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Mapping the Groundwater Potential in Lubuk Buaya Subdistrict, Padang City Using the Wenner Configuration Geoelectrical Method

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ABSTRACT

Population growth and urbanization in Lubuk Buaya Village, Padang City, have increased the demand for clean water, which has not yet been fully met. Most residents still rely on shallow dug wells with turbid and odorous water at depths of 2–3 meters. Water production in Padang City reaches 50,567,776 m³ per year, but only 32,732,482 m³ can be distributed by the Public Water Supply Company (PDAM), highlighting challenges in distribution and service coverage. This study employs a quantitative descriptive approach using field methods. Primary data was obtained through geophysical data acquisition using the ARES system with a Wenner configuration. The data was then interpreted using the Robust Constraint inversion method with the assistance of Res2dinv software. Data interpretation was supported by geological map information and observations of residents' dug wells to identify the types of rock formations and groundwater potential. Groundwater potential in Lubuk Buaya Village varies with resistivity values ranging from 0.18 to 44.1 Ωm, indicating three types of layers: sand and gravel (potentially brackish water), silt (groundwater potential), and alluvial (freshwater aquifer zone). Transects 2, 3, and 4 show groundwater potential, particularly in sand layers with moderate to high resistivity. Transect 2 has a free aquifer in alluvial sand (turbid water). Transect 3 is dominated by sandy silt at the top, with potential for a confined aquifer in alluvial layers at depths >2.5 meters. Traverse 4 has high-porosity alluvial sand (free aquifer, turbid water). Traverse 1 has low potential due to the dominance of silt and brackish water. Groundwater quality is still influenced by the physical properties of the constituent rocks.

Keywords : Geoelectricity, Groundwater, Wenner Configuration, Resistivity, Lubuk Buaya.

I. INTRODUCTION

Water is a primary need for all living things. Population growth and economic activity have led to an increase in water demand, especially in urban areas such as Padang City. Geographically, Padang City is located at coordinates 00° 44' 00" – 1° 08' 35" S and 100° 05' 05'' – 100° 34' 09" E. Padang City has 11 districts, with Koto Tangah being the largest district, covering an area of 232.25 km². In the Lubuk Buaya sub-district of Koto Tangah, rapid residential development alongside population growth from 167,791 people (2012) to 203,475 people (2022) has contributed to high demand for clean water [14]. Therefore, efforts to identify and map the potential of groundwater resources are crucial to support sustainable water availability.

Outside of PDAM services, the people of Padang City, including those in Lubuk Buaya Village, manage their own clean water supply through dug wells, bore wells, PMA, and PAH. However, the availability of clean water in this area remains a challenge, as shallow dug wells of 2–3 meters yield cloudy and smelly water. Clean water production in Padang City reaches 50,567,776 m³ per year, while PDAM's distribution capacity is only 32,732,482 m³, resulting in a shortage of 17,835,294 m³ [15]. This discrepancy indicates challenges related to distribution efficiency.

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Lubuk Buaya Village, with its alluvial lithology, has varying groundwater potential. This geological condition is important to study because alluvial rocks can store groundwater if there is an impermeable layer beneath them [8]. However, the current groundwater information, from small-scale geological maps and unintegrated community well data, does not provide a comprehensive picture of the groundwater conditions in the area.

The availability of groundwater varies at different depths, depending on local geological conditions such as rock type, soil structure, and subsurface water flow patterns. Although groundwater is abundant, the community needs information about its availability for proper utilization without damaging the environment [11]. Therefore, identifying the potential of groundwater in Padang City is very important so that it can be clearly known in each area. In general, groundwater is defined as water originating from soil layers, including water in unsaturated soil layers and water in saturated soil layers. Water in unsaturated soil layers (soil water) supports vegetation on the surface. Groundwater is typically found in aquifers, which are rock layers that can be utilized as water sources such as wells or springs [6]. The presence of aquifers depends heavily on the type and structure of the rock layers, where porous and permeable rocks like sand and gravel generally serve as good media for storing groundwater. Therefore, information about the presence of groundwater is essential.

Previous research conducted in Padang City has applied geophysical techniques for a range of subsurface mapping objectives. Among the approaches used is the smoothness-constrained least-squares inversion applied to geoelectrical data with a Schlumberger configuration at Universitas Negeri Padang [5]. Furthermore, the liquefaction behavior of sandy soils in the area has been investigated using microtremor analysis. From a technical perspective, enhancements in the accuracy of geoelectrical data in West Sumatra have been pursued through the implementation of both smoothness-constrained least-squares inversion and robust constraint methods, particularly for the early detection of potential landslide hazards.

