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Site selection for Proposed Construction Using the Electrical Resistivity Method and Some Geotechnical Tests of Soil At Al-Nahrawan Area, Baghdad, Iraq

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Abstract

The study site represents an investigation of a proposed construction site in Baghdad City, in the Al-Nahrawan area, using 2D electrical resistivity and some geotechnical tests for soil samples. A Wenner-Schlumberger configuration was used for 4 parallel lines, each line 120 m long, with 1m spacing between electrodes. Interpretation is made by RES2DINV software. The results showed areas with relatively high resistivity caused by mud cracks and low- resistivity caused by water content (wet soil). The groundwater depth ranges from 5.5 to 5.7 m; these values were matched by comparing with nearby wells using a sounder device. Soil samples from different depths ranging from 0.5 to 4 m were analysed, and the samples consisted mainly of clay > 88% with low liquid and plastic limits <50 (USCS). It is classified as CL, which means Low plasticity. The electric method and laboratory tests were effective in identifying the subsurface image.

Keywords: Engineering Site, Geotechnical test, 2D -Electrical Resistivity survey, Al-Nahrawan area.

اختيار موقع للبناء المقترح باستخدام طريقة المقاومة الكهربائية وبعض الاختبارات الجيوتكنيكية للتربة في منطقة النهروان، بغداد، العراق

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الخلاصة

يمثل موقع الدراسة موقع بناء المقترح في مدينة بغداد، منطقة النهروان، أجريت التحريات بواسطة المقاومة الكهربائية ثنائية البعد وبعض الفحوصات الجيوتكنيكية لعينات التربة. استخدم ترتيب فنر-شلمبرجر ل 4 خطوط متوازية، يبلغ طول كل خط 120 متر، وتباعد 1 متر بين الأقطاب الكهربائية. التفسير بواسطة برنامج.RES2DINV أظهرت النتائج ان المناطق ذات المقاومية العالية نسبيا ناتجة عن التشققات الطينية والمناطق ذات المقاومة المنخفضة ناتجة عن المحتوى المائي (التربة الرطبة). وجد أن عمق المياه الجوفية يتراوح بين 5.5-5.7 م، وهذه القيم متطابقة بالمقارنة مع الآبار القريبة باستخدام جهاز الساوندر. حللت عينات التربة من أعماق مختلفة تتراوح من 0.5 إلى 4 أمتار ووجدت أنها تتكون أساسا من الطين بنسبه أكبر

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88 ٪ مع حدود منخفضة من السيولة واللدونة بنسبة اقل من50(USCS) ، وصنفت على أنهاCL ، يعني الطين منخفض اللدونة. كانت الطريقة الكهربائية والاختبارات المعملية فعالة في تحديد صورة ما تحت السطح.

1. Introduction

Building collapses, which have increased throughout the country in recent years, pose serious threats to human life and severe environmental and civil risks. This structural failure and wall cracking result from a weak foundation through the build stage and an inadequate site investigation [1]. Therefore, to design and build a suitable foundation for a structure, it is necessary to conduct a site investigation before beginning construction to identify any structures or weak areas beneath the construction area that may cause undesirable impacts later on. Furthermore, determining the groundwater level is critical because groundwater seepage directly impacts the stability and safety of buildings and foundations.

In recent years, the emphasis has started shifting to geophysical surveys in addition to engineering testing to characterize the subsoil, and numerous attempts have been made to correlate the result of soil engineering testing to electrical resistivity tomography (ERT) data [2-5]. Different geophysical techniques can image the ground regarding rock association, distribution, and structural deformation, which provides credible details concerning the support that a foundation rock is likely to provide for structural engineering [6-8]. The electrical resistivity technique has been the most extensive [9]. Electrical resistivity imaging (ERI) or tomography (ERT) has been demonstrated to be one of the most effective survey techniques used in subsurface investigation because it generates a semi-true subsurface picture of underground structures and identifies the distribution of subsoil conductivities by making measurements on the earth's surface. It gives good results at a low cost in comparison to other methods. The theoretical foundation of the resistivity prospecting method is the electrical potential created by a current flowing into the earth out of a point source. The geophysical resistivity method is based on the earth's response to the electrical current that flows through it. Where lithological and mineralogical homogeneity, as well as variations in soil temperature and water content, affect electrical resistivity [10], and these variables have varying degrees of influence on electrical resistivity. The resistivity survey provides a picture of the distribution of subsurface resistivity, which converts into a geological picture. Therefore, knowing the standard resistivity ranges for various subsurface materials [11].

The electrical resistivity methods have been used to detect weak zones and determine groundwater in many locations in Iraq. These are some of them; 2D resistivity imaging method was applied for engineering studies at the University of Anbar in western Iraq to investigate the subsurface weakness zones by applying a dipole-dipole array with an n-factor of six and a-spacing of 2 and 5 meters [12]. 2-D ERI approach was utilized as a non-invasive method to assess the influence of soil cracks of a centimetric range on the resistivity of sand. The data were obtained on a laboratory scale utilizing an ABEM SAS 300C Terrameter device implemented with a Wenner array [13]. In the Al-Haqlaniyah area of the Western Desert, 2D resistivity imaging has been applied at five locations utilizing a dipole-dipole arrangement and 2 m electrode spacing to gauge the size and depth of the underground caves [14]. The two-dimensional resistivity method using a Wenner-Schlumberger array was applied to explore the groundwater aquifers in southwest Samawah City at a 10-point survey. The survey line at each point is 1200 m, with 120 electrodes placed every 10 m [15].
Current research aims to detect subsurface cavities and buried structures like pipes or buried concrete, measure water table levels, and provide some geotechnical tests, which will be used in the soil investigations report guaranteeing the safe distribution of loads to avoid subsidence or collapse.

2- Location with the geology of the study site

The current location, with an area of about 9200m^2 (Figure 1), is in southeastern Baghdad Governorate, in Al-Nahrawan, 18 km from the city center. The coordinates are listed in Table 1.

