

Application of the Electrical Resistivity Tomography and Seismic Refraction Methods for Groundwater Investigation in Savannakhet Province, Laos

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ABSTRACT

The hydrogeology information can be revealed from subsurface physical property contrast values through integrated geophysical exploration techniques. The major objective of this research work is to delineate fresh groundwater zones in Savannakhet province through application of electrical resistivity tomography (ERT) and seismic refraction methods. The results obtained from these methods showed that the moderate resistivity regions vary from 15-60 Ohm.m found at the depth of 16-20m, is considered as suitable areas for good groundwater potential areas whereas the seismic velocities distribution analysis ranging from 1200-1800 m/s found at the depth of 16-20m, is considered as groundwater table level. These results also agree well with information obtained from two boreholes in the Outhoumphone district, where samples at depth of 16 to 20 m have been identified as sandstone and siltstone. The geophysical results also verify that the ERT and seismic refraction methods can be an efficient tool for groundwater evaluation in Savannakhet province and integrated geophysical techniques can be used for groundwater evaluation in other similar geological areas in Lao PDR.

1. Introduction

Groundwater is an essential source of freshwater, which is important for domestic usage purposes in some rural areas in Laos. However, many parts of Laos have serious water issues both in quantity and quality such as far from surface water, groundwater dry out in the dry season and poor groundwater quality. Thus, groundwater is an alternative source to supplement water supply for agriculture, irrigation, industry, and household. Whereas groundwater information is limited for monitoring and evaluation activities regarding quantity and quality of groundwater have not yet been carried out to any significant degree. In addition, Laotian commonly use shallow hand dug wells at 5 to 10 m depth, which are not biologically safe sources and usually dry out during the dry season, and poor groundwater quality due to infiltrations of domestic waste and from farm animal [1,2]. In Savannakhet province, information and programs for the monitoring and evaluation of groundwater quantity and quality are limited.

Over 100 boreholes were drilled in the area with about 50 to 60% boreholes can produce good quality wells, and about 50 boreholes have been selected for production wells due to poor water quality [3].

The ERT method has been widely used for groundwater explorations, this technique can determine depth and thickness of various earth layers and groundwater potential zones or aquifers from observed earth electrical resistivity. However, there is ambiguity in interpreting the earth resistivity regions values. Low resistivity values can either indicate higher clay content or higher water content. The results of seismic refraction in term of seismic velocity models may be able to reduce the ambiguity. Therefore, it will be of great benefit if we apply the geophysical methods, especially electrical resistivity tomography and seismic refraction explorations for groundwater investigation and management in Savannakhet province. A range of different methods and software have been developed to delineate subsurface structures at high precision and accuracy [4-7]. Recently, integration of electrical resistivity tomography and seismic refraction methods are the most widely applied for determining reliable subsurface earth structures to many

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different objectives of the research in many different countries around the world, including groundwater investigation [8-10]. However, these geophysical methods have not been widely used yet in Savannakhet province.

The objective of this work is to determine locations of groundwater potential zones and depth to aquifers by using ERT and seismic refraction methods in Savannakhet province. The obtained results are compared to ground-truth from boreholes, including the soil samples information.

2. Geological setting

The two research areas, namely the Outhomphone and Champhone districts, are located in Savannakhet province, Laos. In this article, the study area selected for presentation is only the Outhomphone district where is situated in the northwestern part of the province with elevation between 175 to 200 m and most areas are covered by rice farm and forests. The annual rainfall is estimate 1780 mm, but it depends on regional parts [12].

The geology of the study area is reported by many researchers such as the Savannakhet basin where geology is considered as an extend part of the Sakon Nakhon basin in northeast part of Thailand. The PhuPhan range divides Khorat Plateau into two basins such as the Khorat basin in the south and the Sakon Nakhon basin in the north. These basins cover area of about 36,000 m² and 21,000 m² respectively (Fig. 1) [12,13,14]. On the other hand, these basins are similar geological information to the Maha

Sarakham Formation, which consist of claystone, shale, siltstone, sandstone, anhydrite, gypsum, potash, and rock salt [15,16].

