p-ISSN 1693-1246
e-ISSN 2355-3812
July 2019

Jurnal Pendidikan Fisika Indonesia 15 (2) (2019) 122-128
DOI: 10.15294/jpfi.v15i2.14365

http://journal.unnes.ac.id/nju/index.php/jpfi

Underground Water-Level Monitoring by Integrated Study of Geoelectric, Logging, Cutting and Pumping Data in Industrial Area of Candi Sub-District, Sidoarjo

A. Jufriadi*, H. D. Ayu

Program Studi Pendidikan Fisika, Fakultas Sains dan Teknologi
Universitas Kajuruan Malang, Indonesia

Received: 13 March 2019. Accepted: 30 April 2019. Published: 1 July 2019

ABSTRACT

Monitoring of underground water level with integrated data of geoelectric, logging, cutting and pumping has been done in industrial area of Candi Sub-district, Sidoarjo, which is productive aquifers with widespread area. The integrated study showed that monitoring aquifers in industrial wells has carried out at depths of 140-165 meters. The lithology of the aquifer layer consists of sand layer, clay, and gravel with a low resistivity value of 14.7 to 46.8 ohmmeters. The monitoring results showed that the use of underground water at night was higher than the day and the use on workday was higher than on holiday. The stable debit generated by monitoring wells was 8.41 lt/sec and the groundwater level would return to stable 2.17 meters if the well is rested for 3 hours. The implication of this study was monitorable of the dynamics underground water levels periodically.

ABSTRAK

Monitoring level air bawah tanah dengan kajian terintegrasi data geolistrik, logging, cutting, dan pumping telah dilakukan pada kawasan industri kecamatan Candi – Sidoarjo, yang merupakan daerah akuifer produktif dengan sebaran luas. Kajian terpadu menunjukkan bahwa monitoring akuifer dalam sumur-sumur industri dilakukan pada kedalaman 140-165 meter. Litologi lapisan akuifer tersebut berupa lapisan pasir, lempung, dan kerikil dengan nilai tahanan jenis rendah sekitar 14,7 sampai 46,8 ohm-meter. Hasil monitoring menunjukkan penggunaan air dalam pada malam hari lebih tinggi daripada siang hari dan penggunaan pada hari efektif lebih tinggi daripada hari libur. Debit stabil yang dihasilkan dari sumur pantau adalah 8,41 lt/detik dan muka air bawah tanah akan kembali stabil 2,17 meter apabila sumur diistirahatkan selama 3 jam. Implikasi dari penelitian ini adalah terpantaunya dinamika muka air bawah tanah secara periodik.

Keywords: Geoelectric resistivity; Logging; Water level.

INTRODUCTION

The development of the Candi sub-district, Sidoarjo into an industrial area was followed by a large number of open land changed to be a large residential and industrial land. The use of open land affects the amount of rainwater infiltration into the ground. Stable underground water condition would save an area from water crisis (Eke & Igboekwe, 2011) and the intrusion of sea water. The development of industrial area also demands the availability of water for industry and the daily needs of the population. Excessive and uncontrolled water consumption will cause a damaged ground water system (Khumaedi et al., 2015). Therefore, management of underground water is needed by monitoring the changing in underground water reserves. The use of water in industrial areas requires proper management and monitoring due to long-term impacts on geological and hydrological conditions (Hector et al., 2013). Protection of subsurface conditions can be done by monitoring over-exploitation of underground water, fluctuations, solutes, and contamination (Manna, Walton, Cherry, & Par-

***Correspondence Address:**
Jalan Colombo Nomor 1, Karang Malang, Kec. Depok, Kabupaten Seleman, Daerah Istimewa Yogjakarta 55281– Indonesia
E-mail: rahmiputriz09@gmail.com

ker, 2017). Knowledge and information about the condition of underground water fluctuations in industry area at Candi sub-district, Sidoarjo were poor due to the lack of research on the condition of underground water in that area.