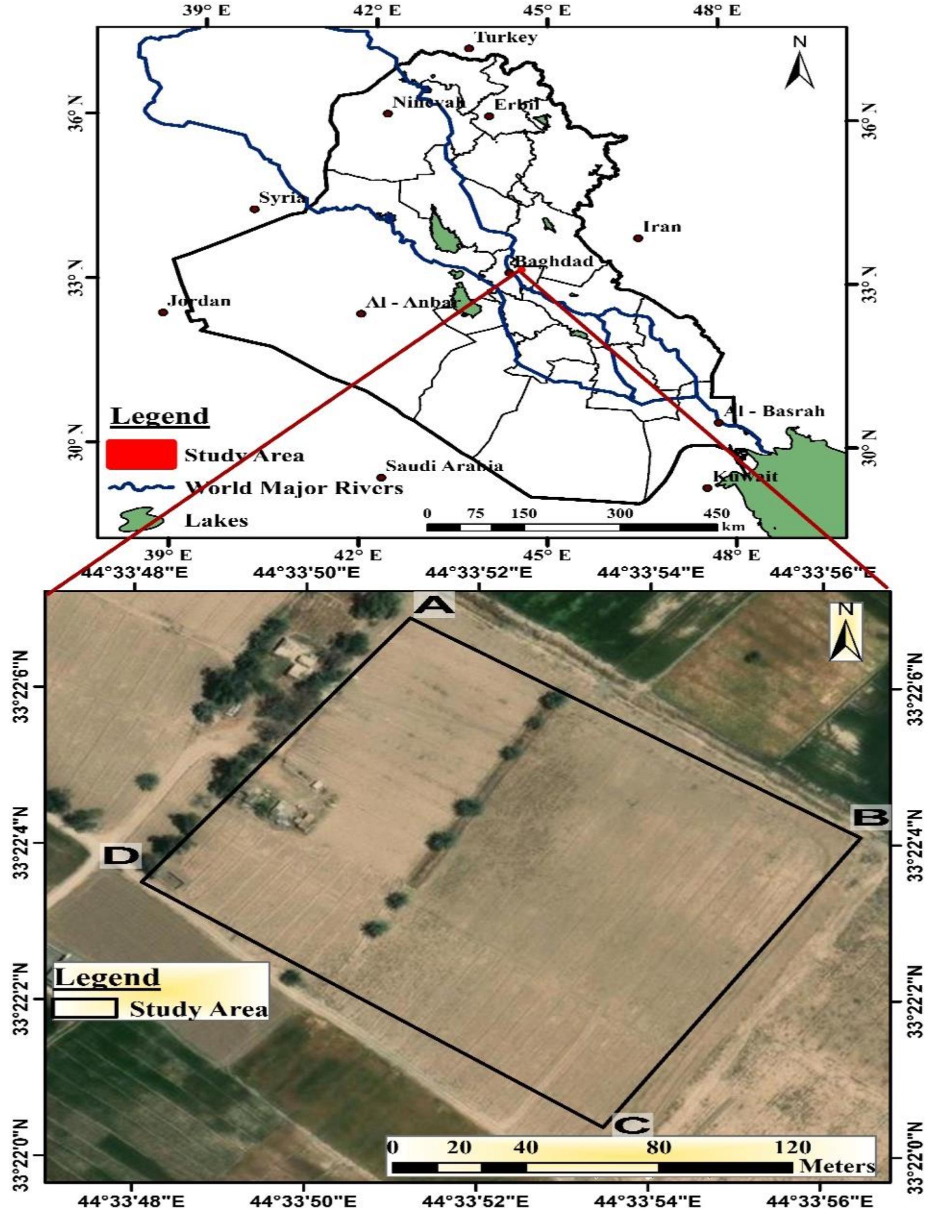

Figure 1: the location map of the study area at Al-Nahrawan area

Table 1: coordinates location in the current study area by GPS

Location of Points	Latitude	Longitude
A	33º22´06 N	44º33´51 E
B	33º22´03 N	44º33´55 E
C	33º22´01 N	44º33´53 E
D	33º22´00 N	44º33´49 E

The site, considered a whole, shows Alluvial deposits of Quaternary sediments for Pleistocene and Holocene deposits [16]. The area covered by Quaternary deposits and exposed Pre-Quaternary rocks is only represented by the Injana Formation of the upper Miocene age [17]. The sediments of floodplain facies are commonly silty clay and clayey silt with thin sand beds or lenses reflecting the effect of small channels of crevasses [18]. The stratigraphic columns in the well near to current area are shown in Figure 2 [19].

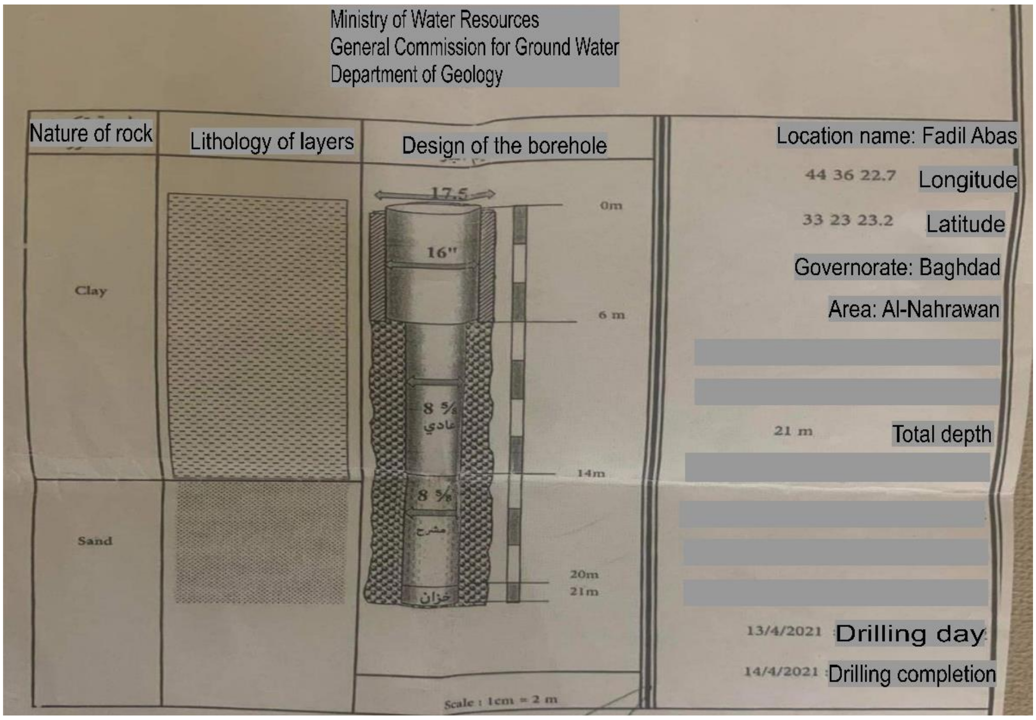

Figure 2: Cross-section of Fadhel Abass's well,2021 in Al-Nahrawan (library of Ground Water, Ministry of Water Resources) [19].

