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Research Article

Groundwater aquifer study on coal mining area: a case of North Samarinda, Indonesia

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Abstract: One of the sectors supporting the economy of Indonesia is the mining industry. In East Kalimantan, coal mining activity has been done widely. Coal-mining open-pit activities play a significant role in the economic growth and the advancement of technology for Indonesia. Therefore, it is necessary to study every critical aspect including the hydrological and hydrogeological studies but especially aquifers, so that mining activities can be well managed and the impact on the environment can be overcome. The study of the aquifer from the study area was based on the resistivity value of the materials obtained through one of the geophysical methods that are the geoelectrical resistivity method, by using Wenner-Schlumberger configuration. In this study, geoelectrical resistivity method was performed in order to find out the condition of the subsurface by injecting two electrodes into the soil using direct current (DC) with certain distance so that potential difference can be known and resistivity information of subsurface layers can be obtained. The obtained resistivity value of the material was then interpreted so that the type of aquifer in the study area can be known. The interpretive results of the resistivity values of the materials in the study area showed that the distribution of aquifers based on measurement of a geoelectrical line of line number one, two and three, ware semi-confined aquifers. Meanwhile, the distribution of aquifers of line number four was confined aquifers. Based on the results of hydrological studies, the area of study has an annual rainfall of 3,053.704 mm/year with a watershed area of 16.586 km^2. The evapotranspiration value of the study area is 1,784.21 mm/year, the surface run-off is 913.51 mm/year, and groundwater recharge is 355.98 mm/year.

Keywords: *geoelectrical, groundwater recharge, North Samarinda, Wenner-Schlumberger*

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Introduction

One of the sectors supporting the economy of Indonesia is the mining industry. In East Kalimantan, coal mining activities have been done widely. Coal-mining open-pit activities contribute significantly to economic growth and technological advancement for Indonesia, but it is undeniable that mining activities can have an adverse effect, especially on the environment. Land clearing for mining activities will affect the availability and quality of groundwater. Changes in land use and morphology due to the existence of open pit mining operations will affect the groundwater conditions. Understanding the concept of hydrological and hydrogeological conditions including aquifer studies is essential to find out the characteristics of aquifers and groundwater flow patterns to know how significant mining activity can affect groundwater conditions (Ouyang et al., 2014). Besides, by understanding the condition of the aquifer, it can be known the influence of groundwater itself to the mining activity. The presence of groundwater is strongly influenced by the characteristics and geometry of the aquifers as the medium that determine the direction of groundwater flow. Groundwater recharge in the aquifer is strongly affected by precipitation, run-off, and evapotranspiration. The distribution of rain and the amount of rainfall is one of the determinants of the quantity of groundwater that correlates with the recharge area which also affects the groundwater flow. One of the methods used to find out the aquifer characteristics is geoelectrical resistivity. Geoelectrical resistivity method aims to obtain the subsurface resistivity values. From the subsurface resistivity values, the subsurface layer can be analyzed and interpreted, since each layer has specific values of resistivity and thickness. The values of resistivity contribute to the structure of lithology in a region in detail, and it is very useful to provide information about the aquifer (Devy, 2018).

Materials and Methods

The method used for this study was an inductive method that began with literature study and observation that was used as a recommendation until the study was done. The approach used was an analytical approach that included hydrological and hydrogeological studies in the form of aquifers. The experiment used in this research was a quasi-experiment which is experiment used for field study (Shadish et al., 2002) where it is difficult to control the existing variables and the absence of different treatment on the study objects. Besides, quasi-experiment research was used because of some data needed in the study cannot be obtained directly during the study (Glass, 2008). The resistivity data from the subsurface of the study area was obtained from the measurement using the geoelectrical device on four lines with the length of each line is 235 meters. First to third lines were on Pulau Balang geological formation while for the fourth line was on Balikpapan geological formation. The resistivity data from the subsurface will provide information about the subsurface layer and the type of aquifer. Groundwater recharge is part of the hydrologic cycle defined by the water balance in a watershed. The hydrologic cycle is influenced by the precipitation, surface run-off, groundwater recharge and evapotranspiration. Precipitation data used in this study is the data of the last ten years precipitation. The quantity of surface run-off is strongly influenced by the condition of the watershed and land use. The value of natural evapotranspiration is also highly dependent on precipitation data and the physical condition of the watershed.

Results

Geology of the study area

The geology of the study area is a description of the area showing the distribution of the geological structure, rock formations and the relationship between rocks. Based on the Geological Map of the Samarinda quadrangle (Cibaj et al., 2014). The area of study is located on Pulau Balang formation and Balikpapan formation (Supriatna et al., 1995). The Geology of the study area is depicted on the geological map which can be seen in Figure 2. The research area is in two formations:

(a) **(b)**

Figure 1. (a) Alternation of quartz sandstone with clay outcrop; (b) sandstone outcrop

Pulau Balang formation (Tmpb)

Pulau Balang formation is composed of alternating greywacke and quartz sandstone intercalations with limestone, claystone, coal and dacitic tuff. Greywacke, greenish grey, compact, the bed is 50-100 cm thick. Quartz sandstone, reddish grey, locally tuffaceous and calcareous, the thickness of layers is between 15-60 cm. Limestone, yellowish to light brown, contains large foraminifera, either as an intercalation or as lenses in quartz sandstone. The thickness of beds is between 10-40 cm. Limestone exposed in Loa Haur River contains abundant large foraminifera, such as *Austrotriliana hawchini, Borelis sp., Leidocyclina sp., Miogypsina sp.,* which indicates a Middle Miocene age and terrestrial to the shallow marine depositional environment. Claystone, blackish grey, the thickness of beds is between 1-2 cm, locally intercalating with coal, some of them reach to 4 m thick. Dacitic tuff, white is as thin intercalations in the quartz sandstone. Based on a survey in the field, study areas that are in Pulau Balang formation are much dominated by quartz sandstones from fine to coarse grain with medium thickness. Alternation of quartz sandstone and clay, as well as, sandstone and clay can be found in the study area. Meanwhile, the geological structure that developed in the research area was identified based on direct observation in the field. Geological structures encountered in the form of folds and fractures.

