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# Exploring Potable Groundwater Sources Surrounding Manchar Lake

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## ABSTRACT

**This study was carried out to explore the groundwater quality in Manchar Lake's surroundings, (one of Asia's largest lakes in Sindh Province of Pakistan), to discover sites where potable groundwater is available. To achieve this objective, Vertical Electrical Sounding (VES) was employed at 21 sites in shallow depths by adopting Schlumberger electrode array alignment. The maximum distance chosen between current electrodes (A & B) was 300 m, and 20 m was between potential electrodes (M & N). ABEM terrameter SAS 4000 and IX1D resistivity software was used for data collection and interpretation, respectively. The results revealed that except for two sites (13 and 19), all other sites do not have potable groundwater at any depth. At site 13, one out of three layers lies under a high resistivity zone, while at site 19, two out of four layers lie under a high resistivity zone, which indicates the presence of potable water. To verify VES findings, water samples from 5 trial bores made by hand percussion method were collected and analyzed for Electrical Conductivity (EC) and Total Dissolved Solids (TDS), which revealed saline water from all trial bores. To sum up, potable groundwater is not available in the vicinity of Manchar Lake at shallow depths.**

**Keywords: Vertical Electrical Survey, Groundwater Quality, Manchar Lake**

## 1. INTRODUCTION

The necessity for the quality and accessibility of water assets has consistently been the main concern of our societies particularly in semiarid and arid regions. The matter of obtaining enough supply of potable water is main issue nowadays due to consistently expanding of population, irrigation, industrialization and dumping of untreated effluents in the freshwater resources. Because of these circumstances, another alternative *i.e*. groundwater must be searched so that people can get potable water [1]. The community near Manchar Lake (one of the Asia's major lake, located near Sehwan in Sindh Province of Pakistan) is one such place that needs alternative source of warer (groundwater) for drinking purpose because Manchar lake water is contmainated with various toxic and heavy metals [2] and is unfit for drinking. Because of an absence of other drinking water sources, individuals close to lake are constrained to use its contaminated water, which results in poor health impacts. Furthermore, according to World Health Organization (WHO-1998), the groundwater in the region of the lake is too salty to even consider for drinking. While numerous investigations have been led to assess the water quality of Manchar Lake [4-7], no examination has been led to investigate the groundwater quality in the region of the lake [3]. Therefore, this study investigates consumable groundwater encompassing Manchar Lake utilizing an electrical resistivity survey.

Globally many studies have been conducted to explore

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groundwater quality using electrical resistivity survey [8]. In Pakistan, on the other hand, very few studies have explored groundwater quality [9]. One study conducted in Nigeria bears a similar scope to the present inquiry. In the community of Kwale near the Niger River, Oseji *et al.* [10] utilized Vertical Electrical Sounding (VES) to examine different features of aquifer and potential of groundwater. The goal of their investigation was to investigate groundwater for household and indutrial purposes, which recently used River Niger water for household water needs. However, the Niger River water is currently unfit for human utilization because of expanding industrialization. This scenario is similar to that of Manchar Lake.

VES has proven an effective technique for the investigation of groundwater. In an exploration of groundwater quality, Sikandar [11] inferred that the VES could be utilized successfully to identify subsurface aquifer layers and to describe the salinity of groundwater.

Since VES plays a vital role in the determination of groundwater quality, there are a few limitations of electrical resistivity surveys, including:

- Like vevery single geophysical technique, resistivity information is indistinct; various models can create similar information.
- For measurement we have to insert electrodes into the ground which makes resistivity process slow.
- The ERS information is influenced by surface conductive layers. Along highly conductive layers, current moves all around effectively. If the surface where ERS is conducted is highly conductive, it may not be practical to gather information beneath that layer [12].

Therefore, in this research, VES is adopted in a shallow depth grid (5 x 5 km$^2$) for the investigation of groundwater quality. To validate VES findings, trial bores are constructed where water samples are collected and examined for Electrical Conductivity (EC) and Total Dissolved Solids (TDS).

## 2. MATERIALS AND METHODS

### 2.1 Site Selection

The locations where VES was conducted were nominated randomly in the surrounding area of the Manchar Lake. However, to validate VES findings, trial bores were constructed on five sites (see Fig. 1).