3- Method and material

3-1 Data acquisition and processing

First stage: After conducting a reconnaissance 2D electrical survey of the area and preparing an appropriate plan, a measuring sequence was set up using the ElectrePro Computers software. The fieldwork started on July 26 and continued until July 30, 2022 (Table 2). Four parallel lines were chosen, as shown in Figure 3, so that the local structures or features would allow for accomplishing the given goals and by using an automatic multi-electrode switching system, Syscal Pro, which is a multi-node resistivity device with several uses, including combining the transmitter, the switching unit, and the receiver into a single unit. When the user selects the required settings, the measurements are automatically performed and saved in the internal memory [20]. Data were collected by transmitting an electrical current through various pathways at different depths and measuring the resultant voltages with the Wenner-Schlemberger array. The measurement procedure is defined as an n range from 1a to -6a to avoid theoretical mistakes.

Table 2: shows the summary of electrical survey acquisition geometry for the resistivity data

Line No.	Length (m)	Wenner – Schlumberger	Electrode spacing (m)	Spacing between lines (m)	Direction of survey	Elevation above sea level (m)
Line 1	120	✓	1	20	NW-SE	37
Line 2	120	✓	1	20	NW-SE	37
Line 3	120	✓	1	20	NW-SE	37
Line 4	120	✓	1	20	NW-SE	37

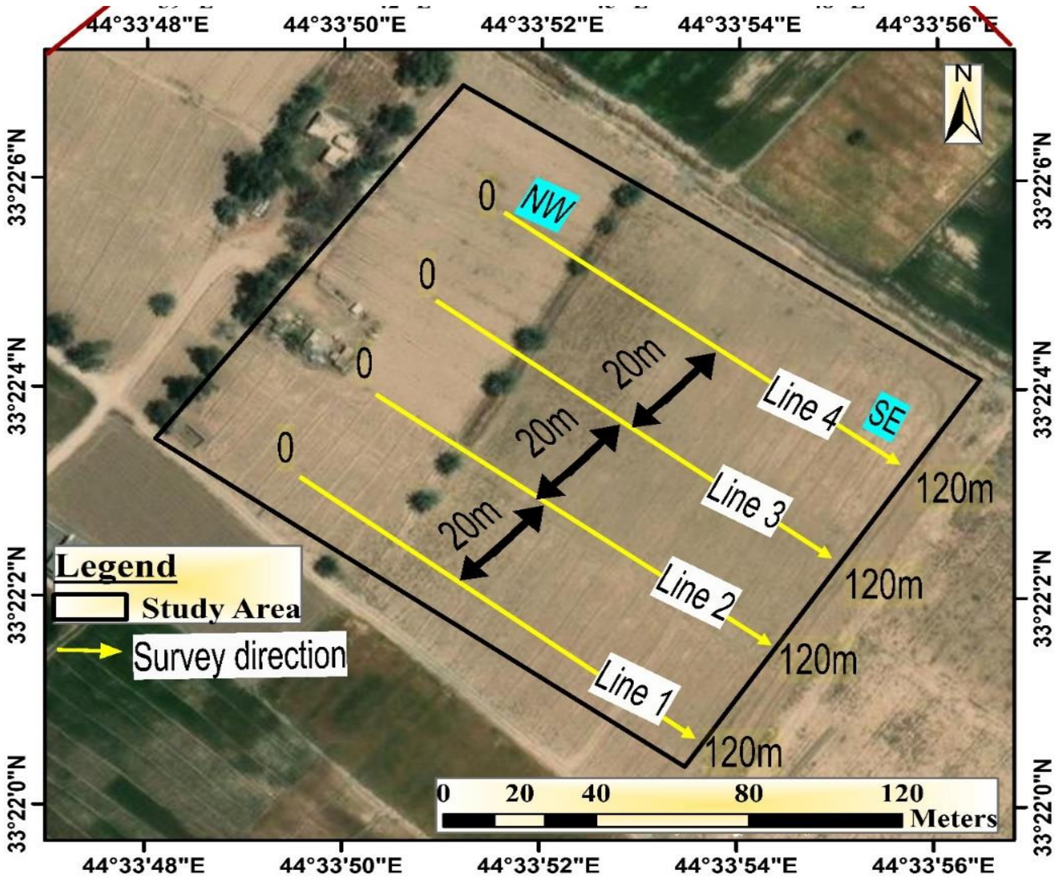

Figure 3: four resistivity lines of the current study showing the spacing between lines, length, and the direction of the survey.

The field data set was transformed into a format that can be readable by processing and modelling software. The RES2DINV program, version 4.8.12, was used to process the electrical resistivity. The program automatically generates a 2D resistivity model for the subsurface from field data measurements [21].

It is not easy to interpret and compare the apparent resistivity profiles. Therefore, it is necessary to invert the calculated apparent resistivity from the forward modelling to compare it with the actual inverted field data. The finite-difference method was used since all lines are positioned on a flat area.

A low initial damping factor of 0.2, a low minimum damping factor of 0, and a flatness filter of 1 was used because the data is not noisy. Because it is more accurate, the inverse method was chosen to use the Gauss-Newton standard, and Robust Inversion Model Constraints were applied to all lines.

Using additional data from various sources to constrain geophysical inversion is one technique to lessen geophysical inversion's non-uniqueness [22] to demonstrate the resistivity image more clearly after determining contrast locations for high and low relative resistivities on inverted sections.

Second stage: The second stage of fieldwork was done, which included collecting soil samples by drilling for 7 pits (5 samples were collected from the surface to 1.5m and another sampling to 4m depth) with an excavator to collect brittle soil samples, as shown in Figure 4. During this stage, seven samples were collected with different depths ranging from 0.5–4 m from line 2 within the sites of electrodes 22–23, representing relatively high resistivity, and line 3 for electrodes 99–100, representing relatively low resistivity, as shown in Figure 4. Then laboratory tests were conducted on selected soil samples to determine or identify some geologic analysis and how it affected resistivity values, which included soil's physical and chemical properties, geotechnical analyses where all the tests were carried out following ASTM standards, including

- Atterberg Limits (L.L, P.L, and PI), using a Gasagrande device in the lab.
- Natural Moisture Content (M.C)
- Grain Size analysis (sieve and Hydrometer testing) [23].