The selected research site is an active economic and population is growing and related to the increasing quantity water in the research area, but there are no mechanisms for data collection, compilation and storage, no protocols or entities tasked with the implementation of new groundwater resources.

3. Methods

3.1. Resistivity measurement

The aims of electrical resistivity survey are to measure the resistivity distribution in the subsurface layers by conducting measurements along the ground surface. The electrical resistivity tomography method is an important geophysical exploration method used to provide a high-resolution earth subsurface image of the electrical resistivity values. The earth resistivity values vary greatly due to different subsurface geological information. The various geophysical exploration techniques distinguish subsurface when a contrast exists in their electrical properties. The earth resistivity depends on porosity, permeability, saturated water and the concentration of dissolved solids in pore fluids within the earth subsurface layers (Table 1) [17]. The earth electrical resistivity of clean sand, saturated aquifer can be expressed via Archie's law:

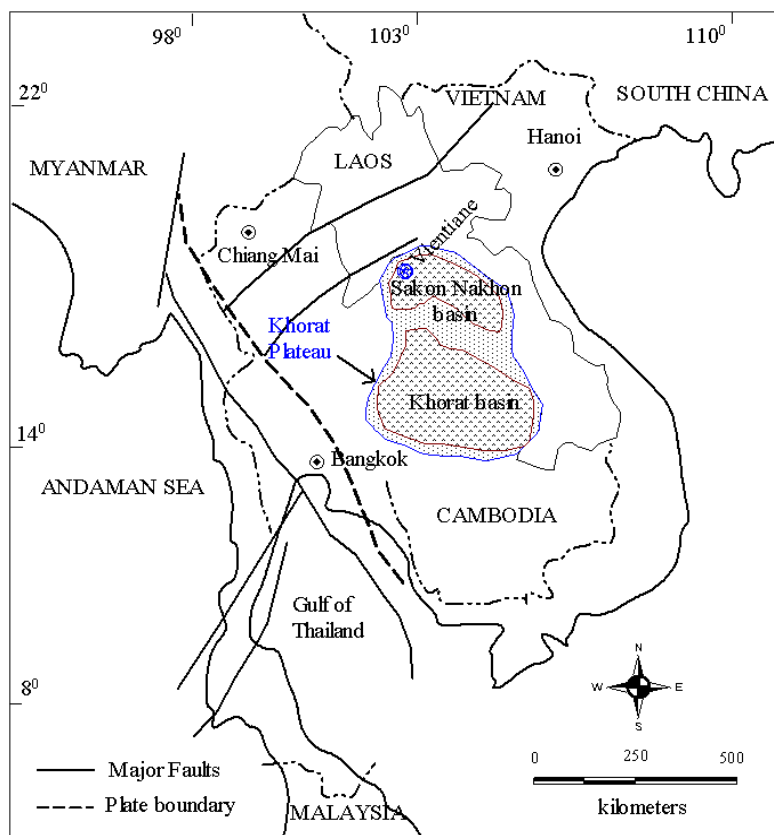


Fig.1. Map of the Khorat and the SakonNakhon basins in the Khorat Plateau [11]

$$\rho_r = a\rho_w\phi^{-m} \tag{1}$$

Where: ρ_r is resistivities of rock

ρ_w is resistivities of rock water

a is the saturated coefficient ($0.6 < a < 2.0$)

m is the cementation factor ($1.3 < m < 2.2$)

ϕ is fractional porosity

Table 1: Typical electrical resistivity values for various earth materials [17,18]

Earth materials	Resistivity values (Ohm.m)	
	[17]	[18]
Clay	1-100	1-100
Sand	60-1000	50-1050
Gravel	100-5000	600-10 ⁴
Mudstone	-	-
Siltstone	20-150	-
Shale	20-2000	2-2000
Sandstone	10-5000	
Sandy clay	30-215	
Alluvium	10-800	
Groundwater	10-800	
Fresh groundwater	20-160	
Salt water	0.25	0.2

