

# Geophysical survey for groundwater potential investigation in peat land area, Riau, Indonesia

N Islami\*, M Irianti, Azhar, M Nor and Fakhrudin

Physics Education – FKIP, University of Riau  
Jl. HR Soebrantas, Km. 12.5, Pekanbaru, 28293, Indonesia

\*Corresponding Author : nurislami@lecturer.unri.ac.id

**Abstract.** Tropical forests, especially peat lands, are particularly vulnerable to forest fires. Fires are the most common disasters in peat lands in the dry season, especially in Riau Province, Indonesia. In the process of extinguishing the peat fire, several substantial problems arise to stop peat fires during this period. This study aims to determine the possibility of using ground water as a source of water to anticipate the early mitigation of peat land fires disaster. The geoelectrical resistivity surveys were used to predict the subsurface geological data including peat thickness and depth of aquifers. The geometry of peat land was determined using geostatistics based on geoelectrical resistivity interpretation data. Peat land thickness varies up to 4 m in the north, and is thinner to the south. A shallower and deeper aquifer is available at a depth of 13 m to 18 m and 70 m to 90 m respectively. In general, the potential of groundwater in the shallow aquifer is predicted to be sufficient for peat land watering anytime.

## 1. Introduction

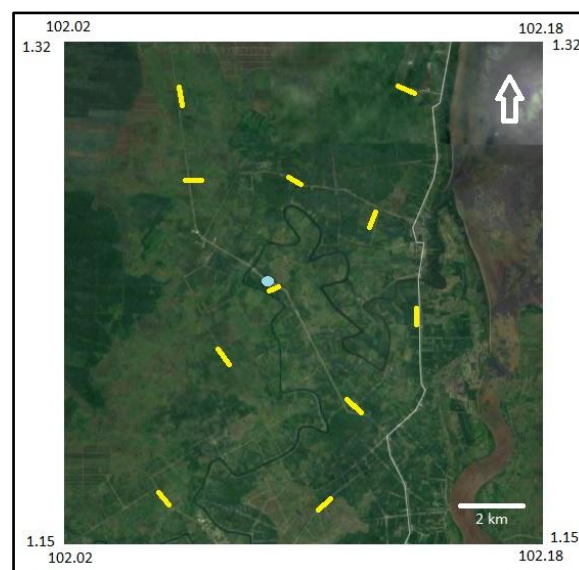
The depth and thickness of sedimentary rocks that are not consolidated vary for certain places even within the same area. This depends on the conditions under which the rocks are formed and also depends on the weathering process and the geological precipitation processes occurring in the area. In groundwater exploration, porosity and sediment thickness variables determine the amount of groundwater reserves beneath the surface. The thickness of the unconsolidated sediment depends on how far the bedrock is found in the area. If the bedrock is available at relatively shallow depths, this causes a thinner sediment thickness that can store groundwater.

Almost the area of Central Sumatera basin is located in Riau Province. One of the rivers that crosses this basin is the Siak River. The upper surface of the Central Sumatra Basin consists primarily of peat that is vulnerable to peat fires [1]. Meanwhile, alteration of peat land functions for agriculture occurs almost in all peat lands in Indonesia [2,3]. In this regard, the main problem occurring in the Sumatran basin, especially along the Siak plains and coastal areas is forest fires as a result of illegal agricultural and agricultural activities [4]. Wildfires are often out of control due to lack of water to stop them [5]. This is because peat soils have a specific structure [6,7]. The need for water to stop fires in the forest increases dramatically in case of fire on peat lands. This problem can be better addressed if water sources for forest fires are extracted from groundwater in the area.



