GROUNDWATER DETECTION USING ELECTRICAL RESISTIVITY TECHNIQUE IN FORT ABBAS, DISTRICT BHAWALNAGAR, PUNJAB, PAKISTAN

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A thesis submitted to Bahria University Islamabad, in partial fulfillment of the requirement for the degree of BS in Geophysics

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ABSTRACT

A total of 03 observation points were done in the Fort Abbas, District Bahawalnagar, Punjab. The details of field survey conducted, methodology, analysis of the data collected, results and recommendations are presented in this dissertation. Survey is conducted for detection of groundwater using electrical resistivity technique. Survey was conducted by using four electrodes, stiffly mounted in the ground for measuring of potential drop between two of the electrodes (potential electrodes). Values of resistivity obtained is apparent resistivity which later gives us true resistivity values. At the end resistivity values are plotted on map through computer software IPI2Win, to generate a resistivity curve that helps us in interpretation of subsurface strata. Lithological columns were also made in practice to get knowledge about what is the picture of subsurface lithology and where did fresh water and saline water encountered. Fresh water zones were selected at the end and then we proposed which site is most suitable for tube well installation.

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Dedication

To "Parents and Teachers"

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CHAPTER 1
INTRODUCTION

1.1 Introduction

The project area lies in District Bahawalnagar. Punjab province of Pakistan. It is located 364 km to the southwest of Lahore. The district is divided into five tehsils, namely Bahawalnagar, Chishtian, Fort Abbas, Haroonabad and Minchinabad. Total approximately population of district is 2,561,447 and annual growth rate is 2.8%. It is spread over an area of 8,878 square kilometres. Bhawalnagar is bordered by India to its south and east. The main crops are sugarcane, cotton, wheat, rice, tobacco and mustard seed. There are 24,195 acres of forest.

In order to assess the potential for ground water investigation and availability in term of quality and quantity within the area acquired. Electrical resistivity survey was proposed. Most of the project area is covered with very fertile soil.

Water is always the vital component of earth. As time goes by, water demand by public or agriculture sector is getting more and more. When we talk about water, water itself is found in different settings in different states. Water which is important privately and economically is groundwater. Groundwater is the water stored within rock layers. Rock body or rock layer which can yield sufficient amount of water for longer period of time is called aquifer and they get recharged by various hydrological processes like percolation of rain water, surface water (rivers, streams) and glacial water. Important discussions within the arena of groundwater are the questions about how to locate them? How to identify water quality, whether it is suitable of drinking purpose or not? Is it the fresh water or brackish water? Geophysics plays important role in answering these question adequately and accurately. Various geophysical techniques are known to be significant which are used to identify and locate shallow water bodies. Geophysical exploration techniques play major part in identifying shallow water bodies and groundwater (Rubin and Hubbard, 2006). Geophysical techniques are important in delineating subsurface features, subsurface resistivity conditions in locating aquifers and classifying aquifer parameters and in selecting appropriate sites for water wells for exploitation and usage of groundwater.

The technical objectives of the survey were to ascertain the sub-surface resistivity conditions, the nature of sub-surface material to select prospective location for the designing of earthing and the groundwater quality and the nature of sub-surface material distribution to select prospective locations for the development of potable groundwater through installation of tube well in the area acquired. In this regard, 03 vertical electrical soundings (VES) were conducted. ERS was conducted on three points of 150m estimated depth for ground water investigation which was done by deploying Schlumberger electrode configuration.

In-addition to the findings of the resistivity survey, a brief account of field operations and data processing has also been given to provide the basis of the method. It includes the interpretation of VES data presented in the form of columnar section, depicting subsurface hydrogeological conditions. Based on the interpretation of the resistivity data the sub-surface material has been classified into different resistivity zones as abridged in the legend, each resistivity zone signifies typical hydrogeological conditions. The sub-surface columnar section drawn for sounding point shows the interpreted picture of the sub-surface groundwater conditions in the area investigated.

1.2 Location

Project area lies in the Bhawalnagar district. It is surrounded by Pakpattan in the north, Vehari in the west and east and south touches the Indian Territory and River Sutlej is on the northern side. District spreads over an area of 8878 sq.km. It lies between longitude 73°15′ East, latitude 29°57′ North, with an elevation of 163m (535ft) above sea level. District is connected through proper road link N-5/AH2.

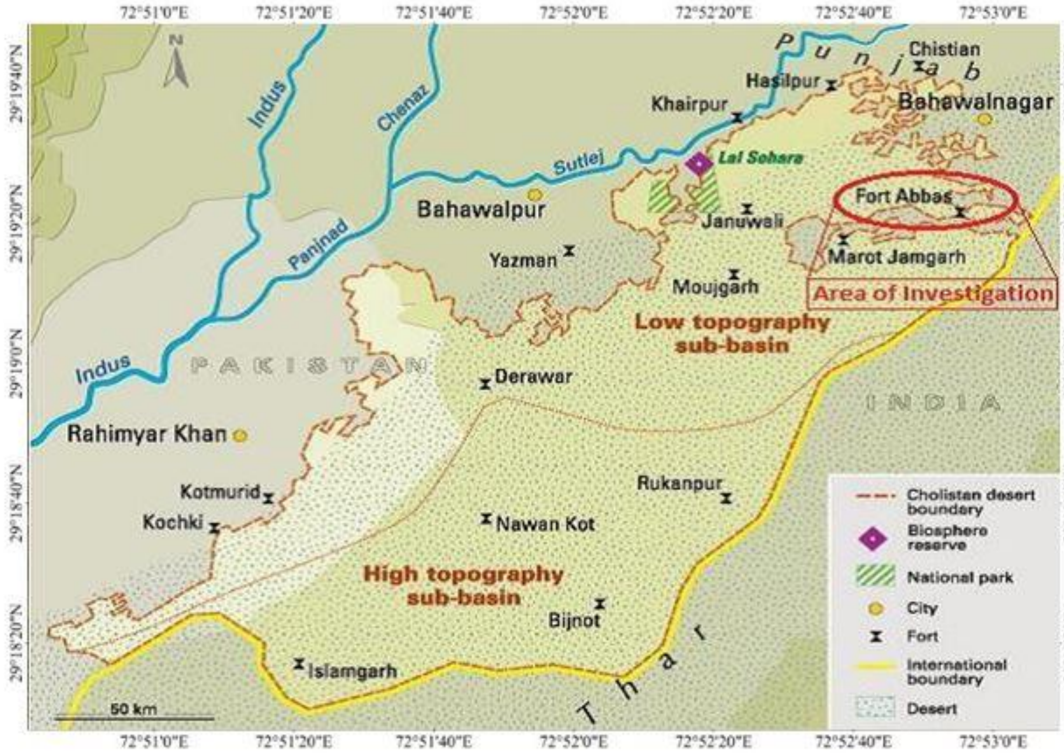


Figure 1.1. Location map of Fort Abbas. (WWDR3, 2009)

1.3 Climate

The climate of Bahawalnagar district has a very hot and very dry climate in summer, with a maximum temperature reaching above 45°C. Bahawalnagar's climate is a desert one. There is virtually no rainfall during the year. According to Köppen and Geiger, this climate is classified as BWh. The climate in winter is very dry and cold. The hottest month is June, where average highs routinely exceed 50 °C (122.6 °F). The coolest month is January, with temperatures variable by location. The minimum temperature recorded was below 11°C. Wind and storms are uncommon during the summer. The average annual rainfall is just below 99 mm. The average low is 6°C (40.6 °F) in January, while the average high is 50 °C (122.6 °F) in June. The highest temperature recorded was 52 °C (122.6 °F) in June, in every season, days are hot but nights are very cold due to plain areas and cool wind breeze from Cholistan desert.

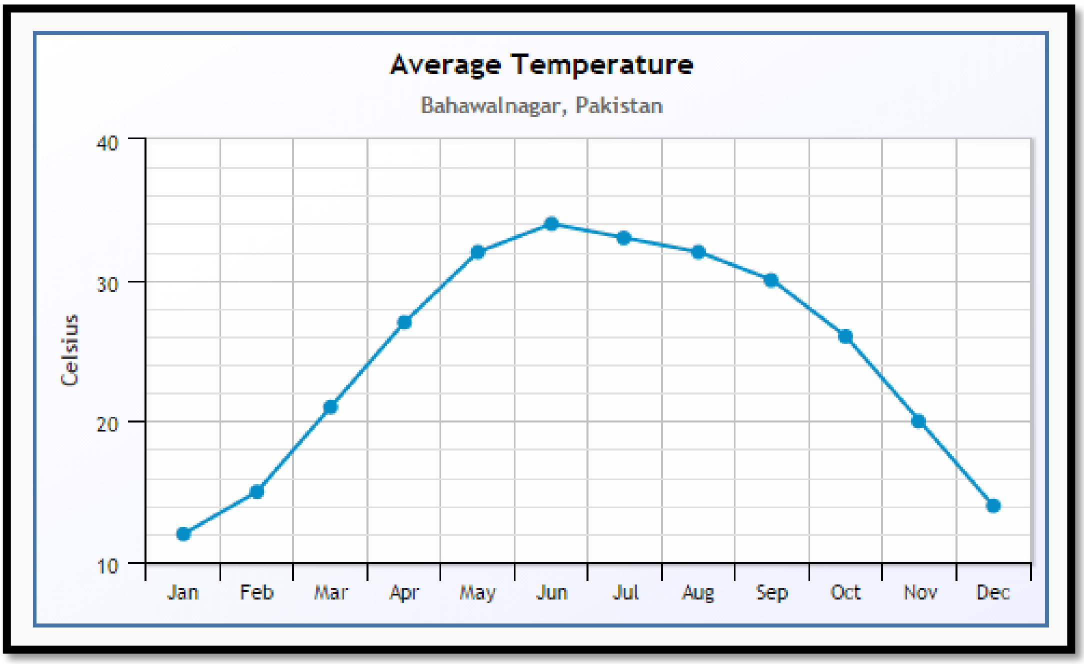


Figure 1.2. Yearly average temperature of Bahawalnagar. (Weatherbase, Bhawalnagar)

1.4 Water sources

Bhawalnagar district having less annual rainfall doesn't have much of its own water resources hence; the main source of water is by the Sutlej River. The district is divided into two parts: the rive rain area and the canal irrigated plain.