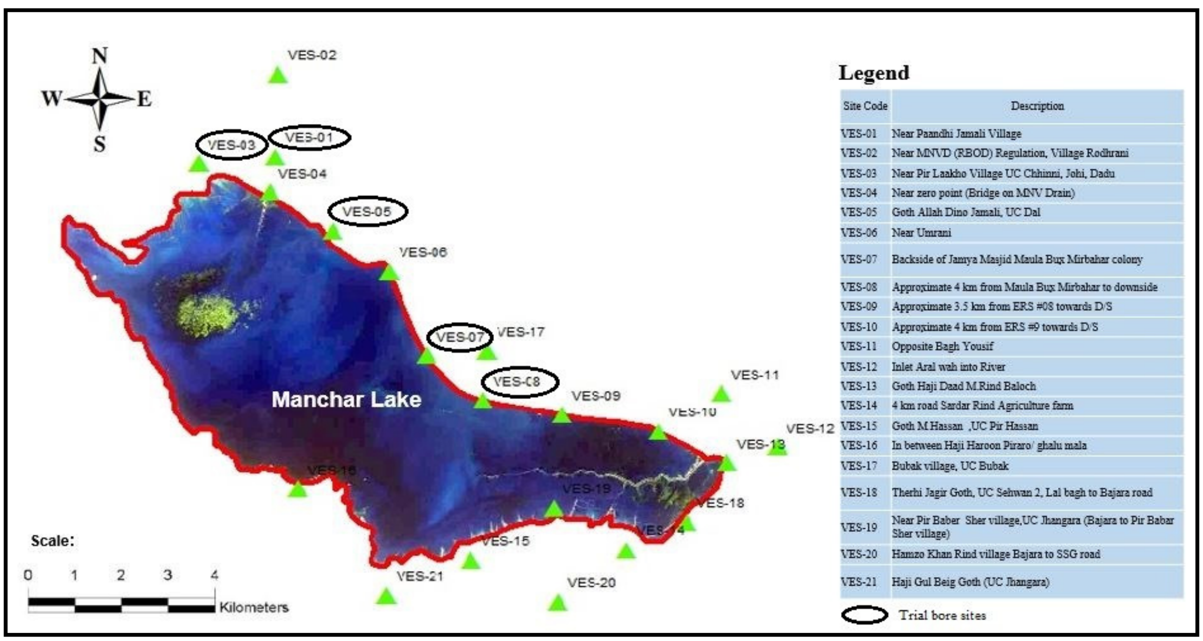


Fig. 1: Vertical electrical sounding sites

### 2.2 Instruments Used

The terrameter SAS 4000 (ABEM, Sweden) was used for conducting VES. Other accessories with the terrameter included two measuring tapes, two large wires (A - B), two small wires (M – N), data forms, four metal electrodes, two hammers, an external battery source, an external battery connector, walkie talkies, a calculator and connecting cables [13, 14].

### 2.3 Electrode Configuration

The arrangement of electrodes while measuring resistivity is known as electrode array [15]. Different electrode array arrangements are available, such as Pole-Pole, Dipole-Dipole, Pole-Dipole, Schlumberger and Wenner array, but the Schlumberger array is found to be the most appropriate and suitable among all of these arrangements for groundwater exploration [16]. In this research, most commonly used Schlumberger electrode array was adopted; it includes A and B current electrodes, and M and N potential electrodes which are placed outside and inside, respectively in one straight line (see Fig. 2).

To increase depth range, the position of current elctrodes is changed to a new position while the position of potential electrodes remain unchanged. When the distance between current and potential electrodes becomes too wide then position of potential elctrodes must also be changed. Otherwise, the potential difference becomes too small to be measured with sufficient accuracy [14].

### 2.4 Electrical Resistivity Survey (ERS)

ERS is classified into Vertical Electrical Sounding (VES) and horizontal profiling [18]. The VES technique is designed to solve groundwater problems such as determination of the line between saline and freshwater zones [12,19], as well as aquifer thickness, depth, and limit [20, 21]. Furthermore, VES aids in the evaluation of groundwater quality [22, 23] and exploration of geothermal reservoirs [24]. In this study, VES is implemented for the exploration of groundwater quality. It has been verified as a traditional method due to its smooth field operation, availability of the equipment, less filling pressure, greater depth of penetration, and is manageable by modern computers [9]. The VES involves passing an electrical current into the ground through two current electrodes; the resulting potentials created in the field are measured through two potential electrodes [25]. The maximum half distance between two current electrodes (AB/2) is set to 300 m, whereas the maximum half distance between potential electrodes (MN/2) is set to 20 m as adopted by [13]. The distance between current electrodes is proportional to the distance, as you increase the distance between current electrodes, it means you are going deeper in depth [13]. In this study, we are intrested in 1000 ft depth, therefore the maximum half distance between current electrodes is adopted as 300 m. However, MN/2 distance is always kept small as relative to AB/2, and is changed only when the observed voltage becomes too small to measure [28]. Therefore, in this study it is adoped as 20 m.

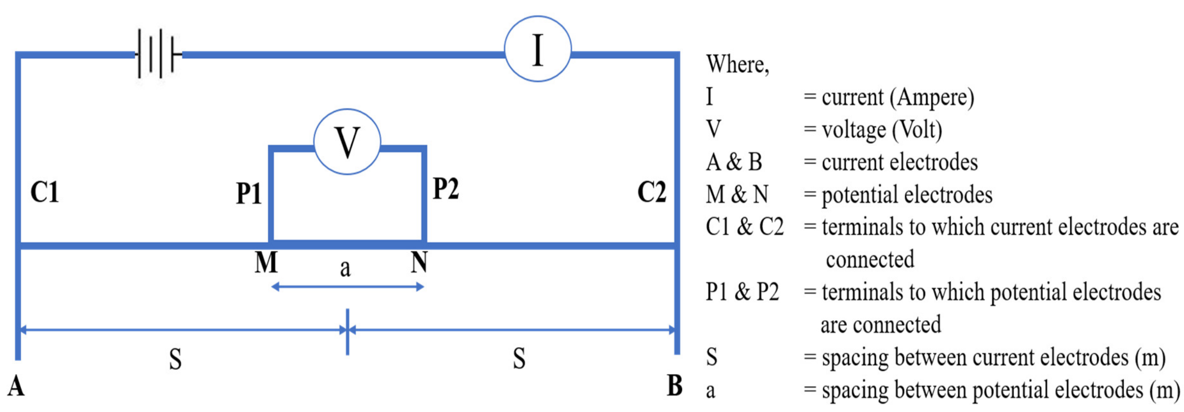


Fig. 2: Geometric Arrangement of the Schlumberger Array Configuration [17]

### 2.5 Procedure

- An ABEM SAS terameter was placed halfway between the potential electrodes, and P1 and P2 terminals were connected to the terminals M and N, respectively.
- The current electrodes—namely A and B are attached to the C1 and C2 terminals, respectively.
- The current and potential electrodes were driven at their respective position into the ground with hammers.
- Resistivity mode was set, if it is not set.
- The selected method was sounding and the layout was Schlumberger.
- The measuring knob was activated for performing measurements.
- Proceeded to next position for next measurement. [26].