Geophysical survey as the one of in-destructive, fastest and low cost survey method is widely used to explore the subsurface condition for the several problems. The use of resistivity survey has been reported that the method is possible to differentiate contrast between the area that has been applied with fertilization for long duration and non-fertilization [8,9,10]. This method was also used to investigate geomorphology of gravity-flow channels in a rift basin using seismic survey [11] and Interpretation of the deep-water geomorphology of the glaciated Irish margin from high-resolution marine geophysical data [12]. Geophysical data also gave the better result when combine it with the Lansat images in the interpretation [13]. In this study the use of geoelectrical resistivity will be discussed for the subsurface mapping and groundwater investigation in the Siak River delta, Indonesia. Findings of this study are very important in development of the knowledge especially for peat land, hydrogeology and geomorphology, and to develop the subsurface geological model. A part on that, particularly, for the local government is also important as the guidance to manage the groundwater resources in term of the peat fire rescue.

The location of the research area is given in Figure 1. The study area has an altitude between 8 to 12 meters above mean sea level. The yellow lines in the figure representing the direction of the resistivity data, but the length of the line does not indicate the length of the path, whereas the blue circle is the location of the wellbore. The research area is bounded at the eastern part with the Siak River, where this area is part of the Biosfere Giam Siak Kecil Reserves area, Bengkalis Regency, Riau.



**Figure 1.** Satellite image of the research area (source: Google Earth)

## 2. Methodology

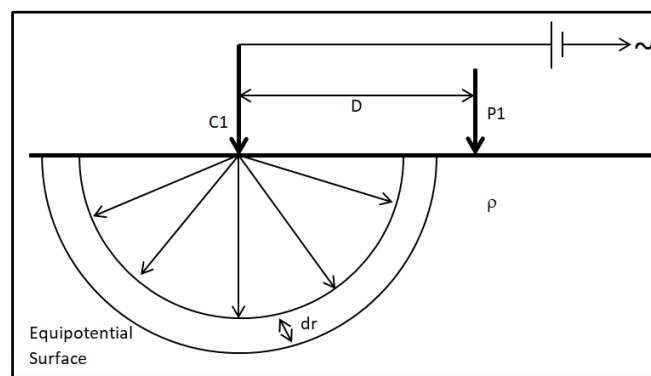
In this research, the geoelectrical resistivity survey and soil property analysis were used to study the groundwater and peat land characteristic. The geoelectrical resistivity was calibrated with a geological data obtained from drilled well to attain a more accurate interpretation and with the peat soil sample. Uninterrupted peat lands were sampled using homemade equipment with a volume of 500 ml from a depth of 50 cm in some locations. Peat soil samples were then dried and the dried peat samples were watered to obtain total porosity[14]. The porosity of peat land is then used to predict water requirements for the entire study area.

The geoelectrical resistivity method with Schlumberger configuration was used to survey the study area of about 130 km<sup>2</sup>. The data collection used an in-house resistivity meter with 4 electrodes for each measurement. The electrodes spacing was placed from a distance of 50 cm until more than hundred meter for covering the high resolution at the near surface. Inversion of the raw data from the

field in order to obtain resistivity data was done using Progress1D inversion program. Dominant resistivity value at each depth was used as an input data in generating a three dimensional resistivity slice maps. Krigging technique was employed to produce contour of resistivity data.

Based on the Ohm's law, the potential difference is equal to the multiplication of current and material constraints. When combined with material properties, material durability will depend on the type of resistance material, then the resistance of the material type can be determined if the measurement geometry is known. Finally the potential difference can be determined using Equation 1. Fig. 2 is a moving electrical ray in the earth media of one electrode, and the negative electrode is assumed to lie at a great distance, which will produce potential at point h.