(i) The rive rain area lies close to the Sutlej river which flows in the northwest along its border with Okara, Pakpattan, Sahiwal and Vehari districts. The land in this area is irrigated by non-perennial canals. During the summer monsoons, it is generally inundated by the river water.

(ii) The canal irrigated area is a plain which has been brought under cultivation by the canals. The main canal which is Sadqia canal irrigates almost all the tehsils except Chishtian. This canal travels in round with the border of Pakistan and India.

1.5 Significance of electrical resistivity survey

There are numerous geophysical exploration techniques but among all of them we will discuss electrical resistivity technique. Electrical resistivity method is widely accepted for detecting and delineating groundwater potential zones, aquifers and also helpful in identifying fresh water zones as well as salt water zones (Anderson & Woessner, 2007). Electrical resistivity method is also used in identifying shallow subsurface lithological systems (Burger, 1992). Main concept behind electrical resistivity technique is to find resistivity of different subsurface layers and then interpreting possible resistivity contrast between targets area and surrounding area. Greater the contrast, much better the geophysical interpretation will be carried out for the best results (Zohdy et al, 1974). Electrical resistivity techniques also has its importance in the various fields because subsurface information can be carried out easily and considerably without any disturbance to soil layers and without any tool working hesitations (Samouelian et al, 2005). In this widely accepted technique current is transferred into the subsurface without any digging and current distributes itself according to the conductivity of geological materials present within that targeted zone. Electrical resistivity method is less expensive and very easily accessible and without any drilling into ground one can obtain results of the subsurface target, aiding us to know about the groundwater location and condition and also gives the best sites to drill water wells for maximum yield and maximum economic benefits. (Alile et al, 2008). This technique can be used from local level to regional level and we can utilize it for 1, 2 or 3 dimension and that choice depends upon the anomaly or heterogeneity that exits within specific targeted zone (Samouelian et al, 2005).

1.6 Principles of resistivity method

Among the various geophysical methods of subsurface exploration, electrical resistivity method has been successfully employed for finding Resistivity values of different layers in the sub-surface. Thickness and lateral extent of layers and groundwater investigations, particularly where electrical resistivity contrast exists between the water bearing formation and surrounding soils or rock.

Considering the variable electrical properties of the subsoil, the technique of electrical resistivity survey makes use of measuring the current and potential differences of various subsoil materials at the surface. In general, current is conducted electrolytic ally in the soils containing interstitial fluids. The resistivity is controlled by porosity, water content, as well as the quantity of dissolved salts. Clay minerals, however, are capable of storing electrical charges and current conduction in clay minerals is electronic as well as electrolytic. Thus the resistivity of soils depends directly on the amount of contained electrolyte and clay minerals and is inversely related to the porosity and degree of saturation of the formation. Therefore, resistivity of soil varies considerably not only from formation to formation, but also within the same layer. In particular, the resistivity variations can be large in unconsolidated sediments. It has generally been observed that the resistivity increases progressively from fine grained to coarse grained material.

1.7 Reconnaissance survey

After the reconnaissance survey, that was done at study area increased the basic knowledge about the lithology that is present there. It also in finding out some information about the water table depth and condition of the water quality and quantity. Meetings with local residents and drillers who enlightened with the information of water wells (tube wells). As discussed earlier signs of water were found within range of 4m-17m. Some old water wells were observed (almost 15 to 20 years earlier) which were totally dried out for past few years. The difference in water table depth and drying of water wells developed our interest to choose this area and start research there and find all possible answers. This would help in gaining experience in near surface geophysics and will surely help locals of that area to drill new wells at different locations with specific defined water table depths for fresh water.

The use of specific geophysical technique was also a decision making break. There are numbers of surface geophysical techniques. Seismic technique is based on the propagation of acoustic energy (seismic energy) from any medium which is further related with elastic moduli and density of materials. In same way gravity method is related with density of the material with checks change in gravity due to different densities. Magnetic method is another important method for mineral prospecting but again its use in groundwater exploration is very less because it deals with magnetic properties and it is the least thing we care about while dealing with water. For many years electrical resistivity technique considered the most functioning and most significant for groundwater exploration as it deals with resistivity of material though which electric current is passed and here in our research our wholly and solely focus is on water and when we talk about conductivities and resistivity, they are best observed in case of water, therefore , electrical resistivity method is the best to use for attaining knowledge for water table depth, water conditions in geologic settings and salt intrusions.

1.8 Literature review

Reconnaissance survey was done before the actual electrical resistivity sounding. Different tube wells and hand pumps sites were visited which gives the general information about the water table depth and water quality in our zone of study. Thick alluvium deposits were experienced, which later changed to dominant sand bodies, local drillers tell about the water table at shallow depths and some at deeper depth irrespective of the water table thickness and water quality.

1.9 Objectives

The sole purpose of thesis work aims to find appropriate groundwater resources of the area. On the other hand, we also have other important objectives, further helping us for accurate and précised identification of aquifers.

Following are the objectives of our work:

(i) To determine subsurface lithological layers and their resistivity values of subsurface layers.

(ii) Delineation and demarcation of fresh water zone from salt water zones and their thickness.

(iii) Recommendation for best suitable site for drilling of water well for public use interest.

CHAPTER 2

GEOLOGY AND STRATIGRAPHY OF STUDY AREA

2.1 Introduction

The project area lies in the Central Indus Basin and is near the Indian border. There are no exposures for the consolidated rocks within this region. The study area comprises of the eolian deposits laid down by the winds. The Cholistan desert is the part of this area and it consist of mostly fine sands.

2.2 Tectonics of study area

Selected Fort Abbas area which is a part of Bhalwalnagar district, Punjab is located in between longitude 73°15′ East, latitude 29°57′ North, this area is a part of Middle Indus Basin located geographically on the central Pakistan. Tectonically it is bounded by Indian Shield in the east, in west it is bounded by marginal zone of Indian Plate and Sukkur Rift contributes as a southern boundary. The oldest rocks exposed in the basin are of Precambrian age. Tectonically middle or central Indus Basin is relatively stable. The basin is comprised of duplex structures characterized mostly by large anticlines and domes.

2.3 Geology of study area

Well drilled in Punjab platform area reveals most of the geology and adds information to our knowledge about the geology that encountered from basement till top. Over the basement, rocks of Paleozoic to Cenozoic are present. In the subsurface, Punjab Platform is formed but most of the marine Mesozoic, Paleozoic and Neogene sediments and Paleogene sediments overlain by Neogene fluvial deposits. The Punjab Platform zone is characterized by regional unconformities.

2.4 Regional stratigraphy of Middle Indus Basin

The Middle Indus Basin contains a sedimentary sequence ranging from Precambrian to recent the Punjab Platform contains several tectonic and sedimentary periods starting from the Infra-Cambrian Salt Range Formation adopted by the Cambrian clastic-carbonate-evaporite cycles. The Cambrian cycle is followed by Permian tillite-clastics-carbonate cycle after a long hiatus. A thick Mesozoic is also there. Finally, the siwalik molasses covers the complete sequence. The oldest unit in the sequence is salt range formation comprising of marl, clay-shale, sand-silt, dolomite, gypsum and salt (Kazmi and Jan, 1997).

2.5 Stratigraphy of Bhawalnagar

The stratigraphy of study area is established in the notes with the aid of Well drilled in the Bhawalnagar district, most of the stratigraphy was encountered during drilling of wells Marot -1 and Bahawalpur East -1 drilled by Shell to the southwest of Fort Abbas -1. The siwaliks were encountered at 420 m with a laterite zone marking the regionally spread molasses unconformity The Paleocene shale and the sand are characterized by a coaly zone towards the base, followed by condensed sequences of Cretaceous and Jurassic. After that the well encountered the Permian clastic sediments that contain abundant brachiopods shell pieces with Tobra conglomerates at its base around 607 m depth. The Cambrian succession contains Baghanwala, Jutana / kussak and the Khewra Formation, dominantly having sandstone, subordinate siltstone, claystone and dolomite with bottom at around 1400 m. The Salt Range Formation drilled has a thick white dolostone zone with few thin layers of anhydrite and some algal and coaly shale.

