Applied Resistivity Method to Investigate Ngawonggo Archaeology Subsurface at Malang Indonesia

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Abstract. It is necessary to carry out further research to determine the mapping and distribution of buried archaeological objects in Ngawonggo Village, Tajinan, Malang Regency. The geoelectric resistivity dipole-dipole configuration method is one of the appropriate geophysical methods to be used to find the existence of buried archaeological objects. The study was conducted with four scattered tracks having a space of 1 m in each track. The first track has a stretch of 64 m and found site rocks at a depth of 0–2 m. The second track has a stretch of 64 m and archaeological rocks are found at a depth of 2–5 m below ground level. On track three has a stretch of 32 m and found archaeological rocks at a depth of 2–7 m below the ground surface. While on track four with a stretch of 32 m, no archaeological rocks were found.

Keywords: Geophysics · Resistivity · Dipole-dipole Configuration · Ngawonggo

1 Introduction

Indonesia is a country that has various tribes and cultures with many historical sites that have been found in several places in Indonesia. One of these discoveries is the archaeology of Ngawonggo which is located in Nanasan Backwood, Tajinan Village, Malang Regency. The existence of the Patirtaan Ngawonggo site has been known for a long time but its historical value has only been known since 2017 [1].

The Patirtaan Ngawonggo site is a relic of the Medang Kingdom during the Mpu Sindok Government which is a Hindu holy place. According to Poesponegoro (1990), the King of the Medang Kingdom, namely Mpu Sindok, who had a daughter named Isyana Tunggawijaya who succeeded him on the throne. In the Gedangan inscription (950 AD), Queen Isyana married Sri Lokapala who was a noble from Bali and blessed with a son named Makutawangsawardhana where he became the next King [2]. According to the Pucangan inscription (1041), the next throne was occupied by Dharmawangsa Teguh who was the crown prince of the previous king. During his reign, Dharmawangsa moved the capital to Watan, which is now known as the city of Madiun. Dharmawangsa

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has a younger brother named Mahendradatta who later became engaged to Udayana Warmadewa, a King of Bedahulu in Bali [3].

Ngawonggo archaeology has the shape of a pond which is known to function as a place of self-purification in Hindu religious beliefs. It is suspected that Ngawonggo archaeology still has several buried archaeological objects. In order to find out the distribution of the existence of buried archaeological objects, subsurface research is needed without destroying the site. One method that can be used is the geoelectric resistivity method [4, 5].

According to Ekinci [6] in his research looking for a city buried in a plot of land with contours shaped like a hill, he was able to find the whereabouts of the lost city of Amorium in Turkey. In his research he used the resistivity method.

The geoelectric method is an investigation method carried out to study the subsurface conditions of the earth with the approach of the physical sciences in the form of the earth's electrical properties. Investigations are carried out based on the physical properties of rocks in the form of electrical properties of rocks that have resistivity values (according to rock type), rock age, electrolyte content, rock rigidity, mineral count, rock porosity, rock permeability and so on [7].

The Geoelectric method is divided into several methods, including: Self Potential (SP), Induced Polarization (IP), Magneto Telluric (MT), Electromagnetic (EM) and Resistivity or Specific Resistance [8, 9].

According to Kearey [10], the resistivity geoelectric method uses the assumption that the earth is a large resistor. The resistivity geoelectric method also has a variety of configurations. Each configuration satisfies the same geometry correction factor equation. The value of the geometry correction factor follows the pattern of the distribution and arrangement of the electrodes according to the conditions below the earth's surface, the value of the geometry correction factor on the double potential electrode in general is:

$$K = \frac{2\pi}{\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\}} \tag{1}$$

While the geometric correction factor for a single potential electrode is:

$$K = 2\pi\left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right)\right] \tag{2}$$

with K is geometry correction factor, 2π constant, r_1 is the distance between the first current electrode $C1$ and the first potential electrode P_1, r_2 is the distance between the second current electrode C_2 and the second potential electrode P_1, r_3 is the distance between the first current electrode C_1 and the first potential electrode P_2, r_4 is distance between the first current electrode C_2 and the first potential electrode P_2 (Fig. 1).

