HYDROLOGICAL FRAMEWORK AND ESTIMATION OF AQUIFER HYDRAULIC PARAMETERS USING GEOELECTRICAL DATA; VICINITY OF RAWALPINDI, ISLAMABAD

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DEDICATION

With all my love and admiration this work is unequivocally dedicated to my beloved father Raja Khalid Javed and my mother.

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ABSTRACT

The main objective of this research is to carried out the Electrical resistivity survey in Islamabad different regions to determine the depth of water and to propose new well location to full fill the demands of protective fresh water aquifers. The methodology used for this procedure is Vertical Electrical Sounding using the Schlumberger configuration. The maximum spread is about 1m to 150m. According to our results, it is concluded that potential of groundwater zone in the study area exists at the depth greater than 36m. Dar Zarrouk parameters calculations used to find the aquifer properties and their capacity. VES-05, VES-07 and VES-08 have high longitudinal conductance values which makes them the highest priority in terms of groundwater. Based on the results of Transverse resistance at VES-02 and VES-04 shows the high transverse resistance values which indication of high transmissivity and have good groundwater potential. Combining these results, probable well location can be at VES-01, VES-04.

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ACRONYMS AND ABBREVIATION

AMSL	Average Mean Sea Level
EC	Electrical Conductivity
EW	East West
GPS	Global Positioning System
NASA	National Aeronautics and Space Administration
NE	North East
NESPAK	National Engineering Services Pakistan
NSL	Natural Surface Level
NW	North West
SDO	Small Dams Organization
SE	South East
Sq. km.	Square Kilometer
SW	South West
TDS	Total Dissolved Solids
UNDP	United Nations Development Programme
WAPDA	Water and Power Development Authority
WASA	Water and Sanitation Agency

PHED	Public Health Engineering Department
ERS	Electrical Resistivity Survey
PPM	Parts per Million
GSP	Geological Survey of Pakistan
VES	Vertical Electrical Sounding
S	Sounding

CHAPTER 1

INTRODUCTION

1.1 General Overview

In order to sustain and survive on earth, water is the most important commodity (Kablown and Majeed, 2005). It is a well-known fact that there will be no life on this planet without water as being the most extraordinary gift bestowed upon us by the nature in many forms like subsurface aquifers, snow and precipitation. Water holds a special place as a vital ingredient for life and a vibrant research component (Adagundodo et al., 2018). It is very difficult and almost theoretically impossible to assess precise amount of subsurface water present in aquifers around the globe. The total amount of water in the earths reservoirs is between 15 to 60 millions kilometer cube. Among this amount of groundwater only 8-10 million kilometer cubes of water are considered to be fresh water where remaining portion is brackish and saline water.(Margat, 2008).

According to worldwide viewpoint, around 4430 kilometers cubes of water is documented around the globe, of which 25% is utilized by Industrial and 5% by Domestic and large number is consumed in agriculture which is approximately 75% (Kinzelbach et al., 2003). Globally, about 2 billion individuals hinge exclusively resuorces of groundwater to satisfy daily needs, among these groundwater resources 273 spreads beyond the international border of neighboring countries fulfilling the requirements of different nations (ISRAM, 2009). Several domestic, industrial and agriculture requirements are satisfied by groundwater which is a fundamental source of freshwater.

Because of domestic, industrial and agriculture and anthropogenic exercises, the aquifers of that region have a more noteworthy danger and are more powerless with respect to groundwater contamination and the impacts set off in the consequence of this large number of exercises can end in present moment or these impacts extremely durable and never-ending harm or loss of groundwater, the remediation of the subsurface water to purge it from the foreign substances is a very complex task and quite expensive. (Secunda, et al., 1998).

The contamination of subsurface aquifers disturbs the ecological system and itis harmful to human health besides that damaging direct or indirect socio-econocmic effects, (Milovanovic, 2007). Chemical, Physical and Biological causes can be examine through the quality assessment of the subsurface water (Thomas, 2003), but due to penetration chance and type of various anthropogenic actions causing an enormous quantity of harmful and poisonous chemical elements as effluents, the chemical factors have acquired relatively more significant in evaluation of groundwater quality and these chemical parameters have great importance in management practices of subsurface water. According to the report of United Nation’s World Health Organization (WHO, 2008) shows that about 3.3 million people dies in World War IIIdue to poor water supply and poor sanitation arrangements because contaminated subsurface water intake as drinking water. Main cause of this surging groundwater associated ailments is linked to the point that aquifers are more susceptible to contaminated triggering events as compare to the water bodies on surface. Surface andsubsurface water are the main two primary sources used in maintaining life on this planet, constant increase in human advancement and exponential increase in populationhave polluted these source to a concerning degrees (Rosello et al., 2009; Soomro et al.,2019).

In Pakistan, subsurface groundwater is considered to be dependable mean of water used for agriculture as well as for drinking purposes, it satisfies around 35% of agriculture necessity. Increase in population cause mismanaged urbanization and enlargement of agriculture and industrial activities. Due to these consequences, the groundwater quality is under risk and threats in Pakistan. The industrial solid waste along with sewage waste without any management and the use of chemical fertilizer and pesticides has amplified the probability of pollution of groundwater. The dumpingof industrial and sewage is very common in Pakistan and due to this many shallow aquifers are compromised, particularly in cities (BGS, 2002). Industrial areas of the cities like Gujranwala, Lahore, Faisalabad and Haripur, groundwater is prone to pollution due to huge volume of contaminated unprocessed expulsion of toxic waste from various industries like leather, textile, pharmaceutical, chemicals and sports etc. These cities and zones solely rely upon groundwater for consumption and the wastes from industrial sector contaminates the drinking water of people living in nearby areas(Mehmmod et al., 2011).

According to PCRWR, underground water level depth increased with throught different years.

Years	Depth (Meters)
2002	35.1
2005	36.47
2008	36.60
2010	38.90
2017	39.6

1.2 Ground Water

Groundwater is the water that exists underneath the World's surface in the soaked zone of soil, silt, and rock arrangements. It occupies the spaces between particles or breaks in the subsurface, shaping what is known as a spring. Dissimilar to surface water tracked down in lakes, streams, and streams, groundwater is situated underneath the ground and can be found at different profundities relying upon the geographical states of the area.

Figure 1.1 Geophones recording the groundwater situation beneath the surface.

Groundwater begins fundamentally from precipitation, for example, downpourand snow, which invades the dirt and permeates descending through the unsaturated zone until it arrives at the immersed zone where all the accessible pore spaces are loaded up with water. The water in the soaked zone moves gradually through the springaffected by gravity and strain angles.

1.2.1 Types of Ground Water

Groundwater can be broadly categorized into two main types based on its occurrence and availability:

1.2.1.1 Confined (Artesian) Groundwater

Restricted groundwater is found in springs that are sandwiched between impermeable layers of rock or earth, shaping a bound or artesian spring. These impermeable layers keep water from effectively moving in or out of the spring, bringing about pressure development inside the bound spring. At the point when a wellis penetrated into a restricted spring, the tension can compel the water to transcend thehighest point of the spring, frequently streaming normally to the land surface without the requirement for siphoning. This is known as an artesian well.

Restricted springs can store huge measures of water and are by and large safeguarded from surface pollution since the impermeable layers go about as a characteristic boundary. Nonetheless, over-siphoning from bound springs can prompt a diminishing in tension and cause the water level to decline, which might bring aboutland subsidence and decrease the maintainability of the water asset.

1.2.1.2 Unconfined (Water Table) Groundwater

Unconfined groundwater, otherwise called the water table, is the water situatedin the zone where the pore spaces and cracks in the dirt or rock are soaked with water.The upper surface of this zone, where the water pressure is equivalent to climatic strain,is known as the water table. The water table changes in light of elements like precipitation, vanishing, and groundwater withdrawals.

On their chemical composition, groundwater can be classified as:

1.2.1.3 Fresh Groundwater:

New groundwater is described by low degrees of disintegrated salts and is reasonable for different purposes, including drinking, water system, and modern cycles. Normally found in springs are not impacted via seawater interruption or criticaldraining of salts from the encompassing rocks.

1.2.1.4 Saline Groundwater

Saline groundwater contains high convergences of disintegrated salts, making it unacceptable for most pragmatic purposes, including drinking and water system. Salinegroundwater is generally found in seaside regions where seawater has meddled into freshwater springs, delivering them saline.

1.3 Climate

According to Pakistan Metrological Division (commun, 1988), Islamabad has a subtropical environment with five seasons:

Seasons	Time Period
Spring	March to April
Summer	May to June
Monsoon	July to August
Autumn	September to October
Winter	November to Feb.

In Islamabad temperature vary from cold to mild, rarely dropping below zero. January is the most, coolest month of the year with temperature varies from one area to another. There is an extra snowfall on the slopes during winters. June is the hottest month of the year, where temperature usually exceeds 36ºC, whereas July having heavy rainfall and thunderstorm. Weather temperature from June to January usually ranges from 46 °C to least 2 °C, respectively.

1.4 Hydrology

Islamabad lies at the foot of the Margalla Slopes in the north and Kotli Sattian Slopes and Murree on the east which benefits this region from the natural slope in terms of surface water resources. Kurang and Soan rivers are the main streams and their primary tributaries are Ling river and Gumreh Khas, draining northwestward into Soan and GumrehKas draining southward into Kurang. The headwaters of Kurang and Soan the extensive forest reserves benfit the quality and quantity of supply (Sheikh et al., 2007). Liquid waste from Rawalpindi carries by the Lai Nala and has major contribution in polluting the Soan river.

Sambli and Rawal Lakes have dammed the Soan and Kurang rivers to provide water to the cities. Water used for headwork is redirected from springs at Saidpur, Shahdara, and Nurpur. The Kurang River appears to empty somewhere other than the Rawal Dam. Groundwater is mostly produced by quaternary alluvial gravels in both private and public wells. Saturated zones are found between 1 and 18 meters below the surface of the common ground at Margalla Hills, where the water table varies in depth from 600 meters to less than 450 meters near the Soan River.

The Haro River, which flows through Khanpur Dam to the north of the Margalla Hills, supplies both household water for Islamabad's use and irrigation water for the city's businesses and farms. The dam has a 130,000,000 cubic meter storage capacity. Likewise, the Sam dam is situated 30 kilometers east of Islamabad on the Soan River. Snowmelt and Murree Hills' natural springs provide its nourishment. It is the biggest drinking water reservoir serving the people of Islamabad. The dam has a volume of approximately 35,460,000 cubic meters.

1.5 Hydrogeology

Islamabad's hydrogeological study has revealed the existence of both shallow and deep aquifers. According to Sheikh et al. (2007), the upper Pleistocene alluvium units and Holocene make up the shallow aquifer, whereas the deeper aquifer is constituted of the Pleistocene Lei Comglomerate. There are five aquifer layers in the region, according to the HESC assessment, albeit not all of the area appears to have this aquifer structure. The intercalation of huge clay-type lenses, which causes division and, consequently, an insignificant connection in certain sectors that are not exactly located, demarcates the presence of these aquifers.

The region's bedrock is primarily faulted and folded, with rocks from the Rawalpindi Group, Kuldana Group, and harder limestone of the Chorgali Formation extending northward and southward, respectively, as well as rocks from the Siwalik Group and the Chorgali Formation extending northward. Over most of the region, the bedrock is more than 100 meters deep (Sheikh et al., 2007; Khalid et al., 2021).

1.6 Dar Zarrouk Parameters

Hydrogeologists utilize the Dar-Zarrouk parameters as hydrogeological values to characterize and evaluate the behavior of water in the ground. Initially, the resistivity and thickness of the material were taken into account. The amount that a material resists the flow of electricity is known as its resistivity. The idea of Dar Zarrouk parameters was first put forth by Mailet in 1947. It suggests that the longitudinal conductance, transverse resistance, and correlative resistivities of a lithological subsurface layer can be determined when its resistivity and thickness are known. Enhancing the interpretation of groundwater survey is made possible by the utilization of Vertical Electrical Sounding (VES) surveys. The purpose of Dar Zarrouk parameters is to obtain data regarding the location, distribution, and quality of groundwater bodies.

1.7 Transverse Resistance

One criterion used to identify target regions with good groundwater potential is traverse resistance. The highest T values are most likely a reflection of the highest transmissivity values found in aquifers or aquiferous zones. It is directly correlated with transmissivity.