The data obtained from the Terrameter was resistivity (V/I) and apparent resistivity ($\rho_a$), calculated by Ohm's Law (equation (1)).

$$\text{Apparent Resistivity} = K \times (V/I) \tag{1}$$

where K= Geometric factor and is calculated by Equation (2).

$$K = \frac{\pi\{(AB)^2 - (MN/2)^2\}}{MN} \tag{2}$$

where AB/2 shows half spacing of current electrodes (m) and MN/2 shows half spacing of potential electrodes (m) and MN is the total distance between potential electrodes [13].

### 2.6 Trial Bores

Trial bores were drilled using the hand percussion method up to 100 ft. depth, from where samples were collected at intervals of approximately 10 ft. Due to financial constraints, the bores were drilled up to 100 ft. depth, whereas, to make interval distance uniform, the samples were collected at 10 ft. interval. The collected samples were transported to the laboratory of the Pakistan Council of Research in Water Resources (PCRWR) in Karachi for analysis.

### 2.7 Analysis of Survey Data

The data obtained from vertical electrical sounding The data obtained from vertical electrical sounding was interpreted by IX1D software. The resistivity models were produced by fitting acquired data with the least root mean square error ( < 5 %) between the data generated by the models and the real data.

## 3. RESULTS AND DISCUSSION

### 3.1 VES Results

**VES-01 (Near Paandhi Jamali Village)**

The study area is divided into four resistivity zones depending on the field geology [9] as low (0-5 ohm-m), medium (5-15 ohm-m), high (15-50 ohm-m), and very high (>50 ohm-m) (see Table 2). At site VES-01, a total of four layers were discovered. The top two layers were in the low resistivity zones with values of 4.7 ohm-m & 2.6 ohm-m at a depth of 1.3 and 11.3 m, respectively. These two layers were underlain by other low resistivity layers with resistivity values of 4.74 ohm-m up to a depth of 77.8m and 1.9 ohm-m up to an infinite depth (see Fig. 3).

At site 1 all layers lie in the zone of low resistivity values which indicates fine material such as clay and sand along with presence of salty water (see Table 2).

**VES -03 (Near Peer Laakho Village UC Chhinni, Johi, Dadu)**

At site 3, a total of four layers were discovered with the first layer lying in a medium resistivity zone, which indicates the presence of intermediate sand with some clay; meanwhile, the last three layers lie in a low resistivity zone, which indicates the presence of saline or less saline groundwater (see Fig. 4). The first layer has a resistivity value of 5.23 ohm-m up to a depth of 1.39 m. The second layer has a resistivity value of 1.56 ohm-m up to a depth of 10.40 m, which is underlain by two other low resistivity layers with resistivity values of 2.75 and 0.96 ohm-m. The third layer has a depth of 31.5 m and the last layer was found to have an infinite depth (see Table 1 and 2).

**VES -05 (Goth Allah Dino Jamali, UC Dal)**

Site 5 consisted of four layers lying within the low resistivity zone, which indicate fine material with the presence of saline water (Fig. 5). The resistivity values of the top two layers were 4.84 ohm-m to a depth of

1.43 m and 3.24 ohm-m up to a depth of 15.6 m. The bottom two layers, one with a depth of 145 m, showed resistivity of 1.56 ohm-m, while the other had an infinite depth with 1 ohm-m resistivity (see Table 1 and 2).

**VES -07 (Backside of Jamya Masjid Maula Bux Mirbahar colony)**

At site 7, a total of four layers were discovered. The top three layers lie in low resistivity zones with resistivity values of 0.58, 1.68 and 1.97 ohm-m up to a depth of 0.14, 7.4 and 18.6 m., respectively. However, the bottom layer lies in a medium resistivity zone with an infinite depth and a resistivity value of 6.4 ohm-m (see Table 1 and 2). The fact that the first three layers lie in low resistivity zones indicates that saline groundwater is available up to a depth of 60 ft. However, the last layer lies in a medium resistivity zone, which indicates the presence of intermediate sand with some clay (see Fig. 6).

Table 1: Detail of strata depth with resistivity values of all VES sites

| Site | Type of soil | Depth | R ( Ω-m) |
|---|---|---|---|
| VES-01 | Clay/shale | 1.3561 | 4.7006 |
| | Clay/shale | 11.324 | 2.6762 |
| | Clay/shale | 77.802 | 4.7429 |
| | - | - | 1.9636 |
| VES-03 | Sand Clay | 1.3964 | 5.2354 |
| | Clay/shale | 10.408 | 1.5695 |
| | Clay/shale | 31.577 | 2.7502 |
| | - | - | 0.96099 |
| VES-05 | Clay/shale | 1.4325 | 4.8459 |
| | Clay/shale | 15.696 | 3.2416 |
| | Clay/shale | 145.05 | 1.5669 |
| | - | - | 1.0282 |
| VES-07 | Clay/shale | 0.14629 | 0.58153 |
| | Clay/shale | 7.4629 | 1.6847 |
| | Clay/shale | 18.689 | 1.9715 |
| | - | - | 6.4764 |
| VES-08 | Clay/shale | 4.9295 | 2.6758 |
| | Clay/shale | 47.413 | 3.9767 |
| | - | - | 0.90974 |

Table 2: Correlation between resistivity ranges and hydrogeology for investigated area [9,27]

| Resistivity Zone | Resistivity (ohm-m) | Relationship between geological formation and water content quality |
|---|---|---|
| Low | 0-5 | It indicates fine materials like clay/shale, with rare sand and consequently having salty water potential. |
| Medium | 5-15 | This zone demonstrates the existence of mixture of sand with some clay. It might likewise demonstrate the presence of alternate bedding of sand and clay/shale. The arrangement can yield groundwater if underneath the water table. |
| High | 15-50 | This zone indicates existence of coarser material i.e., sand with good quality of groundwater |
| Very High | >50 | High value of resistivity indicates existence of unsaturated zone and bedrock if above and below the water table respectively |