Geophysical methods are generally used for hydrogeological research (Boubaya, 2017), underground water investigations (Laxmi & Ramadass, 2012), underground water level investigations (Kitila, Lemessa, Gebrekidan, & Alamirew, 2013), and specifically the geoelectric method, an important and widely used method in underground water investigations (Khan, Waheedullah, & Bhatti, 2013). This is due to the fact that this method is easy, fast, and efficient (Wiyono, Lailatin, & Jufriadi, 2019), and there is a strong correlation between the hydrogeological conditions of underground water and the resistivity of the soil layer (Boubaya, 2017). The presence of water filling the cavities in the subsurface layer will cause a decrease in the resistivity value of the soil layer and air-filled cavities will cause an increase in the resistivity value (Maryanto, Suciningtyas, Dewi, & Rachmansyah, 2016). In addition, geophysical methods are more widely used in subsurface modeling because this method is able to model subsurface in 2-D or 3-D (Ronczka, Hellman, Günther, Wisén, & Dahlin, 2017). Vertical electrical sounding, 2-D and 3-D models can provide vertical or horizontal resistivity distribution of subsurface layers especially in water-binding formations (Abd El-Gawad, Kotb, & Hussien, 2017). This is also consistent with previous studies that the resistivity of the subsurface layer corresponds to geological parameters such as fluid, porosity, and rock minerals (Jufriadi & Ayu, 2014), and the distribution of resistivity in each layer to a depth of several meters below the surface (Pranata, Jufriadi, Ayu, & Wahyuningsih, 2016). Resistivity geoelectric data needs to be integrated with logging data to provide accurate information about subsurface conditions (Benjumea, Macau, Gabàs, & Figueras, 2016), although the use of logging data is not effective especially if it is used in investigations in large area scales because drilling is needed. The logging data provides information on geophysical parameters, including self potential, resistivity, and temperature (Hodlur, Dhakate, & Andrade, 2006). It is very important to have information about the physical properties of the soil such as porosity and resistivity in groundwater exploration. Porous soil formations containing groundwater are lower than dry formations.

The use of open land and over exploitation of underground water will cause a negative impact on environmental balance and water crisis. The existence of several large factories, especially in one district, has an impact to the surrounding community certainly, such as the reducing of water supply. It is very important to conduct a detail study about geological, hydrogeological, and subsurface conditions, especially by monitoring the aquifer-levels of underground water to prevent water crises.

Location, Geological Condition, and Hydrogeology Research Area

This research was conducted in Candi industrial area, Sidoarjo, East Java. Based on geological and hydrogeological maps (Figure 1), Sidoarjo's condition generally consists of alluvium deposits, upper quarter volcanic rocks, sandy tuff, and middle quarter volcanic rocks (Budiono, Handoko, Hernawan, & Godwin, 2010).

Candi sub-district is a lowland dominated by alluvium deposits (QA) consisting of gravel, sand, and clay. Alluvium deposits in Sidoarjo sub-district is a wide spread of young rock. It is

(a) Sidoarjo geological map (b) Sidoarjo hydrogeological map

Figure 1. The geological and hydrogeological condition of the research area

a medium productive aquifer area in wide distribution. The aquifer has a moderate to low continuity, and groundwater levels vary from near ground level to depths of more than 10 meters with a common debit of about 5 liters/second. This work was studied about geological conditions, hydrogeology, subsurface conditions, and underground water aquifer. Addition, the main purpose of this work was monitoring the fluctuations and dynamics of underground aquifers periodically.

METHOD

The determination of geoelectric data acquisition area was carried out by considering the distance between acquisition data and industrial company drilling-wells. The results of geoelectric interpretation data will determine aquifer location which would be analyzed in monitoring wells to control industrial wells. Therefore, the monitoring results of groundwater aquifer fluctuations provides information and data on the occurrence of ground water level fluctuations surrounding industrial wells. Geoelectrical data acquisition has been carried out in the area covered by industrial wells accorded to the location of the drilling wells, (Figure 2).