1.8 Longitudinal Conductance

The groundwater potential target area is defined by this geoelectric parameter. High S values should be given top priority when it comes to groundwater potential because they indicate a relatively thick succession. (Okonkwo and Ugwu, 2015)

1.9 Problem Statement

Groundwater is a basic part of the hydrological cycle and the accurate estimation of aquifer hydraulic parameters, like porosity, transmissivity, storativity, and hydraulic conductivity, is fundamental for effective groundwater resource management and sustainable development. Customary strategies for aquifer characterization and parameter estimation, such as well drilling and pumping tests, often suffer from limitations in spatial coverage, cost, and time requirements.

Geoelectrical techniques, especially induced polarization (IP) and electrical resistivity tomography (ERT), cost-effective alternative and non-invasive for subsurface characterization. These geophysical procedures give important data about the dispersion of electrical properties, which can be corresponded with hydrological properties, in this manner supporting the assessment of spring water driven boundaries.

In spite of the possible benefits of geoelectrical information joining with hydrological displaying, there are a few difficulties and gaps that need to be addressed:

Lack of Comprehensive Hydrological Framework: There is a need to create a hearty hydrological system that can successfully incorporate geoelectrical information with existing hydrogeological ideas and models. This structure ought to represent the mind boggling cooperations between geographical, hydrological, and geophysical boundaries to determine exact evaluations of spring pressure driven properties

Validation and Calibration of the Integrated Approach: Approving the precisionand unwavering quality of the assessed water driven boundaries got from the geoelectrical-hydrological approach against free informational indexes or conventional techniques is fundamental to lay out the believability of this coordinated philosophy.

1.10 Research Objective:

Followings are the primary objectives of our research:

i. To find aquifer properties using Zarrouk parameters.
ii. To determine the depth of water table throughout the Islamabad.
iii. To propose new and probable well location.

CHAPTER 2

GEOLOGY AND TECTONIC SETTING

2.1 Geology of Islamabad and Rawalpindi

Around 20 million years ago, a tectonic event occurred with the collision between the Indian and Eurasian plates. This collision continues to have a profound impact on the geology of the region, with ongoing tectonic activity resulting in the uplift of the Himalayas and the occurrence of various geological events. Dominant tectonic forces are due to the formation of series of thrust faults formed after the collision and these faults brought the older rocks to the surface, which are depicted in Margala Hills (Sheikh et al., 2008). The city lies in Main Boundary Thrust, which experiences moderate to strong earthquakes (Waseem et al., 2020). Geologists worldwide have extensively studied the diverse structures and stratigraphy formed as a result of this collision.

In order to understand and document the geography of the area, a few guides have been distributed by respectable organizations like the Geographical Survey of Pakistan (GSP) and other study gatherings. The land planning of the Rawalpindi and Islamabad zone is best analyzed by alluding to the geologic guide distributed by (William et al. in 1999), as it offers comprehensive information and analysis of the region's geology.

The project site is located in the part of Potwar plateau. The proposed area is bounded by Margalla Hills and Khair-I-Murat ridge on the north, by Kalachitta Rangeon the northwest and by Salt range on the south. Khair- I-Murat ridge is one of the major isolated hills rising from the general level of the Potwar plateau. The topography of the site area is rolling with general slope from southeast to northwest. The site areais mostly covered with fine grained loess deposits comprising brown to reddish brownclay / some boulders and gravels. These loess materials have been deposited by the combined action of wind and water.

Rocks in area belong to Murree Formation of Miocene age and mainly consistof alternations of shale, sandstone and siltstone. The sandstone is grey in color while siltstone and shale are red to reddish brown.

2.2 Geological History

Islamabad is situated at the Himalayas lower regions, one of the structurally dynamic zones between Indo-Pak and Eurasian structural plates. In the Islamabad region, sedimentary rocks dating back around 150 million years can be found, enveloping the geologic history from the mid-Jurassic to the Quaternary time frame. During this timetable, marine statement was predominant, joined by minor structural movement. Notwithstanding, between 2 to a long time back, there was a shift to mainland statement with somewhat more slow subsidence. Accordingly, following 2 million years, broad disintegration and huge structural action happened, with limited affidavit occasions.

The lithology uncovered in Islamabad and its surrounding regions contains Jurassic to the Pleistocene, having clastic and carbonate inputs is older and moreyouthful ages, respectively. The depositional climate of the most established rocks of the area is shallow marine, while, because of impressive variance, younger rocks are kept in deltaic to fluvial conditions (Shah, 2009). Murree, Kamlial, Chinji, Nagri, Dhok Pathan, Soan Formations and Lei conglomerate are deposited in the non-marine fluvial environment with more than 7000 m thickness and 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 (Khattak et al., 2017; Shah, 2009).

Preceding the impact between the Eurasian and Indian plates, the most seasoned rocks in the space were the dolomite and limestone stores from the Jurassic age, arranged on the mainland side of the Indian plate. An unconformity can be seen between the Chichali and Samana Suk Developments, addressing a hole in the age record. During the late Jurassic to early Cretaceous period, shale with glauconite and sandstone from the Chichali Development gathered in a climate portrayed by an absence of oxygen and a synthetically decreasing air (Khan et al., 2017).

2.3 Project Area

The project usually lies in the Potwar plateau filled with tertiary and Pre-Tertiary sediments in geosyncline trough known as Indo-Gangetic Synclinorium. This geosyncline trough usually lies between the foothills of Himalayas and Salt Range. The rocks which are exposed here, are mainly of Miocene to Pleistocene age belongs to Rawalpindi and Siwaliks Groups. These groupsconsist rocks like sandstone, shale, siltstone, mudstone, conglomerates and clays formed as a result of disintegration of pre-existing rocks transported by water or wind and depositedin lakes, ocean bed or spread over the land.

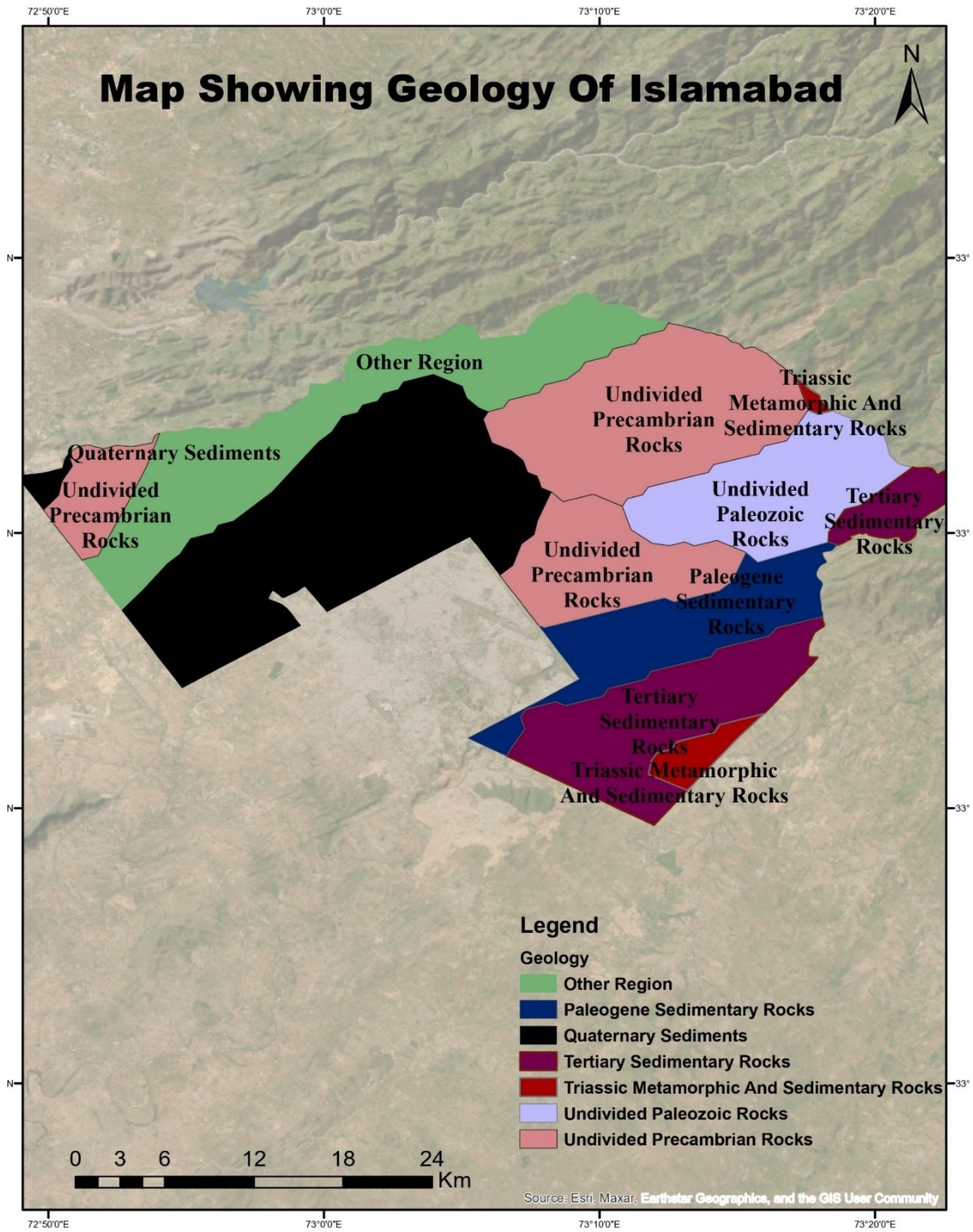

Figure 2.3(A): Map showing the geological region of Islamabad with the age of rocks.

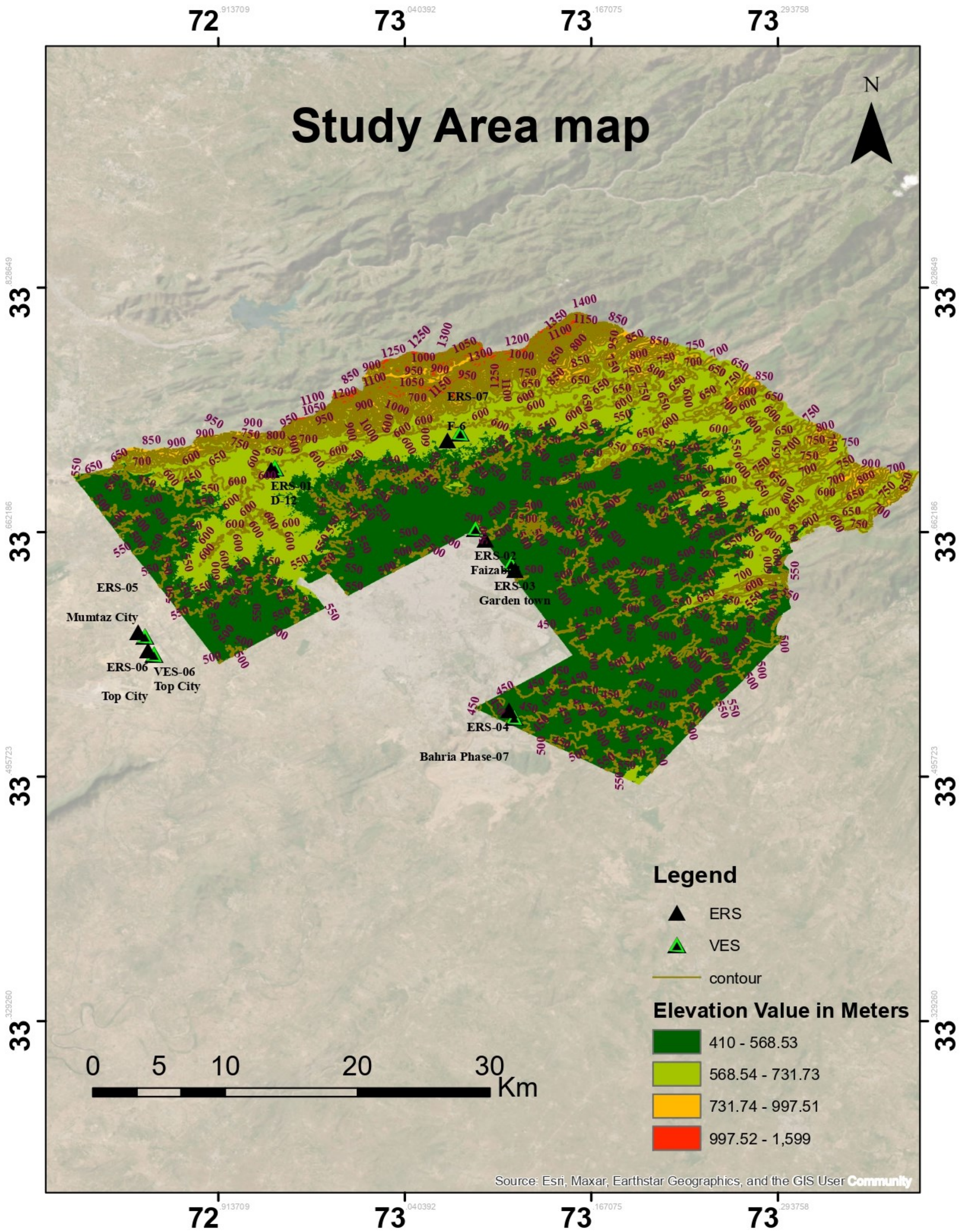

Figure 2.3(B): Showing the Locations of ERS and VES points throughout the region of Islamabad and Rawalpindi, Pakistan

2.4 Stratigraphy

The three main/ upper basins of Pakistan are the Hindukush-Karakoram (the southern slope of Asia plunged into Tethys, a part of Laurasia), the Indus (a portion of Gondwana), and the Balochistan-Kohistan-Ladakh (a portion of Tethys). The Indus super basin is further divided into the lower/ southern/ Kirthar, upper/ northern/ Kohat-Potwar, middle/ central/ Sulaiman, and upper/ northern/ Khyber-Hazara-Kashmir basins. The stratigraphy of Indus Basin as shown in figure 2.3.