The 2D electrical resistivity measurement is conducted by injected current into the earth subsurface through the two current electrodes and measures the potential difference at the other two potential electrodes on ground surface. The commonly electrodes arrays of 2D resistivity measurement are usually arranged in a linear array. The apparent resistivity is known as the bulk average resistivity of earth subsurface layers affecting the current. The apparent resistivity can be calculated by the ratio between the measured potential difference and the input current, and multiplying by a geometric factor for the specific array will be used in the 2D data acquisition [18]. In this work, Wenner electrode array (Fig. 2) was selected to use for 2D resistivity data acquisition. These data were measured by manually and automatically by using the ABEM Terrameter SAS 1000. The data integrated in the research area was processed by EarthImager software in order to determine an earth resistivity model that estimates the actual subsurface layers, the median depth of surveying is estimate 0.52 times the electrode spacing for the Wenner electrode array [18].

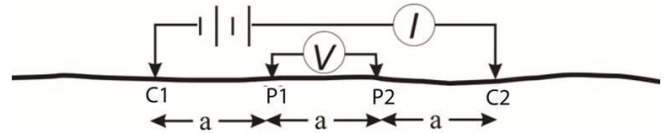


Fig. 2. The Wenner electrode array

3.2. Seismic refraction method

The seismic refraction method utilizes seismic signal that returns to the ground surface after travelling through the ground along refracted ray path, which influences the various seismic velocities in difference earth layers. The seismic signal is conducted into the earth's subsurface layers through an energy source point by using hammer, weight dropped, vibrator and explosives [17]. The first arrival of seismic energy was detected by seismic receivers or geophones arranged along ground surface from a seismic source always represents either a direct ray or a refracted ray (Fig. 3).

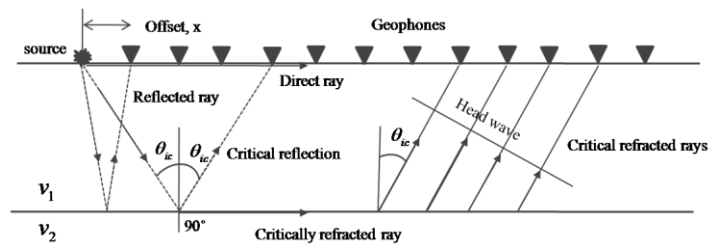


Fig. 3. Seismic ray path of direct, reflection, and refraction waves

The thickness and velocity of earth subsurface layers can be computed by determining the arrival times for direct and refracted waves from seismic signals. The seismic velocities of longitudinal waves, P-wave, V_p and of transverse waves, S-wave, V_s in a homogeneous and isotropic medium are expressed by the equation (2). Seismic velocities depend on the material properties such as composition, temperature and pressure. Table 2 shows seismic velocity value depends on various earth materials [19].

$$V_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} \text{ and } V_s = \sqrt{\frac{2\mu}{\rho}} \tag{2}$$

Many reports on seismic refraction methods have stated that the seismic velocity values can be used to estimate the depth of the water table or aquifer. However, seismic velocity models have ambiguity for interpretation due to a wide range of seismic velocity values in connection to the water table level and these values are not only uniquely correlated to the aquifer layer but also depends on other factors of earth materials. Some authors have determined seismic velocities about 1500 m/s for saturated layers [20]. Meanwhile, another report proposes seismic velocity values vary from 1200 to 1800 m/s in

aquifer layers [21]. Many researchers have been applied the seismic refraction method for the identification of groundwater and structural geology investigations [22-27].