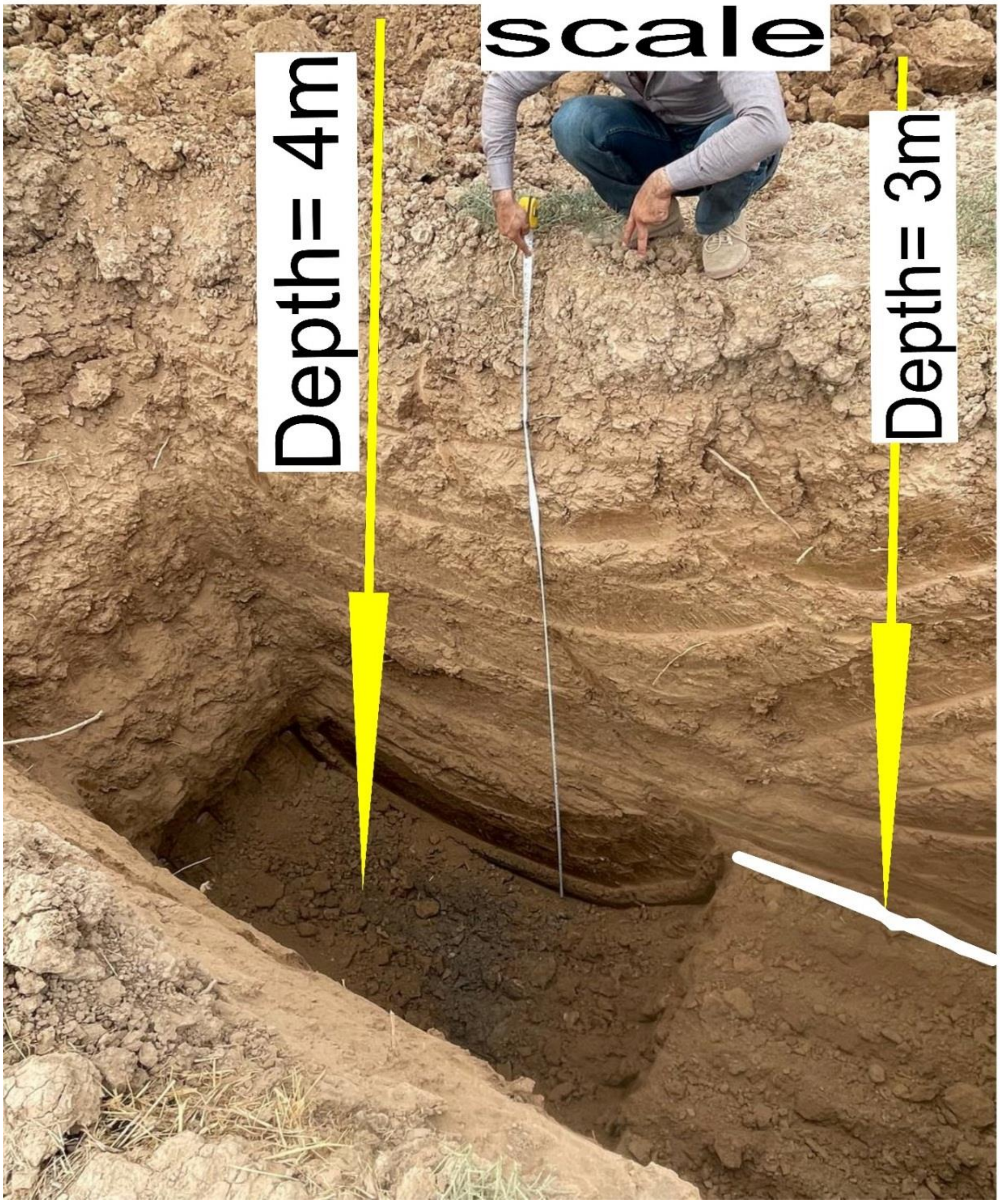

Figure 4: shows the collecting samples, total depth pit for 3 and 4m collecting brittle samples in tubes preparing for laboratory analysis.

Third stage: The final stage of fieldwork was using a sounder device to measure the water table level in two wells located near the study area (Figure 5 and Table 3) (drilled after an electrical survey conducted by normal citizens without notifying the authors). Still, it is also a good opportunity to compare the electrical method with the groundwater level depth measured by a sounder device.

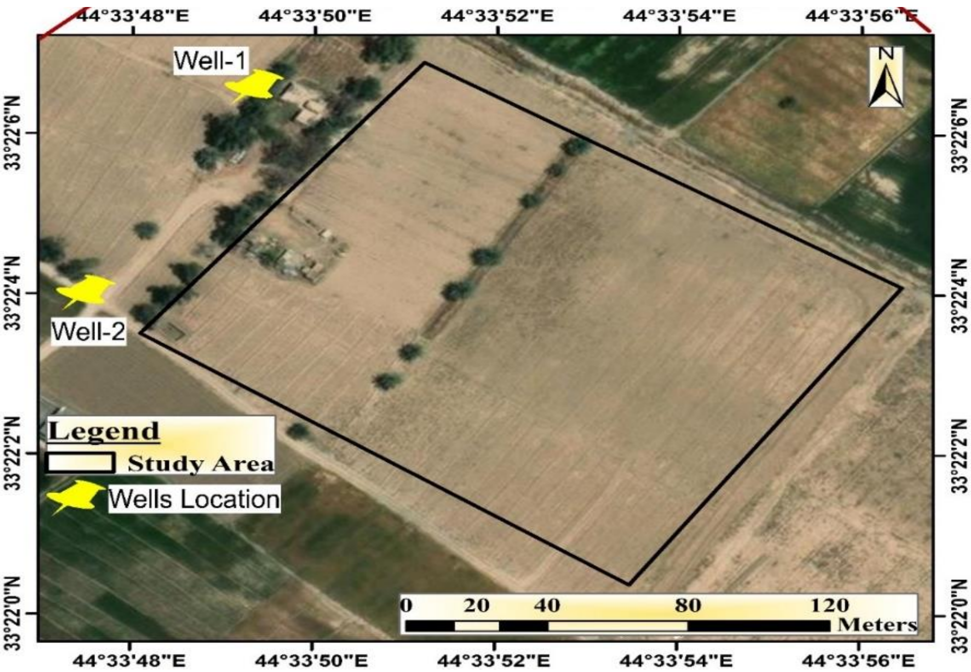

Figure 5: displays map for wells location with elevation 37m above sea level for both wells in the study area

Table 3: coordinate the two wells in the study area

Well no	Latitude	Longitude	Distance from the study area (m)	Total depth (m)	Water level (m)
1	33° 22’ 06”	44° 33’ 49”	60	12	5.50
2	33° 22’ 03”	44° 33’ 46”	50-70	34	5.70

4- Results and discussion

4-1- 2D inversion and modelling

The summary of inverted models for the four lines to be interpreted is shown in Table 4.