The geoelectrical method is widely recognized as an effective technique for identifying subsurface groundwater potential. It is commonly employed in exploration due to its relatively simple implementation and the high sensitivity of rock resistivity to water content [9]. Data acquisition is typically carried out using the Wenner configuration, in which the spacing between current electrodes and potential electrodes is equal [17]. This configuration is preferred because of its strong sensitivity to vertical resistivity variations, making it particularly effective for detecting aquifer layers and groundwater presence at specific depths [12]. In addition, the Wenner array provides good signal quality, as both current and potential electrodes are evenly spaced.

In Padang City, studies have predominantly focused on the mitigation of geological hazards such as landslides and liquefaction, or have been limited to structural analysis of rock formations in specific areas. To date, information regarding groundwater potential in Lubuk Buaya remains partial, as it relies mainly on small-scale geological maps and community well data that have not been systematically integrated. This study employs the geoelectrical method using the Wenner configuration, combined with the Robust Constraint inversion technique, to comprehensively map groundwater potential in Lubuk Buaya Subdistrict.

This study provides important insights into groundwater potential as a vital resource for sustaining daily water needs. The findings contribute not only to the mapping and assessment of groundwater resources but also to the clear differentiation between aquifer layers containing brackish water and alluvial deposits that store fresh water. Subsurface lithology and aquifer characteristics are interpreted based on variations in measured resistivity values. These results offer a scientific basis for sustainable development planning in the context of rapid population growth and urbanization. Furthermore, the availability of accurate and up-to-date data enables stakeholders, including local communities, government authorities, and relevant institutions, to develop more effective and informed water management strategies. Ultimately, this study supports efforts to ensure long-term water availability, mitigate the risk of future water scarcity, and promote environmental sustainability and societal well-being.

The geophysical method is a geophysical method that is widely used to investigate subsurface structures [3]. This method is carried out by using direct electric current injected through two current electrodes into the earth, then observing the potential formed through two potential electrodes located elsewhere [17]. The geophysical method is one of the most effective techniques for identifying subsurface groundwater potential. This method is often used in exploration because it has a simple technique and the resistivity of the rock is highly sensitive to water content [9]. The resistivity of subsurface rock types can be explored using the resistivity geophysical method [1]. The physical principle of the resistivity geophysical method is Ohm's Law. Ohm's Law is mathematically formulated through the following equation:

$$V = I.R \qquad (1)$$

This gives us the apparent resistivity value.

$$\rho = K\frac{V}{I} \qquad (2)$$

Increasing the depth can be achieved by increasing the distance between the current electrodes from a small distance at the beginning to a large distance at the end. Electrode arrays are used to measure current or voltage. Therefore, the actual resistivity of the subsurface can be estimated based on measurements below the earth's surface [4]. Data acquisition is performed using the Wenner configuration, where the distance between the current electrodes and the potential electrodes is the same (Figure 1 [17]). The Wenner configuration is used to measure resistivity values in the literal direction, to distribute the rock structure horizontally [2]. This configuration was chosen because it has high sensitivity to vertical resistivity variations, making it effective for detecting aquifer layers and the presence of groundwater at specific depths [12]. Additionally, the Wenner configuration produces good signal quality because the current and potential electrodes are equidistant.

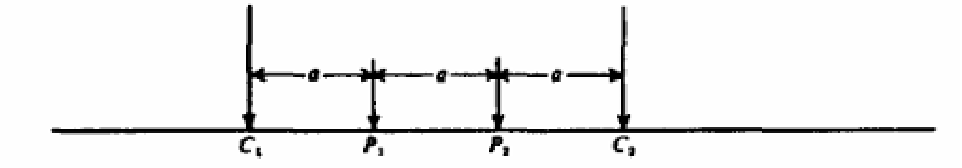

Figure 1. Electrode arrangement Wenner configuration on resistive soil

The geometric factor in the Wenner configuration can be written as equation 6:

$$K = \frac{2\pi}{[(\frac{1}{r_1}-\frac{1}{r_2})-(\frac{1}{r_3}-\frac{1}{r_4})]} \qquad (3)$$

So, the geometric factor of the Wenner configuration is:

$$K = 2\pi a \qquad (4)$$

Description:

K : Geometric factor (the amount of correction of the position of the two potential electrodes relative to the position of the current electrode).

r_1 : Distance frome the positive electrode (current) C_1 to the positive electrode (potential) P_1.

r_2 : Distance from the positive electrode (potential) P_1 to the negative electrode (potential) P_2.

r_3 : Distance from the positive electrode (current) C_1 to the negative electrode (potential) P_2.

r_4 : Distance from the negative electrode (potential) P_2 to the negative electrode (current) P_2.