Table 2: The P-wave velocity of various earth materials [19]

Earth materials	P-wave velocity (m/s)
Air	331.5
Water	1400-1600
Sandstone and shale	2000-4500
Limestone	2000-6000
Sand and gravel	500-1500
Shale	2000-4500
Conglomerate	10-800
Alluvium	500-2000
Sand (Unsaturated)	200-1000
Sand (Saturated)	800-2200
Clay	1000- 2500

The SeisImager software was selected to use for seismic refraction data interpretation in this work. This software consists of a system package for picking the first arrival time for P-wave called the PickWin program. All seismic events were picked the first breaks then the arrival times against distance between the shot and geophone positions. The Plotrefa file package was used for the second step of this procedure, which package was used to run the time as an inversion in order to generate the seismic velocity model in term of the thickness of the earth subsurface layers and a seismic velocity value agree with subsurface geological information under the seismic profile [28].

3.3. Survey profiles

The eight ERT profiles were carried out at the two sites, including five ERT profiles were conducted at the site 1 in Outhomphone district and three ERT profiles were conducted at the site 2 in Champhone district.

The five ERT profiles in Outhomphone district are introduced below, in which there are 4 profiles were oriented in the NE to SW directions, 1 profile left was oriented in the NW to SE directions, maximum length of profile of 440 to 480m (Fig 4). The Wenner electrode array was selected to conduct with electrode spacing of a=10 up to 160 m. The data were recorded by manually and

automatically in the Terrameter ABEM SAS 1000 (Made in Sweden).

The five seismic refraction profiles were conducted at site 1 in Outhomphone district only, used the SmartSeis ST with 12 channels seismograph (Made in USA). The two seismic refraction profiles were conducted on overlies on two selected ERT profiles (2 and 4) in the study area will be presented below (Fig 4), seismic profile length of 330 m, with geophone interval of 5m, and consists of 6 spreads for each seismic profile. In this measurement, consisted of laying out 12 geophones in a straight line and recording arrival times from shot points produced by striking a 6.5 kg sledge hammer into a steel plate at 7 shots per spread: one inter-spread shot, three forward and three reverse shots (Fig. 5). The first geophones of the first spread placed at 0 m and the 12th geophone at 55 m; while the first geophone of the second spread located at 55 m and the 12th geophone at 110 m then move to next spread until reach to the first geophone of spread 6 placed at 275 m and the 12th geophone at 330 m. Additionally, two boreholes were drilled at the study area to match, demonstrate and complement the results of integrated ERT and seismic refraction methods.

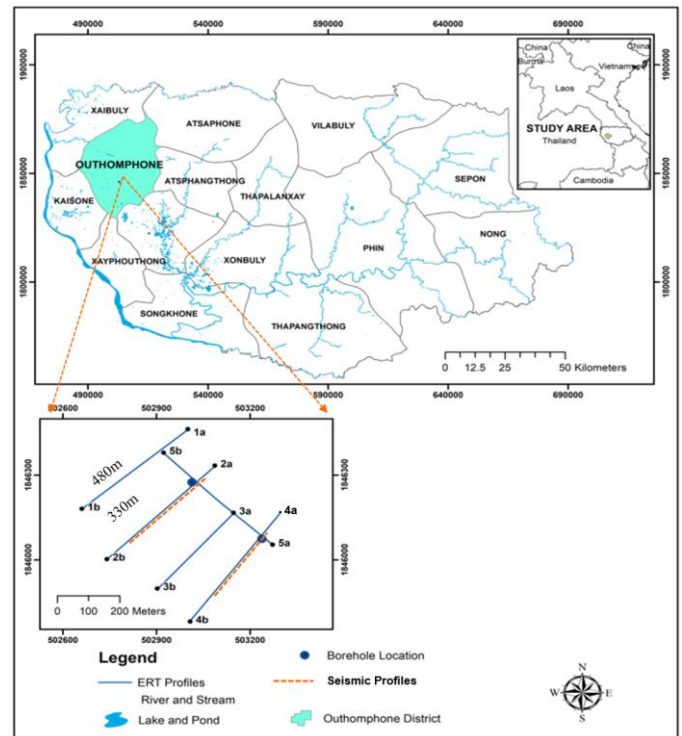


Fig. 4. Maps showing the orientation of ERT and seismic refraction profiles.