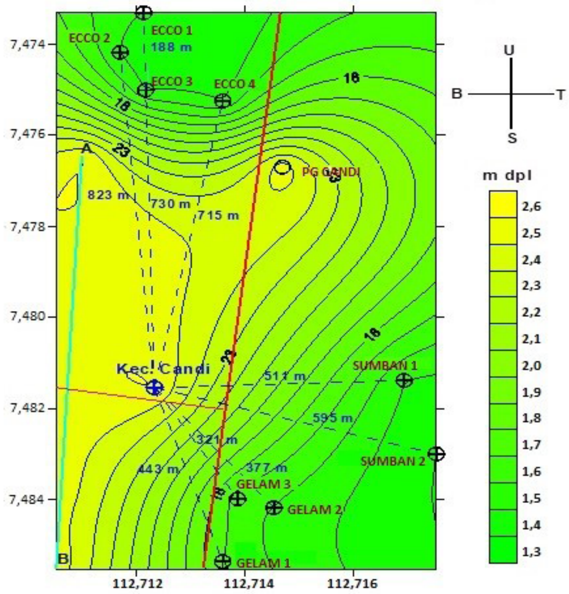

Figure 2. Research area

Geoelectric Resistivity

Data acquisition of geoelectrical resistivity was used a resistivity meter Naniura NRD 300, with wenner configuration, 2D design. The selection of this acquisition model was expected yielding to a very good picture of the subsurface conditions vertically and horizontally (Ayolabi, Folorunso, Odukoya, & Adeniran, 2013). The geoelectrical resistivity method used an electric current that was flowed through two current electrodes, and the potential difference was measured through two other potential electrodes (Anomneze et al., 2014). This method studied the nature of electric currents in the earth and detected them on the surface of the earth (Millah, Khumaedi, & Supriyadi, 2011).

The arrangement of Wenner configuration electrode was: current electrode 1 (C1) - potential electrode 1 (P1) - potential electrode 2 (P2) - current electrode 2 (C2), spacing a (distance between the electrodes) was the same, Figure 3.

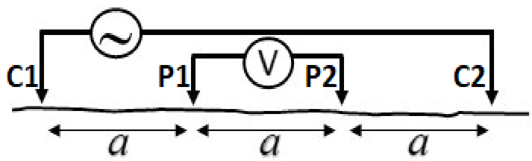

Figure 3. Wenner configuration

Measurements were made along the path with the C1-P1-P2-C2 electrodes sequentially at positions 1-2-3-4 in first measurement. Then, the second measurement was done by shifting the electrode position as far as a spacing, so that the electrode C1-P1-P2-C2 was at 2-3-4-5 position (Jufriadi & Ayu, 2014). Results from current and potential difference measurements for each given distance and distance variation of current and potential electrodes (geometrical factor) determined variations of the specific resistance of measuring point at each layer. In general, the obtained data classically are presented as a cross section of apparent resistivity that describes subsurface conditions (Metwaly & Alfouzan, 2013). The equation used in calculating the apparent resistivity magnitude of the measurement results is

$$\rho_a = 2\pi a \frac{V}{I} = K \frac{V}{I} \quad (1)$$

where ρ_a is pseudo-resistivity (Ωm); K is a geometrical factor; V is a potential difference; I is the current; a is the electrode spacing. Pseudo-resistivity values indicate the value of homogeneous soil layers yielding the same resistance value. Relation between pseudo-resistivity values and resistivity values is actually complicated and complex (Maryanto et al., 2016). Processing and analysis of pseudo-resistivity type data obtained from measurements from the field were used the RES2DINV program that utilizing inversion method with the smallest square based on quasi-Newton optimization techniques (Loke & Barker, 1995).

Well Logging

Data recording done mechanically when drilling was taken resulting as cutting data and after drilling was taken resulting as logging data. Resistivity data, which is spontaneously potential obtained, was a picture of relation between the depth of the rock type and character at any depth below the surface layer. The result of resistivity and potential values indicate the nature and characteristics of the geophysics in the measured soil layer.

RESULTS AND DISCUSSION

Study on Industrial Well Data

Based on a survey about the presence of industrial wells in Candi sub-district (Figure 2), industrial wells in this research area were 10; 4 at PT Ecco with, 1 at PG Candi, 2 at Sumban, and 3 at Gelam area. The distribution of industrial wells was shown in table 1.

Table 1. Data on industrial wells

Industrial Well	Number of Wells
PT Ecco	4
PG Candi	1
Sumban area	2
Gelam area	3

PT Ecco has 4 industrial wells to meet its industrial production needs. The depth of the well was around 150 meters with a filter pipe installed around 114 to 150-meter depth. PG Candi has 1 industrial well, but it was not used to fulfill industrial production processes. The Sumban and Gelam areas have 2 and 3 deep wells with 165-meter depth completed by filter pipes installed at 140 to 160-meter depth. It means that deep well water exploitation was carried out on deep water aquifers with 140 to 160 meter depth, because the placement of filter pipes in drilling wells was based on the position of underground water aquifers (Baiti, Siregar, & Mangkurat, 2016).

Study of Geoelectrical Data

Study of geoelectrical data includes acquisition, processing, and interpretation data. The results of geoelectrical data were subsurface conditions, the depth of aquifer based on distribution of resistivity on the cross section of 2-D subsurface rock layer. Data acquisition was done on the trajectory measurements along 1 km, with the direction of the track north-south. Geoelectrical measurements were made at 98 measurement points along the path, with the distance between the electrodes being 40 meters.

