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Electrical resistivity tomography (ERT) exploration data in drought prone areas case study: Buriram Province, Thailand

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Abstract: An electrical resistivity tomography (ERT) investigation was conducted across four drought-prone districts in the Buriram Province, Thailand. The primary objective was to evaluate and map the potential of groundwater reservoirs as sources of water for household and agricultural purposes during the dry season. It was accomplished through the implementation of the Schlumberger array configuration. An electrical resistivity survey instrument was used to generate a 2D resistivity model of the electrical resistance profiles, or pseudo section profiles. The survey instrument included more than 50 electrodes, enabling the investigation of the profile to a depth of up to 50 m from the ground surface. The resistivity values obtained from the field data were recorded and converted or interpreted using RES2DINV software. The data were analysed by comparing them with the geological information about the site and referencing the geological borehole data as at 50 m depth from the surface. The results of the ERT survey indicated that groundwater in the arid areas of the Buriram Province can be found at shallow depths around 10–20 m from the surface and it is deposited in sedimentary and clay layers, and it has remained relatively stable over a 2-year period with the water level measured by an electric probe in the summer, winter and rainy seasons in Thailand.

Keywords: drought-prone, electrical resistivity survey, electrical resistivity tomography (ERT), groundwater, reserve water

INTRODUCTION

In Northeast Thailand, drought has become a significant concern for residents, agriculture and industry. Especially in the province of Buriram, including districts of Mueang Buriram, Ban Dan, and Huai Rat, the severity of the phenomenon has been exacerbated over the years. It resulted in detrimental impacts on water consumption, agricultural productivity, and industrial operations. The Disaster Prevention and Mitigation Provincial Office Buriram (2020) declared the affected areas as drought disaster areas, subsequently designating direct assistance to affected residents from 2017 to 2036. In addition, the consumption of groundwater in the area has been hampered by salt water. This adversely affected the local populace (Satarugsa, 2011). Nonetheless, it is worth noting that groundwater represents a valuable natural resource that can be desalinated and leveraged to mitigate water scarcity in both short and long term (DGR, 2018). However, the reasonable utilisation of groundwater resources requires a careful approach based on research data in order to prevent potential environmental impacts, such as subsidence and groundwater contamination (Satarugsa *et al.*, 2008; Satarugsa, 2011). There is a shortage of data from geophysical survey of the area. While some parts of the Buriram Province have good-quality surface and groundwater, it is often insufficient to meet consumption demand during the dry season (DMR, 2020). Hence, researchers acknowledge the need to provide research to establish a geographic information database system of groundwater resources by applying geophysical surveying technology, namely the electrical resistivity tomography (ERT). The ERT is an accepted method for effective planning and management of groundwater. It can be used as preliminary tool to assess any subsurface zone by utilising non-invasive non-destructive methods, reducing time and cost (Yasir, Jani and Mukri, 2018).

MATERIAL AND METHODS

ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

The electrical resistivity tomography (ERT) method is a popular method to survey groundwater. It is highly accurate and non-invasive, which means that it does not damage the soil layer or the underground rock system (Yasir, Jani and Mukri, 2018). ERT results can be used to assess groundwater characteristics in gravel-sand layers, rock fractures, or cavities in the rock. The method enables to calculate groundwater depth, thickness, and quality, which can be determined by interpreting resistivity data obtained from field measurements. This information can help to identify whether the groundwater is fresh, brackish, or saline. The ERT is also a quick and straightforward method for interpreting information using the electric discharge current (I). This method involves directing a direct current into the ground through electrodes (C1, C2). The current circulates in all directions in a spherical (half-sphere) pattern penetrating the soil. During the ERT process, some parts of the current flow towards the opposite pole, causing a certain level of voltage between the two terminals. Based on the voltage (V) generated through the electrodes (P1, P2), we may calculate the resistance as shown in Equation (1).

$$V = IR \text{ or } R = V/I \tag{1}$$

where: V = voltage (mV), I = current (mA), R = resistance (Ω).