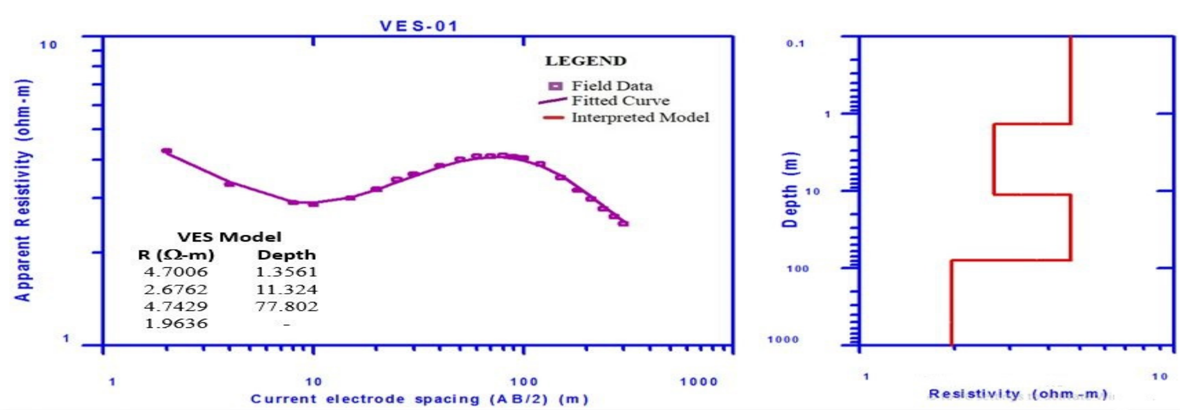


Fig. 3: 1D resistivity model of VES – 01 developed in IX1D resistivity software

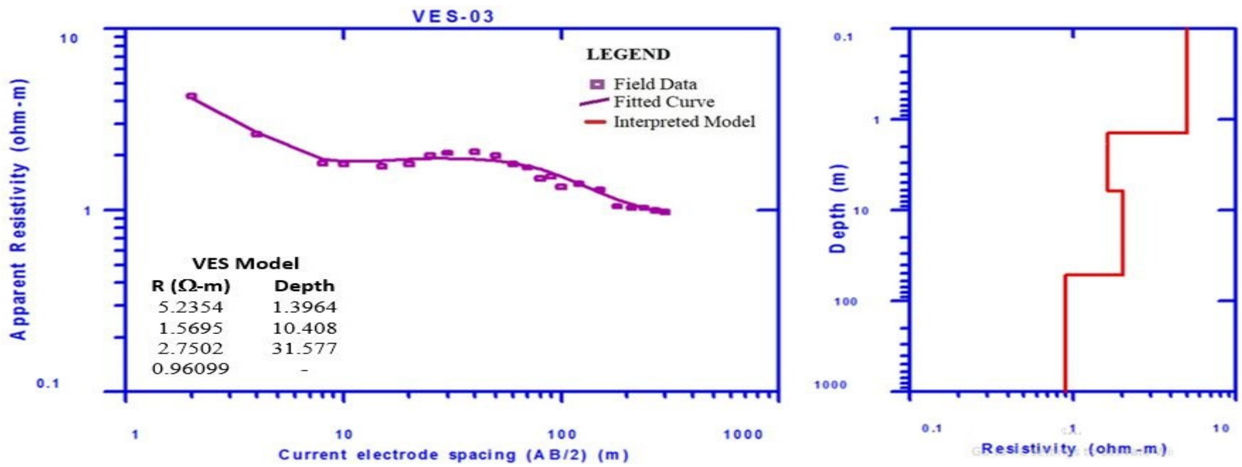


Fig. 4: 1D resistivity model of VES – 03 developed in IX1D resistivity software

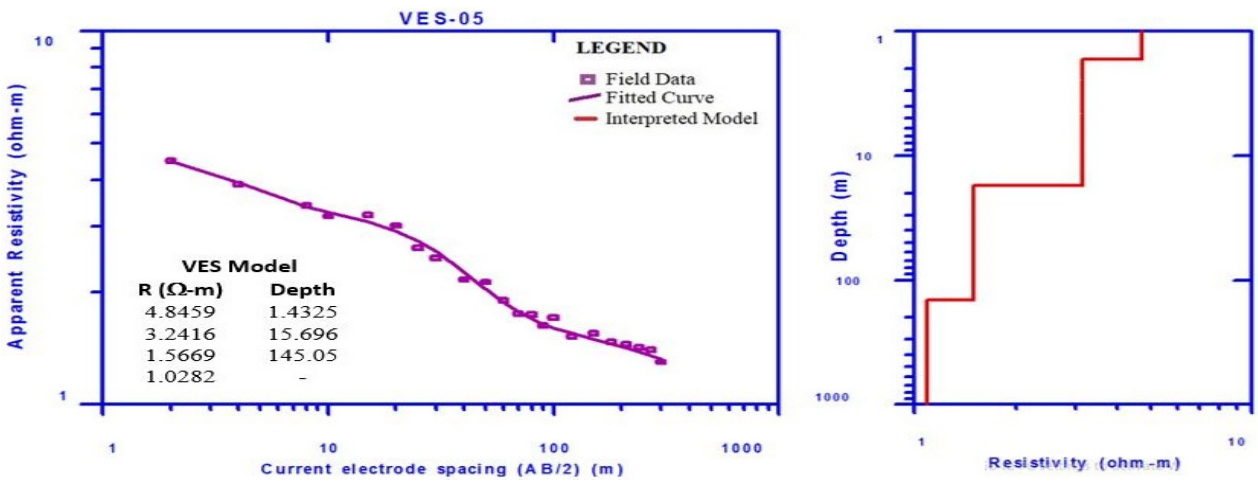


Fig. 5: 1D resistivity model of VES – 05 developed in IX1D resistivity software

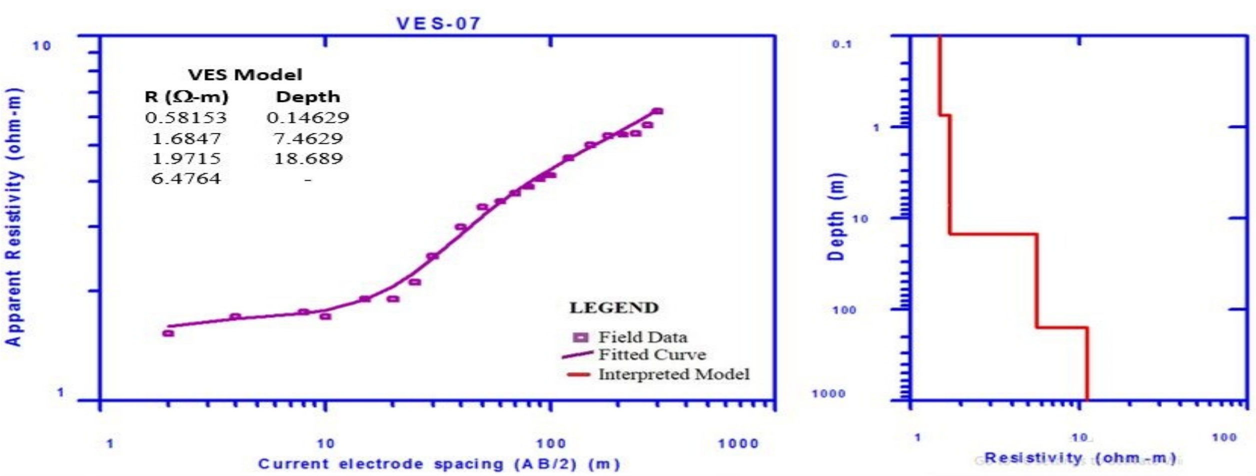


Fig. 6: 1D resistivity model of VES – 07 developed in IX1D resistivity software

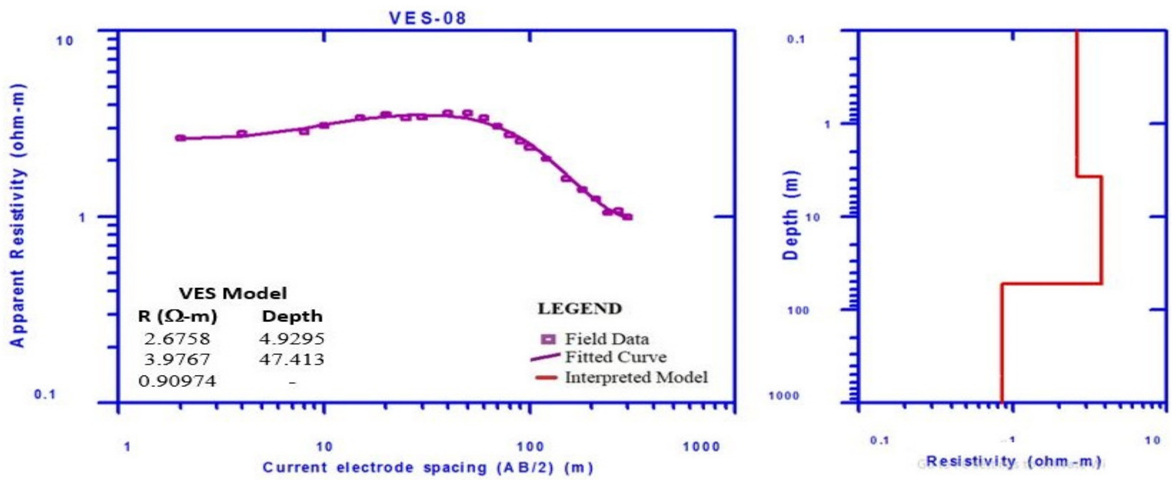


Fig. 7: 1D resistivity model of VES – 08 developed in IX1D resistivity software

**VES -08 (Approximate 4 km from Maula Bux Mirbahar to the downside)**

At site 8, three layers of low resistivity were discovered. The resistivity of the top, middle, and bottom layers were 2.6, 3.9 and 0.90 ohm-m., respectively. The depth of the top two layers was found to be 4.92 and 47.4 m, and both layers were underlain by layer with infinite depth (see Table 1 and 2). The resistivity of all the layers was less than 5 ohm-m., which indicates the existence of saline water (see Fig. 7).

### 3.2 Correlation between VES data and bore data

**VES-01 and Trial Bore-1**

At site VES-01, a total of four layers were found. Every one of the four layers have a resistivity underneath 5 ohm-m, *i.e.