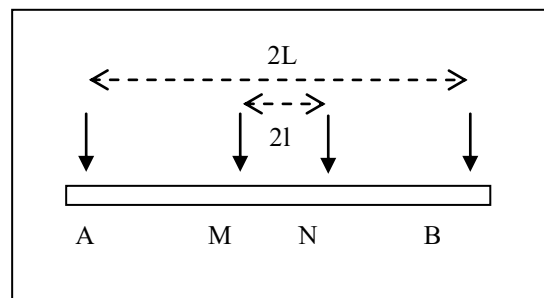
$$dV = iR_{shell} = i\rho \frac{dr}{A} = \frac{dr}{2\pi r^2} \quad (1)$$



**Figure 2.** An illustration of electric current propagation from an electrode [15]

For the Schlumberger configuration (Fig. 3), the distance between the electrodes is as in the figure, so that the sub-surface resistivity is (Equation 2)

$$\rho_a \approx \frac{\pi L^2}{2 l} \frac{\Delta V}{i} \quad (2)$$



**Figure 3.** Schlumberger configuration (modified from Telford 1991)

A new well was drilled to obtain geological data for calibration purposes with geoelectrical resistivity data. Soil samples obtained directly from drilling were taken and analyzed in term of their grain size and color. These data were used to control the resistivity interpretation for whole data.

Semivariogram was used for the data modeling prior to Krigging simulation. The semivariogram is one of the significant functions to show the spatial relations in observations measured at the sample sites. Generally it is given as a graph that shows the variance in the measurement of the distance between all pairs of sample locations with distance  $d$ . A graph is helpful for constructing a mathematical model that describes the measured variable of a sample with another sample location.

In the modeling process, the relationship between the sample locations to show the variability of measurement by the separation distance is called semi-variogram modeling. It is applied in calculations that involve an estimation of an unknown new location value [16,17]. With a simple semi-variogram can be described as a plot between the semi-variant of the distance, which is measured at every distance with difference in lag. The semi-variogram is actually can be expressed mathematically as in the following Equation 3:

$$\gamma_h = \frac{\sum_{i=1}^{n-h} (X_i - X_{i+h})^2}{2n} \quad (3)$$

Further stage, semi-variogram data were a requirement for the Krigging Gaussian simulations process [16]. The krigging process was done after the semi-variogram data was obtained. Simply krigging is a prediction the unknown data at a certain location by considering the direction of whole data trends, the amount of data around the unknown data and distance to the surrounding data.

Mathematically krigging can be illustrated by the equation below. Gama is a semi-variogram, h is a distance and W is a weighting. Finally the data predictions at location p can be obtained [18].

$$\hat{Y}_p = \sum W_i Y_i \quad (4)$$

Where  $\hat{Y}_p$  is the value at the location p which will be in prediction by weighting of the value at the surrounding location based on the given semi-variogram data.

### 3. Results and Discussion

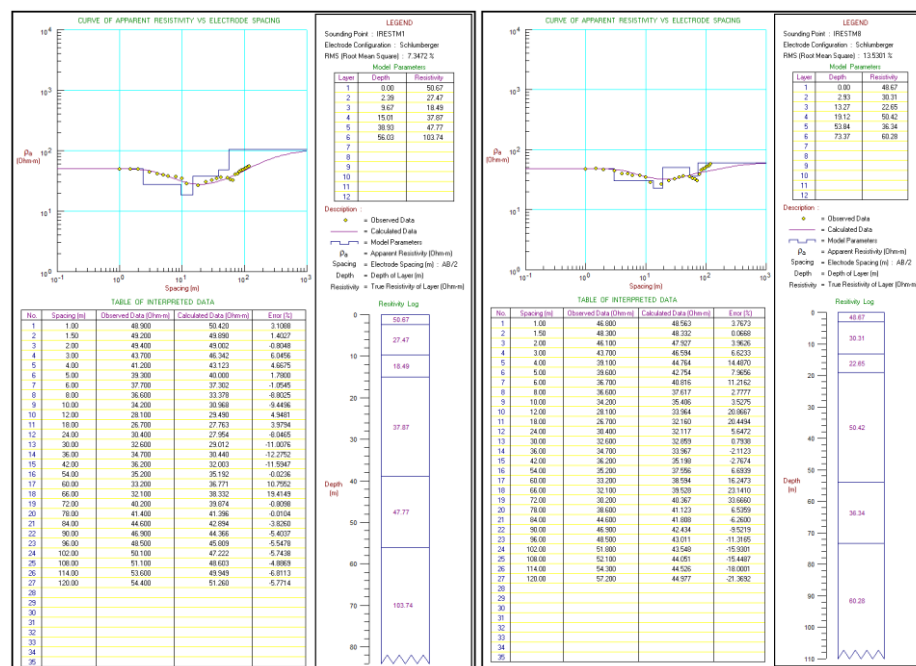
Table 1 is the peat land porosity data obtained from 6 locations. It is seen clearly, the porosity of peat in this research area is quite big with an average of about 41.5%. Although the smallest porosity is obtained from peat lands that are closer to the Siak river (SK2 and SK5), however, the value of porosity at these locations differed only slightly with the porosity of peat land that is relatively far from the Siak River.