The stratigraphy established initially was based on Geophysical and other data collected from nearby wells across the border. But after final results concluded from flush cuttings and core, the scenario became different and the sequence established was totally different.

The generalized stratigraphy of the Punjab platform can be seen in figure 2.1.

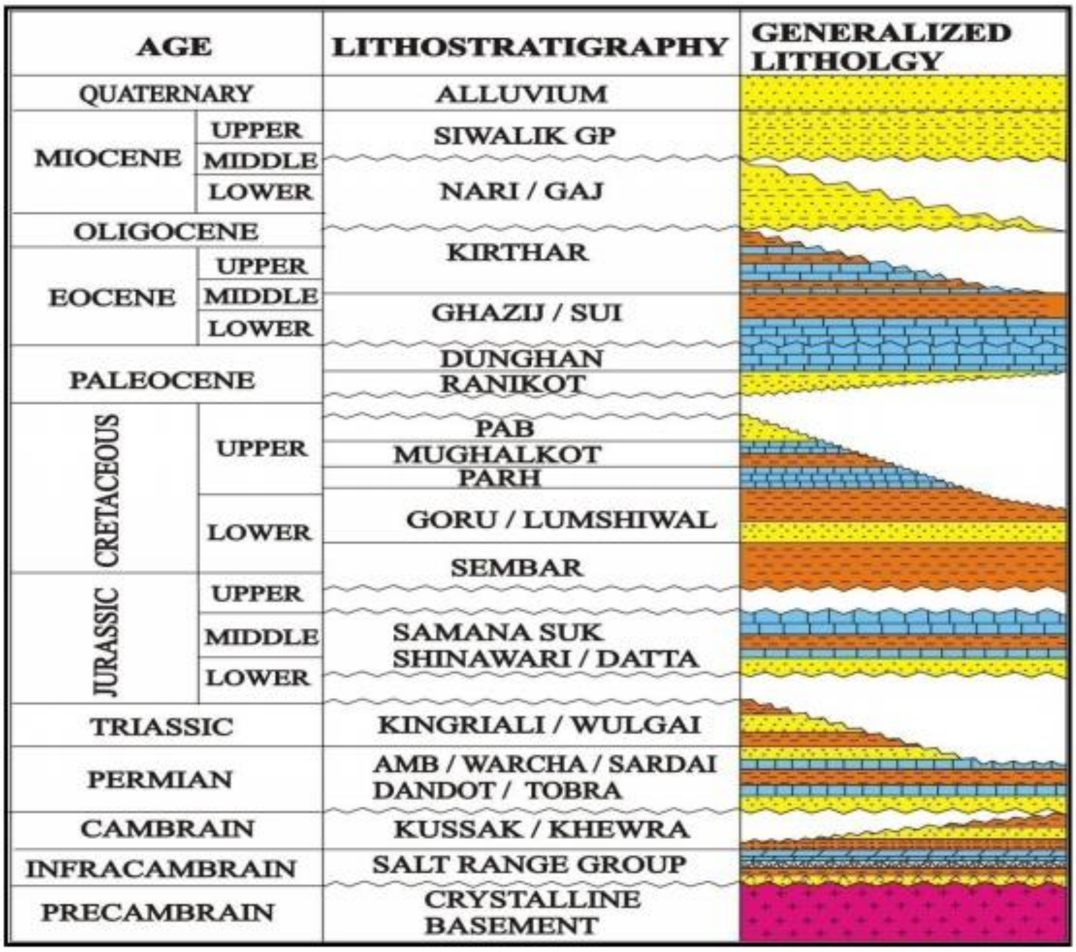


Figure 2.1. Generalized stratigraphy of Punjab Platform. (Khalid et al, 2014)

CHAPTER 3
METHODOLOGY

3.1 Survey locations

In order to obtain data three different locations were selected. Electrical and resistivity survey has been carried out at three specified locations, as shown schematically in figure 3.1.

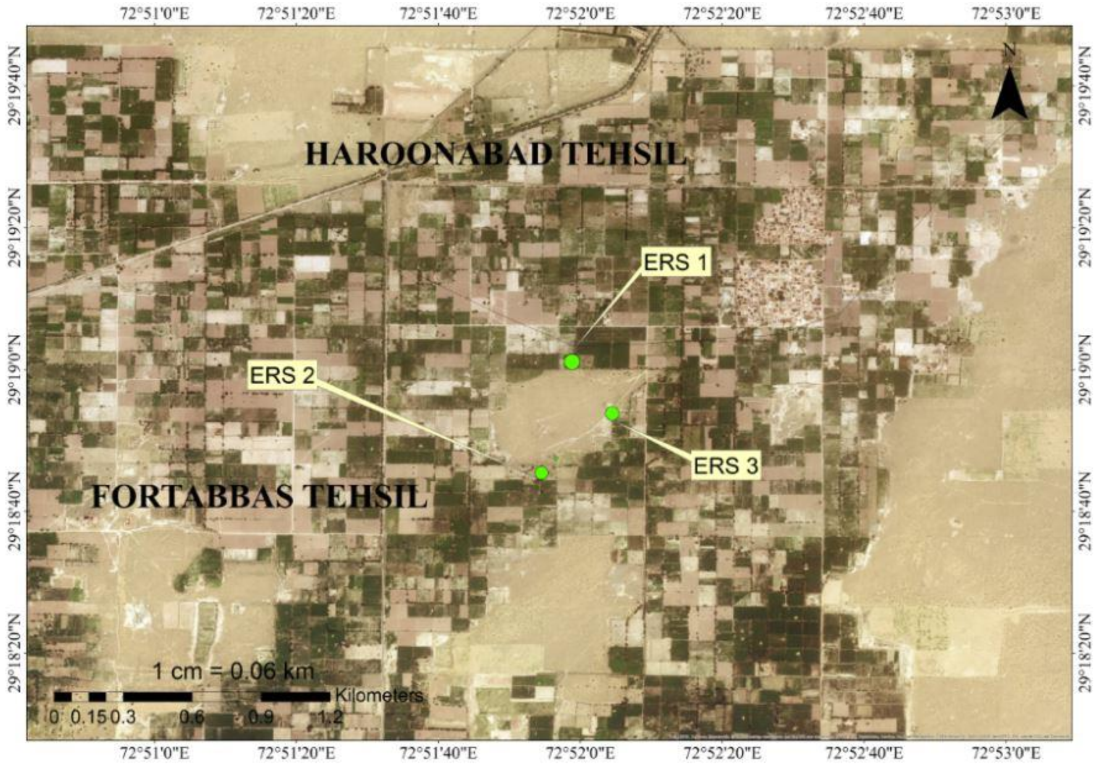


Figure 3.1. Survey locations of the concerned area.

Table 3.1. Geographical Coordinates of ERS points

ERS No.	Latitude	Longitude
1	29˚18′58.50″ N	72˚52′01.40″ E
2	29˚18′47.48″ N	72˚51′56.60″ E
3	29˚18′51.60″ N	72˚52′02.30″ E

3.2 Data acquisition

Schlumberger array was selected in the field where four-electrode array, two current and two potential (voltage) electrodes in specific geometric configurations were used, for data acquisition. A very low-frequency or direct current is applied to one of the current electrodes, and the current flows through the earth to the second current electrode, closing the circuit. The potential difference, or voltage, between the two potential electrodes is measured by the instrument, and resistance is determined using a very simplified version of Ohms Law.

Considering the variable electrical properties of the subsoil, the technique of electrical resistivity survey makes use of measuring the current and potential differences of various subsoil materials at the surface. In general, current is conducted electrolytically in the soils containing interstitial fluids. The resistivity is controlled by porosity, water content, as well as the quantity of dissolved salts. Clay minerals, however, are capable of storing electrical charges and current conduction in clay minerals is electronic as well as electrolytic. Thus the resistivity of soils depends directly on the amount of contained electrolyte and clay minerals and is inversely related to the porosity and degree of saturation of the formation. Therefore, resistivity of soil varies considerably not only from formation to formation, but also within the same layer. It has generally been observed that the resistivity increases progressively from fine grained to coarse grained material in the order of clay, silty clay, clayey silt, silt, sandy silt, silty sand, sand, gravel and boulder.

During the resistivity survey, commutated direct or very low frequency (less than 20 Hz) current is introduced into the ground through two current electrodes C1 and C2 inserted in the ground surface.

The potential electrodes P1 and P2 are inserted in the ground between the outer current electrodes C1 and C2 such that all the electrodes are aligned along the straight line and the potential difference is then measured between the two potential electrodes.