Table 4: display some details about inverse model of four lines

Line No.	Max depth investigation	NO. of Iteration	RMS error
1	24.7m	7	1.85%
2	24.7m	7	1.56%
3	24.7m	7	2%
4	24.7m	7	2.1%

A- 2D Resistivity Imaging for Line 1

The resistivity images were verified by comparing them against available geological information nearby the site by drilling using an excavator (Figure 6). According to laboratory analysis of soil samples from different depths, the samples consist of clay mainly using sieve analysis and hydrometer with more than 85%. The water table in the drilled wells at depth ranged between 5.50-5.70m, corresponding to what the electrical method indicated. A zone of high resistivity >45.5 ohms.m is interpreted to be caused by mud cracks seen for distances 1 to around 25 m; the need to process or excavate and remove material to a depth of 0.75 m may cause an engineering problem in the construction. Furthermore, some positions gave high resistivity where the clay was subjected to overburden pressure, particularly beneath electrodes 41 and 42. The zone of low resistivity value (highly conductive) ranged between 2 to approximately 15 ohms.m, extending vertically and horizontally beneath electrodes no 35-120, where increasing groundwater or the presence of a high water concentration with clay. There is a decrease in resistivity values from about 1.5m depth to the saturated zone, and no cavities or gaps are indicated.

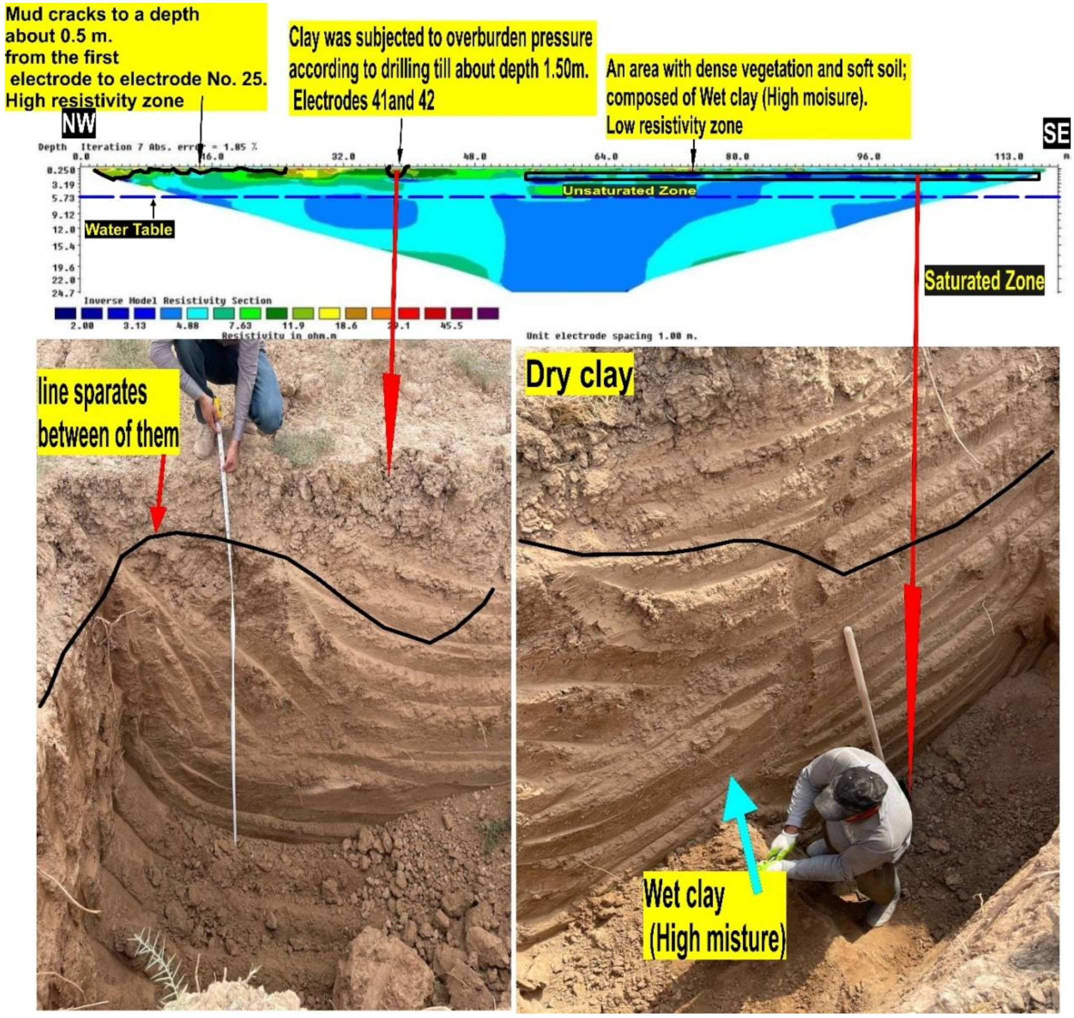

Figure 6: inverted mode for line 1 and show areas of dry and wet clay

B-2D Resistivity Imaging for Line 2

One of the most important effects that necessity be determined before designing a building is the groundwater level because of its relationship with the foundation of the building that drives stand to build (Figure 7). Using the sounder device, it was found that the groundwater level ranged from 5.50 to 5.70 for the two wells. Samples analysis shows that the samples consist mainly of clay over 88%, and sand and silt did not exceed 10% until a depth of 4m, where fine sand and silt increased to 15m. A zone of high resistivity >45.5 ohms.m is interpreted to be caused by mud cracks seen for distances 1 to around 27 m of the line, which need to process or excavated until about 0.75m to avoid an engineering issue, indicating that high resistivity extends from the earth's surface down to a depth of around 1.6 m. Whereas zone of low resistivity values ranging about 2-15 ohms.m occupies the majority of the electrical section, they are distributed vertically and horizontally, interpreted as wet clay and fine sand that appears after roughly 15 m in depth