*, all layers lie in a low resistivity zone. A low resistivity zone indicates the existence of finely ground materials, such as clay/shale, with rare sand. Consequently, the site has saline to less saline water-bearing potential (see table 2). On the other hand, the textural examination of the soil collected from the trial bore-1 shows three layers of soil up to 100 ft. in depth (see Table 4). In this way, the VES information adjusts well to the bore information. The water quality obtained from trial bore-1 at different depths is saline because it has high EC and total dissolved solids (see Table 3). This data again demonstrates the high correlation between VES-01 and the trial bore-1 data.

**VES-03 & Trial Bore-2**

Similarly, to site 1, at site VES-03, four layers were discovered. The first layer lies in the medium resistivity zone and the last three layers lie in the low resistivity zone. The medium resistivity zone indicates the presence of intermediate sand with some clay. It may also indicate the presence of alternate bedding of sand and clay/shale. Similarly, the low resistivity zone indicates the presence of finely ground materials such as clay/shale, with rare sand. Therefore, the site has saline to less saline water-bearing potential. The analysis of soil collected from trial bore-2 shows five layers of soil (silt loam, loam, sandy loam, silt loam, and sandy loam) up to 100 ft. depth (see Table 5). Therefore, the data from the trial bore soil has a high correlation with the VES data. The water obtained from trial bore-2 has high EC and TDS, which shows that water is saline in nature (see Table 3). This data again demonstrates the high correlation between VES-03 and the trial bore-2 data.