By measuring the current (I) flowing between the two current electrodes C1 and C2 and the associated potential difference (V) between the potential electrodes P1 and P2, the resistivity (R) is computed by the following well-known Ohm’s law;

$$R = K^* V/I \qquad (i)$$

Whereas;

K = Geometric factor of the electrode arrangement

V = Potential difference in mV

I = Current passing through ground in mA

In homogeneous subsurface conditions, the above relation gives the true resistivity of the subsurface material, but in anisotropic and inhomogeneous conditions, it represents weighted average resistivity of the formations through which the current passes. Since the subsoil is normally inhomogeneous and anisotropic, the resistivity value computed from the above equation is called apparent resistivity and is denoted by (Ra).

Therefore;

$$Ra = K^* V/I \qquad (ii)$$

The apparent resistivity values are obtained for various depths below the surface by expanding the current and potential electrodes from its center along a straight line, while spacing between the electrodes is maintained.

In case of Schlumberger electrode configuration, the geometric factor K is calculated as:

$$K = \pi x \frac{(AB/_2)^2 - (MN/_2)^2}{MN} \qquad (iii)$$

Equation is the general equation for calculating apparent resistivity in electrical resistivity prospecting. The apparent soil resistivity obtained in this case represents an average value of the soils within the sphere of influence of the test set up.

Schlumberger electrode configuration is commonly used for groundwater prospecting. In this configuration, distance between the current electrodes is very large compared with the distance between the potential electrodes. In this configuration, lateral in homogeneities are easily identified. Moreover, Schlumberger configuration requires lesser electrode spacing at the surface to achieve the required depth of investigation as compared with other configurations.

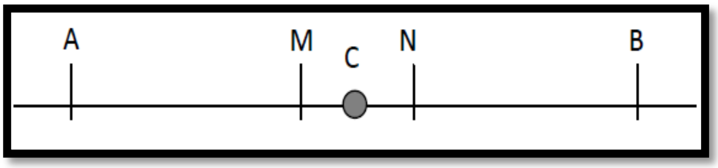


Figure3.2. Schlumberger array. (Parasnis, 1972)

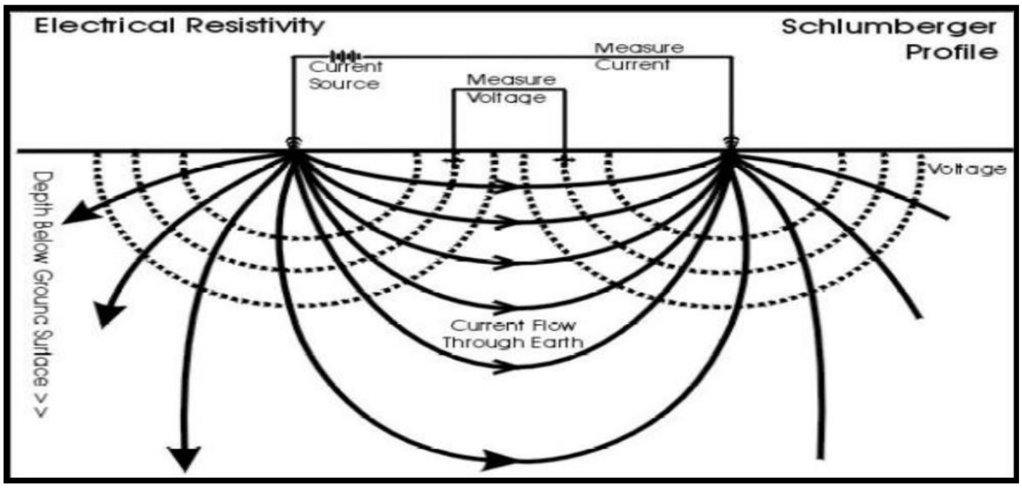


Figure3.3. Current and voltage flow diagram. (Mwangi, 1982)

Following are the technical requirements for carrying out the resistivity survey:

(i) Electrical resistivity contrast should exist between the formations under study.

(ii) While carrying out the electrical resistivity survey using Schlumberger configuration, about two times the space along a straight line is required to achieve the estimated depth of investigation.

(iii) Resistivity values of the alluvial strata and bedrock in an area could be established if the subsurface lithology through at least one test hole or tube well is known in or around the area having similar geological conditions.

(iv) If the soil consists of thin alternate layers, the resistivity obtained at the surface would be the average effect of these alternate layers.

3.3 Resistivity instruments

To measure the resistivity below surface of ground, Schlumberger array and a special instrument must be used. Signal averaging resistivity-measuring equipment (SAS 1000) is used for measuring current and potential values in the field. In the case of the Schlumberger array the electrodes are placed in a straight line symmetrically about the center point. The two outer electrodes A and B are used for the current and the resulting potential difference is measured across the two inner electrodes M and N. The distance of the current and potential electrodes from the center, which are referred to AB/2 and MN/2 respectively, characterizes the array. MN/2 is always kept sufficiently small relative to AB/2. The average potential gradient measured between M and N is a close approximation to the potential gradient at the center of the array.

The ground is energized through the outer A and B electrodes under high D.C voltage and constant current is made to flow through the ground with the help of "Power Pack" provided with the measuring equipment. The constant selected current I (in milli amperes) passing through the two current electrodes and resulting potential difference V (in milli/micro volts) between the two potential electrodes is processed by the equipment and the resistance is displayed for the corresponding reading.

The distance between the two potential electrodes is smaller than the distance between both potential electrode and its adjacent current electrode. Measurements are taken and noted before re-positioning the electrodes. The midpoint of the electrodes is fixed at the sounding location, while the length of the configuration is gradually increased accordingly in order to measure the resistivity at given depth level. At each location, in one sounding, apparent resistivity values are obtained at different specific depths.

3.4 Resistivity methods

Most methods can be divided into either "soundings" or "profiles". Soundings are sometimes referred to as ERS; Vertical Electrical Sounding. Profile methods can be simple or more complex, such as the dipole-dipole technique, which can provide both profiling and sounding information. Profiling is done when lateral data is target, for which whole profile is moved to next point and every electrodes have to move to next position. It is more time consuming and cannot help more in groundwater detection. For groundwater detection sounding is more feasible and accurate.

3.4.1 Vertical soundings

In vertical soundings, a series of field observations are taken, each successive observation has the electrodes at greater separation. The center of each observation remains the same. With the separation small, the apparent earth resistivity of the shallow earth is determined. With the separation greater, the apparent earth resistivity of the shallow (nearer) and intermediate depth is determined. The resistivity of the intermediate earth can be determined by correcting for the already determined shallow earth resistivity. The electrode separation continues to be increased and the apparent earth resistivity of greater and greater depth is determined.

The two most common methods of electrical soundings are:

(i) The Wenner method

(ii) The Schlumberger method

3.4.2 Schlumberger soundings

This method saves the moving of potential electrodes every time the current electrodes are moved. The electrodes are in a straight line and like the Wenner array, the outer electrodes are the current electrodes and the inner electrodes are the potential electrodes. The potential electrodes, usually designated M and N, should never be separated by more than one-fifth the separation between the current electrodes. The current electrodes are usually designated A and B.

Apparent resistivity is given by the following formula where p is 3.14, AB is the distance between the current electrodes, MN is the distance between the potential electrodes and R is the resistance read on the MiniRes. MN can also be designated a and the distance between a current electrode and the nearest potential electrode designated as na.

$$Ra = p\ R\ (AB)\ (AB)/4(MN) = p\ R\ a\ n\ (n+1) \text{ ----------- (ii)}$$

The Schlumberger array has an advantage over the Wenner array. The potential electrodes are moved less often and therefore there is less fieldwork in collecting the data for a sounding. Despite this timesaving, there are great advantages to the Wenner sounding technique. First, the Wenner array gives the highest signal-tonoise ratio. Second, if there is an inhomogeneity in the vicinity of the inner (potential) electrodes, a whole segment of the apparent resistivity curve will have an erroneous offset. With the Wenner method, there would be only one data point having an erroneous offset. If there are numerous surficial in homogeneities, the Wenner method would show the interpreter this important feature of the survey and the smoothed curve fitted through the Wenner data will reflect a truer value for the subsurface. Figure3.4 shows the Schlumberger configuration, C1 and C2 are current and P1 and P2 are potential electrodes.

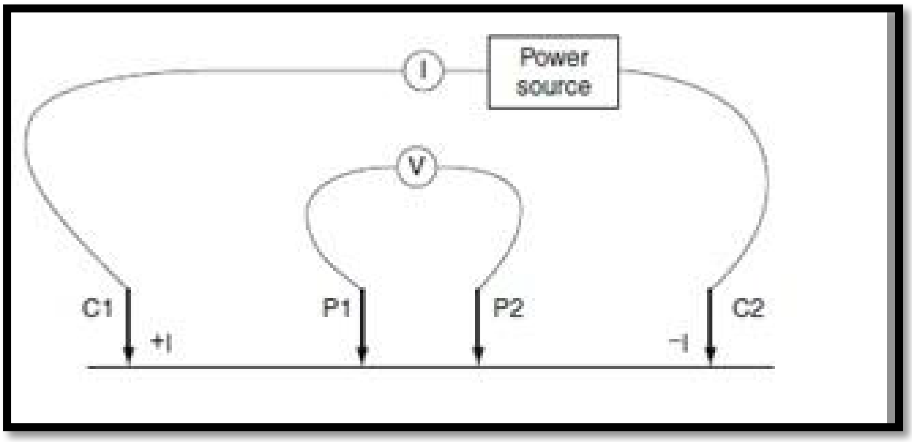


Figure 3.4. Schlumberger configuration of current and potential electrodes. (Koefoed, 1979)

CHAPTER 4
INTERPRETATION OF ELETRICAL RESISITIVITY DATA

4.1 Interpretation of VES data

The interpretation of the measured resistivity leads to the yield of electrical layers of the sub-surface. Such electrical layers are required to be strongly correlated with the geological conditions of the sub-surface. The primary information (test holes) as well as secondary.