ρ_a : Apparent resistivity

V : Voltage (Volt)

I : Injected current (Ampere)

Measured resistivity is a pseudo-resistivity where the distribution of actual resistivity from pseudo-resistivity to depth is estimated using the inversion method [5]. Inversion is used to distinguish between measured and calculated pseudo-resistivity values. The approach used for processing geophysical data is the Robust Constraint inversion approach [10]:

$$(J^T J + \lambda F_R)\Delta q_k = J^T R_d g - \lambda F_R q_k \qquad (5)$$

Where : *Jacobian* matrix of partial derivatives, R_d : weighting factor to sharpen the boundaries between layers, λ: damping factor that serves to accelerate the convergence process, Δq : vector of model parameter changes, Δq_k : the parameter change vector at the iteration k, λF_R to help prevent unstable solution and g : the *discrepancy* vector, which is the vector of mismatch between measurement resukt and the model or the vector of difference between the values of measurement resistance and calculations [13].

Data interpretation using Robust Constraint inversion to simplify the data processing process, thereby improving the accuracy of research data interpretation. In this study, rock layers were identified based on their resistivity values, with groundwater layers marked by low resistivity due to their conductive nature. The interpretation results are supported by secondary data such as geological maps, boreholes, and field conditions to maximize their effectiveness. Supporting parameters for groundwater potential analysis include subsurface lithology, aquifer type, and sandstone layer characteristics.

This research plays an important role in providing insight into the potential of groundwater as a crucial resource for meeting daily needs. The results not only help map and evaluate groundwater resources, but also form the basis for sustainable development planning amid population growth and urbanization. With accurate and up-to-date data, various parties such as the community, government, and related institutions can formulate more effective water management policies. It is hoped that this will ensure water availability, prevent future water crises, and support environmental sustainability and community well-being.

II. METHOD

This study was conducted by analyzing primary data obtained from field data using the Wenner Configuration Geophysical Method. This study is also quantitative in nature, meaning that data collection was carried out directly in the field to obtain detailed information about subsurface geological characteristics, such as rock types, as well as the potential for groundwater. Field data was obtained in the form of current strength (A), potential difference (V), and electrode spacing (a). The orientation of the survey lines was arranged parallel and perpendicular to the presumed groundwater flow direction to provide a clearer representation of aquifer distribution.This research was conducted in Lubuk Buaya Village, Koto Tangah District, Padang City. Data collection used an Automatic Resistivity System instrument with 4 measurement lines as shown in Figure 2. The line length was 155 meters with an electrode spacing of 5 meters. The orientation of the survey lines was arranged parallel and perpendicular to the presumed groundwater flow direction to provide a clearer representation of aquifer distribution. This study was conducted in three stages, namely:

a. Preparation Stage

There are several things to do during the preparation stage. First, a literature review is used to study supporting theories about the research from various sources such as books, journals, and various reports from previous studies that are still relevant to the research topic. Second, an initial survey of the measurement area or research location is conducted to determine the length of the path and the spacing of the electrodes used during measurement (Figure 2) and to understand the geological conditions of the measurement area. The purpose of this survey is to obtain a clear picture of the research area. Third, prepare the tools and materials before conducting the research.