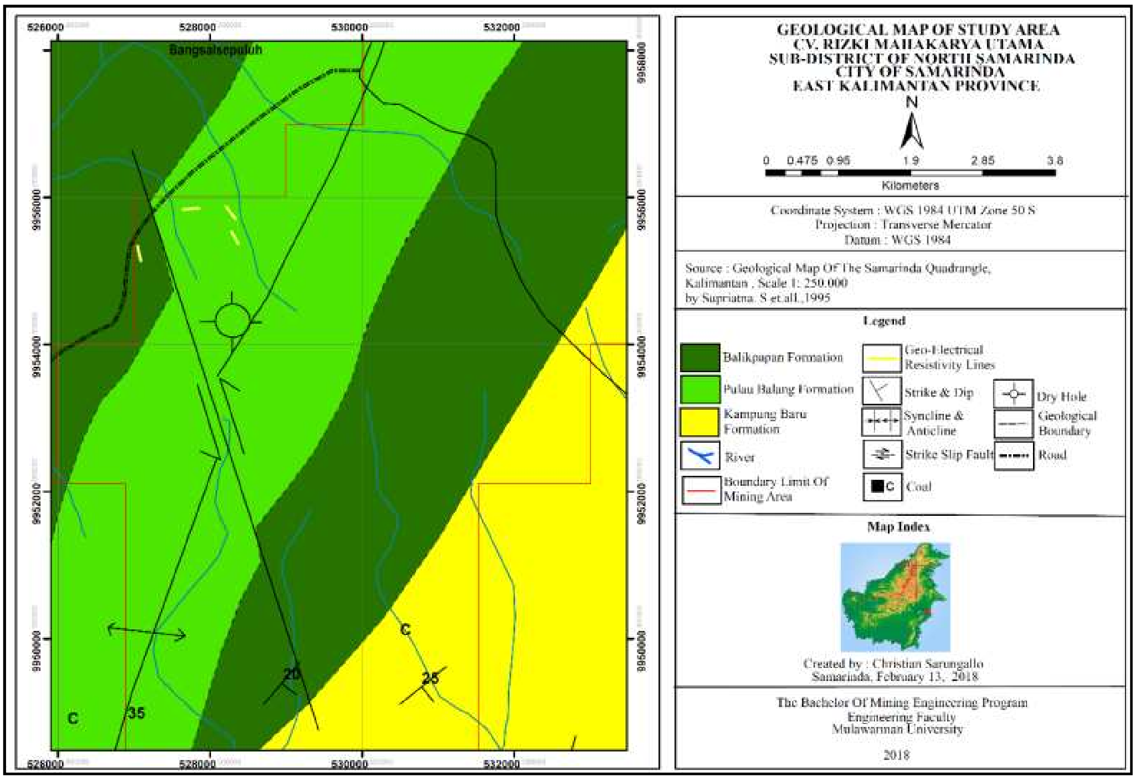

Figure 2**.** Geological map of the study area

Balikpapan formation (Tmbp)

Balikpapan Formation is composed of sandstone alternation and clay intercalations with silt, shale, limestone and coal. Quartz sandstone, white to yellowish, bedding thickness is about 1- 3 m, contains coal layers (5-10 cm). Calcareous sandstone, brown, shows graded bedding and cross-bedding, the thickness of bed is 20-40 cm, contains small foraminifera, intercalated by a thin layer of carbonaceous material. Clay, grey-blackish, locally contains plant remains, iron oxide, which have filled up the cracks of layers, locally contains calcareous sandstone lenses. Calcareous silt, thinly bedded; brownish shale thinly bedded. Sandy limestone contains large foraminifera, molluscs, which point to lower-Late Miocene to upper Middle Miocene age. Depositional environment is regression stage of a delta front to delta plain. The thickness is between 1000-1500 m. The area of study in the Balikpapan formation (Tmbp) is just a small area. Based on the geoelectrical survey the formation consists of sandstone, clay, and silt.

Geomorphology of the study area

Geomorphological processes over a period of time result in the form of landform on the surface of the earth having a distinctive relief. According to Verstappen (1985), several factors determine the landform, i.e. topography and relief image, rock structure and rock formation process. Based on the origin or genesis, the research area is grouped into two landforms, i.e. landform of structural and fluvial processes. Geomorphology map of the study area can be seen in Figure 3.

Landform of structural processes

The structural landforms that exist in the study area are structural plains and structural hills that occupy most of the research area. This hilly structural area is composed of anticlines and synclines. The direction of the fold tends toward east-southwest to the northeast. This landform occupies most of the study area. The lithology of the structural landforms consists of quartz sandstone, clay, silt and a thin layer of coal. The resistance of rock layers in the study area against erosion and weathering varies from moderate to weak. These structural landforms are affected by endogenous forces that work both horizontally and vertically, causing the formation of folds and fault. The folds will be formed when the endogenous forces that work do not exceed the material's elasticity against the pressure. The fracture is formed when the endogenous forces that work exceed the material's elasticity.