In order to interpret the resistivity data, a certain technique is used which is referred to as computer aided iteration technique. The value of apparent resistivity is plotted against the depth in order to generate the curves. In this regard, layer parameters' values are guessed on the trial basis and are compared with the curve of computed apparent resistivity while adjusting it for making the field as well as computed curves to comply with. The guidance of semi quantitative comparison with the curves of two, three and four layers leads to extremely speedy process. Many of the mercenary firms dealing in software have formulated computer programs which are used in such method of obtaining the parameters of the layers by iteration in and robotic way while initiating with the initial estimates gained by the approximate method. In order to interpretation and run the process, one dimensional software of resistivity interpretation is used, referred to as IP12Win which has been developed by Interpex USA.

4.2 Curve Matching

Master curves are the curves which are thought of as theoretical curves. The field cures are compared with such curves in order to interpret the data. The set of supplementary curves is also necessary to be used with the Master curves while interpreting the data. Such supplementary curves are composed of either two or three layers. The software IPI2Win is used to match the curves. Besides, this software is also used by the Pakistan Council of Research in Water Resources (PCRWR) for the interpretation of the data pertaining to resistivity.

In subsurface where three or more strata of distinct resistivity are present there VES master curves used are dependent on the layers of lithology in sub surface. Type of VES resistivity curves are shown in figure below.

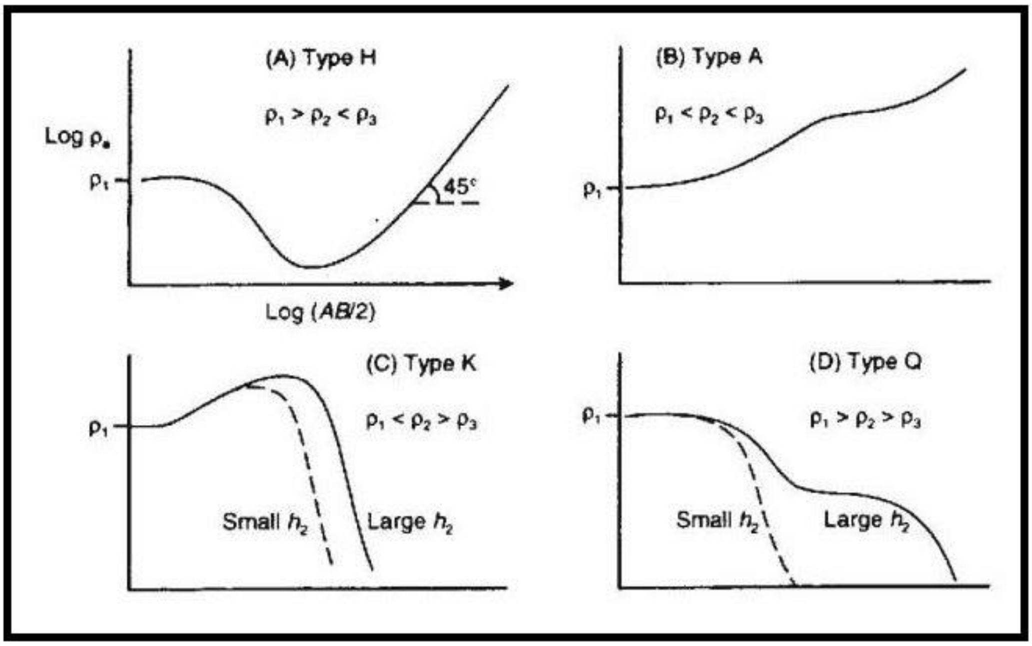


Figure 4.1. H, K, A & Q type VES resistivity curves for three layer sub surface lithology. (UKM, Rahim.)

4.3 Partial curve matching

Such process in which the curves of field are compared with the Master curves is thought of as Partial Curve Matching. The interpretation of Partial Curve Matching relies on the curve's shape which in turn also relies on the various layers individually. The earth models with the composition of three layers usually have four kinds of resistivity curves which rely on the resistivity's relative magnitudes (Oghenekohwo, 2008).

As a result of interpretation, values pertaining to the resistivity as well as thickness are observed which reveals the type of rock present beneath the earth. Therefore, subsurface models can be made.

4.4 Usage of master curve

The interpretation of field curve is done by plotting it on a transparent paper of logarithm similar to the modules of the master curve. After it, field curve shifts over the master curve whereas the coordinate axes are kept parallel, till an appropriate match is gained with interpolated curve or a master curve.

4.5 Interpretation of electrical resistivity sounding (ERS) data

Data obtained as a result of the vertical electrical sounding as well as constant separation traversing techniques are interpreted through different methods. In both of these methods, resistance the apparent resistivity is computed with the help of resistivity which rely on the employed configuration. Typically, data reveals the distances of different potential as well as current electrode, resistance and apparent resistivity for different stations. The interpretation of the measured resistivity yields geological conditions of subsurface.

4.6 Method of evaluation

If the values of the apparent resistivity are plotted against the depths on the graph paper of bi-log, the curves are formed. These curves are thought of as resistivity field curves. Once the curves plotted are smoothed, the complete data of the field are then registered to the computer. The sounds are interpreted through computer as well as software of direct interpretation. The interpretation of the sounding data of resistivity, collected from the region is done through techniques with the help of computers by using INTERPEX USA software, IPI2Win. The calculation of the layer models is done through an iterative approach. The adjustment of parameters of the model and the checking of deviation of the corresponding curve from the standard or measured curve is done while each interpretation. The RMSE (root mean square error), defines the deviation which is revealed after every iteration. Eventually, after calculations, the model has been plotted; resulting in a smallest error, reveals the corresponding thickness as well as true resistivity of the layers.

Practically, the resistivity sounding interpretation is always based on the equivalence principle. According to such principle any resistivity sounding can be compared with different model curves which slightly deviate, which represent different stratifications of sub-surface resistivity while relying on the behavior of the groundwater of that area. In this regard, data's interpreter faces a lot of alternatives solely for a field curve in order to select the most appropriate model of the conditions of strata below the earth surface.

4.7 Limitations

There are number of constraints of such method i.e. it is source of measuring the apparent resistivity instead of true resistivity of the formations of strata and greater in-depth change in resistivity leads to minor effects on the apparent resistivity comparatively other shallow depths. Hence, such method is usually effective in order to determine actual resistivity of deep few hundreds of feet. The real resistivity can be gained solely from similar and isotropic medium. Despite of this, these conditions cannot be possible to exist in the nature under the earth. In this regard, the worth of resistivity of a kind of rock is impossible to be same at various types of locations. It reveals that that there occur variations in the resistivity at different locations because of the environment changes, variations in lithology and changes in temperature etc.

Groundwater is a good conductor of electricity because it is ionic in nature and contains also dissolved solutes of salts. Therefore, it allows electric currents to pass through the earth. In this regard, the measurement of the resistivity of ground and surface gives the probability for the identification of the conditions, important for the presence of water or any other thing apart from water. Generally, the resistivity of the rocks generally relies on the resistivity as well as the porous content of water, the content of the clay and the content of the minerals which are metallic in nature. Following are considerations which are sources of determining the resistivity of the rocks:

(i) A nonporous hard rock or hard rock without any fracture like fresh Precambrian rock resists the flow of electricity.

(ii) Waterless sand or dry sand also shows resistivity.

(iii) Porous or fractured rocks which carry stagnant water are also resistive in nature, relying on the resistivity of water and porous nature of the rock.

(iv) A wet and impermeable layer of the clay layer reveals minor amount of resistivity and is usually unable to yield enough for the successful exploitation of groundwater.

(v) The wet and permeable layers of sand show medium resistivity despite containing quite enough fresh water for the successful exploitation of the groundwater.

(vi) Iron sulphides (mineral ore bodies) reveal extremely minor resistivity (usually 1 or less than 1 ohm-m) because of their electronically conductive nature.

4.8 Results

After completion of research work, different subsurface layers information were gathered. Resistivity of layers, lithological characteristics as well as hydrogeological characteristics, all was studied and results were depicted to the most approximate level. The results of resistivity survey obtained are at three observation points and are explained through graphs and figures. The results of the resistivity survey are also depicted in the form of interpreted curves through computer aided software program namely IPI2Win.