**Table 1.** Porosity of peat soil sample from a depth of 50cm

No	Sample ID	Long (°)	Lat (°)	Porosity (%)
1	SK1	102.050094	1.181669	42
2	SK2	102.116613	1.202139	40
3	SK3	102.072606	1.239806	42
4	SK4	102.063108	1.239455	42
5	SK5	102.129552	1.25016	40
6	SK6	102.073659	1.265075	43
Average				41.5

Figure 4 shows the result of subsurface resistivity obtained from the inversion process for line 1 and line 8. The apparent resistivity data from some locations is then converted to the required data format, so it can be processed to obtain the actual subsurface resistivity value. In Figure 4, the dot of the circle is the data obtained from the field and the line is the calculated resistivity, whereas the blocked graph is the inverse interpretation value. The table to the right is the depth and true resistivity value obtained from the interpretation, where the interpretation is based on the trend curve, yielding the raw data point curve. The table at the bottom shows the configuration and raw data obtained from the field, and error estimation in the inversion process. The column on the lower right side shows the vertical interpretation of the subsurface based on the table above it. In the figure, it can be seen that the resistivity value ranges from 15ohm.m to more than 180 ohm.m. The interpretation of the results of this data is that the subsurface layer consists of 6 main layers, interpreted as peat layer (layer 1), very fine

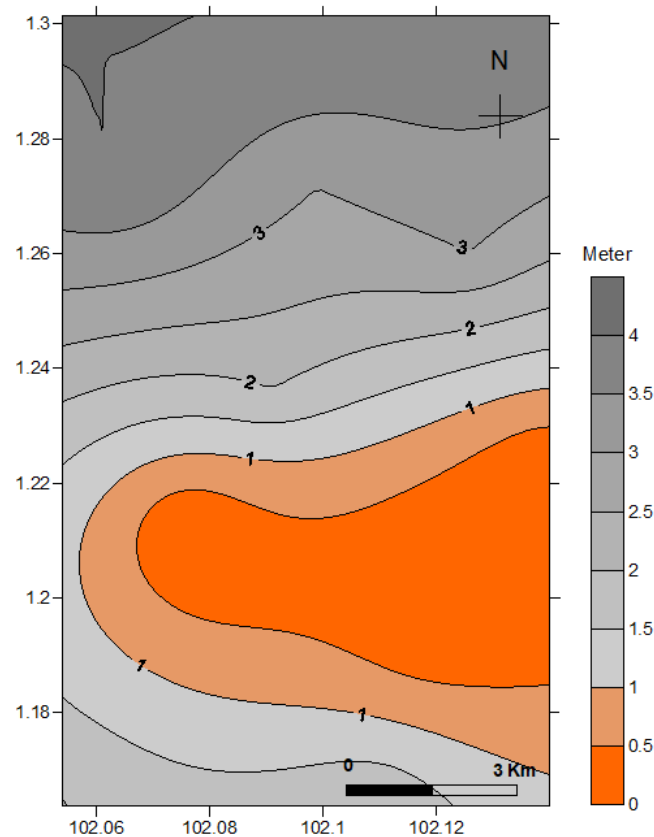
sediments contaminated by marine sediment (layer 2), coarse and coarse sand (layer 3), very fine sediments with relatively white (layer 4) and a deep aquifer zone with coarse sand (layer 5) and the latter is finer clay sediment mixed with sand (layer 6). The well data provides the lithology condition that was taken from direct drilling at survey location 8. This location was chosen because it is in the middle position of the research area, so it is expected to be able as a represent for the overall subsurface geological condition. This well data is used to calibrate the inversion resistivity data so that it can be interpreted in the form of lithology, rather than in the form of resistivity.