Landform of fluvial processes

Landform of the fluvial process occurs due to the flow of water. The process of water flow can be concentrated flow, in the form of river flow or unconcentrated such as surface run-off. This landform occupies the western of the research area, forms a river that extends from east to west. The material of this landform is mostly from the rocks of origin which are weathered then go through the erosion process, transported and sedimented. Based on the analysis of the geological and geomorphological conditions of the study area, it can be concluded that the typology of the aquifer system at the study site is sedimentary folded aquifers. This is indicated by the constituent rocks of the study area consisting of sandstone, rocks and claystone in the folding area. Groundwater potentials in this area are generally small, considering the constituent rocks are waterproof clays and very compact sandstones due to the strong tectonic processes; therefore the possibility of this old sandstone layer as a good aquifer is very small.

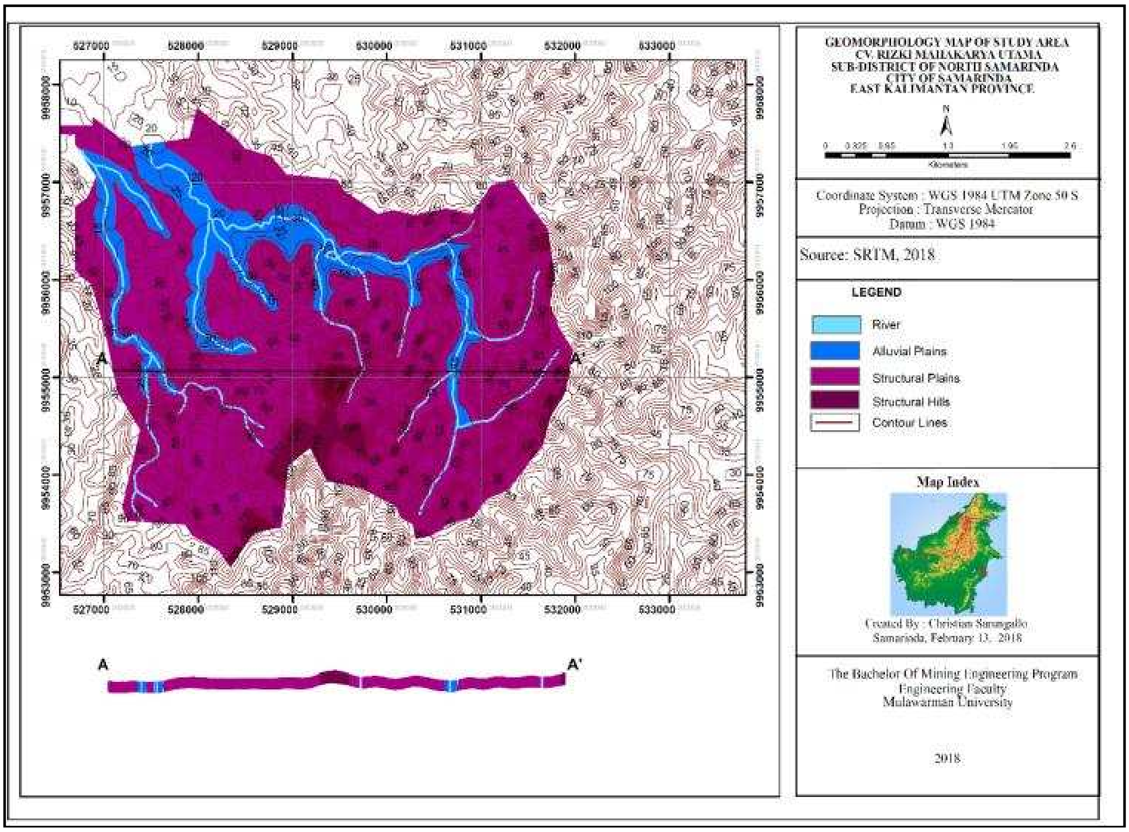

Figure 3**.** Geomorphology map of the study area

Rock resistivity

One of the properties or characteristics of the rock is resistivity which indicates the ability of the material to conduct electrical current (Azhar and Handayani, 2004). The higher the resistivity value of material the harder it will be to conduct the electric current (Suryadi et al., 2015). Because most rocks are poor conductors, their resistivity would be extremely large where it is not for the fact that they are usually porous and the pores are filled with fluids, mainly water. The conductivity of porous rocks varies with the volume arrangement of the pores and even more with the conductivity and amount of contained water (Telford et al., 1990). Resistivity measurements were conducted by installing 48 electrodes on each line of the 4 lines to determine the resistivity of the rock in the area of study. Location of geoelectrical resistivity lines can be seen in Figure 4.