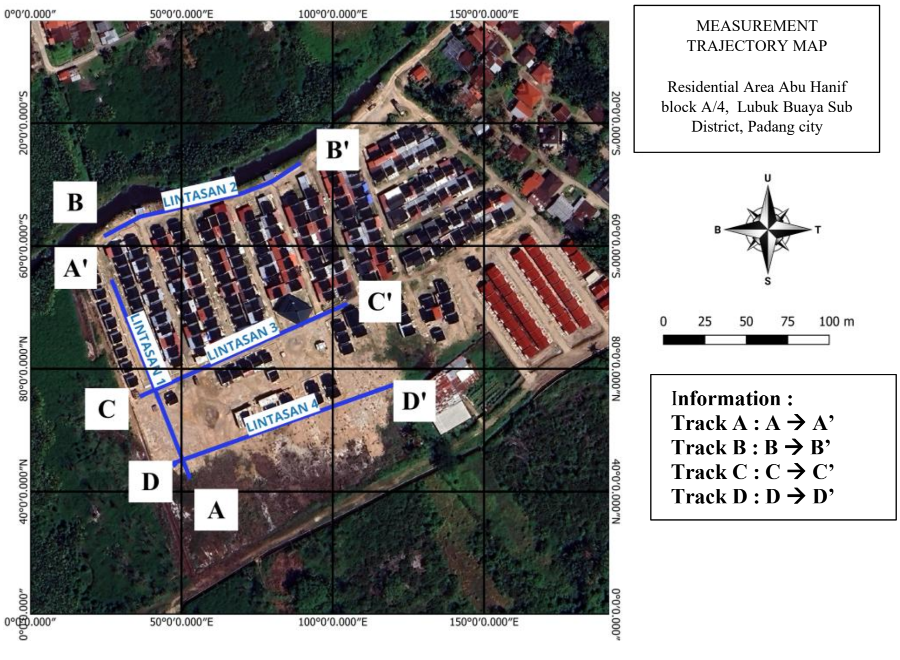

Figure 2. Measurement Line Map

In Figure 1, point A is the starting point at coordinates $0^\circ\ 49'26''LS\ 100^\circ\ 18'54''BT$ on route 1. Point A' is the endpoint at coordinates $0^\circ\ 49'24''LS\ 100^\circ\ 18'53''BT$ on route1. Route 2 B starting point at coordinat $0^\circ\ 49'23''LS\ 100^\circ\ 18'53''BT$ on route 2. Point B' is the endpoint at coordinates $0^\circ\ 49'21''LS\ 100^\circ\ 18'57''BT$ on route 2. Track 3 C is the starting point at coordinates $0^\circ\ 49'26''LS\ 100^\circ\ 18'55''BT$ on track 3. Point C' is the endpoint at coordinates $0°\,49'24''LS\ 100°\ 18'58''BT$ on route 3. Track 4 D starting point at coordinatest $0°\,49'28''LS\ 100°\ 18'54''BT$ on track 4. Point D' is the endpoint located at coordinates $0°\,49'26''LS\ 100°\ 18'59''BT$ on route 4.

b. Data Collection Stage

The data collection stage involves preparing a measurement path in the form of a straight line according to the depth to be reached. The length of the path and the electrode spacing are measured, then electrodes are planted at each spacing. Connect the current source to the electrode cable. Next, activate ARES and ensure the battery is fully charged. After that, calibrate ARES and select the configuration to be used, then proceed with the measurement.

c. Data Analysis Methods

Data analysis techniques were performed by analyzing primary data obtained from field data using the Wenner Configuration Geophysical Method. The data obtained were current strength (I), potential difference (V), and electrode spacing (a). Due to the large amount of data, Microsoft Excel was used to obtain the resistivity value ρ_a and the K value.

Another important consideration is the use of GPS for elevation measurement and a compass for wind direction. This method enables the determination of variations in subsurface resistivity values. Anomalies in this study are expected to show low resistivity values, indicating the presence of groundwater. The objectives of this study are to detect groundwater and rock types beneath the surface, as well as their resistivity values.

III. RESULTS AND DISCUSSION

The measurement data were interpreted using Robust Constraint Inversion with the help of Res2dinv software for 21 iterations. The data interpretation results were in the form of a 2D cross-section model of the subsurface based on variations in resistivity. Variations in resistivity values can be seen in different color images with specific layer depths corresponding to resistivity values. Based on the research conducted in Lubuk Buaya, groundwater potential varies depending on resistivity values (0.18–44.1 Ωm), depth, and subsurface lithology, which consists of sand and gravel, silt, and alluvial deposits. Survey lines 2, 3, and 4 indicate better groundwater potential due to the presence of alluvial sand layers acting as aquifers, although the water quality tends to be turbid. In contrast, line 1 shows lower potential due to the dominance of silt and indications of brackish water. Overall, geological conditions and groundwater quality are strongly influenced by the types of constituent rocks.