**VES-07 and Trial Bore-3**

At site VES-07, a total of four layers were discovered. The top three layers lie in the low resistivity zone and the bottom layer lies in the medium resistivity zone. A low resistivity zone indicates the presence of finely ground materials, such as clay/shale, with rare sand. Therefore, the site has saline to less saline water-bearing potential. Similarly, the medium resistivity zone indicates the presence of intermediate sand with some clay. It may also indicate the presence of alternate bedding of sand and clay/shale. However, the textural analysis of soil collected from trial bore-3 shows two layers of soil (silty loam and sandy loam) up to 100 ft. in depth (see Table 6). Therefore, the data from the trial bore soil has a high correlation with the VES data. The water collected from trial bore-3 is salty, which is revealed from high EC and TDS values (see Table 3). This data again demonstrates alignment between VES-07 and the trial bore-3 data.

**VES-05 and Trial Bore-4**

At site VES-05, four layers were discovered, all of which have a resistivity less than 5 ohm-m, which indicates that all layers lie in a low resistivity zone. A low resistivity zone indicates the presence of finely ground materials, such as clay/shale with rare sand. Therefore, the site has saline to less saline water-bearing potential. The textural analysis of the soil collected from trial bore-4 shows six layers of soil (sandy clay loam, silty clay loam, clay, sandy clay, silty clay and silty loam) up to 100 ft. in depth (see Table 7). Therefore, the data from the trial bore soil has low correlation with the VES data. The water obtained from trial bore-4 has high EC and TDS, which results in brackish water (see Table 3). This data demonstrates high correlation between VES-07 and the trial bore-4 water data.

Table 3: EC and TDS of water samples from five trial bores at different depths

| **Parameter EC (µS/cm) ----- WHO Limit 1500 µS/cm** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Bore-1** | | **Bore-2** | | **Bore-3** | | **Bore-4** | | **Bore-5** | |
| **Depth** | **Value** | **Depth** | **Value** | **Depth** | **Value** | **Depth** | **Value** | **Depth** | **Value** |
| **30** | 17120 | **30** | 15410 | **20** | 18210 | **20** | 5500 | **20** | 3760 |
| **40** | 5000 | **40** | 16050 | **30** | 11910 | **30** | 4390 | **30** | 4410 |
| **50** | 3650 | **60** | 15070 | **50** | 10570 | **40** | 6380 | **40** | 3750 |
| **60** | 8600 | **70** | 16550 | | | **50** | 6250 | | |
| **70** | 6110 | **80** | 19040 | | | **60** | 11300 | | |
| **80** | 9640 | | | | | **70** | 29100 | | |
| **90** | 9040 | | | | | **80** | 35800 | | |
| **Parameter TDS (ppm) ----- WHO Limit 1000 ppm** | | | | | | | | | |
| **30** | 10956 | **30** | 9862 | **20** | 11654 | **20** | 3575 | **20** | 2444 |
| **40** | 3200 | **40** | 10272 | **30** | 7622 | **30** | 2854 | **30** | 2866 |
| **50** | 2336 | **60** | 9644 | **50** | 6764 | **40** | 4147 | **40** | 2438 |
| **60** | 5504 | **70** | 10592 | | | **50** | 4062 | | |
| **70** | 3910 | **80** | 12185 | | | **60** | 7345 | | |
| **80** | 6169 | | | | | **70** | 18195 | | |
| **90** | 5785 | | | | | **80** | 23270 | | |

Table 4: Soil texture of Trial Bore-1

| **Depth (ft.)** | **Soil Texture** | | | | |
|---|---|---|---|---|---|
| | **Silt +Clay** | **Sand%** | **Silt%** | **Clay%** | **Texture Class** |
| 10 | 77.6 | 22.4 | 62 | 15.6 | Silt Loam |
| 20 | 78.8 | 21.2 | 57.2 | 21.6 | Silt Loam |
| 30 | 74.8 | 25.2 | 55.6 | 19.2 | Silt Loam |
| 40 | 78.8 | 21.2 | 61.2 | 17.6 | Silt Loam |
| 50 | 76.8 | 23.2 | 61.2 | 15.6 | Silt Loam |
| 60 | 66.8 | 33.2 | 21.2 | 45.6 | Clay |
| 70 | 60.8 | 39.2 | 19.6 | 41.2 | Clay |
| 80 | 62.8 | 37.2 | 21.6 | 41.2 | Clay |
| 90 | 60.8 | 39.2 | 22 | 38.8 | Clay Loam |

| Table 5: Soil texture of Trial Bore-2 | | | | | |
|---|---|---|---|---|---|
| **Depth (ft.)** | **Soil Texture** | | | | |
| | **Silt +Clay** | **Sand%** | **Silt%** | **Clay%** | **Texture Class** |
| 10 | 70.8 | 29.2 | 51.2 | 19.6 | Silt Loam |
| 20 | 76.8 | 2.2 | 55.6 | 21.2 | Silt Loam |
| 30 | 60.8 | 39.2 | 39.2 | 21.6 | Loam |
| 40 | 31.6 | 68.4 | 22 | 9.6 | Sandy Loam |
| 50 | 77.6 | 22.4 | 58.4 | 19.2 | Silt Loam |
| 60 | 73.6 | 26.4 | 52.4 | 21.2 | Silt Loam |
| 70 | 41.6 | 58.4 | 31.6 | 10 | Sandy Loam |
| 80 | 41.6 | 58.4 | 30 | 11.6 | Sandy Loam |
| 81 | 31.2 | 68.8 | 21.6 | 9.6 | Sandy Loam |