2.4.1 Makarwal Group (Paleocene Age)

For the Hangu, Lockhart, and Patala formations, Shah (1980) took the Makarwal Group into consideration. Malkani and Mahmood (2016a) classified Patala as part of the Hangu Group, however, since it is now thought of as a lateral variation of Hangu. Furthermore, the type section and Hangu formation make it simple. Sangiali Group of the Sulaiman basin and Ranikot Group of the Kirthar basin are comparable to the Hangu Group.

2.4.1.1 Hangu Formation

Hangu Formation was named as Hangu shale and Hangu sandstone after the part south of Stronghold Lockhart in Samana Scope of Kohat region by Davies (1930a) and later Hangu Development was changed by (Cheema et al., 1977). It comprises of sandstone with dark shale and coal most likely most recent Cretaceous age concluded from the connection with Vitakri development of Sulaiman bowl. The Patala Formation is being considered as equivalent word of Hangu Development in view of parallel augmentation of Hangu Development and generally same lithology and practically same skyline. Age Most recent Cretaceous to Early Paleocene. The sequence within the Hangu Formation shows a gradual decrease in grain size as it progresses upward, with a thickness ranging from approximately 6 to 10 meters. Furthermore, the Hangu Formation is found to have a conformable contact with the underlying Lockhart Formation, as reported by (Williams et al. in 1999).

2.4.1.2 Lockhart Limestone

Lockhart Formation mainly composed of limestone of Middle-Late Paleocene age, but it also contains shale and marl. It was named after Fort Lockhart in Samana Range by Davies (1930a). Limestone in this formation characterized by light grey to dark grey color, and which is notable for the presence of fossils. Similarly, the marl within the formation is characterized by a grey to black color and also contains fossils. Lockhart limestone thickness can reach up to 280 meters. Furthermore, the Lockhart Formation is observed to have a conformable contact with the underlying Patala Formation, as documented by Williams et al. in 1999.

2.4.2 Surghur Group (Jurassic to Lower Cretaceous Age)

The Trans-Indus Salt ranges of North Pakistan extend as far east as the Surghar Range, which takes the shape of an arcing mountain belt. As it borders the southern Kohat Plateau, the range generally follows an east-west structural trend; however, along the eastern flank of the Bannu Basin, it shifts to a north-south trend. The range front, which is currently active, maintains a range of structural styles in both outcropping and non-outcropping rocks. The Surghar Thrust, a low angle frontal thrust, is the result of frontal ramping from basal décollement thrusting within the Paleozoic-Mesozoic rocks, which is responsible for the east-west trending segment of the range's evolution. The Surghar Thrust's hanging wall is folded from moderately to tightly, with the most noticeable fault bend fold structure being the Surghar Anticline.

2.4.2.1 Samana Suk Formation

The name Samana Suk Limestone was derived from Samana Range by Davies (1930). The lithology of the formation is mainly gray to brown limestone, with intermittent occurrences of greenish-gray Marl, Age Middle Jurassic. Their thickness ranges from a minimum of 190 meters to a maximum of 360 meters. Formation exhibits an unconformable contact with the overlying Chichali Formation. The exact base of the formation is unknown as it is not exposed, as noted by Fatmi in 1990.

2.4.2.2 Chichali Formation

It was named after the Chichali Pass in Surghar Range by Danilchik (1961). The lithology of this formation encompasses dark greenish grey glauconitic sandstone and glauconitic shale in the lower part, claystone, and milestone. Glauconitic sandstone grain size can vary from fine to coarse grain. The thickness of this formation can reach up to 50 meters, and it gradually transitions into the overlying Lumshiwal Formation, forming a gradational contact. Williams et al. documented these observations in 1999.

2.4.2.3 Lumshival Formation

Lumshiwal Formation was named as Lumshiwal sandstone after the Lumshiwal Nala in the Surghar Range by Gee (1945) and later Lumshiwal Formation was amended due to different lithology by Fatmi (1977). The lithology of this formation primarily consists of consists of cross bedded sandstone and shale (Late Cretaceous) of continental origin, milestone and limestone. Sandstone, has a moderate thickness, contains glauconites and is also known to harbor fossils such as ammonoids and brachiopods in certain areas. Limestone in this formation is characterized by thin beds and has a yellowish coloration with significant sand content. This formation exhibits an unconformable contact with the overlying Hangu Formation, as reported by (Williams et al. in 1999).

2.4.3 Cherat Group (Lower Eocene Age)

The Attock-Cherat Range is split into three east-west trending blocks. These are arranged from north to south as follows: the Northern Block is made up of unfossiliferous argillite, slate, phyllite, and limestone of Precambrian age that have been intruded by dolerite sills and dykes; the Central Block is made up of unfossiliferous flysch of Precambrian age that is overlain by rocks from the Jurassic, Cretaceous, Paleocene, Eocene, and Miocene periods; and the Southern Block is made up of unfossiliferous limestone, dolomite, argillite, and quartzite that are covered in Tertiary sequences that are similar to those found in the Central Block (Yeats and Hussain). The main Kala-Chitta Range is extended in the southern portion of the mapped area by the rock sequence.

2.4.3.1 Margalla Hill Limestone

True to its name, the Margalla Hill Formation is primarily composed of limestone, along with shale and marl. The limestone in this formation exhibits a dark grey color and is characterized by thick, nodular beds. The marl, on the other hand, displays a grey color and is comparatively harder in texture. Additionally, the formation includes splintery shale with a greenish-grey color within the Margalla Hill Limestone. The overall thickness of the formation ranges between 60 to 90 meters, and it is known to have a conformable contact with the underlying Chorgali Formation, as documented by (Williams et al. in 1999).

2.4.3.2 Chorgalli Formation

The Chorgali Formation is subdivided into two distinct parts: the upper and lower sections. In the upper portion of this formation, there is an occurrence of yellowish limestone, which may contain some chert, as well as fossils. The marl within this area displays a light grey color, and the overall thickness of this upper part can reach up to 120 meters.

In contrast, the lower portion of the Chorgali Formation is predominantly composed of greenish-grey shale, although limestone can also be found intermittently. Coquina beds within this lower section contain foraminifera fossils. The entire Chorgali Formation is conformably in contact with the underlying Kuldana Formation, as noted by (Williams et al. in 1999).

2.4.3.3 Kuldana Formation

The lithology in this area is primarily composed of marine and non-marine claystone, marl, limestone, and a small number of sandstones. The marl exhibits a pale greyish color and contains a small amount of gypsum. The limestone, on the other hand, has a color ranging from white to light brown.

The overall thickness of this formation can reach up to 120 meters. It is important to note that this formation has an unconformable boundary with the Murree Formation of the Rawalpindi Group, as described by (Williams et al. in 1999).

2.4.4 Rawalpindi Group (Miocene Age)

The rock comprising the Murree Formation and Kamlial Formation in Kohat Potwar province has been referred to as the Rawalpindi Group by the Pakistani stratigraphy committee, which adopted the term after Pinfold's 1964 proposal for Rawalpindi District. The group is made up of freshwater shale and sandstone alterations.

2.4.4.1 Murree Formation

Murree Formation is exposed in Hazara area, among Potwar Group. Originally referred to as the "Mari Group" by Wynne in 1874, the name of this formation was officially changed to the Murree Formation by the Stratigraphic Committee of Pakistan in 1972, as documented by Fatmi.

Murree Formation usually consists of sandstone and siltstone, with occurrence of conglomerates in smaller quantities. Sandstone is characterized by a reddish-grey color.

Their thickness varies across different areas but can reach approximately 2900 meters, according to Williams et al. in 1999.

This Formation is conformably overlain by the Kamlial Formation, showing a continuous and uninterrupted contact. Murree Formation unconformably overlies the Kohat Formation, as noted by Amjad Ali in 1997.

2.4.4.2 Kamlial Formation

Kamlial Formation is included in the upper part of Murree formation, exhibits a lithology that includes shale, conglomerate, siltstone, and sandstone. One distinctive component of the Kamlial Formation is the event of spheroidal enduring, which separates it from the Murree Development. Also, the presence of abundant tourmaline is another characteristic of the Kamlial Formation.

Thickness of the Kamlial Formation ranges from approximately 1500 to 1600 meters. It is conformably overlain by the Chinji Formation, located about 115 kilometers away from Islamabad, as reported by (Johnson et al. in 1985).

2.4.5 Siwalik Group (Neogene to Pleistocene Age)

The Siwalik system is thought to have originated in the middle Miocene to lower Pleistocene with the uplift of sediment deposited in Tethyd as a result of northward compression, a depression, and a foredeep type of topography that began receiving sedimentation from the northern Himalayan mountains at that time. The outermost Sub Himalayan ranges were originally named the Siwalil group, after Captain P.T. Cautley in the early 1800s.

2.4.5.1 Chinji Formation

The term "Chinji Stage" was approved by the Stratigraphic Committee of Pakistan, as noted by Shah in 1977. Chinji Formation prevalently comprises of brittle siltstone, scattered with sandstone. The sandstone found in the development ordinarily displays a smoky earthy colored tone, frequently with a block red tone, which adds to its popularity. Chinji Formation has a thickness going somewhere in the range of 850 and 1170 meters and is comparably overlain by the Nagri Formation, as portrayed by (Johnson et al. in 1985).

2.4.5.2 Nagri Formation

Nagri Formation is named after Nagri village by Lewis (1937). Nagri Formation, initially known as the Nagri Stage of Pilgrims, was later renamed by Lewis, a change that was agreed upon by the Stratigraphic Committee of Pakistan, as mentioned by Shah in 1977. This formation is principally portrayed by sandstone, which shows a greenish-grey variety and contains earth layers. In specific regions, conglomerates can be tracked down inside the formation. One particular component of the Nagri Formation is its salt and pepper design, which is shaped because of the presence of ilmenite and magnetite

2.4.5.3 Dhok Pathan Formation

Dhok Pathan Formation is named after the Dhok Pathan village by Pilgrim (1913). The name "Dhok Pathan" was first proposed by the Pilgrim, but it was later changed to

"Dhok Pathan Formation" by Cotter in 1933. Therefore, this name was formalized, as verified by Fatmi in 1973. The Dhok Pathan Formation is portrayed by orange-colored siltstone, alongside grayish sandstone and hard claystone. Its thickness ranges somewhere in the range of 500 and 820 meters. The formation is similarly overlain by the Soan Development, as depicted by (Johnson et al. in 1985).

2.4.5.4 Soan Formation

Soan Group was named by Malkani and Mahmood (2016) which comprises of the Pleistocene coarse clastic Lei (Mirpur/Kakra) Conglomerate and afterward Holocene mixed fine and coarse clastic of Soan Formation. Soan Group comprises of coarse clastic with comparative with Potwar Group. The name "Lehri Formation" was accepted by the Stratigraphic Committee of Pakistan after it was proposed by Kravtchenko in 1964, as mentioned by Rahman in 1968. Lithology of the Lehri Formation includes siltstone, sandstone, claystone, clays and conglomerates. Sandstone grains in the formation exhibit a greenish-grey color, while the claystone has a light pink and brownish hue. Thickness of the Lehri Formation varies from 200 to 300 meters. It is conformably overlain by the Lei Conglomerates, as described by Johnson et al. in 1982.