Graph is formed by using values that were obtained during field (observation data). Resistivity values of the layers encountered during first observation point were given in tabular form in “Appendix 1”. The curve is not the real curve as the real curve is considered only if Earth is Heterogeneous and Standard curves that aid in creating resistivity curves are also applicable if and only we considered Earth as a Homogeneous material. Therefore, Resistivity Curve must be corrected with precision for précised matching with standard curve.

For all three ERS points Resistivity curves were formed showing different layers encountered as well as thickness of layers. Curves are shown below through diagrammatic representation.

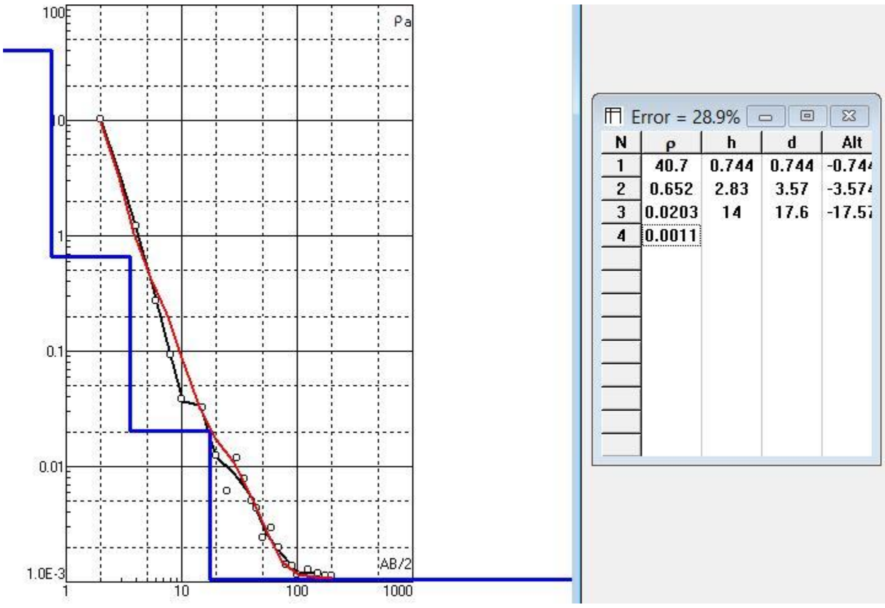


Figure 4.2. Actual resistivity curve (Q-type) of field data for ERS point#1. Thickness and depth are given in meters. Y-Axis: Apparent resistivity (ohm-m) X-Axis: Spacing (m). Red: Master curve. Black: Actual curve. Blue: Layers encountered.

Resistivity curve formed by the values obtained during survey does not match any master curve. Hence interpolation of different points is required which is done manually by software by rearranging the points and the curve closest to master curve is formed, shown below.

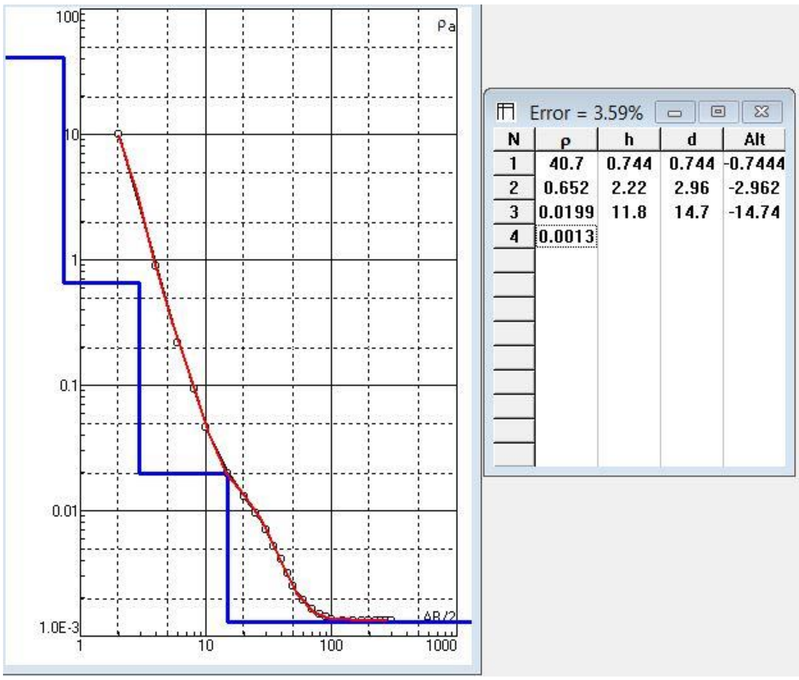


Figure 4.3. Interpolated Q-type resistivity curve for ERS point #1. Thickness and depth are given in meters. Y-Axis: Apparent resistivity(ohm-m) X-Axis: Spacing (m). Red: Master curve. Black: Actual curve. Blue: Layers encountered.

For the first ERS point, three layers were encountered, and resistivity curve formed is Q-type as ρ1>ρ2>ρ3. For the upper first layer which is surface layer is a dry layer and thus showing maximum resistivity i-e 40.7 ohm-m which shows that it's highly resistive zone, dominantly of clayey sand or sandy clay. First layer is form 0-0.744 m. Then in second layer which is from 0.744-2.96 m shows less resistive zone, dominantly occupied by silty sand or sandy silt with some moisture content. As we go deep third layer is encountered from 2.96-14.7 m which is a thick zone of silty sand or sandy silt with high water saturation, due to which resistivity values drastically changes. This zone is considered Fresh Water Zone having high conductivity thus showing less resistivity. Fresh water zone encountered is of almost 12m thickness.

After 14.7m there is again a drastic decrease in resistivity values which shows highly conductive zone of water with dissolved salts.

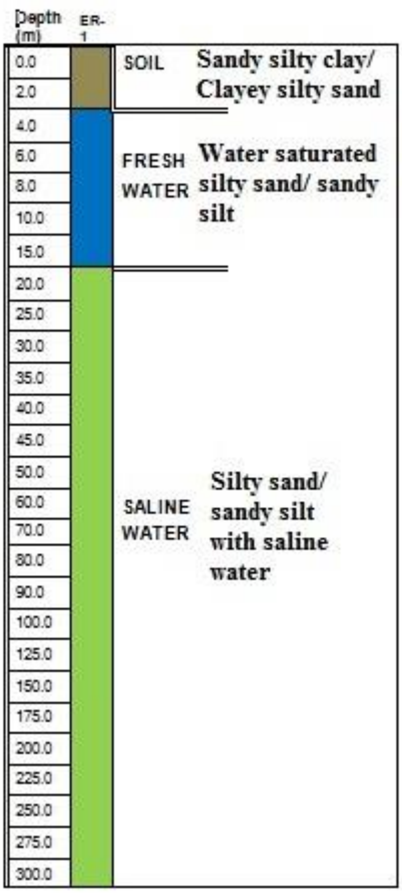
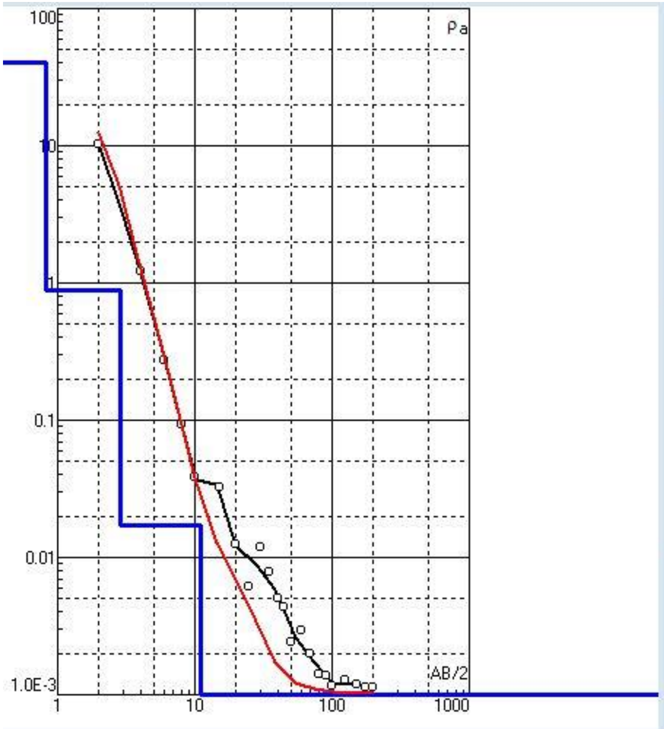


Figure 4.4. Hydrogeological columnar view of ERS point# 1.

Lithological column in figure 4.4 shows resistivity values with particular depths. For soil (sandy silty clay or clayey silty sand) resistivity values are maximum but as going deep where water is present with Sandy clay or Clayey Sand, at that point, resistivity starts to decrease as conductivity is increasing. From almost 3-15m true resistivity value lies within the range of 15-45 ohm-m, which is actually the range for Resistivity of Fresh Water Bearing Zone (Palacky, 1987). After 15m resistivity starts to decrease till it reaches minimum value which shows the Zone after 15m is highly conductive and more preferably it is Saline Water Zone.