| Table 6: Soil texture of Trial bore-3 | | | | | |
|---|---|---|---|---|---|
| **Depth (ft.)** | **Soil Texture** | | | | |
| | **Silt +Clay** | **Sand%** | **Silt%** | **Clay%** | **Texture Class** |
| 10 | 73.6 | 26.4 | 56.4 | 17.6 | Silty Loam |
| 20 | 77.6 | 22.4 | 51.6 | 26 | Silty Loam |
| 30 | 79.6 | 20.4 | 62 | 17.6 | Silty Loam |
| 40 | 71.2 | 28.8 | 58 | 13.2 | Silty Loam |
| 52 | 77.6 | 22.4 | 62 | 15.6 | Silty Loam |
| 60 | 22 | 78 | 11.6 | 10.4 | Sandy Loam |

| Table-7 Soil texture of Trial bore 4 | | | | | |
|---|---|---|---|---|---|
| | **Soil Texture** | | | | |
| | **Silt +Clay** | **Sand%** | **Silt%** | **Clay%** | **Texture Class** |
| 10 | 90.8 | 9.2 | 64.8 | 26 | Sandy clay loam |
| 20 | 83.2 | 16.8 | 51.2 | 32 | Silty clay loam |
| 30 | 82.4 | 17.6 | 50.4 | 32 | Silty clay loam |
| 40 | 70 | 30 | 24 | 46 | Clay |
| 50 | 41.2 | 58.8 | 21.2 | 20 | Sandy clay |
| 60 | 51.2 | 48.8 | 21.2 | 30 | Sandy clay |
| 70 | 91.2 | 8.8 | 46.4 | 44.8 | Silty clay |
| 80 | 94.8 | 5.2 | 76.8 | 18 | Silty loam |
| 90 | 99.2 | 0.8 | 87.2 | 12 | Silty loam |

**VES-08 and Trial Bore-5**

At site VES-08, three layers of low resistivity were discovered, indicating the presence of finely ground materials, such as clay/shale with rare sand and has saline to less saline water-bearing potential. The textural analysis of soil collected from trial bore-5 shows one layer of soil (sandy clay) up to 100 ft. in depth (see Table 8). Therefore, the data from the trial bore soil has a low correlation with the VES data. The water collected from trial bore-5 has high salt content, indicated by its high EC and TDS values (see Table 3). This data demonstrates high correlation between VES-08 and the trial bore-5 water data.

| Table 8: Soil texture of Trial Bore-5 | | | | | |
|---|---|---|---|---|---|
| **Depth (ft.)** | **Soil Texture** | | | | |
| | **Silt +Clay** | **Sand %** | **Silt %** | **Clay %** | **Texture Class** |
| 10 | 40.8 | 59.2 | 24.8 | 16 | Sandy clay |
| 20 | 31.2 | 68.8 | 21.2 | 10 | Sandy clay |
| 30 | 29.2 | 70.8 | 21.2 | 8 | Sandy clay |
| 40 | 30.4 | 69.6 | 18.4 | 12 | Sandy clay |

## 4. CONCLUSIONS AND RECOMMENDATIONS

Excluding sites 13 and 19 all sites lack drinkable water. Water samples collected from bore holes at sites 1, 3, 5, 7, and 8, shows saline water because of high EC and TDS i.e. above WHO limits, which in results validate VES findings.

However, at site 13 (**Goth Haji Daad M. Rind Baloch**), three layers were discovered with first, second and third layer lie in the high, medium and low resistivity zone respectively. The first layer had depth of 2.9 m with resistivity value of 17.7 ohm-m. The second (38.2 m deep) and third layer (300 m deep) had resistivity of 6.6 and 1.5 ohm-m respectively. Since out of three layers only first layer of site 13 lies in the high resistivity zone which indicates availability potable groundwater.

At site 19 (**Near Pir Baber Sher village, UC Jhangara-Bajara to Pir Babar Sher village**), top two layers had 24.6 and 19.4 ohm-m resistivity which shows high resistivity zone and ultimately indicates the presence of high-quality groundwater up to 14.2 m depth. Moreover, at same site third and fourth layer had 6.5 and 3 ohm-m resistivity which shows medium and low resistivity zone and eventually shows non potable drinking water up to a depth of 300 m.

To conclude, it is found that most of the groundwater at shallow depths at all sites is non potable. Moreover, due to financial and time constraints this study was limited to few bore holes. Therefore, it is recommended to conduct study at deeper depths which may be carried out by increasing the space between the current electrodes and to include enough trial bores to validate the VES findings. Additionally, other water parameters which are not icluded in this study such as (hardness, analysis of different metals, total coliform, e.coli form *etc*.) must be analyzed.