There are various types of electrode configurations supporting the use of the resistivity method. In this research, Schlumberger configuration was used to calculate the electrical resistivity for the following reasons: (i) small movement of the electrodes needed; (ii) lateral variations cause smaller errors when current electrodes are moved than when potential electrodes are moved; (iii) duplication of readings with the same values with half current electrode spacing but different values of potential electrode spacing also allows a fairly accurate correction to be made for lateral variation (Bayowa and Adigun, 2012). A key difference between the spacing between the current and potential electrodes accounts for a major difference between Schlumberger configuration and others (such as Wenner and dipole-dipole configuration). Let the potential electrodes be represented as M and N. In the Schlumberger arrangement, the spacing between the potential electrodes (a) is fixed, and it is less than the separation between the current electrodes L which is progressively increased during survey (Loke, 1999). However, it is important to note that this value is not the actual resistivity of soil or rock. It represents the apparent resistivity, which is the resistivity of a homogeneous soil providing the same with the same arrangement of electrodes. The relationship between apparent resistivity and true resistivity is complex (Loke, 1999; Loke and Lane, 2004). Therefore, the inversion method is used to interpret resistivity data using computer-based methodology.

FIELD EXPLORATION AND EQUIPMENT

The study area in the Buriram Province, Thailand, consists of 1 – Khok Lek Subdistrict, Huai Rat District, 2 – Mueang Fang Subdistrict, Mueang District, and 3 – Ban Dan Subdistrict, Ban Dan District (Fig. 1). In 2011–2020, the Department of Disaster Prevention and Mitigation declared the study area to be affected by drought (ADRC, DDPM, 2022).

The Geomative GD-10 Series was the geophysical survey instrument for measuring resistivity in this study. Its purposes were to investigate groundwater and assess the resistance of soil or rock in three districts of the Buriram Province, namely Ban Dan, Huai Rat, and Mueang Buriram (Fig. 1). The GD-10 was

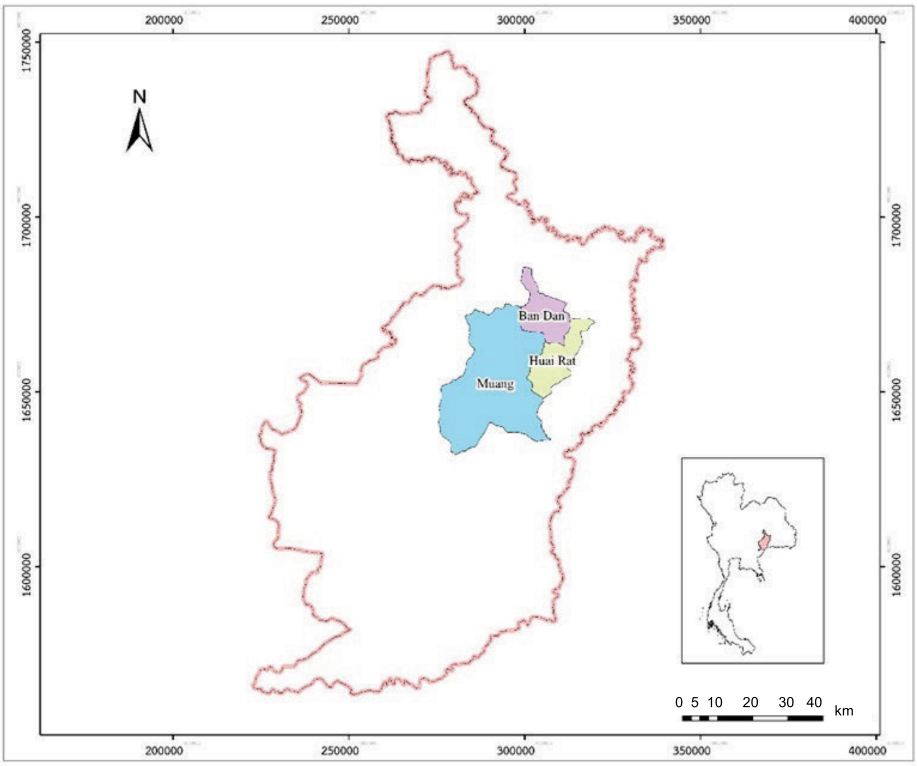

Fig. 1. Map of the Buriram Province, Thailand, with the three study areas; source: own elaboration