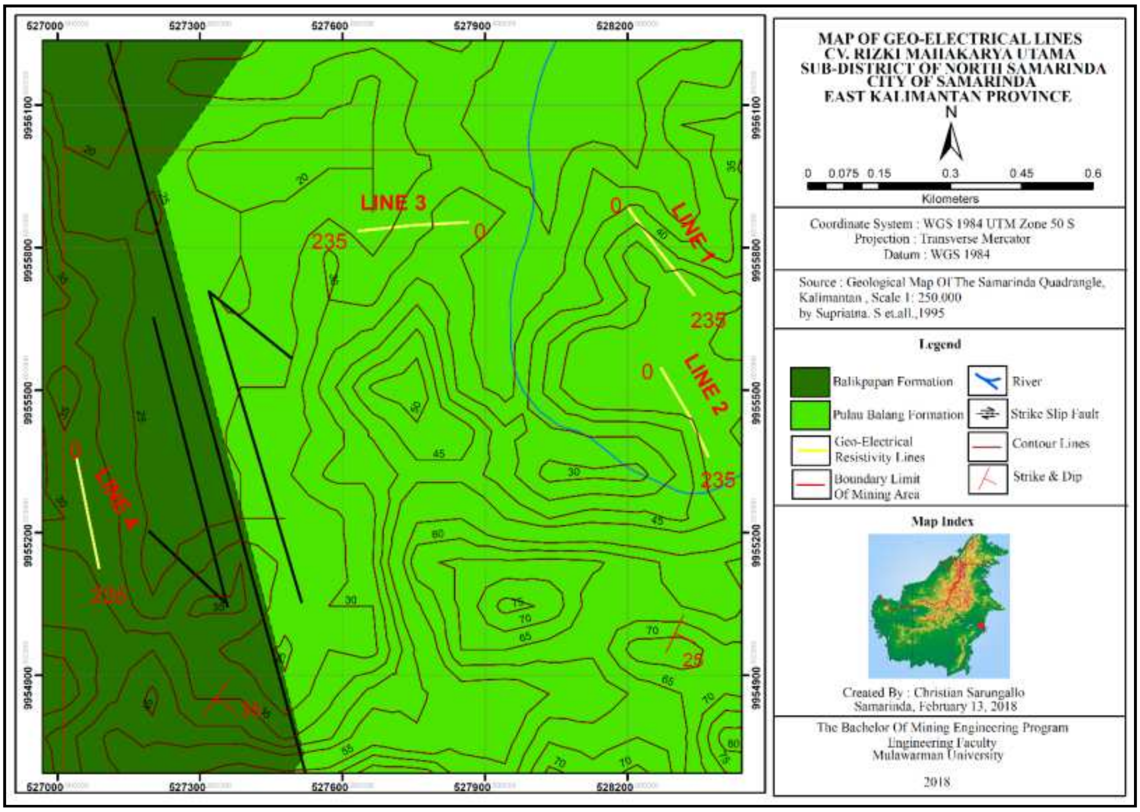

Figure 4. Line of geoelectrical

Based on the measurement results in the field, two-dimensional (2D) cross-section of 4 lines with each line length of 235 meters and 5 meters spacing of each electrode can be seen as follows:

Line 1

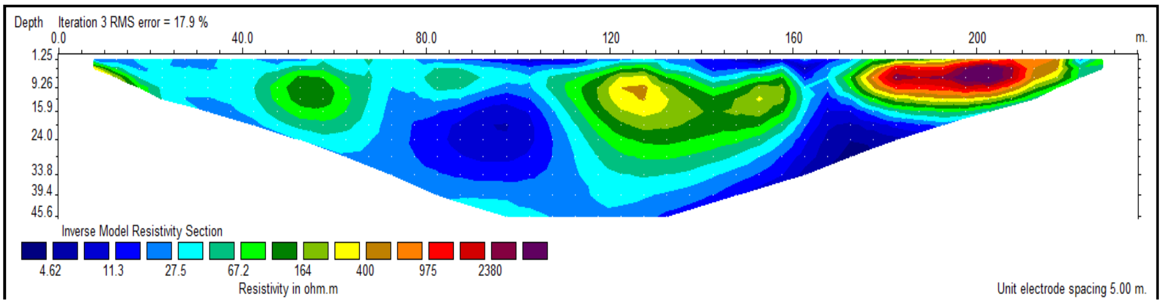

Figure 5. Geoelectrical cross section

Table 1. Resistivities of materials based on the geoelectrical cross-section of line 1

No.	Colour Range	Resistivity (Ωm)	Materials
1.		4.62 - 11.3	Clay
2.		27.5 – 67.2	Silt
3.		164 – 2,380	Sandstone

Line 2

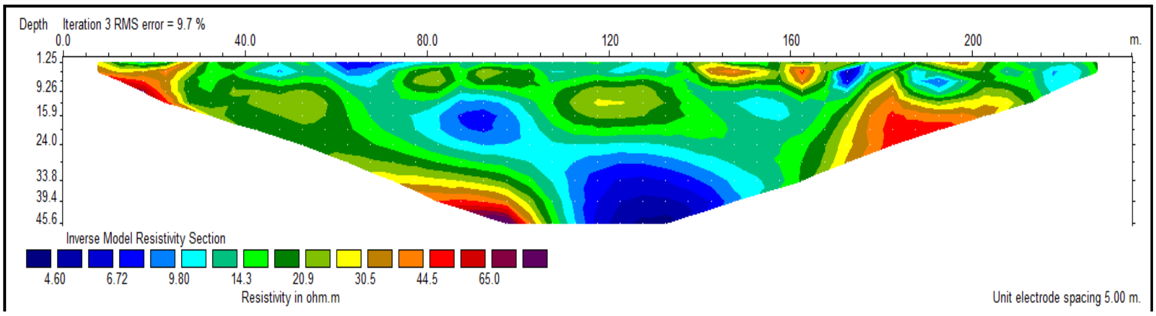

Figure 6. Geoelectrical cross section

Table 2. Resistivities of materials based on the geoelectrical cross-section of line 2