2.4.6 Units on Surface (Pleistocene to Holocene)

2.4.6.1 Lei Conglomerate

Lei Conglomerate was presented by Gill (1952) for the Pleistocene coarse clastic (synonym Mirpur/Kakra formations). The expression "Boulder Conglomerate" was at first proposed by the Pilgrim in 1910, however later, in 1952, Gill presented the name

"Lei Conglomerates." The region where these conglomerates are found is generally level and nearer to the sea level. However, there are neighborhoods overlays and faults are available.

Lei Conglomerates overlay both the Siwalik and Rawalpindi groups. The volcanic ash found in the area is younger than the Soan Formation but older than the Lei Conglomerates. The age of the Lei Conglomerates can be roughly estimated using the fission track method, which suggests that their maximum age ranges from around 1.6 to 18 million years, as described by (Johnson et al. in 1982).

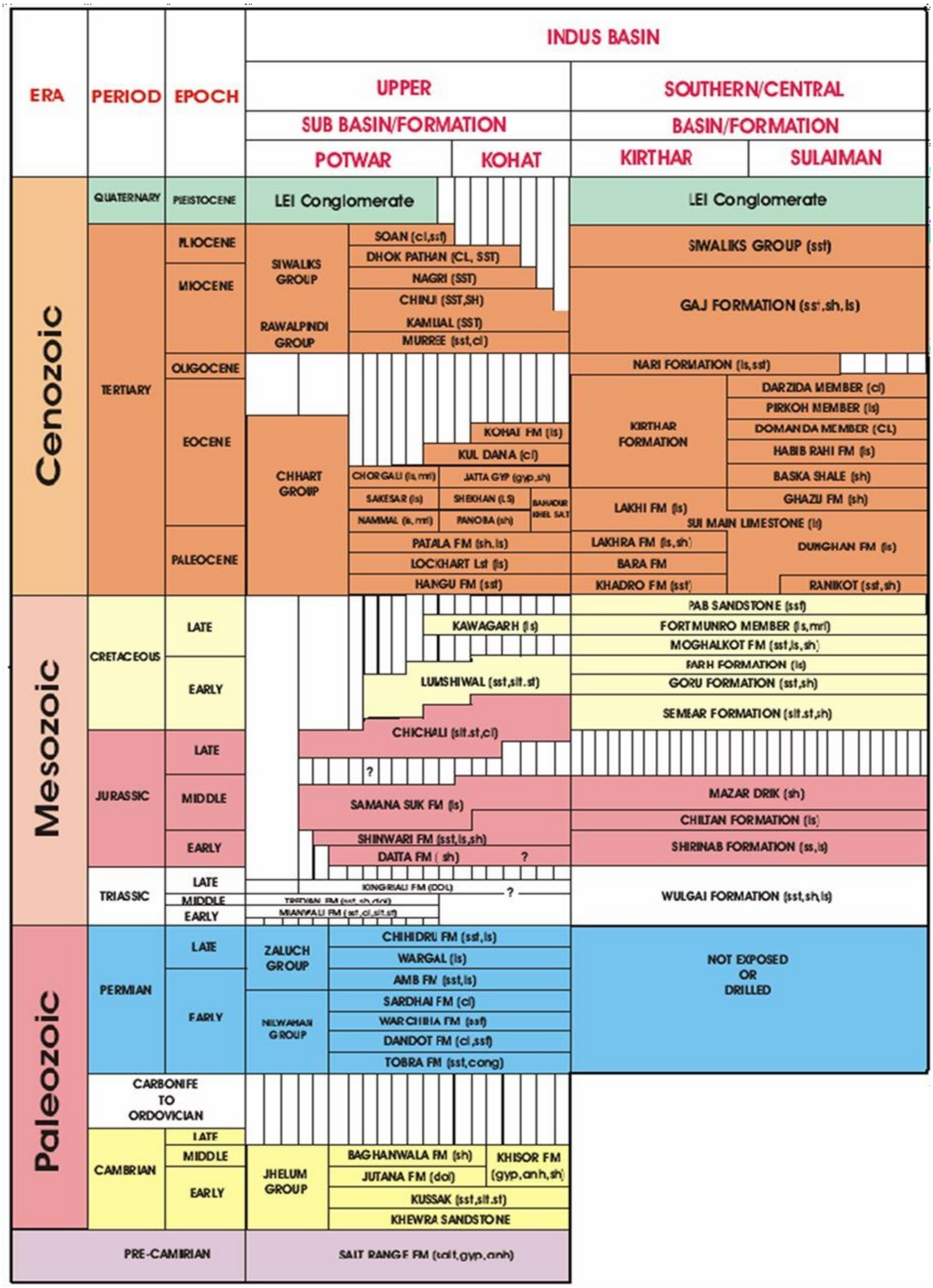

Figure 2.4 Showing the generalized stratigraphy of Pakistan

CHAPTER 3

METHODOLOGIES

For the above mentioned objectives it is necessary to make plan to achieve our goals which are enlisted below:

1. Mark the resistivity points in different regions of Islamabad
2. To acquire data of ten different location.
3. Processing of the data and their interpretations.
4. Identify different layers in the sub surface.
5. Calculate Dar Zarrouk parameters of aquifer.

3.1 Electrical Resistivity Method

Electrical resistivity survey is carried out using sounding techniques for hydrogeological studies and application of Dar Zarrouk parameters to in order to determine the aquifer capacity and to give probable well location in different regions of Islamabad and Rawalpindi. Schlumberger electrode is used for the acquisition of sounding data to evaluate groundwater potential. Electrical resistivity method has been successfully employed among various geophysical methods for groundwater investigations, particularly where electrical resistivity contrast exists between the water bearing formation and surrounding soils or rock.

Considering the sub-soil variable properties, the technique of electrical resistivity survey makes use of measuring the current and potential differences of various subsoil materials at the surface.

The porosity, water content and quantity of dissolved salts are the factors which usually controls the resistivity. However, clay minerals are capable of storing electrical charges andcurrent conduction in clay minerals. The resistivity of soils depends directly on the amount of contained electrolyte and clay minerals and it is inversely related to the degree of saturation and porosity of the formations.

The resistivity survey technique is used for different purposes such as groundwater salinity, assessment, exploration and investigation. Some other methods to determine depth and thickness and boundary of different layers of aquifer (Zohdy, 1969, Young et al., 1998 and Soupios et al., 2007). The resistivity of pure water is can be reduced by contamination, this is usually due to increase in ion concentrations (lashkaripour, 203; Oseji et al., 2006). Resistivity surveys are also used to solve different groundwater issues such as thickness and boundaries of aquifers, assessment of strata and the determination of the high potential zones in an aquifer (Oseji et al., 2005), estimation of boundaries between saline and fresh water zones (El-Waheidi et al., 1992).

3.1.1 Principal of Resistivity Survey

The resistivity survey is usually done by injecting two currents electrodes (A and B) into the ground, which resulting in measurement of potential differences at two potential electrodes (M and N) which are placed inside. The values of apparent resistivity (pa) can be calculated from the values of current "I" to voltage "V" by formula:

$$\text{Apparent Resistivity (pa)} = k\,\frac{V}{I}$$

Where "k" is the geometric factor, dependent on electrodes arrangement.

Value of resistance is normally measured by resistivity meter,

$$R = \frac{V}{I}$$

Apparent resistivity value can be calculated as:

pa = kR

It is the apparent resistivity value. Apparent resistivity is the homogeneous ground resistivity that give the same resistance value for the same arrangements of electrodes.

For current "I" driven into subsurface through current electrodes A and B, potential difference δV is measured between two points M and N at the surface of the earth.

The voltage δVcan be determined by:

$$\delta V = 2(\frac{PI}{2\pi})(\left\{\frac{1}{s-b}\right) - \left\{\frac{1}{s+b}\right\})$$

Where, "pa" = is the apparent resistivity,

"s" = is the half of distance of spacing between electrodes,

"b" = is the half distance between potential electrodes,

"I" = is the current.

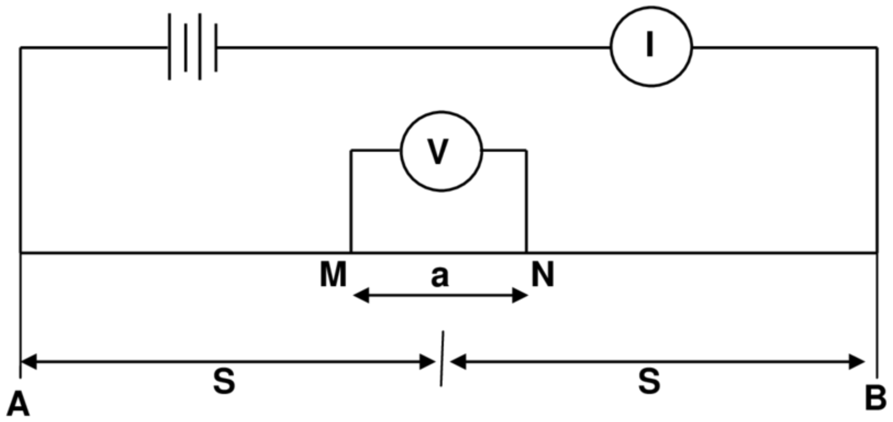

Figure 3.1.1: Showing the Schlumberger array configuration.

For groundwater prospecting Schlumberger electrode configuration is used. The distance between the current electrodes (A and B) is very large as compared to the distance between the potential electrodes (M and N). In this configuration, lateral in-homogeneity are easily identified. Moreover, this configuration requires lesser electrode spacing at the surface in order to determine the required depth of site area ascompared with other configurations.

3.1.2 Instrumentations

The equipment used for the survey are enlisted below:

1. Measuring Tape
2. Hammers
3. GPS
4. Current and Potential Electrodes
5. Coiled wire
6. ABEM Terrameter SAS 1000
7. DC Battery

3.1.3 Field Procedure and Evaluation Profile

The resistivity measuring instrument like Mini Sting of AGI USA and using the Schlumberger electrode array electrical resistivity measurements of the subsurface were taken in the field. Terameter is used to records the value of resistivity R in ohms. To concentrate on the variety of resistivity with profundity, Vertical Electric Sounding (VES) method was utilized. In this strategy, clear resistivity values are gotten for different profundities by expanding the ongoing terminals dividing at the ground surface, keeping the focal point of cathode exhibit fixed at the perception point. In view of the hydrogeological data gathered during the surveillance review, vertical electric soundings were directed at ten (10) perception focuses inside the review region. Electrical resistivity was carried out using ABEM Terrameter acquired from Bahria University, Islamabad.

On the logarithmic scale, apparent resistivity value versus depth is plotted usually obtained in the field. Interpreting the resistivity sounding makes use the method of curve matching, the field curve compared with standard curves or with the curve plotted with a computer program. The standard bends as well as computer bends relate to an arrangement of sub-surface layers and their particular electrical resistivity, which could be connected with the hydrogeological qualities of the dirt of a specific region. The last translation utilizes the accessible nearby hydrogeological information of the cylinder wells.

Among different bend matching strategies, fractional bend matching strategy utilizing helper point technique was utilized to decide the genuine resistivity model. For this purpose, a set of Ebert auxiliary graphs (Orellana and Mooney 1966) was used. Last investigation of the resistivity bends was made by utilizing a computer program. This program yields conceivable earth layer model from the field resistivity bend utilizing programmed techniques.

Classification of quality of groundwater profile in the study area

Table 3.1.3 showing the classification of quality of groundwater profiles

TDS values(ppm)	**Concentration**	**Color codes**
<500	Low-Good	
1000-2000	Mild-Marginal to Fair	
2000-4000	High-Brackish	
>4000	Very High-Saline	

Total dissolved solids TDS of the hand pump (500-1000GPH capacity) in the projectarea up to the depth of 40m range 410 ppm.

3.2 Working Principle of BR 700 Pro

BR 700 Pro is sending waves and electric shocks in the ground, which measureall frequencies and soil resistance by analyze readings the groundwater. It has been provided with feature to know the depth of water in exact number and appear on then screen and we can get knowledge about water power in details. BR 700 PRO can distinguish between fresh, salt, and mineral water and in the case of the discovery of water immediately shows the water type on the screen if fresh or salty or mineral water.

3.3 Purpose and Scope of ADMT S-300

The main purpose of these techniques is to define / delineate the subsurface lithological units, depth of bed rock, thickness of unconsolidated and depth of water bearing formations. It is very important in groundwater investigation to identify porous& permeable formation and fractured subsurface strata which have fair amount of groundwater and sustainable quantity / quality of groundwater, through which installation of water well is recommended.