To improve the accuracy of the interpretation results, data from observation wells owned by residents around the research location is very helpful. Data from observation wells, such as groundwater depth, types of exposed rock layers, and aquifer thickness, can be used to match the results of 2-dimensional cross-section interpretation. The consistency between field data and interpretation results indicates that the geophysical method effectively represents subsurface hydrogeological conditions, particularly in identifying water-bearing layers and layer boundaries. Groundwater potential can be estimated by determining the hydrogeological characteristics of an area, such as subsurface resistivity, rock porosity, and the presence of aquifers [16]. The measurement data is processed through an inversion process to generate a two-dimensional mapping of aquifer distribution, thereby assisting in determining exploration locations and sustainable groundwater management. The following is an explanation of the 2D cross-section results from measurements in the Abu Hanif residential area, Block A/4, Lubuk Buaya Village, Koto Tangah District, Padang City.

A. Result

a. Track 1

Field data measurement was conducted on track 1 starting from $0°\,49'27''LS\ 100°\ 18'54''BT$ until $0°\,49'24''LS\ 100°\ 18'53''BT$.

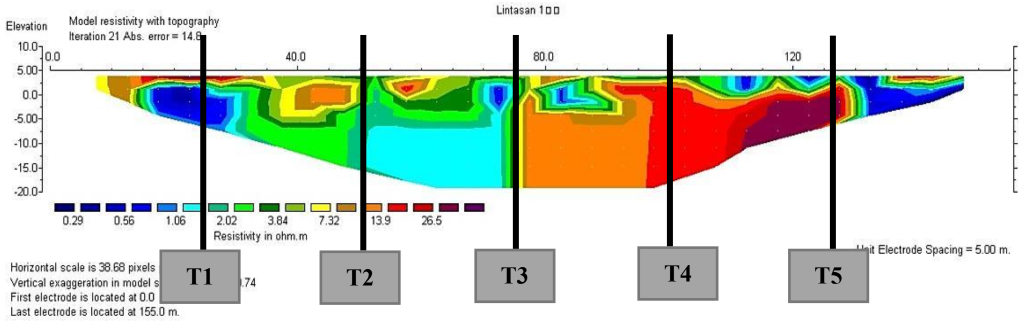

Figure 3. 2D Resistivity Model Cross-Section of Line 1

Figure 3 shows a cross-section of the 2D resistivity model of Track 1 using Robust Constraint inversion with the help of Res2dinv software, with an error percentage of 14.8% obtained at the 21st iteration. The maximum depth detected was 25 meters. The distribution of resistivity values for Type 1 ranges from 0,29 – 26,5 Ωm.

b. Track 2
Measurement of track 2 starts from coordinates $0°\ 49'23''S\ 100°\ 18'53''T$until $0°\ 49'21''S\ 100°\ 18'57''T$.

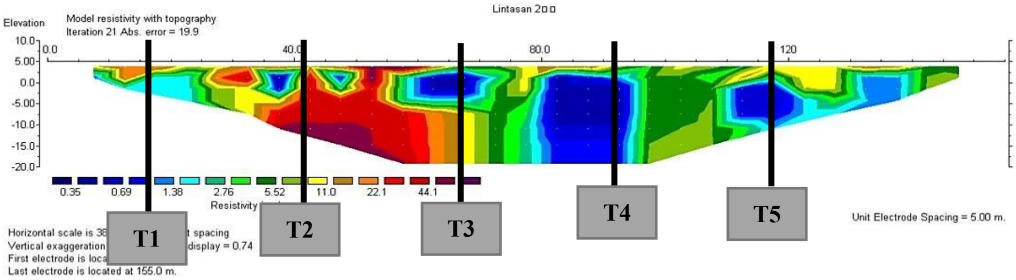

Figure 4. 2D Resistivity Model Cross-Section of Line 2

Figure 4 shows a cross-section of the 2D resistivity model of Track 2 using Robust Constraint inversion with the help of Res2dinv software. The error percentage obtained in the 21st iteration was 19.9%. The maximum depth detected was 25 meters. The distribution of resistivity values for Track 2 ranged from 0,35 – 44,1 Ωm.

c. Track 3
Measurement of track 3 starts from coordinates $0°\ 49'26''S\ 100°\ 18'54''T$ until $0°\ 49'24''LS\ 100°\ 18'58''BT$.