developed based on the digital and analogue circuitry techniques, comprising the multi-functional direct current (DC) method (Geomative, no date). This equipment can be adopted in electrical resistivity and vertical survey configurations, subsurface profiling using both two-dimension (2D) and three-dimension (3D) survey series. The ERT techniques were utilised to simulate the subsurface structure, locate features, and determine the extent of subsurface disconformities.

DATA COLLECTION AND INTERPRETATION

RES2DINV software is widely used for interpreting and collecting data in geophysical surveys to determine 2D and 3D resistivity model for the sub-surface (Loke and Barker, 1996; Loke, 2000; Loke and Lane, 2004; Castilho and Maia, 2008), investigate disconformities (Araffa *et al*., 2014; Mesbah *et al*., 2017), survey groundwater resources (Ayolabi *et al*., 2009; Satriani, Loperte and Soldovieri, 2012; Abdul Raman *et al*., 2020), and explore holes, ventricles, and underground salt layers (Gómez-Ortiz and Martín-Crespo, 2012). It can invert large data sets with a large number of electrodes and with a non-uniform electrode spacing (Griffiths and Barker, 1993). The RES2DINV can be optimised to generate models with smooth boundaries (Loke *et al*., 2003), such as chemical plumes, or irregular boundaries, such as Fracture Zones. In addition, it has the capability to integrate resistance data from boreholes and other sources with the aim to limit the inversion process, especially in the case of sudden changes in electrical resistance. The latter can then be incorporated into the inversion model.

The interpretation data generated through the inversion method is presented in a 2D model. Electric current flows through various materials depending on their conductivity. The conductivity occurs in materials such as metals and semiconductors. The study of conductivity in saturated materials that utilised engineering methods by Loke (2000) and Loke and Lane (2004) demonstrated that free electrons flow through the material and the conductivity is stimulated by the movement of ions such as Na^+ and Cl^-. The conductivity of a material plays an important role in the interpretation of resistance data.

In this research, apparent resistivity data were processed by using RES2DINV (ver. 4.8.17). The software is capable of measuring the electrical resistance and utilises Gauss-Newton's least squares inversion method (Sasaki, 1992) to construct a 2D model of soil or from the apparent resistivity. The software produced a pseudo-section which a numerical description of spatial resistivity variations, both measured or computed. The inverse model section included a tomogram displaying the modelled depth and shape resistivity. The results of inversions are shown in the next section.

RESULTS

GEOPHYSICAL SURVEY RESULTS

The results of groundwater surveys in the study area were obtained using geophysical techniques that involved the use of an electrical resistance instrument. This paper presents the outcomes of the survey collecting resistivity apparent data. The results and interpretation of outcomes are shown below.

Location 1: coordinates N15°01'24.8" E103°13'22.6", Khok Lek Subdistrict, Huai Rat District, Buriram Province, the data was processed using inversion modelling in RES2DINV software, as a 2D model as shown in Figure 2. The area was 300 m long. The electrode spacing was 5 m. The maximum depth to be measured was 50 m. The error of interpretation was 2.5%. The results from this study area are described below.

Layer 1: electrical resistivity 1–8 Ω·m at 2 m below the surface, it could be identified as top soil.

Layer 2: electrical resistivity 10–17 Ω·m at a depth of 2–30 m, it could be identified as sedimentary rock.