CHAPTER 4

DISSCUSION OF RESULTS WITH COMPUTER INTERPRETED MODELS

4.1 ERS-01

The maximum spread-length of the current electrodes were 150 meters and using schlumberger offset configuration. The AB electrodes traverses through undulation and dry floor, which could be affected the data. Processing and interpretation of the data indicated that this sounding location not is favorable for further groundwaterexploration through test drilling.

Table 4.1: Showing the different depths along their resistivity value in ERS-01

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2.7 to 14.5	18.6	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	14.5 to 74.1	24.3	Gravels and Sands are embedded with dominantly clay, showing low yield of groundwater.
3	74.1 to 150	14.6	Largely clay

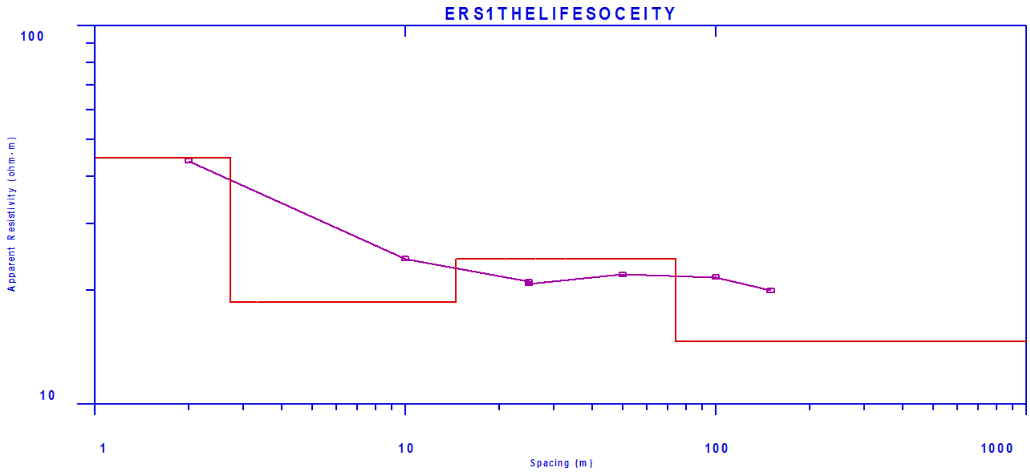

Figure 4.1: ERS-01 resistivity model

4.2 ERS-02

The maximum spread-length of the current electrodes were 150 meters and using schlumberger offset configuration. The AB electrodes traverses through fields and dry floor. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling up to 150m depth.

Table 4.2: Showing the different depths along their resistivity value in ERS-02

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	0.95 to 11.3	28.9	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	11.3 to 34.6	12.14	Largely clay
3	34.6 to 150	23.2	Sandstone dominant with shale

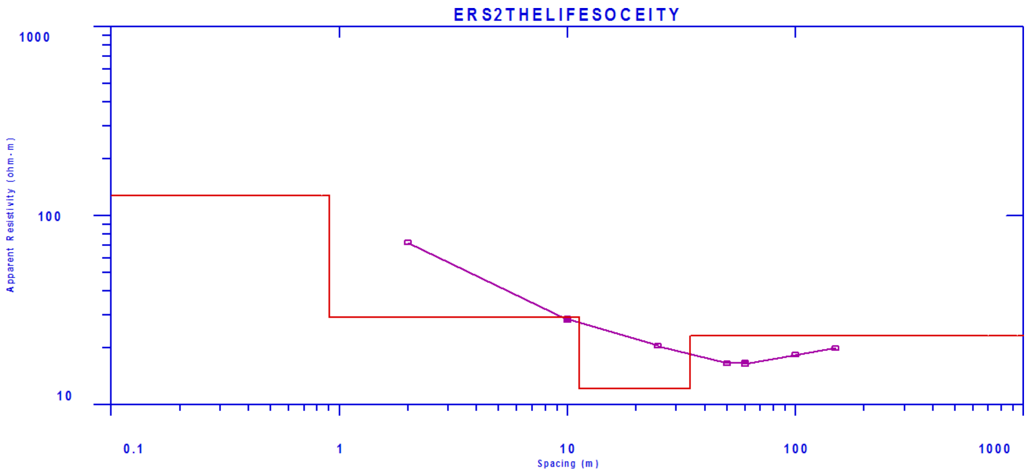

Figure 4.2: ERS-02 resistivity model

4.3 ERS-03

The maximum spread-length of the current electrodes were 150 meters and using schlumberger offset configuration. The AB electrodes traverses through nurseryand dry floor. Processing and interpretation of the data indicated that this sounding location is not favorable for further groundwater exploration through test drilling.

Table 4.3: Showing the different depths along their resistivity value in ERS-03

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2 to 5.2	25.9	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	5.2 to 48.9	20.5	Sandstone and gravel with dominant clay
3	48.9 to 150	18.5	Largely clay

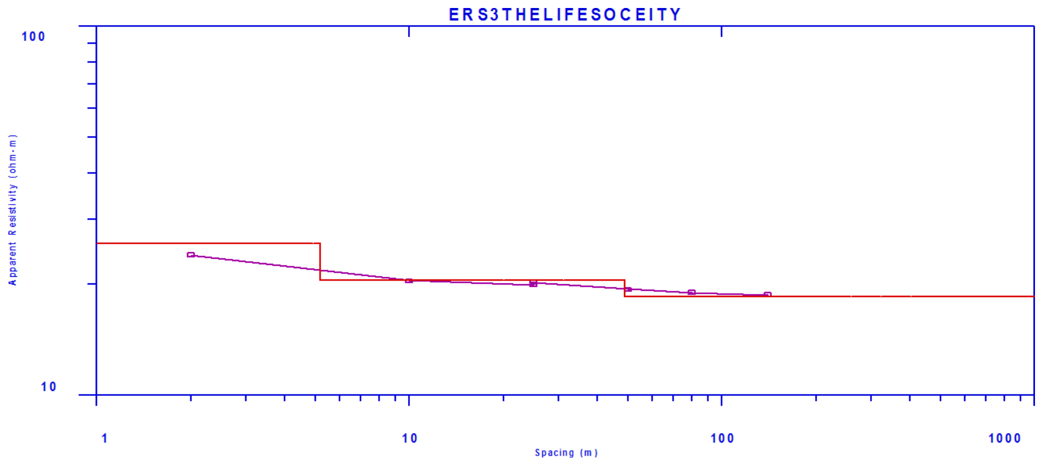

Figure 4.3: ERS-03 resistivity model

4.4 ERS-04

The maximum spread-length of the current electrodes were 150 meters and using schlumberger offset configuration. The AB electrodes traverses through Nallah and dry floor. Processing and interpretation of the data indicated that this sounding location is not favorable for further groundwater exploration through test drilling.

Table 4.4: Showing the different depths along their resistivity value in ERS-04

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2 to 9	20.3	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	9 to 50.2	20.4	Sand and gravels with dominant clay
3	50.2 to 150	17.5	Largely clay

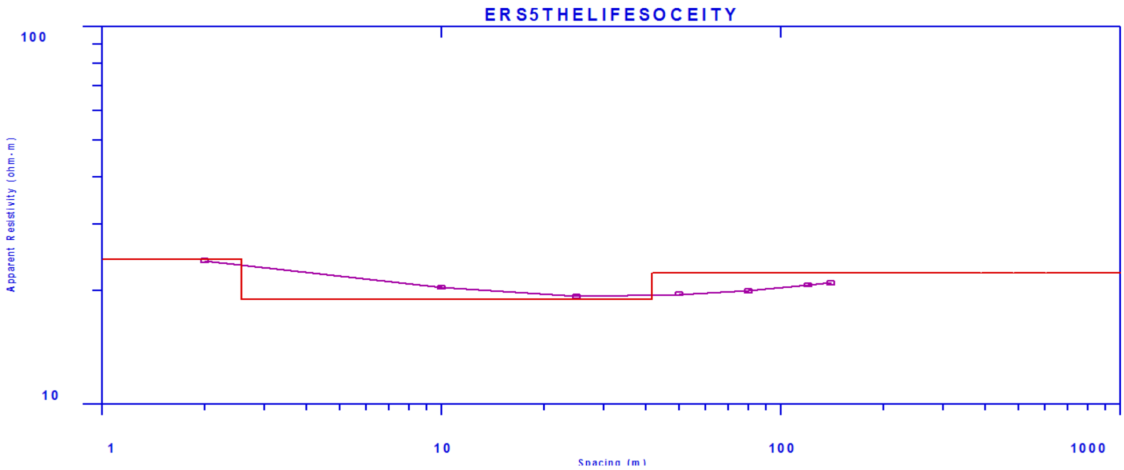

Figure 4.4: ERS-04 resistivity model

4.5 ERS-05

The maximum spread-length of the current electrodes were 150 meters and using schlumberger offset configuration. The AB electrodes traverses through fields and moderately wet floor. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling.

Table 4.5: Showing the different depths along their resistivity value in ERS-05

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2 to 2.6	24.3	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	2.6 to 41.7	19.0	Largely clay
3	41.7 to 150	22.2	Sandstone with dominant shale

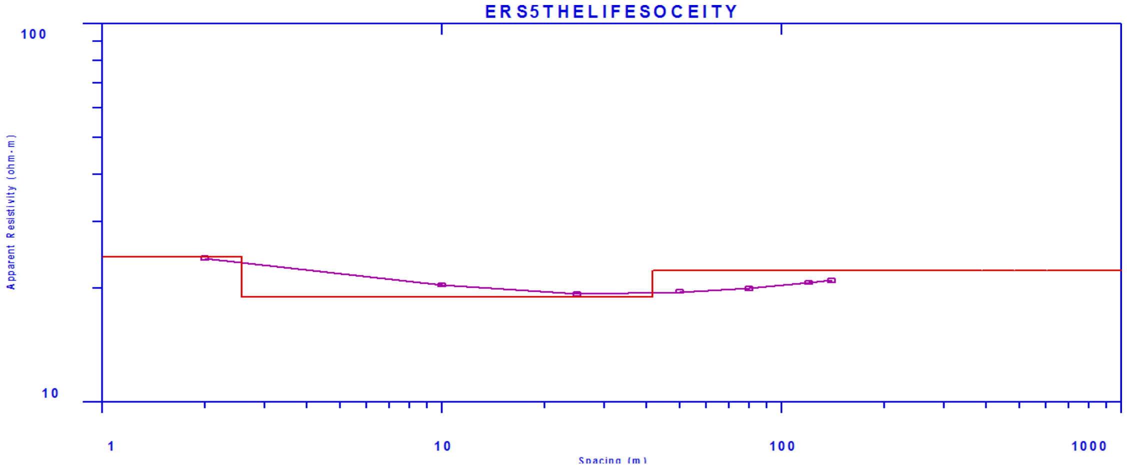

Figure 4.5: ERS-05 resistivity model

4.6 ERS-06

The maximum spread-length of the current electrodes were 150 meters and using Schlumberger offset configuration. The AB electrodes traverses through near creek and moderately dry floor. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling up to the depth of 150m.

Table 4.6: Showing the different depths along their resistivity value in ERS-06

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2 to 5.6	24.2	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	5.6 to 41.5	19	Largely clay
3	41.5 to 150	22.3	Sandstone with dominant shale

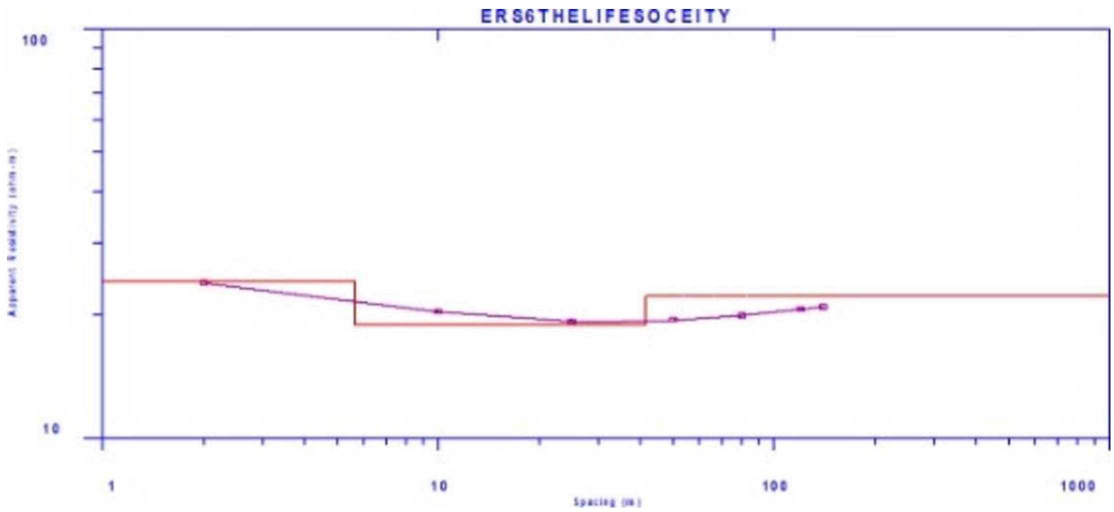

Figure 4.6: ERS-06 resistivity model

4.7 ERS-07

The maximum spread-length of the current electrodes were 150 meters and using schlumberger offset configuration. The AB electrodes traverses along the parallelof pound and moderately dry floor. Processing and interpretation of the data indicated that this sounding location is not favorable for further groundwater exploration through test drilling.