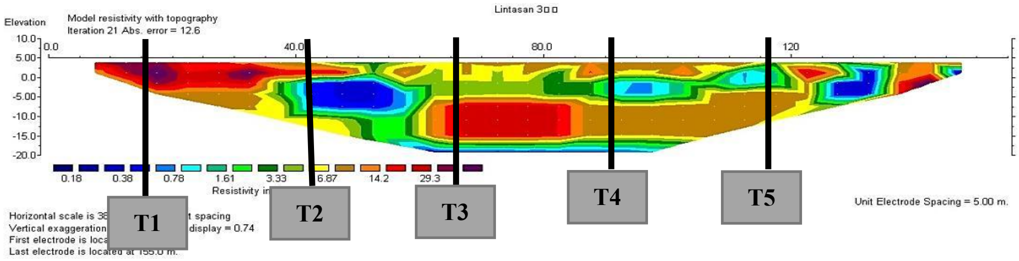

Figure 5. 2D Resistivity Model Cross-Section of Line 3

Figure 5 shows a cross-section of the 2D resistivity model of Track 3 using Robust Constraint inversion with the help of Res2dinv software. The error percentage obtained in the 21st iteration was 12.6%. The maximum depth detected was 25 meters. The distribution of resistivity values for Track 3 ranged from 0.18 – 29.3 Ωm.

d. Lintasan 4
Measurement of track 4 starts from coordinates $0°\ 49'28''S\ 100°\ 18'54''T$ until $0°\ 49'26''S\ 100°\ 18'59''T$.

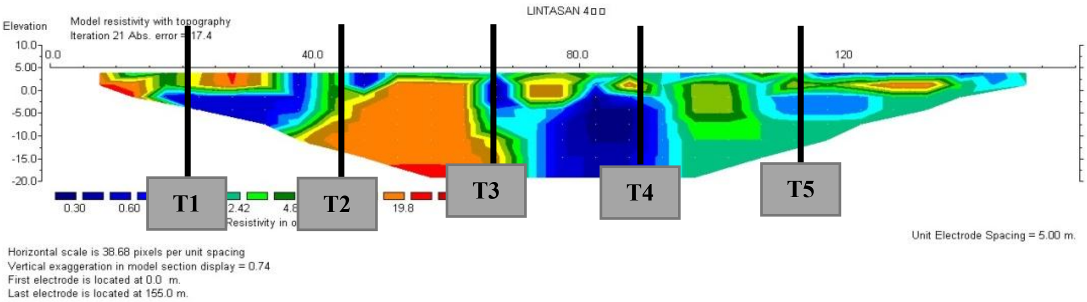

Figure 6. 2D Resistivity Model Cross-Section of Line 4

igure 6 shows a cross-section of the 2D model of the Lintasan 4 resistivity using Robust Constraint inversion with the help of Res2dinv software. The error percentage obtained in the 21st iteration was 17.4%. The maximum depth detected was 25 meters. The distribution of the Lintasan 4 resistivity values ranged from 0.30 – 39.9 Ωm.

B. Discussion

Groundwater is one of the most important natural resources for human life. The potential of groundwater can be interpreted using the Geophysical Resistivity method. Geophysical measurements in the study area at the Abu Hanif Residential Area Block A/4, Lubuk Buaya Village, Koto Tangah Subdistrict, Padang City, revealed variations in subsurface resistivity values, indicating the presence of different subsurface rock layers. Based on the interpretation results, zones with low resistivity values were identified and interpreted as aquifer layers. These results align with geological map information [18], which indicates that the Lubuk Buaya Village area is dominated by alluvial deposits with potential aquifer characteristics. Additionally, data from nearby dug wells indicate groundwater levels at depths of 2.5–3 meters.

On track 1, a two-dimensional cross-section estimated the presence of layers beneath the surface, including sand and gravel, with a low resistivity range of 0.29-1.06 Ωm. Sand and gravel rock types were found at a depth of 2.5-12 meters with a thickness of 9.5 meters at a measurement point along a 25-meter length. The low resistivity values indicate the potential presence of groundwater containing brackish water. This layer has the potential to serve as an aquifer but poses a risk of low water quality. Resistivity values <1 Ωm do not include freshwater. Sandy silt with resistivity values ranging from 2.02 to 7.32 Ωm at a depth of 2.5 meters with a thickness of approximately 2.5 meters along the 25-meter measurement point. These results indicate that the presence of groundwater in this layer is supported by the location of dug wells 7 and 8 near the 1st cross-section, where turbid water was found at a depth of 2.5 meters. This layer is highly susceptible to high water content (water saturation). Alluvial deposits have a resistivity range of 13.9–26.5 Ω at depths of 0–2.5 meters, 0–2.5 meters, and 2.5–12.5 meters at measurement points 25 meters, 100 meters, and 125 meters. Alluvial rock can store groundwater if there is impermeable rock beneath it [8]. Alluvial rock is a good aquifer because it has high porosity for storing groundwater.