Fig. 5. A typical seismic refraction data acquisition layout and location of shot points for seismic refraction survey profile.

4. Results and discussion

Four parallel NE to SW oriented profiles (1,2,3 and 4) at the study area showed similar results (Fig. 6). High resistivity regions greater than 100 Ohm.m found at 15-80m depth along these profiles with unclear thickness are considered as sandstone or bedrocks layers of these profiles. The relatively low resistivity regions less than 10 Ohm.m appear at some zones for each profile with unclear thickness are considered to be a thick clay zone. However, moderate resistivity values of 15 to 60 Ohm.m are observed at 16 to 80m depth along these profiles are interpreted to be appropriate groundwater potential zones. In order to correlate the positions of the earth subsurface layers in research site, a fifth profile (profile 5) was arranged crossing the two parallel profiles (2 and 4) in an ES to WN direction, with crossing points of profiles 2 and 4 at 60 m and 330 m respectively (Fig. 7). High resistivity values greater than 100 Ohm.m found at 10-80m depth, distances between 0 and 160 m at the depths of unclear, is considered as sandstone or bedrocks layers of the profile. The relatively low resistivity regions less than 10 Ohm.m

appear at some zones for this profile with unclear thickness are considered to be a thick clay zone. However, moderate resistivity regions of 15 to 60 Ohm.m are observed at 18 to 80 m depth along these profiles are interpreted to be suitable groundwater potential zones.

In addition, two seismic refraction profiles (1 and 2) were conducted at over lied on selected ERT profiles (2 and 4), the starting point of seismic profile located at 55 m of ERT profiles while the end of seismic profile located at 385 m of ERT profile (Fig. 8). The results of both two seismic profiles (1 and 2) were well correlated with 2D geoelectric cross section of ERT profiles 2 and 4. The ERT and seismic results show moderate resistivity values of 15 to 60 Ohm.m and seismic velocity range from 1200 to 1800 m/s are considered to be the water table at depth of about 16-20m. The low resistivity regions less than 10 Ohm.m and seismic velocity range from 800 to 1200 m/s are interpreted to be a thick clay zone (with unclear thickness), whereas high resistivity regions greater than 100 Ohm.m and seismic velocity greater than 1800 m/s are interpreted as sandstone or bedrocks subsurface earth layers.