Layer 3: electrical resistivity 20–50 Ω·m at a depth of 30–50 m, it could be identified as a sedimentary aquifer.

Location 2: coordinates N14°47'46" E103°28'0", Mueang Fang Subdistrict, Mueang District, Buriram Province, the total length of the survey was presented, along with the soil layer, and the orientation of the groundwater, including the boundaries, thickness, and depth as shown in the 2D model (Fig. 3).

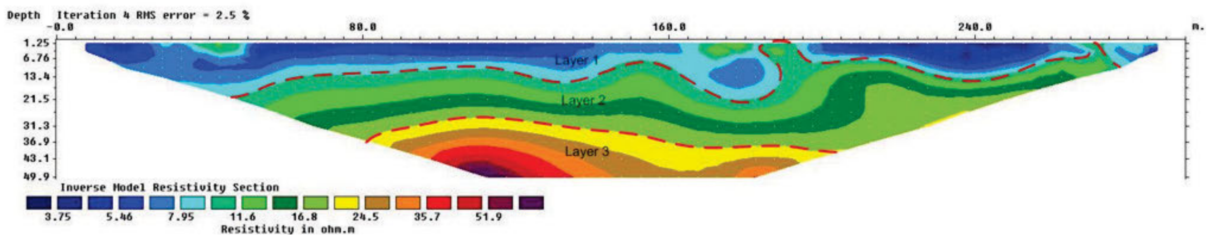

Fig. 2. 2D model of location 1 (Khok Lek Subdistrict, Huai Rat District, Buriram Province) with 5 m of electrode spacing; source: own study

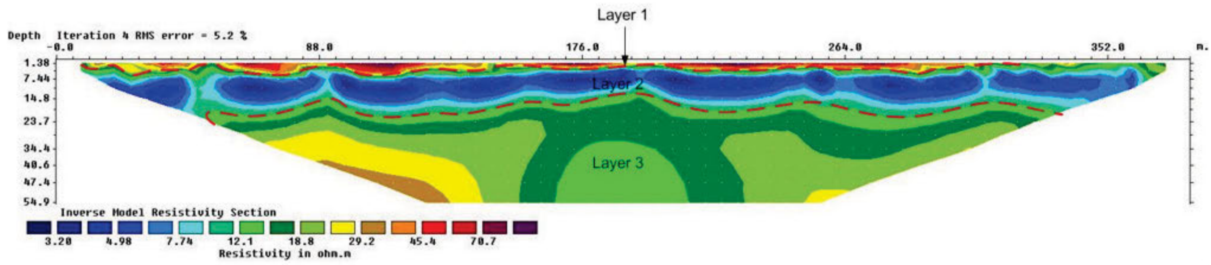

Fig. 3. 2D inversion model of location 2 (Mueang Fang Subdistrict, Mueang District, Buriram Province) with an electrode spacing 5 m; own study; source: own study

Regarding the survey point location 1, Muang Fang sub-district, the total length of the survey was 374 m, the maximum depth was 55 m, and the error was 5.2%. The results of data interpretation are summarised below.

Layer 1: electrical resistivity 30–100 Ω·m at a depth from the surface up to 3 m, it could be identified as top soil.

Layer 2: electrical resistivity 1–10 Ω·m at depths of 3–20 m indicated that it was a soil or sedimentary aquifer.

Layer 3: electrical resistivity 20–40 Ω·m at depths of 20–50 m, it could be identified as sedimentary rock that accumulates or uncoffins an aquifer.

Location 3: coordinates N15°06'22.5" E103°09'38.5", Ban Dan Subdistrict, Ban Dan District Buriram Province, the total length of the survey was 264 m, the maximum depth was 55 m, and the error was 3.5%, as a 2D model as shown in Figure 4. The data interpretation is summarised below.

Layer 1: electrical resistivity 30–173 Ω·m at up to 5 m below the soil surface. It could be identified as a layer of soil and layer of soil reclamation because the resistivity differed significantly.