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## REFERENCES

1. Abdullahi M. G., Toriman M. E., Gasim M. B., "The Application of Vertical Electrical Sounding (VES) for Groundwater Exploration in Tudun Wada Kano State, Nigeria", *Journal of Geology & Geosciences,* Vol. 04, No. 01, 2015.
2. Arain M. B., Kazi T. G., Jamali M. K., Jalbani N., Afridi H. I., Shah A., "Total dissolved and bioavailable elements in water and sediment samples and their accumulation in Oreochromis mossambicus of polluted Manchar Lake", *Chemosphere*, Vol. 70, No. 10, pp. 1845–1856, 2008.
3. WHO, "Health Criteria and Other Supporting Information - Addendum," *Guidelines for Drinking Water Quality*, Vol. 2, p. 127, 1998.
4. Mastoi G. M., Shah S. G. S., Khuhawar M. Y., "Assessment of water quality of Manchar Lake in Sindh (Pakistan)," *Environ. Monit. Assess.*, Vol. 141, No. 1–3, pp. 287–296, 2008.
5. Kazi T. G., Arain M. B., Jamali M. K., Jalbani N., Afridi H. I., Sarfraz R. A., Baig J. A., Shah A. Q., "Assessment of water quality of polluted lake using multivariate statistical techniques: A case study," *Ecotoxicology and Environmental Safety*, Vol. 72, No. 2, pp. 301–309, 2009.
6. Channar A. G., Rind M. A., Mastoi G. M., Almani K. F., Lashari K. H., Qureshi M. A., Mahar N., "Comparison Study of Water of Manchhar Lake with Drinking Water Quality Standard of World Health Organization", *American Journal of Environmental Protection*, Vol. 3, No. 2, p. 68, 2014..
7. Mastoi G. M., Lashari K. H., Palh Z. A., Soomro A. N., Laghari Z. A., Almani K. F., Mastoi G.-e-R. A. W., Abbasi A. R., "Water quality assessment of Manchar Lake during the month of August and November 2011 by analyzing selected trace elements", *African Journal of Pure and Applied Chemistry*, Vol. 8, No. 11, pp. 176–181, November 2014.
8. Ehirim C. N., Nwankwo C., "Quality Assessment

and Evaluation of Groundwater Potentials in Parts of Buruku and Gboko Local Government Area Councils in Benue State," *International Journal of Geosciences.*, Vol. 07, No. 09, pp. 1064–1073, 2016.

9. Arshad M., Cheema J., Ahmed S., "Determination of lithology and groundwater quality using electrical resistivity survey," *International Journal of Agriculture and Biology,* Vol. 9, No. 1, pp. 143–146, 2007.
10. Oseji J.O., Atakpo E A, Okolie E.C., "Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale Delta State, Nigeria", *Journal of Applied Sciences and Environmental Management*, Vol. 9, No.1, pp. 157-160, 2005.
11. Sikandar P., "*Groundwater Management Using Vertical Electrical Sounding Survey and Tubewell Auditing at Farmers' Fields*", PhD Thesis, University of Agriculture, Faisalabad, 2010.
12. Reynolds J.M., "*An Introduction to Applied and Environmental Geophysics*", John Wiley & Sons, 2011.
13. Ullah Z., Junaid M., Ullah R., "Assessment of Groundwater Strata by Resistivity Survey at Specific Locations in District Buner," *Journal of. Earth Science and Climate Change*, Vol. 06, No. 10, 2015.
14. Alile O. M., Ujuanbi O., Evbuomwan I. A., "Geoelectric investigation of groundwater in Obaretin – Iyanomon locality , Edo state , Nigeria," *Journal of Geology and Mining Research*, Vol. 3, No. 1, pp. 13–20, 2011.
15. IS 15736, "Geological exploration by geophysical method (electrical resistivity) - Code of practice [WRD 5: Geological Investigation and Subsurface Exploration]", 2007.
16. Khan G. D., Waheedullah, Bhatti A. S., "Groundwater Investigation by Using Resistivity Survey in Peshawar, pakistan", *Journal of Resource Development and Management*, Vol. 2, pp. 9–20, 2013.
17. Anomohanran O., "Geoelectrical Investigation of Groundwater Condition in Oleh , Nigeria", International Journal of Recent Research and Applied Studies, Vol. 15, pp. 102–106, April 2013.
18. Bairu A., Yirgale G., Gebrehiwot G., "Application of Vertical Electrical Sounding and Horizontal Profiling Methods to Decipher the Existing Subsurface Stratification in River Segen Dam Site , Tigray , Northern Ethiopia," *Environmental Earth Sciences*, Vol. 3, No. 10, pp. 42–55, 2013.
19. Khalil M. H., "Geoelectric resistivity sounding for delineating salt water intrusion in the Abu Zenima area, west Sinai, Egypt", *Journal of Geophysics and Engineering*, Vol. 3, No. 3, p. 243, 2006.
20. Omosuyi G. O., Adeyemo A., Adegoke A. O., "Investigation of groundwater prospect using electromagnetic and geoelectric sounding at afunbiowo, near Akure, Southwestern Nigeria", Pacific Journal of Science and Technology, Vol. 8, No. 2, pp. 172–182, 2007.
21. Bello A. Abdulmajeed, Makinde, and Victor, "All correspondence should be directed to 2 above," vol. 3, no. 2, pp. 36–44, 2007.
22. Yusuf K. A., "Evaluation of roundwater Quality Characteristics in Lagos-City," 2016.
23. Ahmed A. M., Sulaiman W. N., "Evaulation of Groundwater Quality in a Landfill Using Resistivity Survey," pp. 1–6, 1996.
24. El-Qady G., "Exploration of a geothermal reservoir using geoelectrical resistivity inversion: case study at Hammam Mousa, Sinai, Egypt," *J. Geophys. Eng.*, vol. 3, no. 2, pp. 114–121, 2006.
25. Danielsen J. E., Dahlin T., Owen R., Mangeya P., Auken E., "Geophysical and hydrogeologic investigation of groundwater in the Karoo stratigraphic sequence at Sawmills in northern Matabeleland, Zimbabwe: A case history," *Hydrogeol. J.*, vol. 15, no. 5, pp. 945–960, 2007.
26. ABEM, *Instruction Manual, Terrameter LS,* ABEM Product Number 33 3000 95, 2010.
27. Robinson E.S., Coruh C., "Basic exploration Geophysics" John Wiley, 1988.
28. Hassan E., Rai J. K., Anekwe U. O., "Geoelectrical Survey of Ground Water in Some Parts of Kebbi State Nigeria , a Case Study of Federal Polytechnic Bye-Pass Birnin Kebbi and Magoro Primary Health Center Fakai Local Government", *Geosciences Journal*, Vol. 7, No. 5, pp. 141–149, 2017.