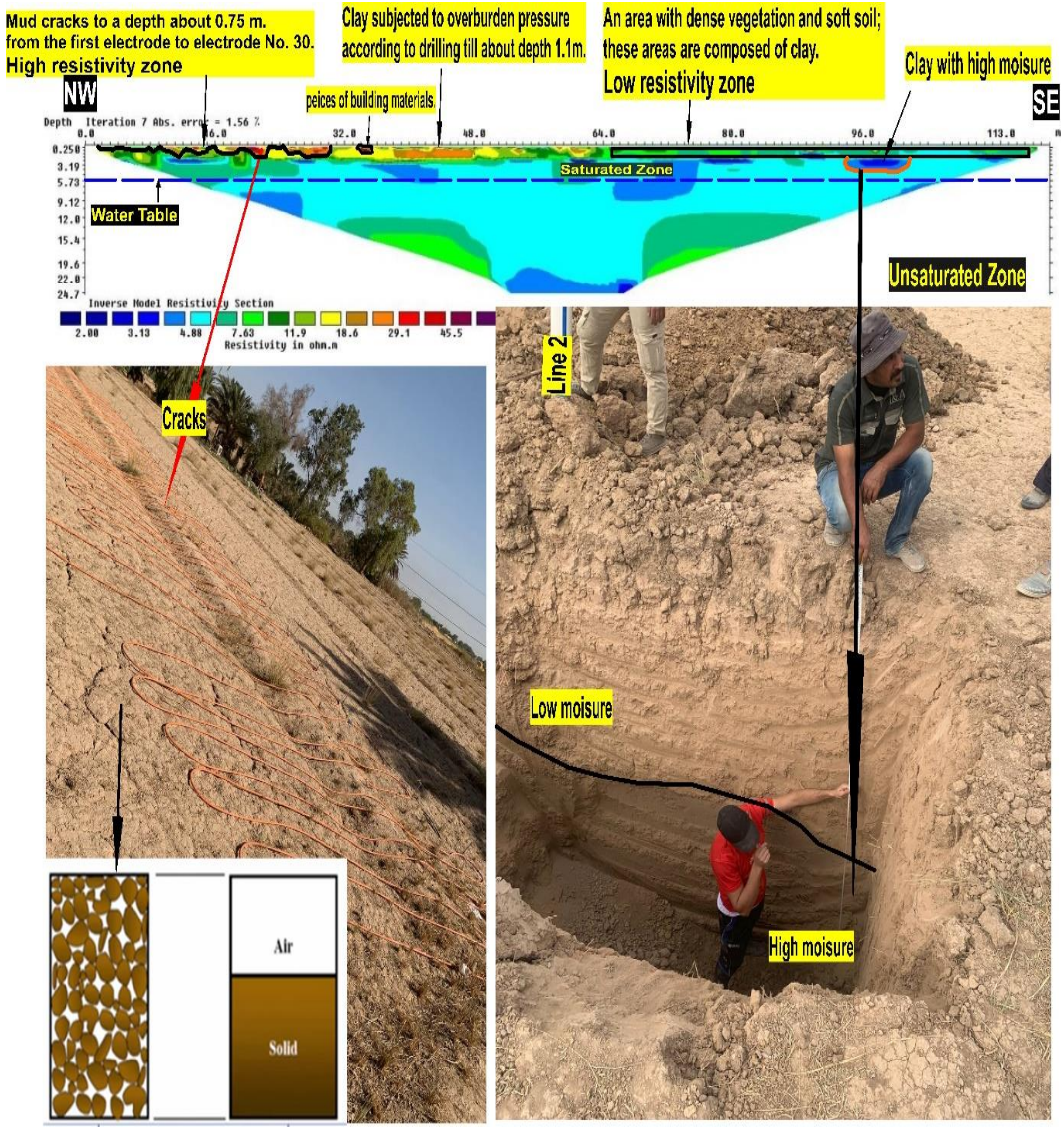

Figure 7: inverted mode for line 2 shows mud cracks areas and dry and wet clay

C-2D Resistivity Imaging for Line 3

The interpretation of subsurface imaging until 4m was proven by laboratory analysis of samples for different locations like electrodes 22 and 96, but after 4 m, according to comparison with drilled boreholes surrounding or near the study area (figure 7). It was found that the groundwater level ranged from 5.50 to 5.70 for two wells using the sounder device. The high resistivity zone was associated with mud cracks that penetrated about 0.75m in depth and dehydration until approximately 1.5m in depth, where the results revealed a range of resistivity values ranging from about 25 to more than 45 ohms.m. The zoning of low resistivity values ranged about 2-15 ohms.m, it was interpreted as clay mostly spread vertically and horizontally, with fine sand appearing after about 12 m in depth. The basis of the engineering issue in the construction might be identified based on these results, which also emphasize the most important electrical method findings.