Geoelectric measurement data was processed with RES2DINV software, so that the resistivity cross section was clearer and more accurate (Dahlin & Bing, 2004). This software used quasi-Newton optimization techniques, the results of it were almost the same as the Gauss-Newton technique (Loke & Dahlin, 2002). The results of geoelectric data processing were in the form of 2-D subsurface layers, shown in figure 4.

2-D subsurface cross section showed the prospect of free aquifers that were widespread from point 0 to point 960 on the measurement track. The existence of free aquifers was in accordance with previous research which showed that a free aquifer was generally located at a relatively shallow depth of less than 40 meters (Darsono, 2016). At the monitoring well point (MW) with 520 coordinates on the measurement track, the prospect of a surface aquifer was indicated 50 meter depth and a deep aquifer at 140 to 170 meter depth, about below ground level.

When the industrial wells was projected on the measurement trajectory, the position

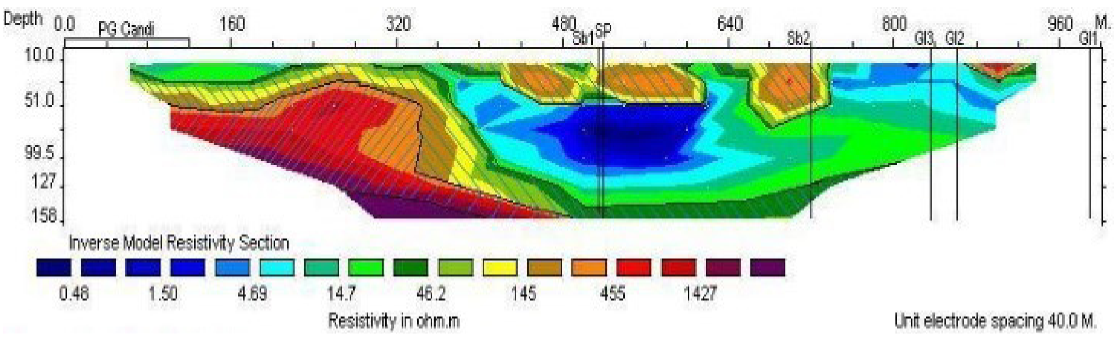

Figure 4. Cross-section of 2-D subsurface

of each deep well was at coordinates 515 for Sumban 1 (Sb1), coordinates 720 for Sumban 2 (Sb2), coordinates 835 for Gelam 3 (Gl3), coordinates 862 for Gelam 2 (Gl2), and coordinates 900 for Gelam 1 (Gl1).

Based on the study of industrial well data which showed the exploitation of industrial well water was carried out at a depth of 140 to 160 meters, and cross section of the subsurface 2D, it can be concluded that the industrial wells exploited water in the aquifer layer with low resistivity between 14.7 up to 46.8 ohms (the first green to the fourth green). The low resistivity value showed potential aquifer groundwater (Susilo, Sunaryo, & Fitriah, 2018). In other-hand, drilling well monitoring was carried out to a depth of 170 meters with a filter pipe position at a depth of 142-165 meters.

Integrated Study of Geoelectric Data, logging, cutting, and Pumping Test

Cutting data or rock samples data taken each depth of 1 meter during the drilling process at the point MW (Monitoring Well). Sand and clay formation were in the underground layers of the drilling area. The formation further strengthens that the area had the prospect of surface aquifers and deep aquifers, because groundwater aquifers had lithological characteristics composed of sandstone and clay (Maria, Rusydi, Lestiana, & Wibawa, 2018). The cutting data obtained was almost the same as the result of interpretation from logging data showed in table 2.