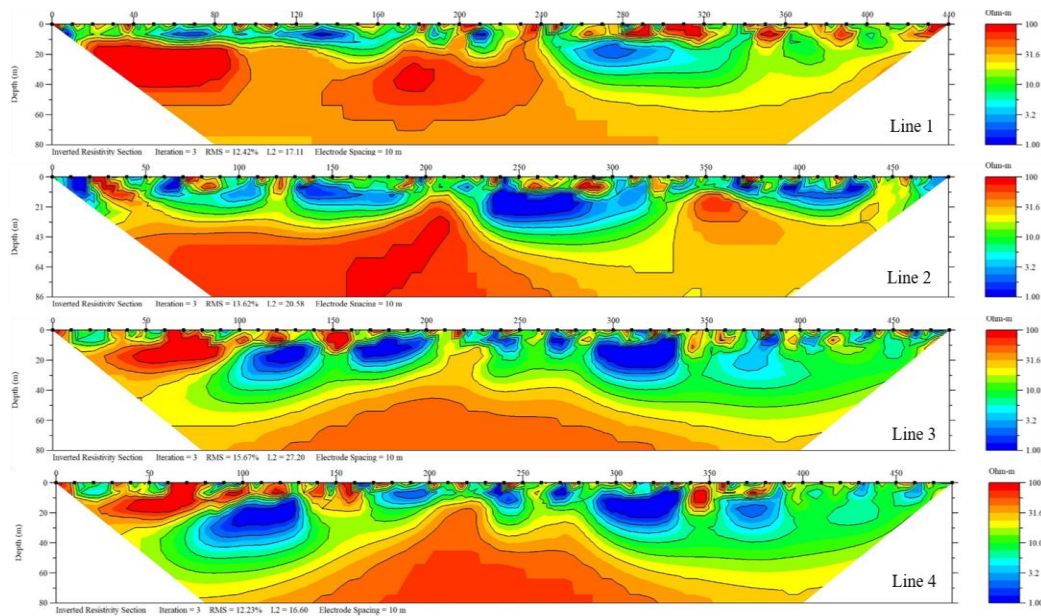


Fig. 6. 2D geoelectric cross sections at profiles 1, 2, 3 and 4.

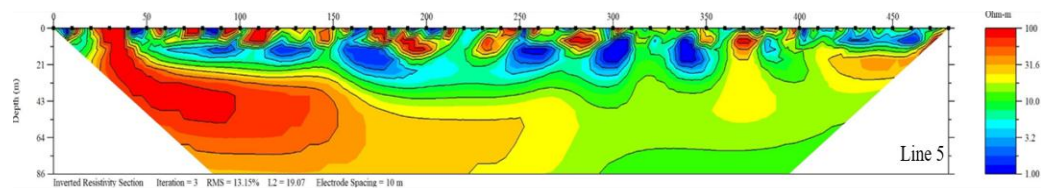


Fig. 7. 2D geoelectric cross section at profile 5.

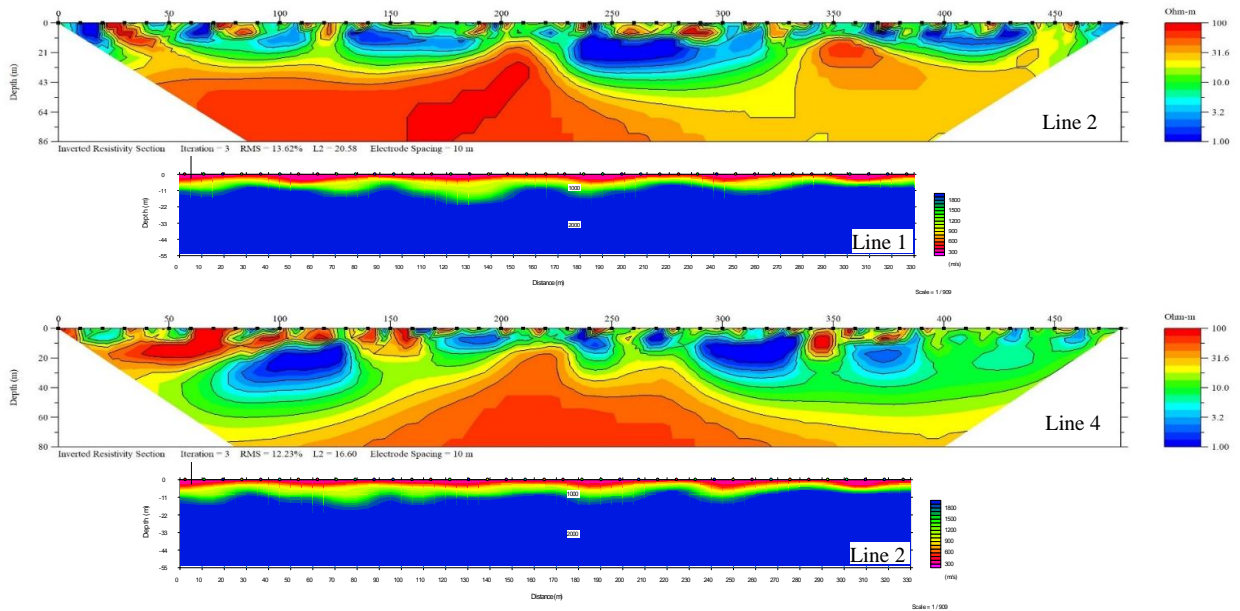


Fig. 8. 2D geoelectric cross sections at profiles 2 and 4 versus seismic velocity models at profiles 1 and 2.