Layer 2: electrical resistivity 3–15 Ω·m, at a depth of 5–20 m, it could be identified as a sedimentary rock or aquifer.

Layer 3: electrical resistivity 30–55 Ω·m, at depths of 20–50 m, it could be identified as a sedimentary rock with a zone of saturation.

DRILLING EXPLORATION AND WATER LEVEL IN THE OBSERVATION WELLS

The drilling exploration was conducted following a geophysical survey that measured conductivity in the field. This was done to investigate the accuracy of the resistivity interpretation and to monitor and measure groundwater levels in the study area. Due to the COVID-19 situation, the survey drilling operations were limited to a single area in the Muang Fang Sub-district, Muang District. This is due to measures to prevent the spread of COVID-19 by introducing lockdown. Therefore, the research team was unable to drill observation wells and collect data in other study areas. The drilling extended from the surface to a depth of 50 m, with a 101.6 mm (4 in) diameter drill bit. The location of the exploration well is shown in Figure 5.

Explorations

At a depth of 2.0–3.5 m from the surface, the exploration revealed a layer of soil consisting of sediments, gravel and sand (clastics rock). From 2.5 to 30 m, the soil consisted of clay contaminated with gravel sediment (clastics rock) and sand, appearing as light brown and not solidified. A grey clay layer was found at 13–15 m in well no. 4 and at 10–14 m in well no. 5. ERT survey data indicate that groundwater accumulates at the depths of 30–50 m. The layer was brown to dark, brown mixed with Greenwich grey

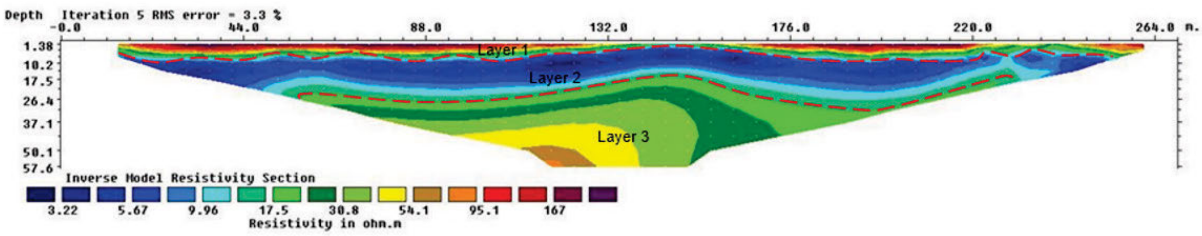

Fig. 4. 2D inversion model of location 3 (Ban Dan Subdistrict, Ban Dan District Buriram Province) with an electrode spacing 5 m; source: own study