No	Colour Range	Resistivity (Ωm)	Materials
1.		4.60 - 14.3	Clay
2.		20.9 - 44.5	Silt
3.		65	Sandstone

Line 3

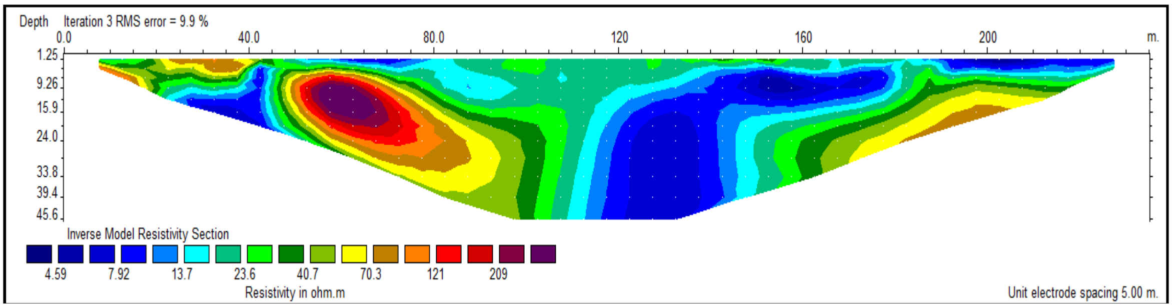

Figure 7. Geoelectrical cross section

Table 3. Resistivities of materials based on the geoelectrical cross-section of line 3

No.	Colour range	Resistivity (Ωm)	Materials
1.		4.59 – 13.7	Clay
2.		23.6 – 40.7	Silt
3.		70.3 – 209	Sandstone

Line 4

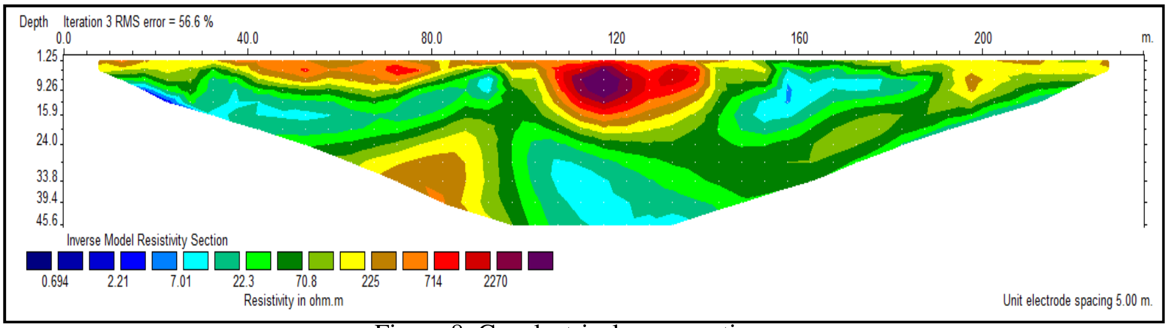

Figure 8. Geoelectrical cross section

Table 4. Resistivities of materials based on the geoelectrical cross-section of line 4

No.	Colour range	Resistivity (Ωm)	Materials
1.		0.694 – 2.21	Groundwater
2.		7.01 – 22.3	Clay
3.		70.8	Silt
4.		225 – 2,270	Sandstone-hard rock

Geoelectrical cross-section and interpretative results show that the surface from line 1 to line 4 is sandstone with a value of resistivity in the range 0.694 Ωm - 2,380 Ω m. While the sandstone layer with a value of resistivity 65 Ωm - 2,380 Ωm is suspected as a confined aquifer because it is overlain by confining layer, made up of clay with resistivity 7.01 Ωm - 22.3 Ωm. In line 4 is found a layer with a low resistivity value of 0.695 Ωm - 2.22 Ωm which is interpreted as confined groundwater.

Hydrology

The circulation of water on earth, called the hydrologic cycle, involves the processes and pathways by which water evaporates from the earth's surface to the atmosphere and returns to the surface as precipitation or condensation. With the earth's surface being about 70% water, most of the atmospheric water originates from the oceans and other water bodies. With few exceptions, much of the precipitation falling on land surfaces does not reach the oceans as streamflow or groundwater flow but instead evaporates back into the atmosphere (Brooks, 2013). In this study, critical hydrological aspects are the condition of the catchment area, precipitation and climate. The hydrological aspect plays a vital role in determining the quality of surface water and groundwater as well as having a significant influence on mining activities. Hydrological aspects such as precipitation and air temperature are used in determining the amount of surface runoff, evapotranspiration and groundwater recharge in the target area of study.

Rainfall intensity

The amount of rainfall on the surface of the earth is expressed in water depth (usually mm), which is considered to be equally distributed throughout the catchment area. Rain intensity is the amount of rainfall in units of time, which is usually expressed in mm/hour, mm/day, mm/week, mm/month, mm/year, and so on. There is some definition of rainfall. The average daily rainfall is the amount of rainfall in a month divided by the number of rainy days in a month. Average monthly rainfall is the amount of rainfall in one year divided by 12. Annual rainfall is the amount of rainfall per month in a given year. Rainfall is a significant factor affecting the research area. Determination of rainfall intensity is done by taking data from monthly rainfall divided by the number of rainy days on average in that month. The amount of rainfall data that will be used in rainfall intensity analysis is 120 data (10 years). Based on the data, it can be concluded that the amount of monthly rainfall in the research area is 254.475mm / month and annual is 3,053.70 mm/year. The amount of monthly rainfall in the area of study is presented in Table 5.