**Figure 4.** Inversion of resistivity data at survey line 1 and line 8, and subsurface interpretation

The average resistivity value of the first layer is 48 ohm.m with thickness of 2 meters to 4 meters, this layer is the top layer interpreted as peatland. This can be known through the supporting data obtained from direct resistivity measurement, which the average peat resistivity value is about 45-52 ohm.m. Figure 5 shows contour of the peat thickness obtained from the interpretation of the geoelectrical resistivity survey data. This peat layer is not evenly distributed in this research area. In the northern part, the peat layer is found with a thickness of approximately 4 meters. But in the south, it is only with a depth of 2 meters. While in the middle of the research area, peat layer is almost not found. The peat layer resistivity in general has a decreasing trend towards the north. This is due to residual effects of sea water remaining in the peat.

The second layer is the resistivity value zone of about 25 ohm.m with a thickness of 7 meters to 9 meters, interpreted as clay layer with marine deposit. The third layer is the zone with the resistivity of 18 ohm.m to 25 ohm.m with a thickness of 8 meters on average. This layer is interpreted as sand layer which is estimated to contain brackish groundwater (aquifer). The fourth layer is the zone with average resistivity value of 40 ohm.m with average thickness of around 25 meters, this layer is interpreted as Clay layer. The fifth zone is the layer with average resistivity of around 40 ohm.m with the average thickness of 18 meters, this layer is interpreted as deep aquifer. And the last layer is the clay which is the deepest zone with a resistivity value of 70 meter.