Table 4.7: Showing the different depths along their resistivity value in ERS-07

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2 to 5.2	22.4	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	5.2 to 51.8	20.5	Sand and gravel embedded with dominant clay.
3	51.8 to 150	7.1	Largely clay

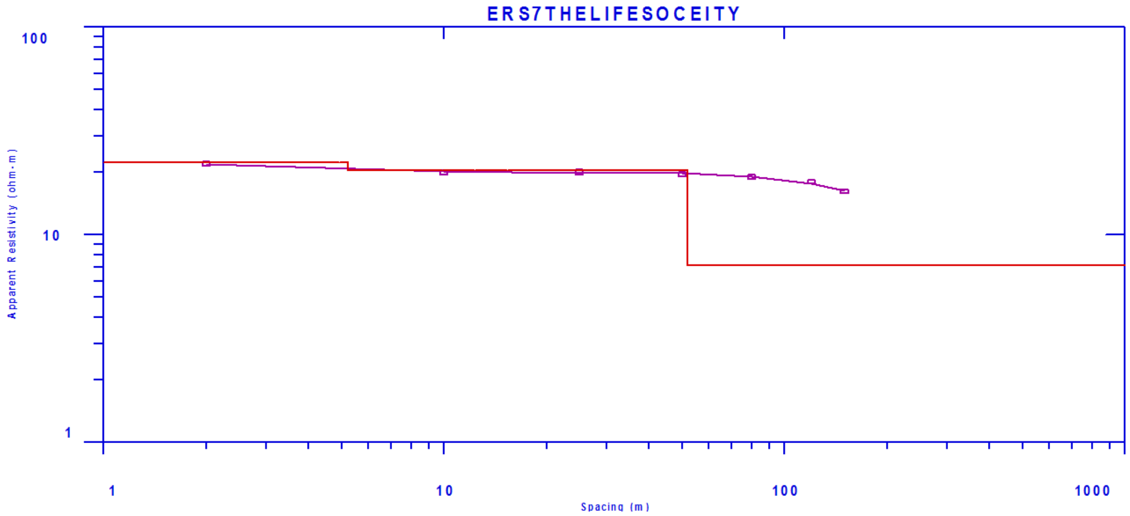

Figure 4.7: ERS-07 resistivity model

4.8 ERS-08

The maximum spread-length of the current electrodes were 150 meters and using schlumberger offset configuration. The AB electrodes traverses through main dam catchment area and moderately wet floor. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling up to the depth of150 m.

Table 4.8: Showing the different depths along their resistivity value in ERS-08

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2 to 8.3	24.6	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	8.3 to 72.6	21	Sand and gravel embedded with dominant clay.
3	72.6 to 150	8.2	Largely clay

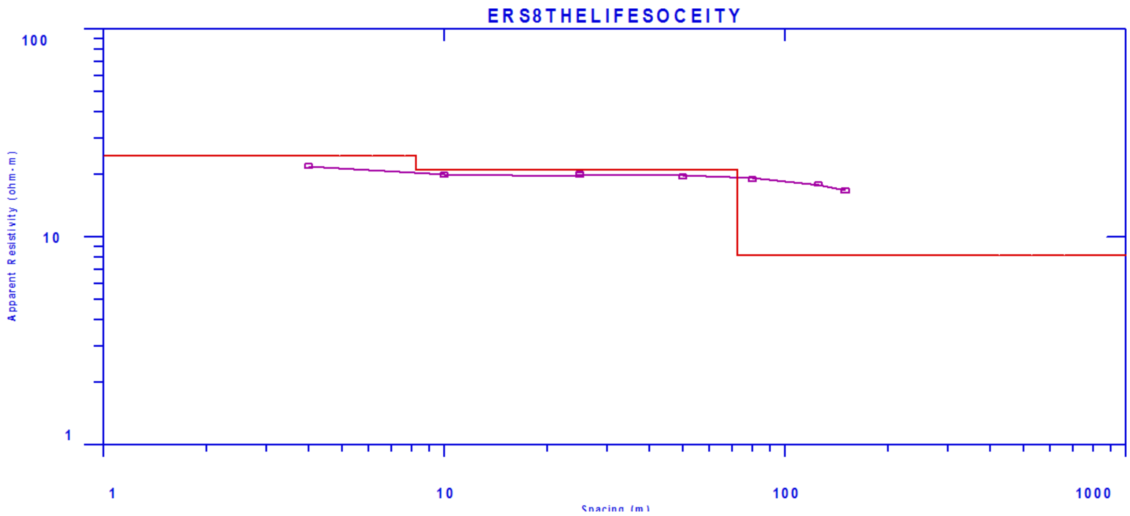

Figure 4.8: ERS-08 resistivity model

4.9 ERS-09

The maximum spread-length of the current electrodes were 150 meters and using Schlumberger offset configuration. The AB electrodes traverses through bushes and moderately dry floor. Processing and interpretation of the data indicated that this sounding location is not favorable for further groundwater exploration through test drilling.

Table 4.9: Showing the different depths along their resistivity value in ERS-09

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	2 to 8	64.3	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	8 to 61.5	20.4	Sand and gravel embedded with dominant clay.
3	61.5 to 150	16.4	Largely clay

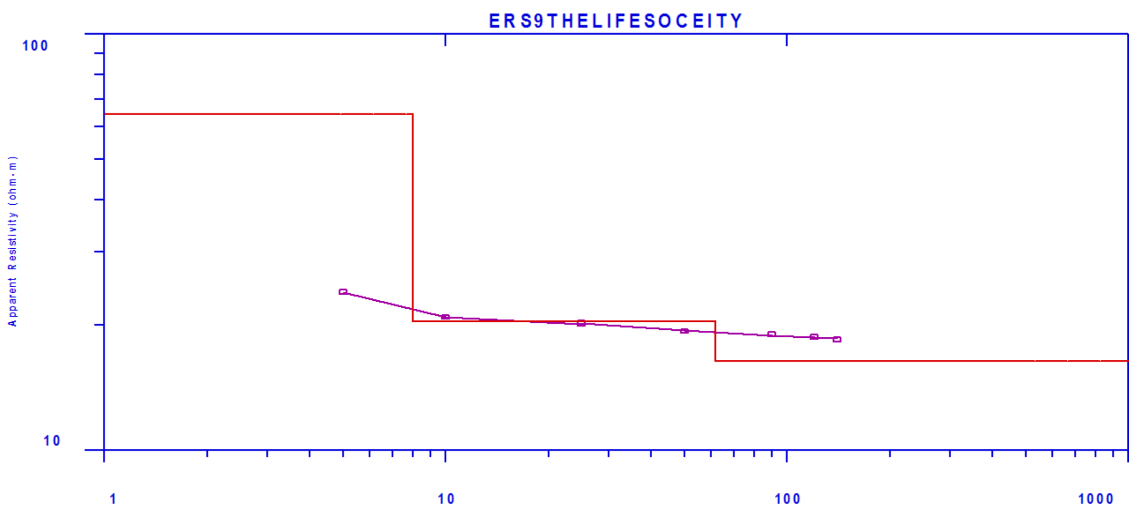

Figure 4.9: ERS-09 resistivity model

4.10 ERS-10

The maximum spread-length of the current electrodes were 150 meters and using Schlumberger offset configuration. The AB electrodes traverses through garden and moderately wet floor. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling up to the depth of150m.

Table 4.10: Showing the different depths along their resistivity value in ERS-10

Layers	Depth (m)	Resistivity (Ohm.m)	Interpretation and Lithology distribution
1	4.5 to 21.4	19.8	Alluvium comprises gravels with different grades of sand and is dry like above water table. Minimum values of Resistivity in this zone indicates presence of fine materials like silt/ clay.
2	21.4 to 86	24.3	Sand and gravel embedded with dominant clay.
3	86 to 150	15.5	Largely clay

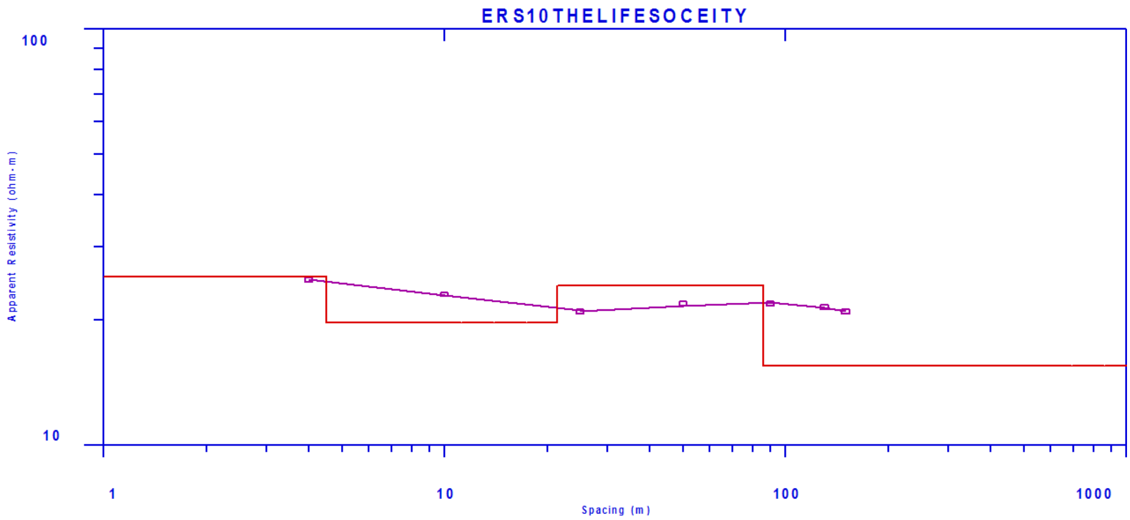

Figure 4.10: ERS-10 resistivity model

4.11 VES-01

The maximum spread-length of the current electrodes were 150 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling for small scale groundwater development up to the depth of 80m.

Table 4.11: Showing the different depths along their resistivity value in VES-01

Layers	Depth (m)	Resistivity	Interpretations and Lithology distribution
1	2.68 to 13.9	20.2	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	13.9 to 26.8	10.7	Dominant shale with sandstone
3	26.8 to 51.8	8.25	Dominantly hard shale
4	51.8 to 79	10.7	Dominantly shale with interlayers of sandstone
5	79 to 150	6.39	Dominantly hard shale

4.12 VES-02

The maximum spread-length of the current electrodes were 150 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling for small scale groundwater development up to 100m depth.

Table 4.12: Showing the different depths along their resistivity value in VES-02

Layers	**Depth (m)**	**Resistivity**	**Interpretations and Lithology distribution**
1	2.68 to 13.9	20.2	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	13.9 to 26.8	10.7	Dominant shale with sandstone
3	26.8 to 51.8	8.25	Dominantly hard shale
4	51.8 to 79	10.7	Dominantly shale with interlayers of sandstone
5	79 to 150	6.39	Dominantly hard shale

4.13 VES-03

The maximum spread-length of the current electrodes were 150 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling for small scale groundwater development up to 70m depth.

Table 4.13: Showing the different depths along their resistivity value in VES-03

Layers	Depth (m)	Resistivity	Interpretations and Lithology distribution
1	2 to 3.728	17.8	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	3.728 to 13.98	15.6	Dominant shale with interlayers of sandstone.
3	13.98 to 26.8	8.25	Dominantly hard shale
4	26.8 to 70	10.7	Dominantly shale with interlayers of sandstone
5	70 to 150	6.39	Dominantly hard shale

4.14 VES-04

The maximum spread-length of the current electrodes were 200 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling for small scale groundwater development up to 140m depth.