In order to match electrical resistivity and seismic results, two boreholes were drilled at 100 m along ERT profiles (2, 4) and 45 m along seismic profiles (1, 2) for verifying the positions of water table or aquifers layers (Fig. 9 and 10). The results obtained from the boreholes 1 and 2 (BH-1 and BH-2) showed the water table at about 16 m depth for borehole 1 and 20 m depth for borehole 2. The

soil samples collected from both two boreholes have been classified as sandstone and siltstone at water table level (Fig. 9c and 10c), which respond well for electrical resistivity regions of 15 to 60 Ohm.m (Fig. 9a and 10a) and seismic velocity range from 1200 to 1800 m/s were identified for groundwater potential zones (Fig. 9b and 10b).

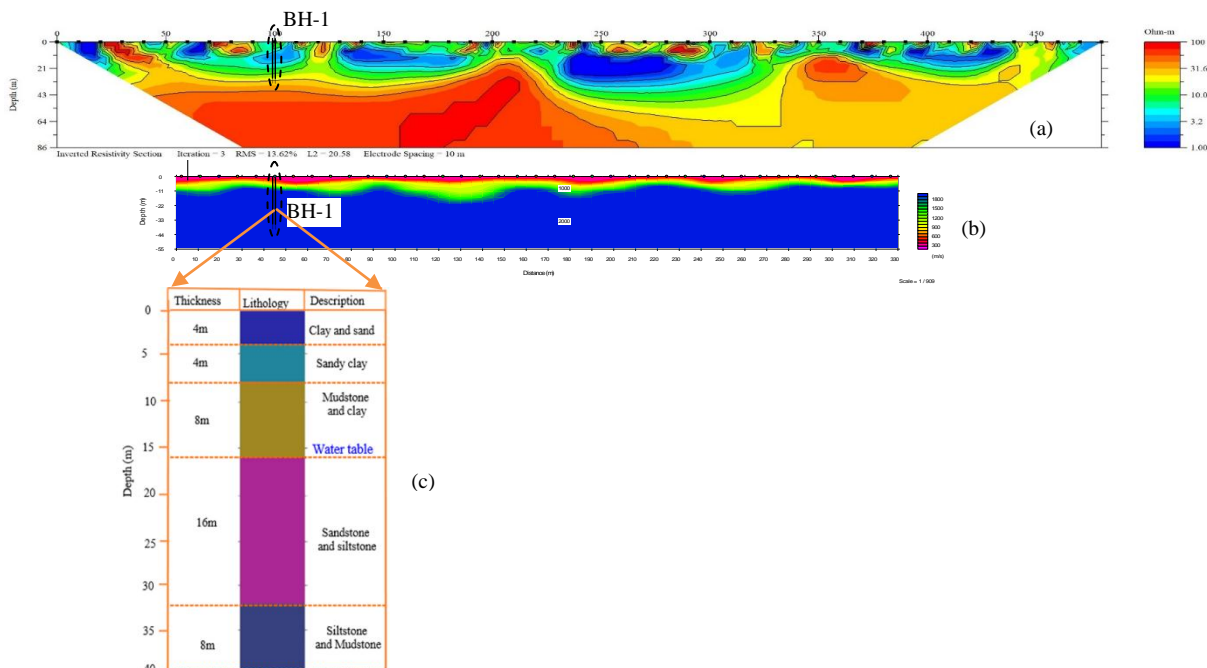


Fig. 9. (a) 2D geoelectric cross section at profile 2, (b) The seismic velocity models at profile 1, (c) vertical geological section of borehole 1 (BH-1) at 100 m along ERT profile 2 and 45 m along seismic profile 1.