The result of measuring the resistivity geoelectric method in a rock layer at the time of measurement in the field is apparent resistivity. The earth is assumed as if the earth is isotropic homogeneous, so that the results of field data acquisition of a measured point are having the same resistivity value and do not depend on the varying current and potential electrode distances.

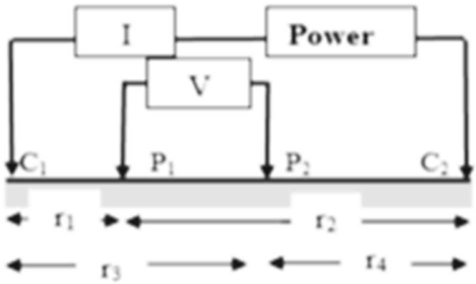

Fig. 1. Arrangement of Double Electrodes on Surface

The principle used in conducting the geoelectric resistivity method is implemented by injecting an electric current into the earth through two current electrodes and measuring the electric potential value at the two potential electrodes. Here is the apparent resistivity value at the value of each point with the equation:

$$\rho_a = K\frac{\Delta V}{I} \tag{3}$$

where ρ_a apparent resistivity, ΔV potential difference at the double potential electrode, I is the electric current. The values of ΔV and I can be known from the measurements indicated by the electrodes, and K is a geometry correction factor whose value depends on the configuration value used. In geoelectrical data processing, the value of K must be included in the calculation of the apparent resistivity value so that the measurement results approach the truth value and the subsurface model approaches the actual situation [11].

2 Research Methodology

The working principle of the resistivity geoelectric method is that the current electrode and potential electrode are plugged into the ground according to a predetermined path (one straight line) and stretched with a predetermined space, then the current electrode and potential electrode are given an electric current to be forwarded into the ground so that the flow of the electricity will hit the material that is below the surface then the apparent resistivity value of the rock is obtained, which value will be recorded by the tool and stored in several data formats. Data acquisition was carried out using the Multichannel Multielectrode Resistivity Meter by MAE geoelectric tool.

The configuration used is a dipole-dipole configuration. This configuration is suitable for searching on a narrow scale such as searching for subsurface sites, the following is an array of dipole-dipole configurations.

Based on Fig. 2 and the general configuration equation, the correction factor for the geometry of the dipole-dipole configuration is:

$$K = \pi an(n+1)(n+2) \tag{4}$$

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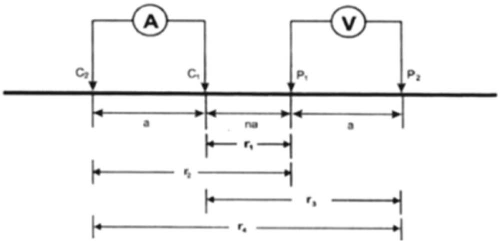

Fig. 2. Dipole-dipole configuration

isotropic homogeneous, so that the results of field data acquisition of a measured point are the same resistivity value and do not depend on the varying current and potential electrode distances.

The fact that the earth is not homogeneous isotropic given that the earth is composed of various layers of rock layers. Measurements using the geoelectrical resistivity method at a measuring point will get the apparent resistivity value. This situation can provide varying resistivity values, so that field data acquisition must be carried out with more than one measuring point. At the time of field data acquisition, the value of each measuring point has a different resistivity value, this proves that the earth is an anisotropic heterogeneous medium [12]. The principle used in conducting the geoelectric resistivity method is executed by injecting an electric current into the earth through two current electrodes and measuring the electric potential value at the two potential electrodes [13].

The results of resistivity data processing will be interpreted based on the resistivity distribution of the data based on colour gradations in the 2D modelling results from the Res2dinv Software inversion results which are then correlated with local geological data and conditions in the field to determine the condition of the subsurface structure of each track.