**Figure 5.** Thickness of the peat layer based on the geoelectrical resistivity interpretation data

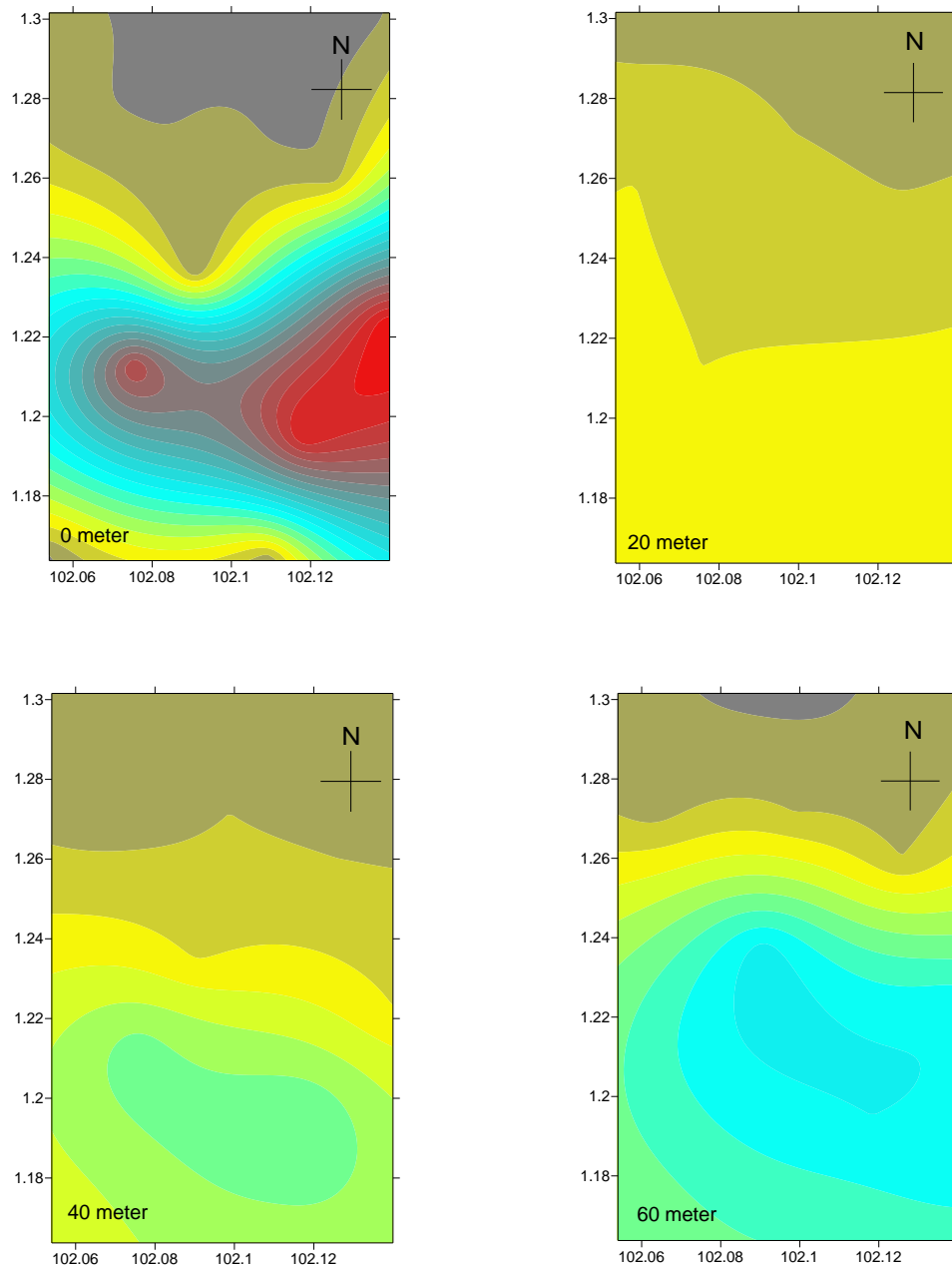
Figure 6 shows a subsurface resistivity depth slice for several depth resulting from the krigging simulation of all available resistivity data. In the krigging process, each location at the same depth in the sample data was used for the interpolating process. Semi-variogram modelling was done before krigging simulation. The result of semi-variogram analysis provides that the data trend direction is from the north of an angle about  $10^0$  to the west. At the center of the study area (Figure 5), at the 0 m deep, a relatively large resistivity value of around 200 ohm.m can be observed. These values are collected from direct resistivity measurement at the zone of relatively dry claysoil. It is a representative of more dense of clay soil with low water content in the pore of the soil. Around this site, peat soil was not found.

In the southeastern part, it can be seen that the resistivity value is relatively high at the depth ranging from 0 m. This value indicates the presence of relatively dry clay. This interpretation is supported by the presence of dry clays in the data collection zone in this area. In addition, the interpretation is also proved by calibration at wells indicating slightly dry clay having a resistivity value of more than 200 ohm.m