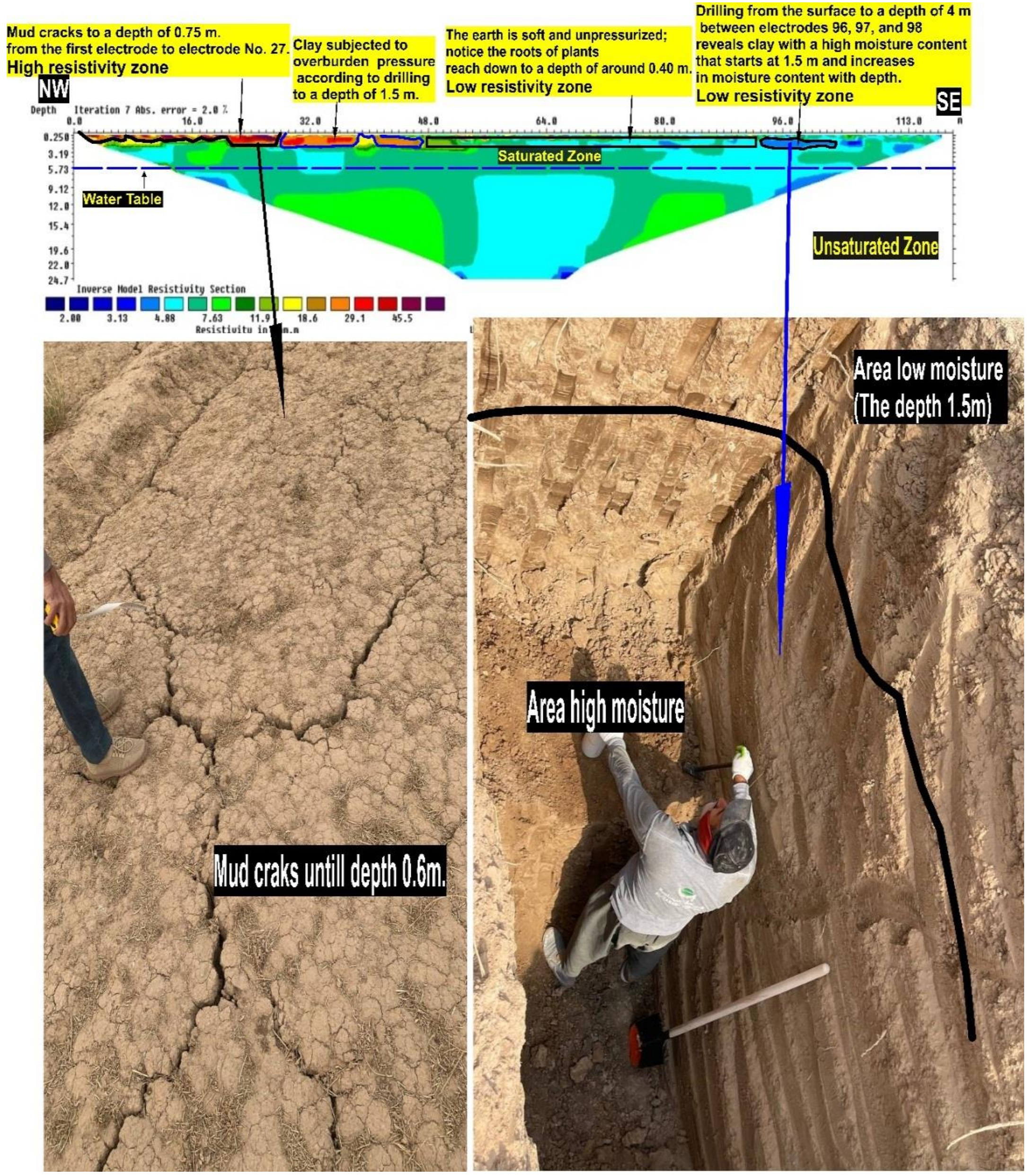

Figure 7: inverted mode for line 3 shows mud cracks areas with dry and wet clay

D-2D Resistivity Imaging for Line 4

Line 4 reflected the subsurface resistivity within the study area. In addition, there is a great similarity in interpreting the subsurface distribution of resistivity values with other lines (Figure 8). The groundwater level for two wells ranged between 5.50 and 5.70 using the sounder instrument. A zone of high resistivity is interpreted as mud cracks. This expanded approximately 27 m from the starting point of the line and achieved a depth of about 0.75 m caused by dehydration where the resistivity values were highest within this zone greater than 55 ohms.m, and it was composed of clay exceeded 88%. The zone of low resistivity values varied about 2-15 ohms.m. This was interpreted as clay distributed vertically and horizontally, with fine sand showing after about 12 m in depth and vegetable remains.

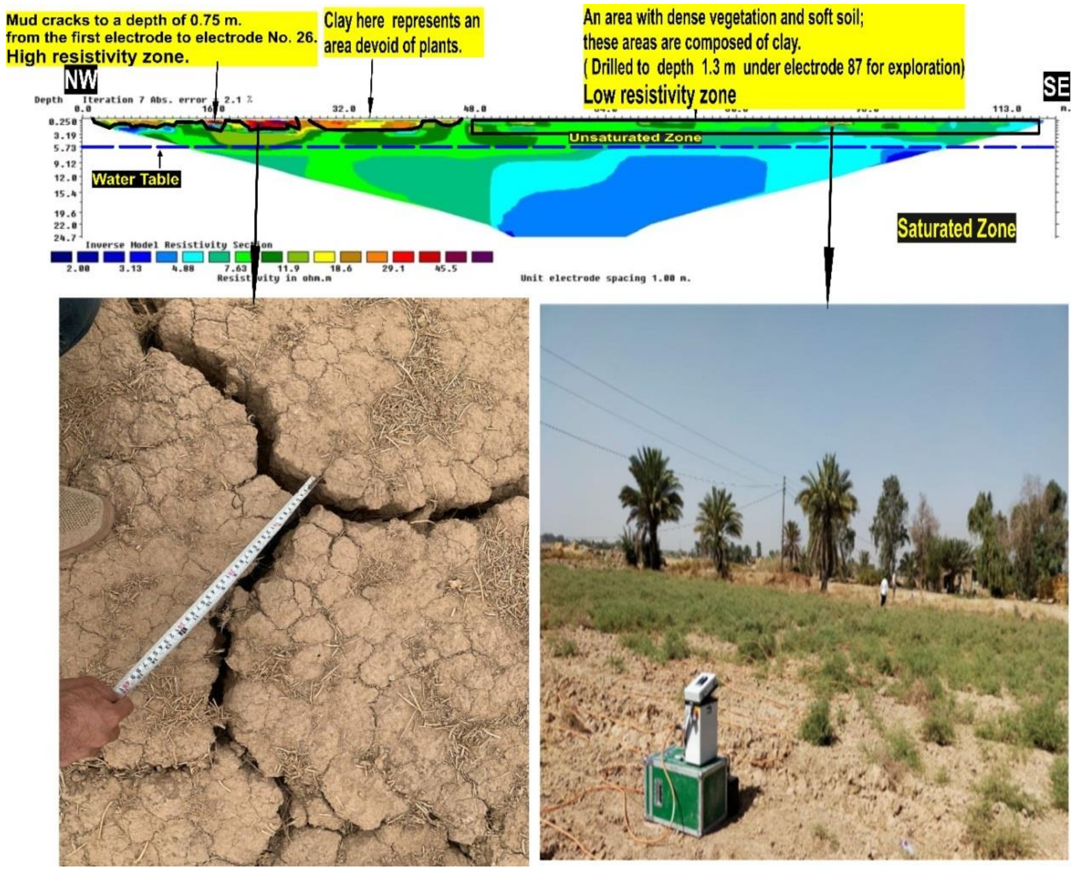

Figure 8: inverted mode for line 4 shows mud cracks areas and dry and wet clay

In summary, electrical resistivity detected no cavities, gaps, or burial structures for four lines. The water table was marked at a depth of approximately 5.5-5.7m, which corresponded to the depth in the nearby wells. After collecting soil samples from different depths of 0.5–4 m and conducting laboratory geotechnical analyses as mentioned in methodology on 7 soil samples, which showed a similarity in results of more than 96%, current samples of two pits representing high and low resistivity were taken, as shown in Tables 5 and 6 [22].