3 Results and Discussion

The Ngawonggo Malang Archaeological Area is located in a mountainous area, with topographic conditions influenced by the Tengger Mountains in the east, Mount Kawi and Kelud in the west, and Mount Arjuna-Welirang in the north. Meanwhile, the geological formations that develop in the Tajinan Sub-District are derived from the activity of the Tengger Volcano (Qvt; pyroxene andesite lava, olivine basalt and pyroclatic falls), Mount Buring (Qpvb; pyroxene olivine basalt lava, sandy tuff) and Mount Ronggo (Qpvb). Tajinan Sub-District generally has four geological formations in the form of Malang tuff formations (Qptm; coarse-fine tuff, pumice rock and andesite fragments), namely Mount Buring and Mount Arjuno-Welirang (Qvaw; volcanic breccia, lava, tuff and tuff breccia) formations. to the north, the Tengger and Mount Semeru Volcano formations (Qvs; andesite to basalt lava, volcanic clastics and lahars) in the east, the Quarter Volcano formation (Qpv; volcanic breccias, tuff, lava, agglomerates and lahars, are an association of Mount Kawi-Butak, Mount Ronggo, Tengger Mountains and Mount Buring) in the south west [14].

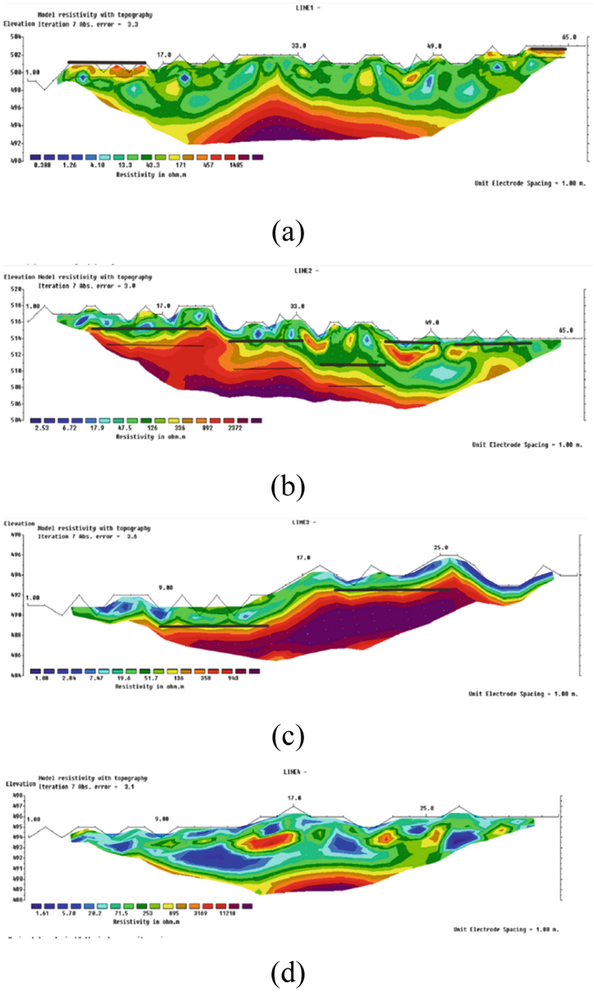

Fig. 3. Inversion with Topography (a) Track 1 (b) Track 2 (c) Track 3 (d) Track 4

The resistivity values of andesite are in the range of 1,7 × 10^2 Ωm (*dry*)–4,5 × 10^4 Ωm (*wet*). In his journal Carara (2001), it states that the modelling shown is the resistivity and conductivity of subsurface homogeneous polygonal rocks, which is the actual resistivity which is the average value [15].

Based on the modelling, in Fig. 3 (a), an interpretation is obtained by estimating archaeological rocks made from andesite stone from the results of the inversion of path one indicated by a resistivity value of 170–457 m. The position of the site rock is at a depth of 0–3 m below the ground surface with a length of 10 m and a thickness of ±2 m.