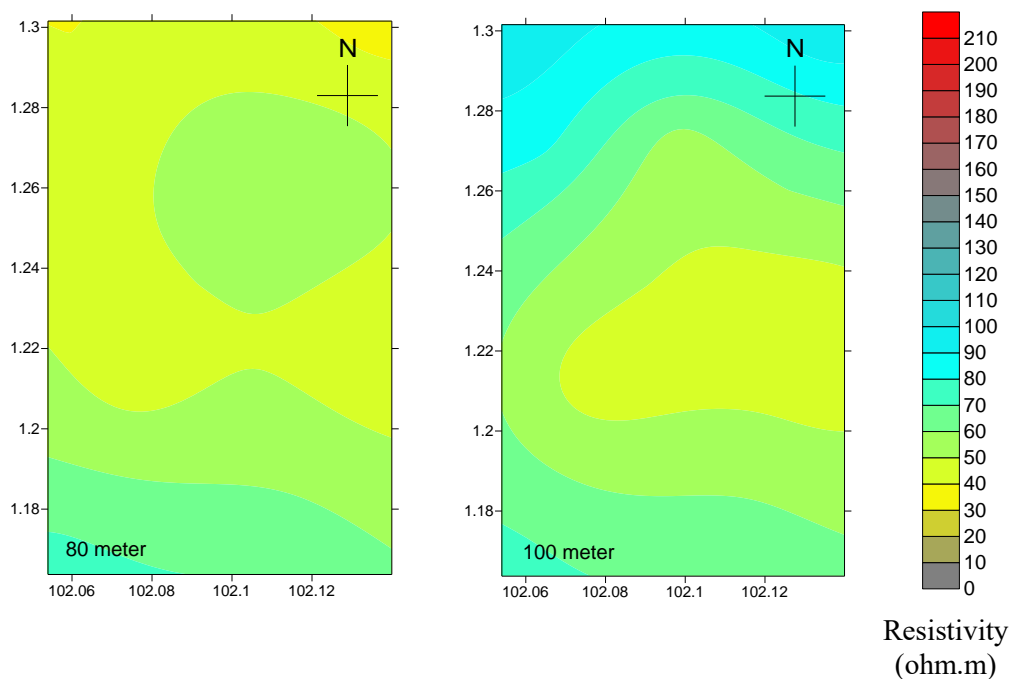
The clay soil on the surface spreads to the south with the depth of 5 m deep. Overall it is seen that the upper layer sediments are thickening towards the north with a thickness of about 5 m in the south and 30 m in the north. It can be seen also that the shallow groundwater potential is greater in the northwest. This is indicated from the relatively low resistivity of around 50 ohm.m in the area.

The possibility of deeper aquifers can be found at a depth of 60 m in the south part and has a slope towards the northwest at a depth of 100 m in this zone. Furthermore, the volume of peat soil can be calculated by providing the upper and lower boundary as well as other lateral boundary, so that the peat volume is found as much as 146.2 million cubic meters. If it is assumed that the peat porosity is 41.5% on average, then the water requirement for the whole area is 60.7 million cubic meters. Overall,

the thickness of shallow aquifer is obtained 8 meter. Based on the soil obtained from the well data, the aquifer consists of the coarse-grain sand and the aquifer porosity is approximately of 25% then the volume of water present in the shallow aquifer is calculated as much as 195 million cubic meters. It is highly visible that a shallow aquifer is able to inundate the entire peat in the study area.







**Figure 6.** The geoelectrical resistivity in the depth slice that is generated using Krigging process

#### 4. Conclusion

The geoelectrical resistivity method is well examined for detecting subsurface conditions in term of the groundwater resources. It is due to the geoelectrical resistivity is very sensitive to the granular type and the fluid in the pore. Unconsolidated sediments are not dense and have pores and it is connected to each other. This causes the flow of electric current easily if filled by a conductive fluid. This property will cause this sediment to have a small enough resistivity. Peat soil is found in the middle to the north zone of the study area. While in the southern and south eastern parts, peat lands are hardly seen. The aquifers in this study area are found in the shallow depth as well as at the deeper depth. In general, sedimentary rocks are thickening towards the northwest as well as with shallow aquifers and deep aquifers. The groundwater volume is predicted more than enough to watering the peat land in order to rescue peat fire.

#### Acknowledgments

Thank you to the Institute for Research and Community Service (LPPM) University of Riau, which has funded this research. Acknowledgments are also shared with field colleagues who assist in obtaining data during the survey.