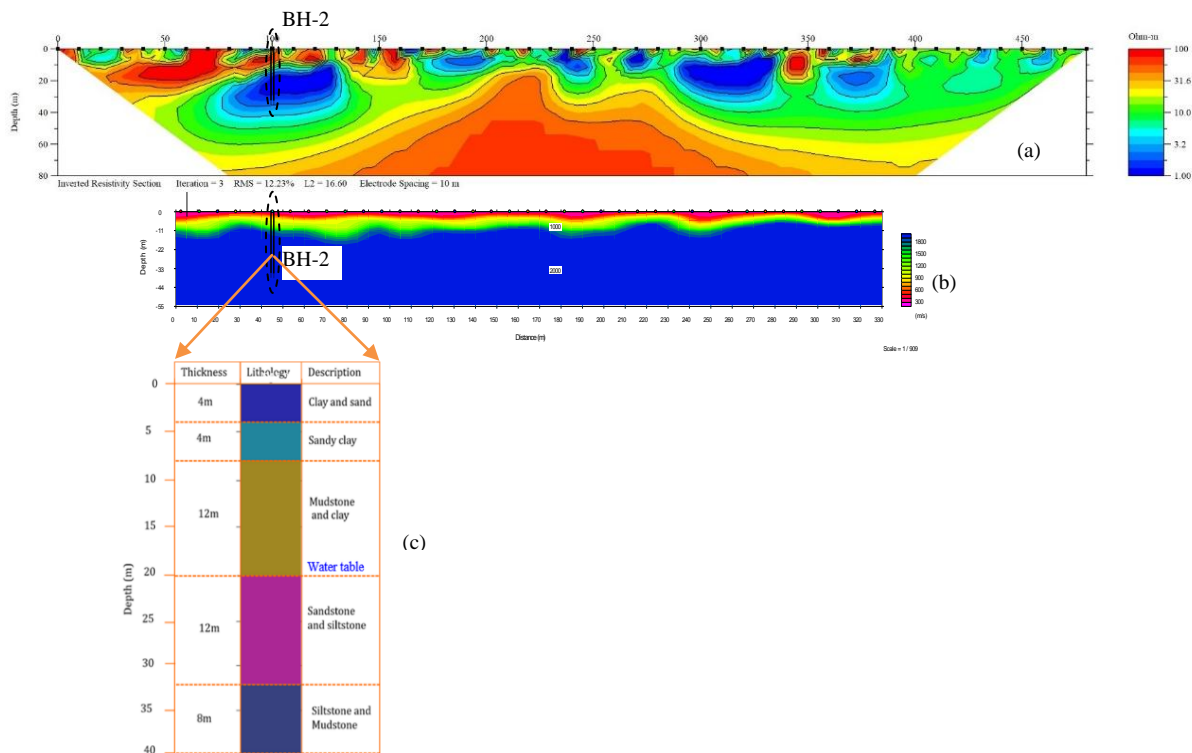


Fig. 10. (a) 2D geoelectric cross section at profile 4, (b) The seismic velocity models at profile 2, (c) vertical geological section of borehole 2 (BH-2) at 100 m along ERT profile 4 and 45 m along seismic profile 2.

5. Conclusion

The results obtained from this study showed that the relatively low resistivity regions less than 10 Ohm.m and seismic velocity regions of 300 to 800 m/s are considered as clay layers; high resistivity regions greater than 100 Ohm.m and seismic velocity greater than 1800 m/s are interpreted as sandstone or bedrocks layers, and the moderate resistivity regions of 15 and 60 Ohm.m, whereas seismic velocity regions of 1200 to 1800 m/s found at 16 to 20m depth are considered as water table, indicating water table that correlates well with groundwater table from borehole information in the study area. The examples outlined in the text demonstrate that the simultaneous application of the electrical resistivity tomography and seismic refraction exploration methods to identify groundwater is feasible and effective. These results will also be useful for assessment and groundwater investigation and can be applied for groundwater investigation in other similar geological areas in Lao PDR.

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