Estimation of archaeological rocks based on andesite from the results of the inversion of the two paths in Fig. 3 (b) is shown with a resistivity value of 170–892 m. The position of the archaeological rock is at a depth of ±2–7 m below the ground surface with a terraced condition resembling a foundation having a thickness of ±2 m.

Estimation of archaeological objects made of andesite stone from the results of the inversion of path two (Fig. 3 (c)) is indicated by a resistivity value of 170–943 m. The position of the archaeological rocks is at a depth of 2–6 m below the ground surface from the 5th to 16th meters taken around pond 1 and pond 2, so that on track 3 it is suspected that what is recorded is site rock which is the bottom of pond 1 with a length of ±7 m at a depth of 2–4 m, and pond 2 with a length of ±8 m at a depth of 2–4 m.

Estimation on path four (Fig. 3 (d)) with a resistivity value range of 170–3169 m which is suspected to be andesite rock is not included in archaeological rocks. The rocks are thought to be river andesite rocks located at a depth of 1–4 m below the surface. While the volcanic andesite rock formation is at a depth of 5 m below the surface.

The archaeological condition of Patirtaan Ngawonggo is known to have similarities between Patirtaan Empul on the island of Bali and Patirtaan Ngawonggo in Ngawonggo village. According to the excavation results, the BPCB Team stated that Patirtaan Ngawonggo has the same characteristics as Patirtaan Empul where the condition of the patirtaan is in a narrow gap flanked by steep cliffs and has 7 pools. Patirtaan Empul on the island of Bali consists of three parts, namely the outer courtyard (*jaba pura*), the middle courtyard (*jaba tengah*), the inner courtyard (*offal*). The outer courtyard is the outer gate as a place for crowds during traditional ceremonies as a place for purification before entering the sacred pool. The middle courtyard is a pool with a size of 20 × 10 m with a fountain flowing from a higher place. The inner courtyard is a sacred place dedicated to Gods or Bhatara and Bhatari (Fig. 4).

The results of the interpretation found 6 ponds. When referring to this, most likely the existence of the pool is not reachable on the track that is stretched. This is because the conditions of the research site do not allow geoelectric equipment to pass. However, it is possible that route one which is located on the north side of the Manten River is part of the outer courtyard (jaba pura). While the middle courtyard (Jaba Tengah) is suspected to be a sacred pool in pools 1 to 4. Meanwhile, in pools 5–6, it is the inner courtyard (jaba jero).

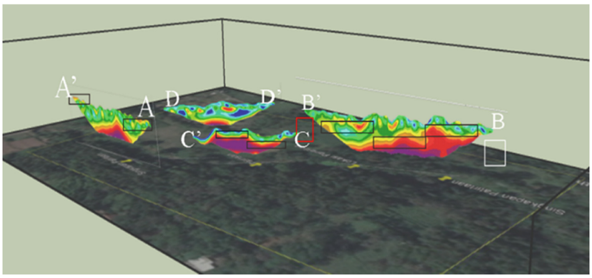

Fig. 4. 2D reconstruction of 4 tracks.

4 Conclusion

Based on the research that has been done, it is concluded that the resistivity geoelectric method can detect the presence of rocks at the Patirtaan Ngawonggo Site. This can be seen based on the resistivity value recorded by the tool in the range of values of $1,7 \times 10^2$ Ωm (*dry*)–4.5×10^4 Ωm (*wet*).

On the first track, site rocks were found at a depth of 0–2 m below the ground surface which was on the north side of the Manten River at 5–15 m and at the end of the track at 60–64 m with a thickness of ±2 m which was suspected as an outer courtyard. While on the second, third and fourth routes, they are on the south side of the Manten River with the distribution: On the second track, site rocks are found at a depth of 2–5 m with a thickness of ±2 m below the ground surface with the division of pools 4, 5, and 6 where. On track three found site rocks at a depth of 2–4 m below the ground surface which is suspected to be the bed site rock for pool 1 and pool 2 with a thickness of ±2 m where pool 1 to pool 4 is the middle courtyard and pool 5 to pool 6 is the inner courtyard. While on the fourth trajectory, no site rocks were found.

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