Table 4.14: Showing the different depths along their resistivity value in VES-04

Layers	**Depth (m)**	**Resistivity**	**Interpretations and Lithology distribution**
1	0 to 26.83	16.61	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	26.83 to 71.97	12.15	Dominant shale with interlayers of sandstone.
3	71.97 to 138.9	11.24	Dominant shale with interlayers of sandstone.
4	138.9 to 150	8.895	Dominantly hard shale

4.15 VES-05

The maximum spread-length of the current electrodes were 200 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is favorable for further groundwater exploration through test drilling for small scale groundwater development up to 140m depth.

Table 4.15: Showing the different depths along their resistivity value in VES-05

Layers	**Depth (m)**	**Resistivity**	**Interpretations and Lithology distribution**
1	0 to 26.83	16.61	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	26.83 to 71.97	12.15	Dominant shale with interlayers of sandstone.
3	71.97 to 138.9	11.24	Dominant shale with interlayers of sandstone.
4	138.9 to 150	8.895	Dominantly hard shale

4.16 VES-06

The maximum spread-length of the current electrodes were 200 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is not favorable for further groundwater exploration through test drilling.

Table 4.16: Showing the different depths along their resistivity value in VES-06

Layers	Depth (m)	Resistivity	Interpretations and Lithology distribution
1	0 to 5.179	14.21	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	5.179 to 13.89	12.15	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
3	13.98 to 37.28	11.24	Dominant shale with interlayers of sandstone.
4	37.28 to 150	9.617	Dominantly hard shale

4.17 VES-07

The maximum spread-length of the current electrodes were 200 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is not favorable for further groundwater exploration through test drilling.

Table 4.17: Showing the different depths along their resistivity value in VES-07

Layers	**Depth (m)**	**Resistivity**	**Interpretations and Lithology distribution**
1	0 to 7.197	16.1	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	7.197 to 26.83	13.74	Dominant shale with interlayers of sandstone.
3	26.83 to 100.01	9.237	Dominantly hard shale
4	100.01 to 150	8.532	Dominantly hard shale

4.18 VES-08

The maximum spread-length of the current electrodes were 200 meters and using Schlumberger offset configuration. The AB electrodes traverses through fields, which could not affect the data. Processing and interpretation of the data indicated that this sounding location is not favorable for further groundwater exploration through test drilling.

Table 4.18: Showing the different depths along their resistivity value in VES-08

Layers	**Depth (m)**	**Resistivity**	**Interpretations and Lithology distribution**
1	0 to 10	14.21	Dry sandstone, Low resistivity in this zone indicates the presence of clay and shale.
2	10 to 26.83	11.24	Dominant shale with interlayers of sandstone.
3	26.83 to 110	10.4	Dominantly hard shale
4	110 to 150	8.895	Dominantly hard shale

Table 4.19: Suitable wells with depth found by ERS with their location

Sr.#	ERS Points	Longitude	Latitude	Drilling Depth (m)	Remakrs
1	ERS-01	72.9493	33.7048	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
2	ERS-02	73.095	33.6572	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
3	ERS-03	73.095	33.6572	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
4	ERS-04	73.1149	33.6363	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
5	ERS-05	73.1108	33.541	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
6	ERS-06	72.8593	33.5938	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
7	ERS-07	72.8593	33.5938	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
8	ERS-08	72.8659	33.5819	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.

9	ERS-09	72.8659	33.5819	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.
10	ERS-10	73.0691	33.7249	110 to 150	Fit for drilling, shows the ground water expected yield in between 1000 to 2000 GPH.

Table 4.20: Suitable wells with depth found by VES with their location

Sr.#	VES Points	Longitude	Latitude	Drilling Depth (m)	Remakrs
1	VES-01	33.706	72.952	80	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.
2	VES-02	33.6645	73.0881	100	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.
3	VES-03	33.6408	73.1123	70	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.
4	VES-04	33.5357	73.1146	140	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.
5	VES-05	33.5912	72.8636	110	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.
6	VES-06	33.5912	72.8636	90	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.
7	VES-07	33.579	72.8698	115	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.
8	VES-08	33.7294	73.0779	145	Fit for drilling showing ground water expected yield in between 500 to 1000 GPH.

4.19 Resistivity and Lithological Logs Correlation

Electrical resistivity survey is carried out throughout the region which has a spread length of about 250m which shows the depth of about 150m from VES-01 to VES-03, whereas VES-04 to VES-08 shows the depth of about 190m. In the subsurface, electrical resistivity values ranges from 4.5 Ωm to 11161 Ωm which indicates the high variation in lithologies in subsurface.

The wells are drilled by the local communities by their own and the information about the wells like water table level and lithologies of the borehole were collected. By evaluating these information and converting the local terms, litho log were plotted. The water table in most of the region in the North of Islamabad is approximately at 67 m but the water over here is muddy so for fresh water further drilling is done up to depth of about 190 m.

Combining the information of lithological Columns of 8 VES points, a combined litho log is made as shown in the figure. Based on interpreted litho log based on resistivity values, it was found that lithologies present are sandstone with clay and limestone and aquifer exits most of the region in Islamabad at the depth > 40 m.

Formation	Resistivity (Ωm)
Clay with fresh water	6 to 15 Ωm
Clay with sand	9 to 25 Ωm
Clay with saltwater	2 to 6 Ωm
Sandstone with fresh water	25 to 150 Ωm
Sandstone with clay	15 to 30 Ωm

From the correlating these lithological resistivity ranges with litho log made from resistivity values and litho log it is not possible to distinguish clear boundary between different subsurface geological units, but most of resistivity values in aquifer zones at depth greater than 40 m shows the presence of sandstone and clay with fresh water in aquifer.

4.20 Dar Zarrouk Parameters Interpretations

The generated geoelectrical parameters shows the electric boundaries which separates different resistivities. The Geoelectrical layer is described by two fundamental parameters i.e. resistivity $(\boldsymbol{\rho_i})$and their thickness $(\mathbf{h_i})$,

i = 1 for the uppermost layer

where "i" indicates the position of layering section.

From the resistivity distribution of the given medium by considering a column of unit square cross section area, Longitudinal Conductance $\mathbf{S_c}\ (\boldsymbol{\Omega^{-1}})$ **and** Transverse Resistance $\mathbf{T_r}\ (\boldsymbol{\Omega}\mathbf{m^2})$ and the coefficient of anisotropy $\boldsymbol{\lambda}$ are derived.

4.21 Transverse Resistance ($\mathbf{T_r}$)

One of the parameters used to define the target area of good groundwater potential and to study variations in thickness of high resistivity materials. The highest values reflects the highest transmissivity value in the aquifer zone.

The total resistance can be measured by:

$$T_r = \sum_{i=1}^{n} h_i\, \rho_i = h_1\rho_1 + h_2\rho_2 + h_3\rho_3 \ldots h_n\rho_n$$

Where,

$\mathbf{T_r}$ is the transverse resistance

$\mathbf{h_i}$ is thickness

$\boldsymbol{\rho_i}$ is apparent resistivity of the aquiferous layer

4.22 Coefficient of Anisotropy (λ)

Anisotropy can be caused by the fracturing in the rocks or by disseminated ore grains. The resistivity in rocks can be determined by the orientation of elongated grains and by the layering of different resistivity values. Coefficient value of anisotropy does not exceed 2 but greater than 1. Value greater than 2 implies that it is due to the intrusive bodies which have high resistivity value than their host rocks.

Coefficient of Anisotropy can be measured in the case of stratified or fractured anisotropic medium:

$$\lambda = \frac{\rho_T}{\rho_L}$$

Where,

$\boldsymbol{\rho_T}$ is Average Transverse Resistivity

$\boldsymbol{\rho_L}$ is the Average Longitudinal Resistivity

For homogeneous isotropic media $\boldsymbol{\rho_T}$ is greater than $\boldsymbol{\rho_L}$ where $\boldsymbol{\lambda}$ =1 ranges from 1 to 2.

Average Longitudinal Resistivity can be measured by:

$$\rho_L = \frac{H}{S_c} = \frac{\sum_i^n h_i}{\sum_i^n \frac{h_i}{\rho_i}}$$

Where,

$\mathbf{S_c}$ is the longitudinal conductance

$\mathbf{T_r}$ is the transverse resistance

'H' is the sum of thickness (h)

And,

Average Transverse Resistivity can be measured by:

$$\rho_T = \frac{T_r}{H} = \frac{\sum_i^n h_i}{\sum_i^n h_i} \rho_i$$

$\mathbf{S_c}$ is the longitudinal conductance

$\mathbf{T_r}$ is the transverse resistance

'H' is the sum of thickness (h)

4.23 Longitudinal Conductance($\mathbf{S_c}$)

It is used to define target areas of groundwater potential. High S values indicate the relatively thick succession and should be accorded with the highest priority in trems of groundwater potential (Okonkwo,2015).

Total longitudinal conductance can be derived from:

$$\mathrm{S_c} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \frac{\mathrm{h_i}}{\rho_{\mathrm{i}}} = \frac{\mathrm{h_1}}{\rho_1} + \frac{\mathrm{h_2}}{\rho_2} + \frac{\mathrm{h_3}}{\rho_3} + \cdots + \frac{\mathrm{h_n}}{\rho_{\mathrm{n}}}$$

Where,

$\mathbf{S_c}$ is the longitudinal conductance

$\mathbf{h_i}$ is the thickness

$\boldsymbol{\rho_i}$ is the apparent resistivity of the aquiferous layer

4.24 Graphical Representation of Longitudinal Conductance (S_c)

The value for longitudinal conductance in our study area ranges from 3.5 to 14.17 (Ω^{-1}). By using the Latitude and Longitude and S_c value contour map of S_c value of study area is prepared. Variation in S_c values can be differentiated on the basis of color. The longitudinal profile running from East towards North shows the increase in values of S_c values. The high value of longitudinal conductance in the North shows the low transimissivity of ground water.

On the basis of longitudinal conductance value VES are categorized into four ranges.

Vertical Electrical Sounding Points (VES)	Longitudinal Conductance (S_c)
VES-01	6.7 to 8.6 (Ω^{-1})
VES-02	4.5 to 6.0 (Ω^{-1})
VES-03	4.3 to 6.2 (Ω^{-1})
VES-04	2.7 to 4.3 (Ω^{-1})
VES-05	4.5 to 6.2 (Ω^{-1})
VES-06	6.9 to 8.7 (Ω^{-1})
VES-07	6.7 to 8.6 (Ω^{-1})
VES-08	6.5 to 8.3 (Ω^{-1})

On the basis of longitudinal conductance value we can tell the protection capacity as the aquifer is present at depth greater than 40 m, this is due to earth surface acting as natural filter to percolating fluid. The highly clayey overburden offers protection to the underlying aquifer. The longitudinal conductance obtained from the study area ranges from 0.1 to 12.57 $\mathbf{\Omega^{-1}}$. Portion ranges from 0.7 to 8.9 $\mathbf{\Omega^{-1}}$ ais considered to be good protective capacity. Portion ranges from 0.3 to 0.71 $\mathbf{\Omega^{-1}}$is classified as weak aquifer protective capacity zone.

4.25 Graphical Representation of Transverse Resistance ($\mathbf{T_r}$)

Transverse Resistance, this parameter is usually used to observe the variation in thickness of resistivity materials and their transverse resistance. Increase in transverse resistance indicate the incress in thickness of high resistivity materials.

Vertical Electrical Sounding Points (VES)	Transverse Resistance ($\mathbf{T_r}$)
VES-01	4232.6-18263.1 $\mathbf{\Omega m^2}$
VES-02	<4225.4 $\boldsymbol{\Omega m^2}$
VES-03	18157.0-141811.3 $\mathbf{\Omega m^2}$
VES-04	Above 141818 $\mathbf{\Omega m^2}$
VES-05	18157.0-141811.3 $\mathbf{\Omega m^2}$
VES-06	18157.0-141811.3 $\mathbf{\Omega m^2}$
VES-07	4227.8-18260.7 $\mathbf{\Omega m^2}$
VES-08	4234.7-18275.3 $\mathbf{\Omega m^2}$

Fresh water can be determined by transverse resistance value ranges from 7000 to 8500 ($\boldsymbol{\Omega m^2}$). Brackish water can be identified by attaining transverse resistance value ranges from 3000 to 7000 ($\boldsymbol{\Omega m^2}$), on the other hand saline water presence can be identified by attaining transverse resistance value ranges from 1000 to 3000 ($\boldsymbol{\Omega m^2}$).

4.26 Graphical Representation of Anisotropy (λ)

On the basis of values and color scheme, five ranges of λ values have been made. From λ 0.0 to 0.5, no VES point is situated. Range from 0.6 to 1.2, VES-02, VES-07 and VES-08 are present. From λ 1.3 to 1.9 value, VES-01, VES-05, VES-06 are present. Value of λ greater than 3.4 λ VES-03 and VES-04 is present.