Table 5: shows the laboratory examination for line 1, which represents relatively high resistivity (electrodes 22-23) [22].

sample no	Depth (m)	particle size distribution sieve Analysis & Hydrometer analysis				Index Properties			Sym USCS	Unit Weight	Water content	Specific Gravity
		Clay %	Silt %	Sand %	Gravel %	LL%	PL%	PI%				
1	0.5 - 1	87	10	3	0	40	20	20	CL	21.87	15.5	2.74
2	1.5 - 2	90	8	2	0	42	23	19	CL	21.14	18.5	2.74
3	2.5 - 3	88	9	3	0	44	21	23	CL	20.64	21	2.74

Table 6: shows the laboratory examination for line 3, which represents relatively low resistivity (electrodes 95-97) [22].

sample no	Depth (m)	particle size distribution sieve Analysis & Hydrometer analysis				Index Properties			Sym USCS	Unit Weight	Water content	Specific Gravity
		Clay %	Silt %	Sand %	Gravel %	LL%	PL%	PI%				
1	0.5- 1	89	9	2	0	41	20	21	CL	21.53	16.7	2.74

2	2 - 3	94	6	0	0	43	21	22	CL	21.0	19.2	2.74
3	3.5- 4	92	8	0	0	45	23	22	CL	20.26	23.1	2.74

The percentage of clay in all soil samples is greater than 88%. When the grain size distribution curves were compared to the typical grain size distribution, discovered that the current soil was uniformly graded. The results for engineering revealed that the soils in all samples are low liquid and plastic limits (LL <50%). Based on the Atterberg tests to determine engineering properties for fine soil (by Casagrande) and using the plasticity chart through the relationship between the liquid limits (LL) and the plasticity index (PI) to classify fine soil, it was found that the type of soil is CL, meaning Low plasticity clay, where LL is < 50.

It is possible to classify clay or soil depending on the proportion of its components, and according to this soil tests found that the consistency of the soil is stiff. References indicate that the higher the soil hardness, the higher the bearing capacity. Laboratory tests showed that the soil is inorganic because the percentage does not exceed 2.02%. Activity (A) indicated normal clay (non-expansive clay) according to its value of 0.75–1.25.
Finally, the soil column is shown in Figure 9.

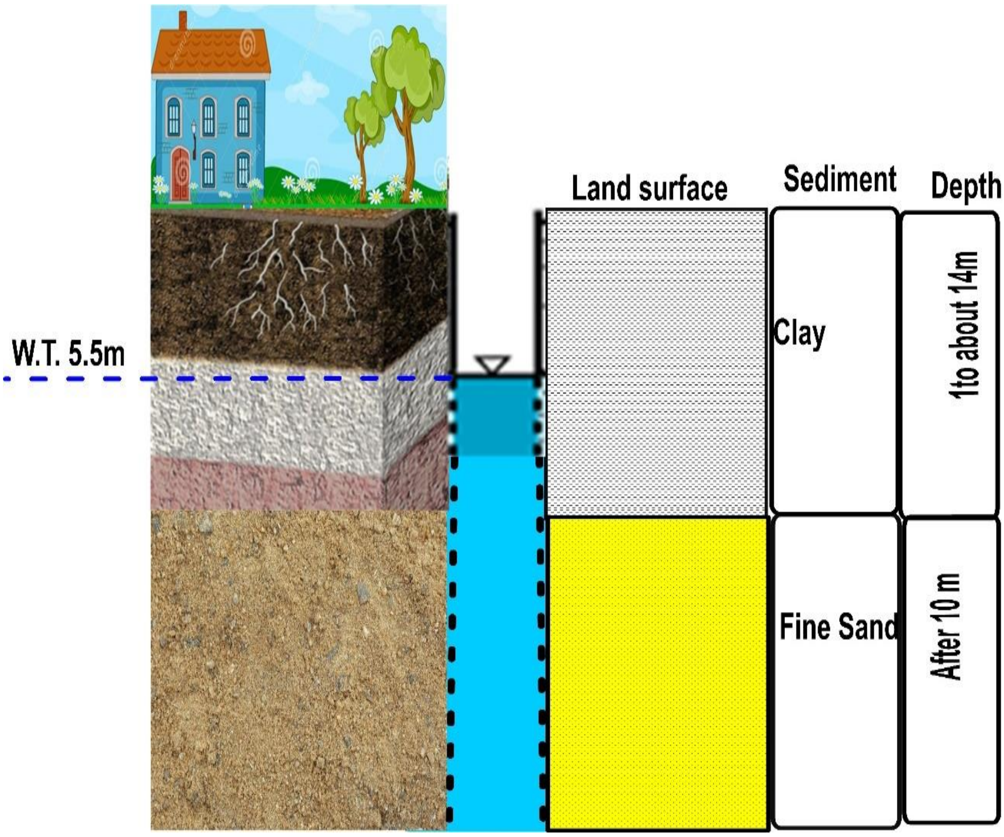

Figure 9: Shows soil column concludes from wells

Conclusions

An important thing in an engineering project before designing the building is to know the groundwater level to determine the proper filter (like a boulder) underneath the building. The electrical method estimates that the water table is between 5 and 6 meters deep, which immediately impacts the foundations' stability and age. It corresponded with the water table in the two wells near the study area, which are about 60 to 70 m from the study area. Areas of low resistivity were interpreted as wet clay, and areas of relatively high resistivity were interpreted as mud cracks, with resistivity values ranging from about 2–45 ohm.m, respectively, where moisture and dehydration all impact electrical resistivity values. Laboratory tests reveal the soil type in the area is mostly clay (more than 88%), an inorganic non-expansive clay (no swelling soil), for many samples that ranged from 0.5-4m in depth. The soil was classified as CL (Low Plasticity) according to Atterberg's limits using the Gasagrande device, where the plasticity index (PI) ranges from 20 to 23 meaning that it is less problematic.

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