Table 5. Rainfall intensity (mm/month)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	124.7	126.7	797.3	1845.3	230.2	176.6	109.41	121.6	76.6	194.3	350.1	374.1
2009	164	196.2	278.9	309.1	186.4	41.2	175.3	122.7	98.5	246.6	165.3	211.3
2010	148.2	161.5	157.2	163.7	222.6	320.1	258.7	144.1	202	235.1	184.8	223.9
2011	351.6	232.2	246.3	192.4	237.1	68.56	84.6	14	177.7	219.2	231.8	236.6
2012	361.2	202.7	110.2	44.8	79.4	764.9	600	576.8	657.5	576.1	977.1	426.8
2013	999.7	1.015.5	1.080.6	291.1	315.72	131.95	139.7	171.33	176.6	201.4	226.7	365.5
2014	250.2	79.3	167.17	210	225.9	135.2	47.8	120.9	58.3	79.9	143.6	142.9
2015	198.6	38.9	225.4	336.3	199.4	98.6	271	145.4	94.1	339.6	304.5	296.5
2016	227.8	206.8	214.6	206.6	306.5	184.6	24.4	97.5	107.7	69.6	190.6	110
2017	306.8	220.4	260.4	339.7	112.3	213.4	278.5	132.9	182.6	181.4	84.6	138.2

Source: PT. Lana Harita Indonesia

Watersheds

Watersheds are areas that are bounded by mountain ridges where rainwater that falls in the area will flow into the main river. In determining the watershed, the Shuttle Radar Topography Mission (SRTM) data is used in the form of the most complete high-resolution digital topography database (Triatmodjo, 2008). In determining the watershed, we know that basically, run-off comes from the highest points and moves toward the lower points in the direction perpendicular to the contour lines. The area bounded by the line connecting the highest points is the watershed. Watershed map of the study area can be seen in Figure 9. The watershed in the study area has an area of 16.59 km^2. This watershed area is used as a parameter in the calculation of groundwater recharge.

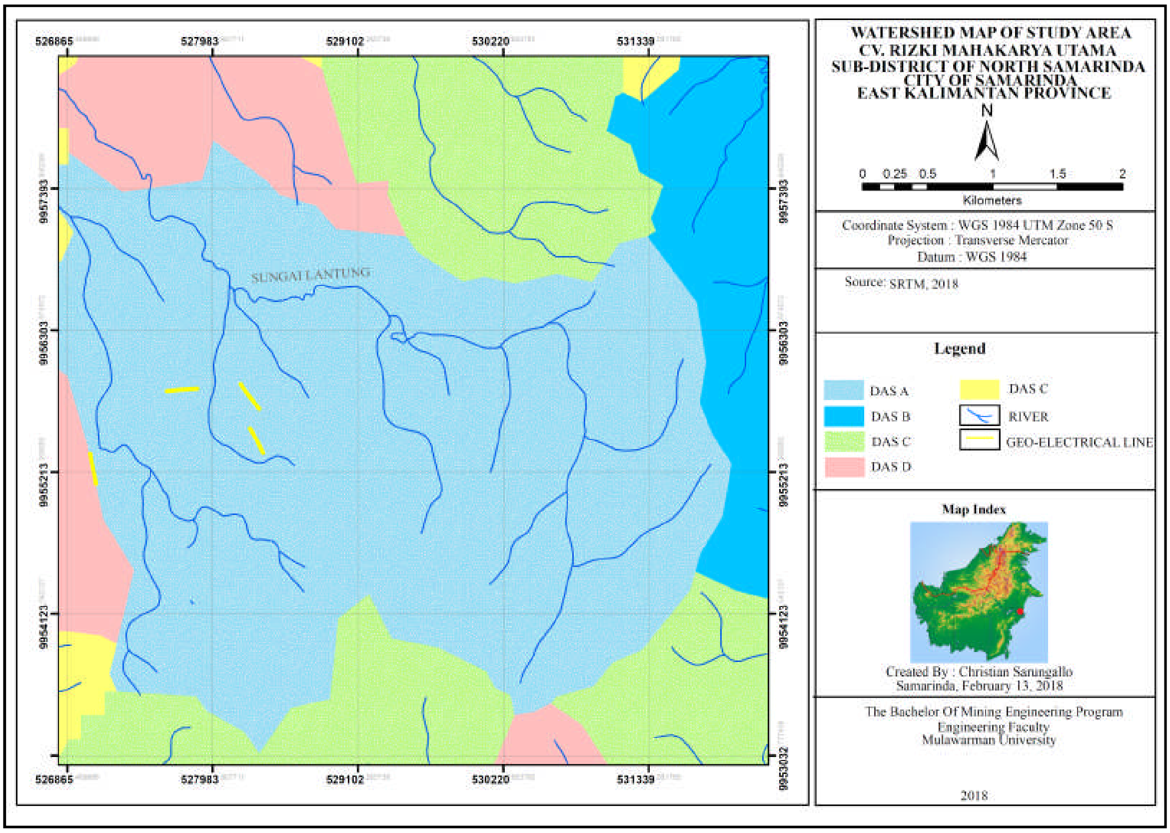

Figure 9. Watershed map of the study area

Evapotranspiration

Evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants. Besides, evapotranspiration can occur when there is enough water in the land that is called potential evapotranspiration. Evapotranspiration is affected by the amount of rainfall and the average annual air temperature in the target area of the study. The air temperature data in the period of 2008-2017 is presented in Table 6.