N	ρ	h	d	Alt
1	40.7	0.824	0.824	-0.82
2	0.894	2.02	2.84	-2.84
3	0.0171	8.08	10.9	-10.9
4	1.0E-3			

Figure 4.5. Actual resistivity curve of field data for ERS point#2. Thickness and depth are given in meters. Y-Axis: Apparent resistivity(ohm-m) X-Axis: Spacing (m). Red: Master curve. Black: Actual curve. Blue: Layers encountered.

Again interpolation is required to bring our resistivity curve close to master curve (red colored curve). Interpolation is done manually by software by bringing every point close to the master curve.

Interpolated curve for 2nd ERS point is shown in figure 4.5.

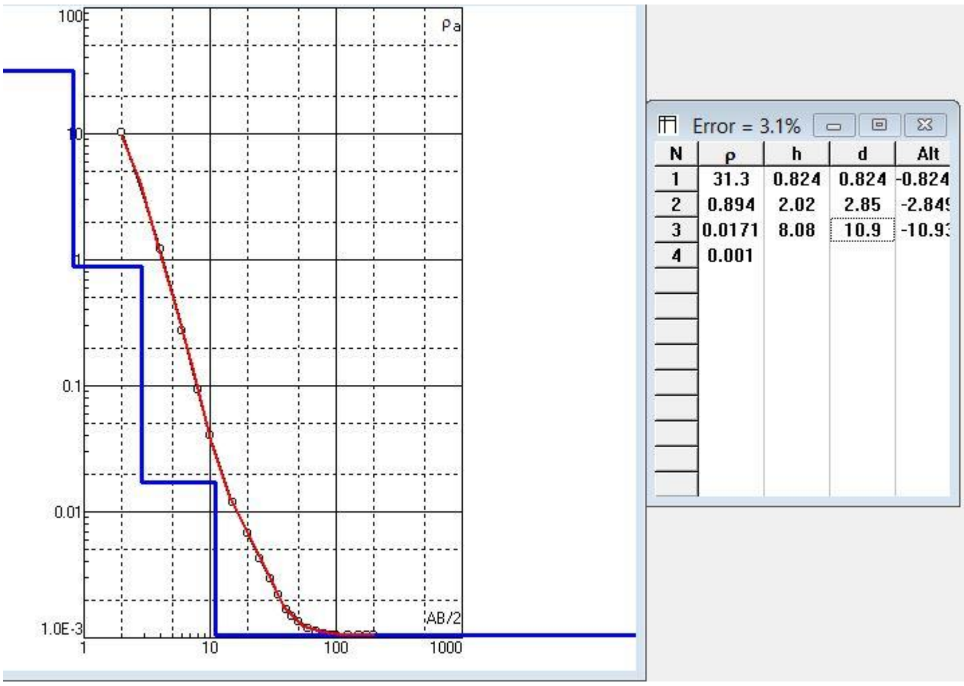


Figure 4.6. Interpolated Q-type resistivity curve for ERS point#2. Thickness and depth are given in meters. Y-Axis: Apparent resistivity(ohm-m) X-Axis: Spacing (m). Red: Master curve. Black: Actual curve. Blue: Layers encountered.

For 2nd ERS point, again three layers were encountered. It's a Q-type resistivity curve as $\rho1>\rho2>\rho3$. First upper layer is surface layer dominantly consisting of clayey silty sand or sandy silty clay showing maximum resistivity value of 31.3 ohm-m because it's a dry zone. It starts from surface till 0.824m. Second layer is of same lithology with some silt and moisture content thus showing decrease in resistivity value and this zone is from 0.824 till almost 3m. Third layer encountered show drastic decrease in resistivity values which shows there is increase in conductivity due to water saturation. Zone is predominantly of silty sand or sandy silt and has thickness of almost 8m from 3-11 m depth. This zone is marked as a Fresh Water Zone.

After 11m there is again a drastic decrease in resistivity values which can only happen if salty water saturation is there. Thus zone after 11m is considered as a Saline Water Zone.

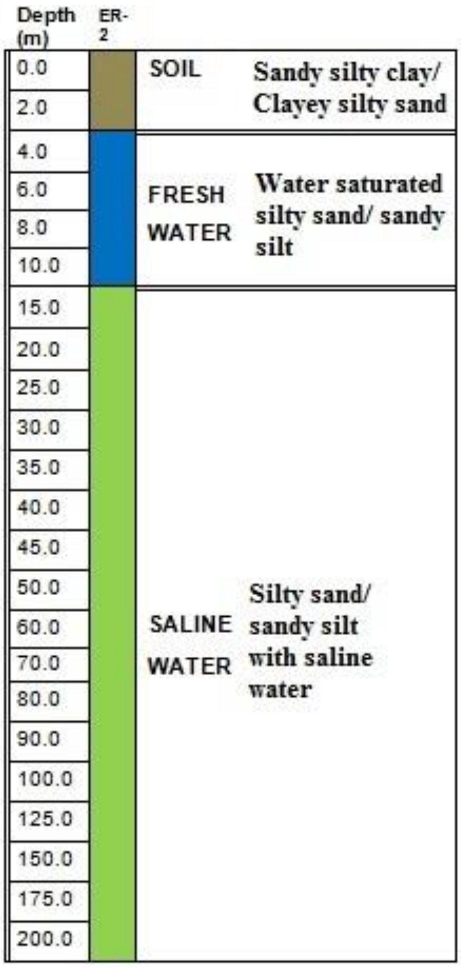


Figure 4.7. Hydro geological columnar view of ERS point# 2

Similarly, like at 1st observation point, resistivity is decreasing with depth. Fresh water zone is encountered at 3-11m having true resistivity values falling within 15-45 ohm-m of range. Zone after 11m shows maximum decrease in resistivity values and maximum increase in conductivity, this drastic decrease in resistivity value is only happen if we hit the zone of water mixed with salts,. Thus after 11m Saline Water Zone is encountered.

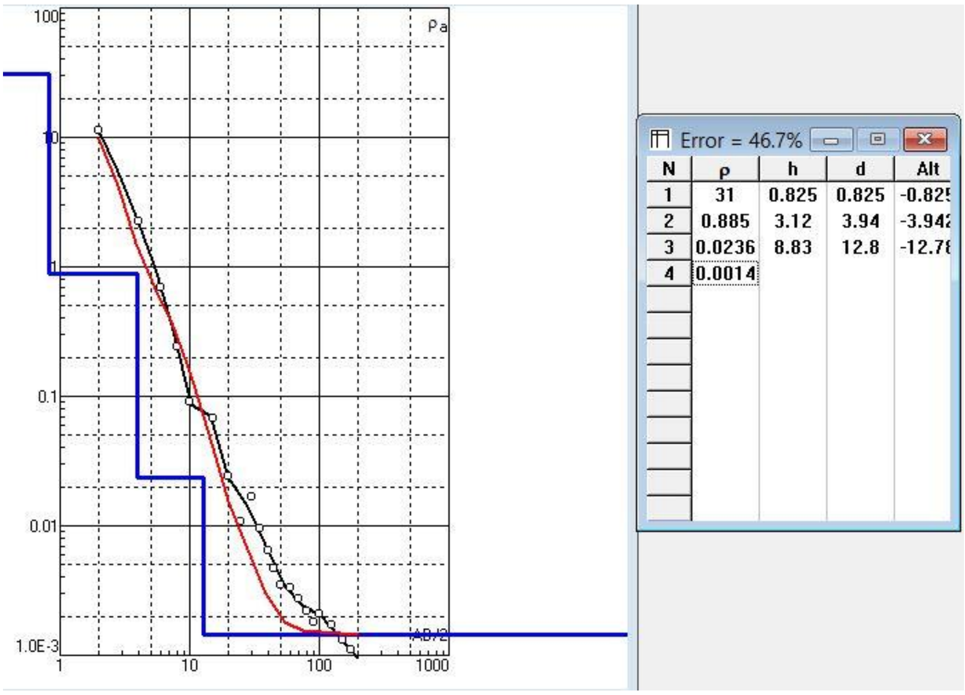


Figure 4.8. Actual resistivity curve of field data for ERS point#3. Thickness and depth are given in meters. Y-Axis: Apparent resistivity(ohm-m) X-Axis: Spacing (m). Red: Master curve. Black: Actual curve. Blue: Layers encountered.

Interpolation is required to bring it close to the master curve. Hence interpolation is done by software for each point and interpolated curve is shown below.

