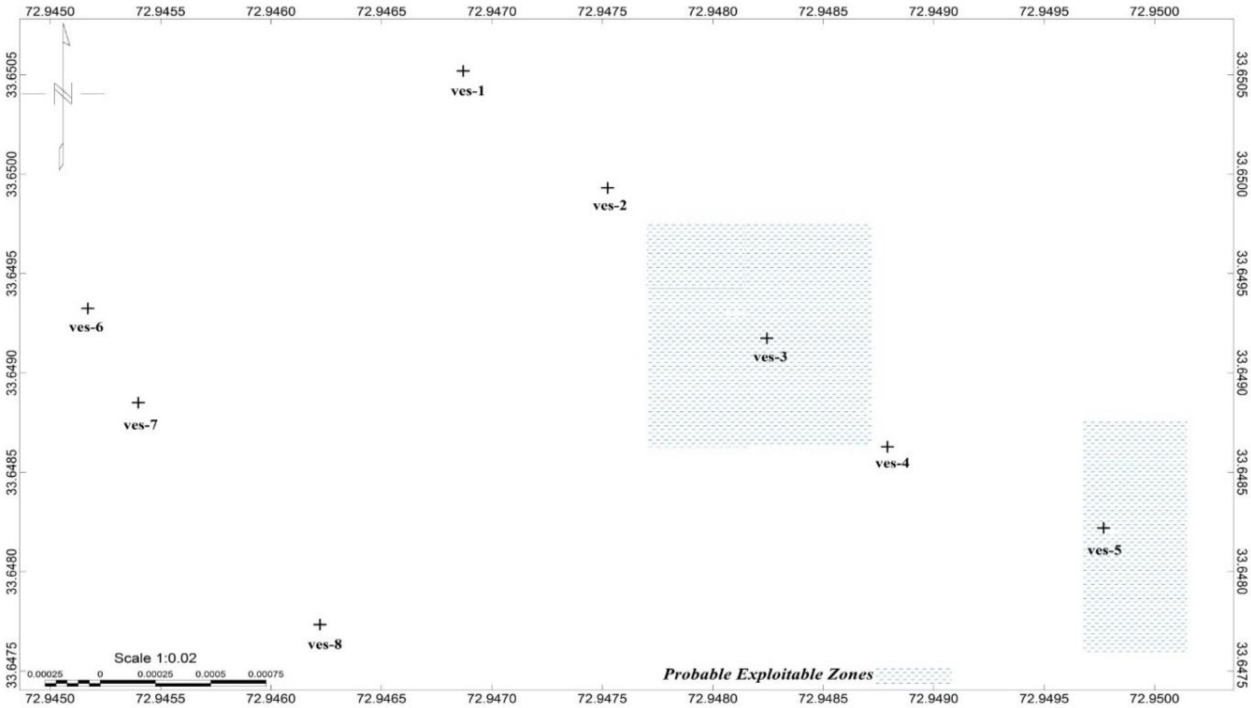

Figure 11 The map shows VES points and probable exploitable well locations, i.e., VES-3 & VES-5.

5. CONCLUSION

The lithology of the study area is variant in terms of composition and thickness. A single layer cannot specify as an aquifer. The VES-3 and VES-5 show good aquifers qualities as the value of protective capacity and coefficient of anisotropy are excellent, and the transmissivity parameter is moderate to good. The VES-1 and VES-7 are having the lowest aquifers potentials indicated by the Dar-Zarrouk Parameters. Variation in the aquifer's qualities indicates a non-continuation of compositionally the same layers due to tectonic activities and erosion. The high value of the anisotropy coefficient also shows the low quality of the groundwater in the study area, indicating that the source of recharge might be Lei Nullah, which carries highly polluted water.

DECLARATIONS

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Author contributions: Zeeshan Ahmed was involved in the writing of the research paper, result analysis, and preparation of different maps. Mr. Mahee Tanweer Ansari has collected the data from the field and helped write and edit the paper. Mr. Muhammad Zahir shares his expertise during this research work, especially in the graphical representation of different results. Mrs. Urooj Shakir supervised the study and was engaged in deciding the suitable study area. Mr. Muhammad Subhan has also supported data collection and field surveying.

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Conflicts of interest: The authors declare no conflict of interest.

Ethical considerations: This study did not involve any ethical issues.

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