On track 2, a two-dimensional cross-section estimated sandstone and gravel with low resistivity values of 0.35–1.38 Ωm at a depth of 10–15 meters with a thickness of 5 meters at the 125-meter measurement point. These results indicate the potential for an aquifer but containing brackish water. A layer of wet, soft sandy siltstone was found at a depth of 0–7 meters, indicating that this layer is highly susceptible to high water content (water-saturated). At a depth of 1–25 meters, an alluvial layer of sand was found, indicating the potential for a higher-quality aquifer compared to the water-saturated sand and gravel layers. Alluvial is a good aquifer because it has high porosity for storing groundwater. Around the route 2 location, wells 5 and 6 (Table 3) have a depth of 2-2.5 meters with turbid water, indicating that the sand layer can convey water, but there is still contamination from the surface or sand mixed with silt, causing a decline in water quality.

On the 3rd cross-section, two-dimensional estimates indicate the rock type as sand and gravel with low resistivity values ranging from 0.18 to 0.78 Ωm at depths of 9–12.5 meters, 22.5–25 meters, and 22.5–25 meters at the 50-meter measurement point, 75 meters, and 100 meters, with a thickness ranging from 2.5 meters. These results indicate the presence of brackish groundwater. This layer is suitable as an aquifer due to its high porosity and permeability, enabling it to store and transport large volumes of water. However, the low resistivity of the groundwater in this layer indicates that the water is unsuitable for use. Moderate resistivity is found in the sandy silt layer, indicating low permeability with high porosity, and the groundwater potential in this layer is highly susceptible to high water content (water saturation). In line with the vicinity of Route 3, Wells 3 and 4 have a depth of 2–2.5 meters with turbid and odorous water conditions. High resistivity was found in the alluvial rock layer:

silt, gravel, and sand, indicating the potential for a confined aquifer zone with better water quality, likely at depths greater than 2.5 meters. Alluvial rock can store groundwater if there is impermeable rock beneath it. Alluvial rock is a good aquifer because it has high porosity for storing groundwater.

On the 4 cross-sections of the 2-dimensional profile, the rock types are estimated to consist of 3 types: sand and gravel with low resistivity values of 0.30–1.20 Ωm at depths of 6–10 meters, 0–3.5 meters, 9–25 meters, 0–2 meters, and 7–12.5 meters at measurement points 25 meters, 50 meters, and 125 meters. These results indicate the presence of brackish groundwater. The type of rock layer, which is wet sandy silt with moderate resistivity, indicates the presence of an aquifer. Rock type with high resistivity Alluvial: the sand layer has high porosity and adequate permeability. This rock has groundwater flow and has the potential to become a free aquifer based on data from wells 1 and 2 at a depth of 3 meters, but the water is turbid.

Based on the interpretation of geophysical data from four groundwater potential measurement transects in the study area, particularly in the sand and gravel layers, the water quality needs to be further investigated as it contains brackish water. The alluvial layer has greater potential as a freshwater aquifer compared to sand and gravel, while the clay layer can retain water flow. Clay has the potential for a confined aquifer in deeper layers, resulting in better water quality. Variations in the depth and distribution of these layers can determine the presence and quality of groundwater in the study area.

IV. CONCLUSION

The results indicate that groundwater potential in Lubuk Buaya is controlled by variations in resistivity (0.18–44.1 Ωm), depth, and lithology. The main aquifers are identified within alluvial sand layers along survey lines 2, 3, and 4, while line 1 shows lower potential due to the dominance of silt and indications of brackish water. These findings confirm that the distribution and quality of groundwater are strongly influenced by subsurface lithology. Track 2 shows potential for a free aquifer despite turbid water quality. Track 3 indicates a confined aquifer at depths >2.5 meters. Track 4 has a free aquifer with high porosity but low water quality. Traverse 1 has low potential due to the dominance of silt and brackish water. Overall, the presence of aquifers is influenced by the physical properties of the constituent rocks and subsurface resistivity.

V. ACKNOWLEDGMENT

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