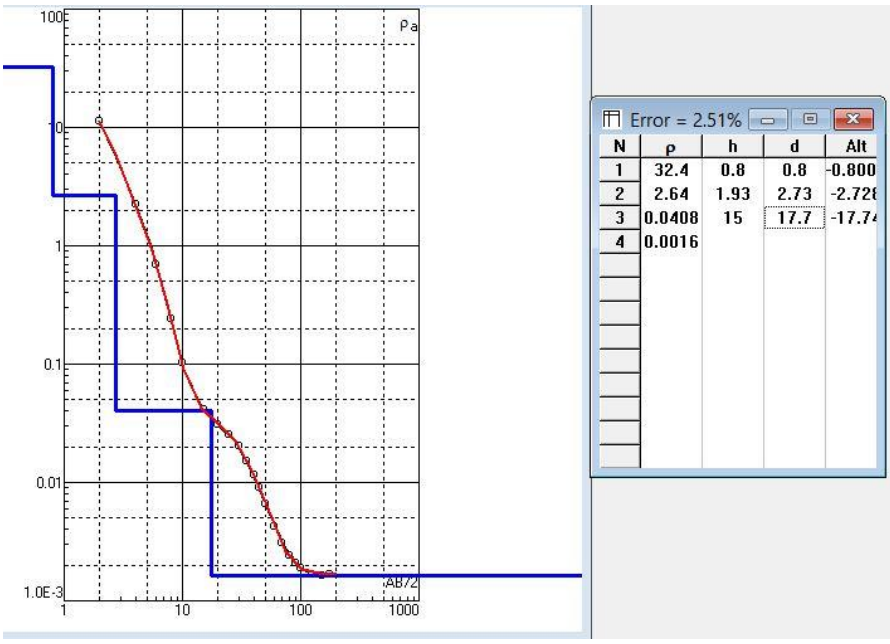


Figure 4.9. Interpolated Q-type resistivity curve for ERS point# 3. Thickness and depth are given in meters. Y-Axis: Apparent resistivity(ohm-m) X-Axis: Spacing (m). Red: Master curve. Black: Actual curve. Blue: Layers encountered.

At 3rd ERS point, again three layer case is experienced. It's a Q-type resistivity curve as ρ1>ρ2>ρ3. First upper layer showing maximum value of resistivity because it's a total dry zone and that zone is occupied by clayey silty sand or sandy silty clay from surface to 0.8m and then second layer is from 0.8-3m which is occupied by silty sand or sandy silt with some moisture content and thus showing decrease in resistivity value but going further deep third layer is encountered which is dominantly sandy silt or silty sand with high water saturation and thus showing further decrease in resistivity value as it is highly conductive due to water presence. That zone is considered to be fresh water zone having thickness of almost 15-16 m.

After 18m maximum decrease in resistivity value is seen due to high conductivity which is because of mixing of salts with water thus making this zone (after 18m) saline water zone.

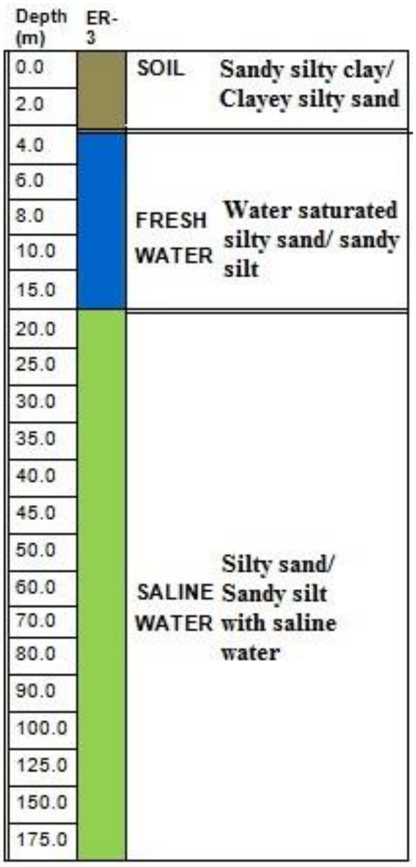


Figure 4.10. Hydro geological columnar view of ERS point# 3

At 3rd ERS observatory point, true resistivity value is near to 45 ohm-m at almost 6-7m depth and is close to 15 ohm-m near 16m depth. But as shown by curve there is an anomalous decrease in resistivity value at almost 3m which shows water saturation within sandy silt or silty sand started to increase at 3m Therefore, Fresh water zone is considered to be in between 3-18m and after 18m zone is highly conductive i-e saline water zone.

In all three lithological columns alluvium, fresh water and saline water zones were marked on the basis of resistivity value encountered at particular depth. Range of true resistivity values of alluvium (clay, sand, silt), fresh water and saline water etc. are given in Appendix 2.

Table4.1. Coefficient K, Apparent and True Resistivity Values obtained during survey.

ERS#1			ERS#2			ERS#3		
K	AR	TR	K	AR	TR	K	AR	TR
11.78	10.15	119.567	11.78	10.232	120.533	11.78	11.323	133.385
49.48	1.3019	64.41801	49.48	1.2071	59.7273	49.48	2.2354	110.608
112.31	0.32656	36.67595	112.31	0.27498	30.883	112.31	0.69571	78.1352
200.28	0.12671	25.37748	200.28	0.09261	18.5477	200.28	0.24376	48.8203
313.37	0.0588	18.4249	313.37	0.03804	11.9197	313.37	0.09049	28.3575
173.57	0.07758	13.46608	173.57	0.03265	5.66723	173.57	0.06819	11.8357
311.02	0.02329	7.243967	311.02	0.01232	3.83114	311.02	0.02392	7.43929
487.73	0.01129	5.506959	487.73	0.00608	2.96325	487.73	0.01066	5.20115
274.89	0.01551	4.263269	274.89	0.01185	3.25607	274.89	0.01689	4.64262
376.99	0.00689	2.598705	376.99	0.00784	2.95383	376.99	0.00954	3.5963
494.8	0.00697	3.446282	494.8	0.00508	2.51151	494.8	0.00644	3.188
628.32	0.01281	8.050664	628.32	0.00439	2.75719	628.32	0.00467	2.93476
777.54	0.00373	2.899447	777.54	0.00243	1.89129	777.54	0.00346	2.68702
549.78	0.00425	2.339039	549.78	0.00292	1.60745	549.78	0.00329	1.8079
753.98	0.00272	2.048413	753.98	0.00198	1.49394	753.98	0.00273	2.05829
989.6	0.00186	1.840458	989.6	0.00142	1.40503	989.6	0.0022	2.18058
1256.64	0.00148	1.863346	1256.64	0.00065	0.81506	1256.64	0.00181	2.27213
1023.64	0.00165	1.688289	1023.64	0.00115	1.17954	1023.64	0.00206	2.10491
1612.68	0.00109	1.75508	1612.68	0.00015	0.24142	1612.68	0.00168	2.70124
2332.63	0.00072	1.668764	2332.63	0.00061	1.41334	2332.63	0.00127	2.97224
3183.48	0.00054	1.729903	2373.87	0.00655	15.5465	3183.48	0.0006	1.90308
4165.23	0.00043	1.773555	3110.18	0.00614	19.0965			
3944.66	0.00043	1.71356						
4877.32	0.00057	2.789339						
5908.16	0.00033	1.966826						
7037.17	0.00031	2.213894						

During survey resistivity values obtained are apparent resistivity values. Later by applying formulas values for coefficient K and true resistivity were found.

At all three observation points, by observing the values it is claimed that starting from the top resistivity values are maximum which them gradually decreases and at the bottom resistivity values are minimum. The initial 2 values at each point shows maximum value of resistivity which depicts that it's Dry Zone. Then we have 3 such resistivity values which come in range of 15-45, which is actually the range of true resistivity value for fresh water bearing zone. The values change in decreasing order and all the rest values shows the resistivity values around 1-2, explaining the factor that resistivity in minimum and conductivity is maximum thus shows the zone of brackish water or saline water.

Same trend is shown in hydro geological columns for Three ERS observatory points demarking conducting fresh water zones. Two main points are highlighted as;

(i) Zone having true resistivity in between 0-15ohm-m. This resistivity zone comprises subsurface materials interpreted as clay, sand and silts having saline water source with medium yield.

(ii) Zone having true resistivity in between 15-70 ohm-m. This resistivity zone is of subsurface materials interpreted as sands and silts showing medium yield of groundwater with inter-bedded beds of clay.

Zone of Grade	**True Resistivity (Ohm-m)**	**Correlation with Geological Formation and Water Content Quality**
Low Resistivity Zone	0-15	This resistivity zone comprises subsurface materials interpreted as clay, sand and silt having saline water source with medium yields.
Medium to high Resistivity Zone	15- 70	Subsurface materials interpreted as sands and silts show medium yield of fresh groundwater with inter-bedded beds of clay.

CONCLUSIONS

(i) Silty fine sand or Sandy Clay or Clayey Sand or clayey silty sand or silty clayey sand is encountered on the surface and subsurface in the study area.

(ii) Aquifers are of silty sand or sandy silt and fresh water table was encountered at 3-17m.

(iii) Saline water is present at deeper depths.

RECOMMENDATIONS

There was unavailability of control well at survey location, therefore recommendation for new tube well site totally rely on the resistivity values obtained during survey and the respective resistivity curves and lithological columns formed from those values.

(i) Sounding point (ERS-1 & ERS-3) is recommended for test drilling on the basis of ERS results and the Hydrogeological studies done in surrounding areas.

(ii) Recommended drilling depth on point ERS-1 & ERS-3 is 10m-17m for fresh water.

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