In Southern part of study area shows the high value of coefficient of anisotropy, while the lowest λ value is present in the North. VES-07 and VES-08 have λ value between 0.3 to 1.1, whereas VES-01 to VES-06 have λ value between 1.3 to 1.8.

When $\lambda = 1$ for homogeneous anisotropic media, value of VES-07 and VES-08 approximately 1 which indicates that there is homogeneous isotropic media in the subsurface of these VES points.

4.27 Data of ADMT S-300

The reading is taken along five profiles with minimum and maximum spread length and grid in order to get maximum data cluster with maximum possible readingto minimize the data error and to improve the data quality and accuracy.

Table 4.28: Showing the data of ADMT S-300

File-ID	Increment	170Hz	67Hz	25Hz	0Hz	Mode	DateTime
Bango Qutbal	1	0	0.095	127.009	17.747	1	12/5/2023 0:00
0	2	0	0.082	21.054	61.333	1	
0	3	4.93	39.327	21.822	246.779	1	
0	4	0	18.157	19.989	11.258	33.57836 72.74632	
P1	5	1.079	34.432	0.045	24.778	1	
0	6	16.932	14.082	63.813	335.086	1	
0	7	0.19	0	0	284.821	1	
0	8	0.603	8.217	102.863	9.376	1	
0	9	6.785	37.413	23.691	250.947	1	
P2	10	7.196	36.101	16.975	1.058	33.57533 72.74926	
0	11	13.265	17.017	9.824	35.45	1	
0	12	1.013	12.538	35.219	455.9	1	
0	13	5.975	4.819	13.223	63.143	1	
0	14	16.641	23.45	27.376	340.691	1	
P3	15	11.962	215.976	87.639	310.295	1	
0	16	60.42	26.977	0.876	43.457	33.5905 72.74898	
0	17	0.003	9.992	64.942	71.474	1	
0	1	2.14	63.154	113.463	546.836	1	

0	2	6.964	26.789	32.981	259.625	1	
P4	3	64.811	29.324	30.539	433.407	1	
0	4	14.629	1.304	96.98	47.194	33.59725 72.74958	
0	5	11.918	8.214	75.042	60.739	1	
0	6	16.205	2.021	2.21	607.418	1	
0	7	20.116	58.479	31.705	290.077	1	
P5	8	3.794	37.206	125.938	17.787	1	

4.27.1 Results of ADMT S-300 Profiles

The images of suitable VLF results and interpreted 2D Profiles

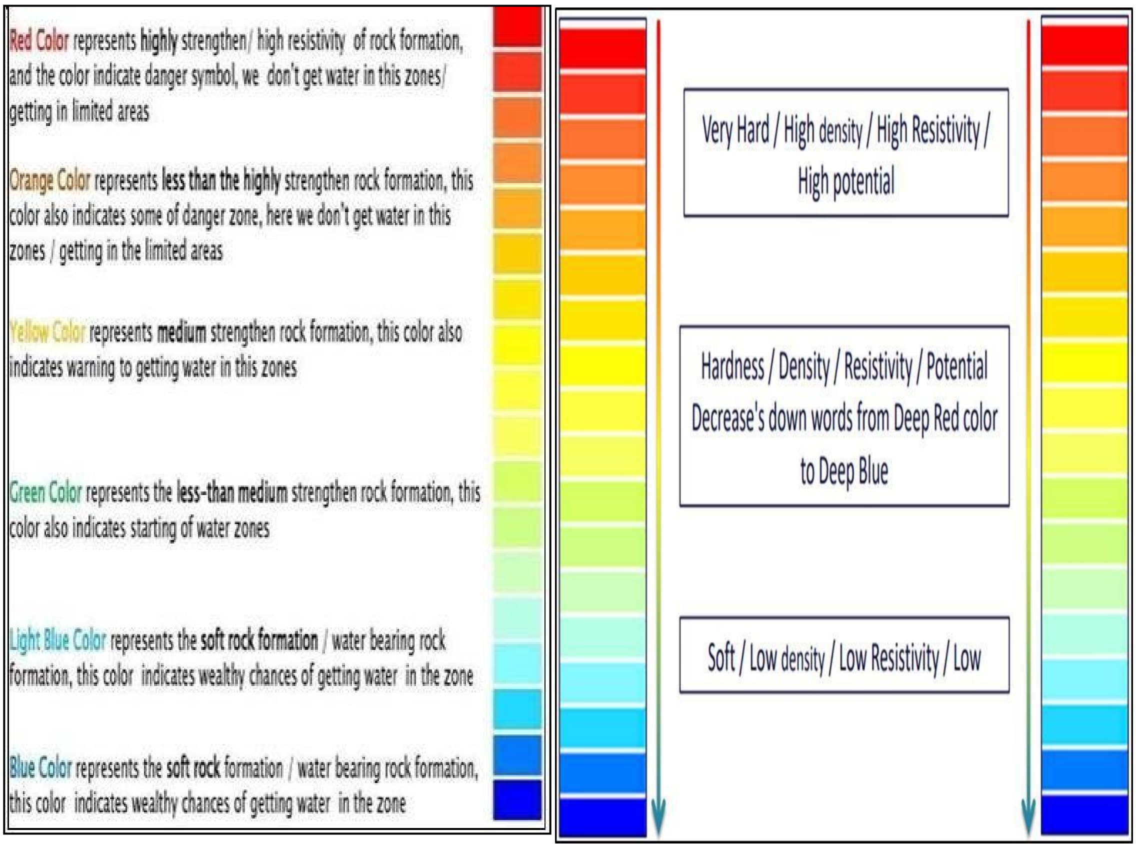

Figure 4.28: Showing the data of ADMT S-300

CHAPTER 5

CONCLUSIONS

According to our study, it is concluded that potential groundwater zone in the study area exists at the depth greater than 36m and the lithology in this zone is sandstone with limestone and clay.

From Longitudinal Conductance it is concluded that aquifer is excellently

Geophysical survey using electrical resistivity soundings were carried out in the acquired land of Life Residencia, near Islamabad International Airport, Islamabadfor groundwater study. On the basis of the results of resistivity survey, it is concludedthat this at a regular interval of depth. However, limited quantity of groundwater in between 1,000 to 2,000 gallon per hour is expected to encounter in the deeper aquifers150 m depth.

- The study of Electrical Resistivity Survey shows that groundwater aquifers exist an alluvial deposits in study area.
- The subsurface materials consist in shallow very low resistivity materials representing fine materials like, largely clay. These sediments are not favorablefor groundwater exploitation, due to their very low permeability.
- The low resistivity values encountered at different sounding locations at different depths with variable thickness, this zone represented by resistivity values 20.4-24.3 Ω-meters representing gravels and sand embedded with clay,showing low yield of groundwater up to the explored depth of 150m, round about 1,000 to 2,000 GPH. The porosity and drainage capacity (permeability) of the aquifer seems is fair, which can drain low yield of groundwater for installation of tube well. Therefore the zone under reference explored for further exploration of groundwater through test drilling up to the depth of 110mto 150m.

- Electrical resistivity sites ERS2, ERS5, ERS6 and ERS10 appear to be have been composed of gravel and sand and sandstone aquifers and fall in the first priority (good category) in terms of groundwater accumulation and transmission. On the basis of results, aquifer thickness and its yielding capability, these sites have been delineated to make further investigation by testboring, water samplings and chemical analysis at a regular interval of depth. However, limited quantity of groundwater in between 1,000 to 2,000 gallon perhour is expected to encounter in the deeper aquifers 150 m depth.
- Potential and the discharging capability of the aquifers are not significant thereby tube-well would produce tentatively yield between 1000 ~ 2000 gallonper hour. Further confirmation should be made by test drilling and compressortesting at the recommended site.

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APPENDIX

Rho(ρ)							
VES-1	VES-2	VES-3	VES-4	VES-5	VES-6	VES-7	VES-8
49.42	32.47	31.43	23.70	16.32	21.61	20.49	17.33
67.57	23.41	31.13	15.64	67.34	37.18	22.30	28.30
6.31	7.73	7.19	5.05	105.11	137.02	17.11	27.58
51.73	22.37	27.45	11180.01	11.24	17.99	6.26	5.80
6.73	18.76	30.27		217.09	5.91	61.80	45.36
17.65	51.39	1457.00		6.54	116.39		
18.03				391.42	3.55		
121.39				12.32	387.85		
21.23				115.70	21.80		

VES name	Latitude	Longitude	Transverse Resistance(T_r)
VES-1	33.706	72.952	5962.50
VES-2	33.6645	73.0881	5830.31
VES-3	33.6408	73.1123	55427.88147
VES-4	33.5357	73.1146	1433237.79
VES-5	33.5912	72.8636	16076.10
VES-6	33.5912	72.8636	1157.33
VES-7	33.579	72.8698	8719.34
VES-8	33.7294	73.0779	6418.55

VES names	Latitude	Longitude	Longitudinal Conductance(S)
VES-1	33.706	72.952	4.67
VES-2	33.6645	73.0881	6.01
VES-3	33.6408	73.1123	4.01
VES-4	33.5357	73.1146	0.10
VES-5	33.5912	72.8636	2.97
VES-6	33.5912	72.8636	6.63
VES-7	33.579	72.8698	2.18
VES-8	33.7294	73.0779	3.08

VES names	Latitude	Longitude	Isotropy(λ)
VES-1	33.706	72.952	1.37
VES-2	33.6645	73.0881	1.09
VES-3	33.6408	73.1123	2.85
VES-4	33.5357	73.1146	0.74
VES-5	33.5912	72.8636	1.37
VES-6	33.5912	72.8636	1.59
VES-7	33.579	72.8698	1.03
VES-8	33.7294	73.0779	1.12

VES names	Latitude	Longitude	Longitudinal Conductance(S)
VES-1	33.706	72.952	6.37
VES-2	33.6645	73.0881	5.67
VES-3	33.6408	73.1123	5.17
VES-4	33.5357	73.1146	4.12
VES-5	33.5912	72.8636	3.63
VES-6	33.5912	72.8636	8.97
VES-7	33.579	72.8698	4.37
VES-8	33.7294	73.0779	4.96

VES names	**Latitude**	**Longitude**	**Isotropy(λ)**
VES-1	33.706	72.952	1.10
VES-2	33.6645	73.0881	2.09
VES-3	33.6408	73.1123	3.54
VES-4	33.5357	73.1146	13.65
VES-5	33.5912	72.8636	1.89
VES-6	33.5912	72.8636	1.95
VES-7	33.579	72.8698	1.27
VES-8	33.7294	73.0779	1.09

VES name	**Latitude**	**Longitude**	**Transverse Resistance(T_r)**
VES-1	33.706	72.952	5263.82
VES-2	33.6645	73.0881	5717.13
VES-3	33.6408	73.1123	55163.13
VES-4	33.5357	73.1146	1432768.23
VES-5	33.5912	72.8636	14943.12
VES-6	33.5912	72.8636	10826.71
VES-7	33.579	72.8698	8327.64
VES-8	33.7294	73.0779	6071.36

VES	Rho(ρ)	Thickness (h)	Depth (m)	(h*p)	T.R (T.r)	L.C(Sc)	H	Average T.R	Average L.R	Isotropy	
VES-01	18.03	23.56	59.63	423.89	5265.79	4.6	126.65	42.56	26.45	1.37	1.1
	121.39	23.86	84.56	3056.65							
	21.23	78.56		1767.54							
VES-02	22.37	31.65	40.21	721.56	5703.65	5.17	165.78	36.12	29.23	1.09	2.09
	18.76	32.12	71.89	598.65							

	51.39	67.89		4392.21							
VES-03	27.45	54.65	67.45	1548.23	55182.65	3.75	145.78	375.12	36.89	2.85	3.54
	30.27	54.32	121.47	1623.89							
	1457	36.45		51961.23							
VES-04	11180.01	127.16	124.85	1432865.32	1432865.65	0.11	126.45	11179.56	12820.01	0.74	13.65
VES-05	12.32	22.63	33.98	269.23	14956.32	3.21	147.85	101.21	45.23	1.37	1.89
	115.7	123.23		14656.56							

VES-06	387.85	22.23	41.01	8393.79	10831.85	5.75	137.56	77.12	23.23	1.59	1.95
	21.8	115.56		2431.56							
VES-07	61.8	132.56	132.56	8331.56	8331.56	2.09	131.56	61.52	61.23	1.03	1.27
VES-08	45.36	136.78	136.78	6071.45	6071.45	3.11	135.23	43.56	43.65	1.12	1.09