#### References

- [1] Supardi A D, Subekty, Sandra G, Neuzil 1993 General geology and peat resources of the Siak Kanan and Bengkalis Island peat deposits, Sumatra, Indonesia, *Geological Society of America Special Papers* **286** 45-62
- [2] Rossie W N and Sudarmadji 2014 Emisi CO<sub>2</sub> Tanah Akibat Alih Fungsi Rawa Gambut di Kalimantan Barat *Jurnal Manusia dan Lingkungan* **21**(3) 264-276
- [3] Wahyunto, Ritung and Suprato 2015 Sebaran Gambut dan kandungan Karbon di Sumatra dan Kalimantan. Program dan Wildlife Habitat Canada, Bogor
- [4] Dian A, Carolien K and Asmadi S 2016 Indonesia palm oil production without deforestation and peat conversion by 2050 *Science of The Total Environment* **557–558** 562-570
- [5] Majalah Riaupos 2015 Solusi Kabut Asap Masa Depan *Riaupos* Edisi 139
- [6] Fereidoun R, Jonathan S P, *et al* 2016 Structure of peat soils and implications for water storage,



- flow and solute transport: A review update for geochemists *Chemical Geology* **429** 75-84
- [7] Yunita L and Haryono S 2015 Dampak pembangunan hutan industri di Lahan Gambut terhadap tingkat kematangan permukaan tanah *Jurnal Manusia dan Lingkungan* **22(2)** 179-186
  - [8] Islami N 2010 Geoelectrical resistivity and hydrogeochemical contrast between the area that has been applied with fertilization for long duration and non-fertilization *ITB J. Eng Sci.* **42(2)** 151-165
  - [9] Islami N, Taib S, Yusoff I and Ghani A A 2011 Time lapse chemical fertilizer monitoring in agriculture sandy soil, *International Journal of Environmental Science & Technology* **8(4)** 765-780
  - [10] Islami N, Taib S, Yusoff I and Ghani A A 2012 Integrated geoelectrical resistivity, hydrochemical and soil property analysis methods to study shallow groundwater in the agriculture area, Machang, Malaysia *Environmental Earth Sciences* **65(3)** 699-712
  - [11] Huaqing L, Zhong H, et al 2016 Sedimentary characteristics and seismic geomorphology of gravity-flow channels in a rift basin: Oligocene Shahejie Formation, Qinan Slope, Huanghua Depression of Bohai Bay Basin, China, *Marine and Petroleum Geology*, In Press, Corrected Proof, Available online 16 February 2016
  - [12] Sacchetti F, Benetti S, et al 2012 Deep-water geomorphology of the glaciated Irish margin from high-resolution marine geophysical data *Marine Geology* **291–294** 113-131
  - [13] El Sayed A, El Gammal, et al 2013 Applications of geomorphology, tectonics, geology and geophysical interpretation of, East Kom Ombo depression, Egypt, using Landsat images, *The Egyptian Journal of Remote Sensing and Space Science* Volume **16(2)** 171-187
  - [14] Jing Guo, Haibo Jiang, Hongfeng Bian, Chunguang He, Yingzhi Gao, 2016, Effects of hydrologic mediation and plantation of *Carex schmidtii* Meinsh on *peatland* restoration in China's Changbai Mountain region, *Ecological Engineering*, Volume 96, Pages 187-193,
  - [15] Telford 1991 Applied Geophysics *Cambridge University Press*, Pages 770
  - [16] Falk H, Vladyslav P, Steffen S, Sabine A 2014 Generating random fields with a truncated power-law variogram: A comparison of several numerical methods *Environmental Modelling & Software*, **55** 32-48
  - [17] Bachmaier, M and Backes, M 2008 Variogram or semivariogram? Understanding the variances in a variogram. Article doi:10.1007/s11119-008-9056-2, *Precision Agriculture*, Springer-Verlag, Berlin, Heidelberg, New York.
  - [18] Kigobe M M, Kizza 2006 Dealing with spatial variability under limited hydrogeological data. Case study: hydrological parameter estimation in Mpigi-Wakiso, *Proceedings from the International Conference on Advances in Engineering and Technology* 211-220