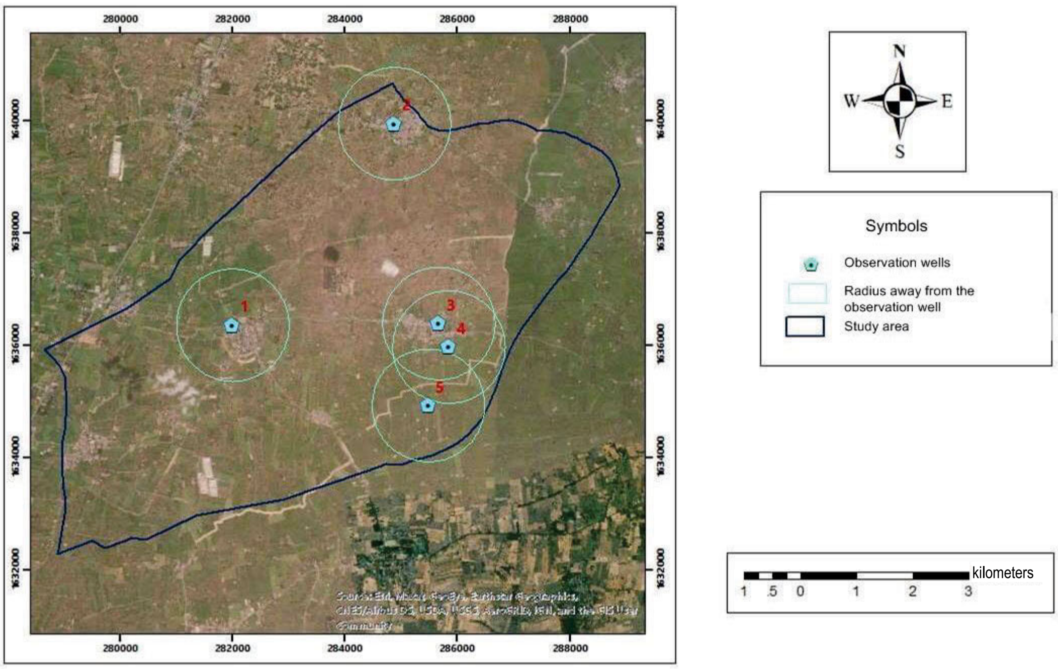

Fig. 5. Location of the exploration well in the study area; own study

sandstone, and there was groundwater retention at this depth. However, during drilling of the observation well, groundwater was found at a depth from 9 to 50 m below the surface. The stratigraphic structure is shown in Figure 6. The results indicated that the unconfined groundwater aquifer consists of sand, gravel, clay, and red-brown sandstone with an average depth from 2.0 to 50.0 m. The amount of water in the well was 30 $m^3 \cdot h^{-1}$, indicating that the groundwater is suitable for utilisation.

ally, the study compares results from this investigation with those of previous research. Geophysical surveying techniques, specifically the ERT, are utilised to estimate the conductivity and resistivity of soil, rock, and groundwater levels in drought areas of the Buriram Province. The aim of this study is to investigate underground water resources and determine locations where groundwater can be utilised for household and agricultural purposes. The ERT results and observation boreholes indicate the presence of sedimentary and sedimentary rock formations containing underground water at depths ranging from 9 to 50 m. This is consistent with Buriram Provincial Geological Survey data announced by the Department of Mineral Resources (DMR) in 2020. They are also unconsolidated Korat group. The findings also correspond to the resistivity of the material proposed by Loke (1999).

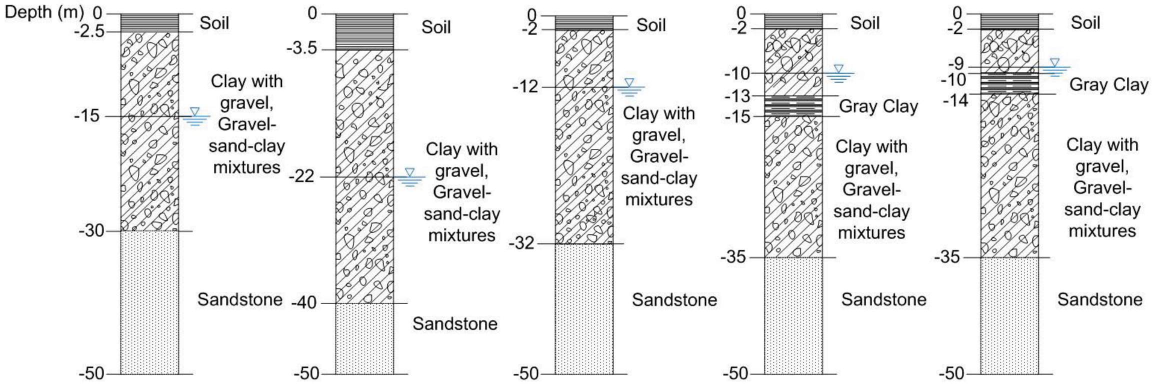

Fig. 6. Stratigraphic unit and water level from five drilling observation wells in the Muang Fang Sub-district area; source: own study

Water level in observation wells

In the Muang Fang Sub-district, Mueang District, Buriram Province, water in 5 observation wells was a depth of 50 m below the surface and a borehole diameter was 101.6 mm. The water level in the well, measured below the surface, is presented in Figure 7. The groundwater level was monitored from June 2020 to May 2022, and there was little variation in groundwater levels during this period.