Table 6. Average air temperature in 2008-2017 (Celsius)

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	27.13	27.25	26.76	26.99	27.39	26.79	26.35	26.44	27.17	27.42	27.42	26.95
2009	26.99	27.13	27.16	27.53	27.86	27.77	27.32	27.90	28.60	27.54	27.78	27.80
2010	27.67	29.02	28.68	28.28	28.32	27.48	27.33	27.27	27.46	27.67	27.36	27.36
2011	27.14	27.01	27.33	27.51	27.72	27.48	27.09	27.88	27.56	27.42	27.66	27.33
2012	27.25	27.50	27.72	27.43	27.97	27.49	27.22	27.38	29.12	28.95	28.81	28.94
2013	29.12	28.48	28.72	28.69	28.74	29.09	28.29	28.33	28.46	28.67	28.95	28.50
2014	28.51	29.30	29.24	29.33	29.00	28.76	29.09	28.42	29.43	30.04	28.89	28.85
2015	27.08	27.38	27.80	29.23	29.16	28.70	28.95	29.58	30.12	30.55	29.92	30.06
2016	30.40	30.64	30.46	30.33	30.18	28.77	29.06	29.35	28.62	28.74	28.84	28.93
2017	28.62	29.24	28.98	29.08	28.86	28.54	28.99	28.50	28.93	29.68	29.41	29.36

Source: https://www7.ncdc.noaa.gov/CDO/cdosubqueryrouter.cmd

The amount of evapotranspiration is directly proportional to the air temperature. The higher the air temperature, the higher the evapotranspiration so that the value of groundwater recharge is getting smaller. The calculation of evapotranspiration can be seen in Table 7.

Table 7. Evapotranspiration Calculation

Rainfall (mm/year)	(P)	3,053.70
Average air temperature (^{o}C)	(Tm)	28.32
Evapotranspiration (mm/year)	(Evp)	1.784,21

The result of evapotranspiration calculation in actual condition is 1,784.21 mm/year. Evapotranspiration in the actual condition of the area of study is affected by the amount of rainfall and average air temperature.

Surface run-off

Surface water is all water present on the ground surface while the surface water that flows is called the surface stream. The most important part of the surface run-off is the peak flow; the time peak flow is reached, volume, and surface run-off (Kodoatie, 2010). The parameters affecting the amount of surface run-off distribution are rainfall, as well as the maximum potential retention obtained from the calculation with the parameter of curve number (CN) in the land use area of the area of study. The surface run-off calculation results can be seen in Table 8. The value of this evapotranspiration will affect the amount of water added into the aquifer zone, hereinafter referred to as groundwater recharge. The higher the surface run-off value, the smaller the value of groundwater recharge.

Table 8. Surface run-off calculation

Rainfall (mm/year)	(P)	3,053.70
Area of watershed (km^2)	(A)	16.59
Average air temperature (^{o}C)	(Tm)	28.32
Run-off (mm/year)	(Ro)	913.51

Groundwater Recharge

In the hydrogeology system, water always undergoes a recycling process called the hydrogeological cycle. In that cycle, the water will always go through the aquifer system called as the recharge process, that is, the addition of water into the aquifer zone. The amount of water added to the aquifer zone can be calculated based on the number of hydrological parameters such as rainfall, evapotranspiration and surface run-off. Groundwater recharge calculation results can be seen in Table 9.

Table 9. Groundwater recharge calculation

Rainfall (mm/year)	3,053.70
Evapotranspiration (mm/year)	1.784,21
Surface Run-off (mm/year)	913.51
Groundwater Recharge (mm/year)	355.98

From the calculation of the amount of rainfall, surface run-off and evapotranspiration, it can be concluded that the value of groundwater recharge potential in the area of study is 355.98 mm/year.

Hydrogeology

According to Irawan and Puradimaja (2015), hydrogeology is the study of the availability, physical properties of hydraulics and groundwater behaviour (saturated zone). Hydrogeology is a combination of body knowledge from both branches of science, the science of geology and the science of hydrology. Hydrogeological aspects discussed in this study are aquifers and groundwater that are analyzed based on geoelectrical resistivity. Research on hydrogeological conditions aims to determine the characteristics and types of aquifers in the area of study and to determine the value of groundwater recharge.

Types of Aquifer

Analysis of aquifer characteristics in this study refers to the rock resistivity obtained by the geoelectric survey in the area of study. By the resistivity value, the aquifer in the measured area can be identified by referring to the concept that the rocks are usually porous and have pores filled with fluid, especially water where resistivity will be higher if the water content in the rock is reducing. In this study, the range of resistivity values of each rock varied. The rock resistivity ≤ 20 Ωm is considered to be a rock with low resistivity which is considered as an aquiclude that rocks can store water but cannot transmit it. The rocks with resistivity values 20 Ωm - 160 Ωm are regarded as rocks with medium resistivity and are considered as aquitard of silt and aquifer of sandstone and rock in the range of this resistivity value is considered as a rock that has good porosity. Rock resistivity value of > 160 Ωm is considered rocks with high resistivity and considered hard rocks and difficult to store water between rock pores. The range of rock resistivity values based on interpretative results on 4 lines measurements in the area of study from the lowest to the highest resistivity is clay by 4.59 Ωm - 22.3 Ωm; silt by 20.9 Ωm - 70.8 Ωm; and sandstone of 65 Ωm - 2,380 Ωm. Considering the range of rock resistivity as well as its relation to rock pores, the rock at the study sites can be categorized as follows:

Table 10. Interpretation of the distribution of resistivity value

No.	Resistivity (Ωm)	Interpretation	Rocks	Formation
1.	≤ 20	Low resistivity	Clay	Aquiclude
2.	20 - 160	Medium resistivity	Silt– Sandstone	Aquifer
3.	>160	High resistivity	Sandstone	Hard layer

Source: Mohammad et al. (2006)

In this study, the type of aquifer was analyzed based on the geoelectrical cross-section of the layer in the research area through a geoelectric survey. Based on the data obtained, the majority of the distribution of aquifers in the study area is dominated by layers of clay, silt and sandstone. Based on the results of the interpretation of geoelectrical cross-section from 4 lines of the area of study, it can be concluded that the distribution of aquifer for line 1,2 and 3 which are in Pulau Balang formation ware semi-confined aquifer. The semi-confined aquifer is a saturated aquifer overlain by an aquitard and underlain by aquiclude. The semi-confined aquifer is contained with groundwater and has no free water table. Meanwhile, it was found a type of confined aquifer which is overlain by aquiclude in the area of line 4 which was located in Balikpapan formation.

Conclusion

Interpretative results of the geoelectrical cross-section from 4 lines concluded that the distribution of aquifers in the research area for lines 1, 2 and 3 in the Pulau Balang formation is a semi-confined aquifer. For line 4 located in Balikpapan formation, it was found the type of confined aquifer. Meanwhile, based on an analysis of the geological and geomorphological conditions of the study area, it is concluded that the typology of the aquifer system at the study was sedimentary folded aquifers. Groundwater recharge in the study area is 355.98 mm/year with average annual rainfall is 3,053.70 mm/year, evapotranspiration 1,784.21 mm/year and surface run-off 913.51 mm/year.

Significance Statement

The significance of this study is a geometry model of the aquifer area of research that is influenced by the syncline structure in the Karang Mumus watershed. Besides, the pattern of groundwater flow is strongly influenced by the boundary of the Karang Mumus River, so that people can know the location of groundwater availability.

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References

Azhar, and Handayani, G., 2004. Application of Schumberger configuration geoelectric method for determination of coal type resistance. *Jurnal Natur Indonesia* 6 (2): 122-126 (*in Indonesian*).

Brooks, K.N. 2013. *Hydrology and The Management of Watershed.,* 4th edition. Malaysia: Willy-Blackwell.

Cibaj, I., Lambert, B., Zaugg, P., Ashari, U., Dal, J.-A. and Imbert, P. 2014. *Stratigraphic Stacking, Patterns of the Mahakam Area, Lower Kutai Basin, East Kalimantan, Indonesia*

Devy, S.D. 2018. Hydrogeology of Karang Mumus Watershed in Samarinda, East Kalimantan Province, Indonesia. *Forum Geografi* 32: 12-23 (*in Indonesian*), http:// journals. ums.ac.id/ index.php/fg/article/view/5229/3868

Glass, G.V. 2008. *Interrupted Time Series Quasi-experiments.* Washington D.C.: American Education Research Association.

Irawan, D.E. and Puradimaja, D.J. 2015. *General Hydrogeology*. ISBN: 9786022582946, Ombak Press, Yogyakara (*in Indonesian*).

Kodoatie, R.J. and Sjarief, R., 2010, Water Management System: Adi Offset, Yogyakarta, p, 247–269 (*in Indonesian*).

Mohammad, F., Mardiana, U., Yuniardi, Y., Firmansyah, Y. and Alfadli, M.K. 2016. Ground water potential based on rock resistivity value in Cangkorah Village, Kecamata Batujajar, West Bandung Regency. *Bulletin of Scientific Contribution* 14(2): 141-152 (*in Indonesian*).

Ouyang, Y., Zhang, J-E. and Cui, L. 2014. Estimating impacts of land use on groundwater quality using trilinear analysis. *Environmental Monitoring Assessment* 186(9):5353-5362. DOI: 10.1007/s10661-014-3784-8.

Shadish, W.R., Cook T.D. and Campbell, D.T., 2002. *Quasi-Experimental Design for Generalized Causal Inference.* Houghton Mifflin Company, Boston. pp. 79-805. ISBN-10: 0395615569

Supriatna, Sukardi and Rustandi. 1995. *Geological Map of the Samarinda Quadrangle, scale 1: 250.000*. PuslitbangGeologi Bandung.

Suryadi, Y., Rustan Efendi, R. And Sandra, S. 2015. Identification of the subsurface layer structure and the temperature distribution of geothermal areas in Mantikole village. *Gravitasi* 14(1): 28-35 (*in Indonesian*).

Telford, W.M., Gerald, L.P. and Sheriff, R.E. 1990. *Applied Geophysics.* Second Edition. Cambridge University Press.

Triatmodjo, B. 2008. *Applied Hydrology*. Yogyakarta: Beta Offset (*in Indonesian*).

Verstappen, H.Th. 1985. Geomorphological Surveys for Environmental Development, Amsterdam: Elsevier Science Publishing Company Inc., USA, 325 p.