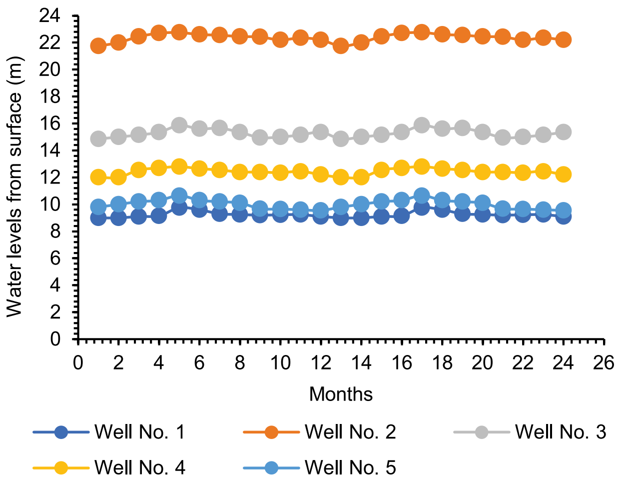

Fig. 7. Measured water level in 24 months (2 years) for five observation wells in the study areas; source: own study

DISCUSSION

This section describes the reliability of groundwater exploration using geophysical surveying and electrical resistivity tomography (ERT). The study evaluates the adequacy of survey results and measurements of groundwater levels in the study area. Addition-

At such a depth, the reliability of the survey is limited as it is not possible to investigate beyond this level. It can be attributed to the distance between the electrode's placement, affecting the vertical signal transmission and electrical resistance measurement. The survey results indicate that no aquiclude was found at this depth. As a result, the depth of the ERT measurement is within the range of 50 m from the surface, which is consistent with the findings of previous studies by Satarugsa *et al.* (2008), Satarugsa (2011) and Loke *et al.* (2015).

Observation wells were utilised to measure changes in groundwater level from June 2020 to May 2022. The data was obtained by measuring the water level in five observation wells located at 50 m below the surface in the Muang Fang Sub-District, Muang Buriram District. During the study period, a slightly stable water level was observed in all five observation wells. However, it was possible that the COVID-19 pandemic might have contributed to the situation, as the research team was unable to conduct additional measurements in the area due to delays caused by the pandemic. Based on the changing groundwater level under this study, the area can be considered suitable for the supply of groundwater to households or agricultural operations without reducing the groundwater level. This finding aligns with the information of the Department of Mineral Resources, DMR (2010) that groundwater levels at depths of 15–40 m from the upper water level of the Korat group can be safely utilised without affecting the environment in the Buriram Province. If groundwater is extracted from a deeper level, there is a higher risk of encountering saltwater produced by melting salt rock (DMR, 2020).

CONCLUSIONS

All objectives and requirements of this study have been met. Conclusions based on the results of the ERT survey, inversion model, and observation wells are described below. The ERT survey of the study area was conducted to determine drought-affected areas, which consisted of 1 – Khok Lek Subdistrict, Huai Rat District, 2 – Mueang Fang Subdistrict, Mueang District, and 3 – Ban Dan Subdistrict, Ban Dan District, Buriram Province, Thailand. Resistivity could be measured at 50 m below the surface. Results of ERT survey and inversion models indicate that ground water is located at 20 m below the ground surface. The close convergence between the ERT model interpretation and borehole drilling observation suggests that the groundwater is a shallow or aquifer unconfined.

The result obtained from the five wells indicate that the stratigraphic unit includes unconsolidated sedimentary and saturated sandstone with water yield from the well of 30 $m^3 \cdot h^{-1}$.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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