Table 2. Lithological conditions based on data logging and cutting

Depth (m)	Cutting data interpretation	Logging data interpretation
0-10	Sandy loam	Clay sandy (Surface aquifers)
10-30	Sand	Sandy
30-40	Clay Sandy	Loam Sandy
40-48	Clay	Clay insertion
48-50	Sand	Sand insertion
50-55	Clay	Clay insertion
55-57	Sand	Sand insertion
57-62	Clay	Clay insertion
62-64	Sand	Sand insertion
64-70	Clay	Clay insertion
70-72	Sand	Sand insertion
72-76	Clay	Clay insertion
76-78	Sand	Sand insertion
78-82	Clay	Clay insertion
82-83	Sand	Sand insertion
83-84	Clay	Clay insertion
84-85	Sand	Sand insertion
85-86	Clay	Clay insertion
86-87	Sand	Sand insertion
87-95	Clay	Clay insertion
95-96	Sand	Sand insertion
96-133	Clay	Clay insertion
133-140	Sand	Sand insertion (Deep Aquifer)
140-141	Clay	Clay insertion (Deep Aquifer)
141-146	Sand	Sand insertion (Deep aquifer)
146-148	Gravel	Gravel insertion (Deep aquifer)
148-150	Clay	Clay insertion (Deep aquifer)
150-162	Gravel	Gravel insertion (Deep aquifer)
162-165	Sand	Sand insertion (Deep Aquifer)
165-167	Clay	Clay insertion
167-168	Sand	Sand insertion (Deep aquifer)

Based on 2-D subsurface cross section and lithology conditions above, it can be stated that the aquifer in the study area with alternating layers of lithology between clay, sand, and gravel was at of 140 to 165 meter depth. The deep aquifer was an aquifer exploited by industrial wells around the research area.

Pumping data comes from pumping test after the process of developing the well was completed. The pumping test was carried out in four stages, including the preliminary pumping test, the multilevel pumping test, the continuous pumping test and the recovery pumping test. This pumping test was carried out to determine the character of the aquifer's ability to refill after the well was pumped (Harjito, 2014). Pumping data based on the top casing of 0.6 m with SWL (from top casing) was 2.17 m and SWL (from ground level) was 1.57 m. So the data generated would be able to monitor a deep and shallow aquifer. The stable discharge generated from the well was 8.41 l/sec and the ground water level will stabilize 2.17 meters if the well was rested for 3 hours (Figure 5).

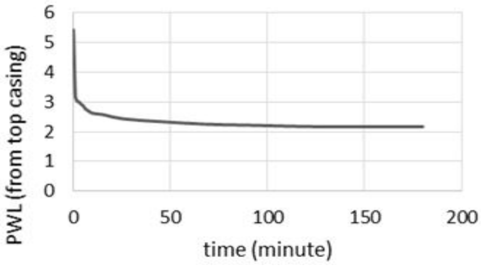

Figure 5. Graph of recovery pumping test on monitoring well

Based on a review of pumping data and others, it can be concluded that the depth of monitoring well for controlling underground water in conformity with other well industries because of the debit obtained was the range of debit produced by the deep aquifer and stability of underground water level. The depth of the aquifer monitored was the depth of the deep aquifer used by several observed production wells.

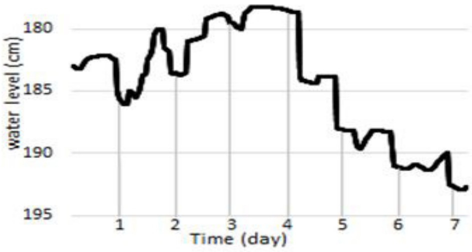

Figure 6. Monitoring of deep aquifer levels

Monitoring the levels of ground water aquifers carried out for 7 days, starting on Thursday (day 1) until Wednesday (day 7). The monitoring results (Figure 6) showed that the decrease in deep aquifer level was higher at night than during the day. This shows that the use of deep water at night was more than during the day. On the effective day, the level of the aquifer in a decline reached 1,929 mm. This shows that the intensity of the use of water in the effective day was very high.

CONCLUSION

Candi sub-district was a lowland area dominated by surface deposition of alluvium consisting of gravel, sand, and clay. Hydrogeological conditions in Candi sub-district were free productive aquifers, with wide distribution. Based on an integrated study, monitoring of aquifers was carried out at of 140-165 meter depth. That aquifer was an aquifer exploited by industrial wells to meet their needs. Therefore, the controlling results of monitoring wells illustrated the amount of exploitation and the use of deep aquifers from these industrial wells.

Monitoring conducted in 7 days resulted that the exploitation and the use of water at night and effective day was higher than during the day and holiday.

The resulting stable debit of wells monitored was 8.41 l/s and ground water level would be stabilized by 2.17 meters when well rested for 3 hours. Thus, the exploitation and use of underground water in the study area was still in normal and did not disturb the equilibrium of underground water.

REFERENCES

Abd El-Gawad, A. M. S., Kotb, A. D. M., & Hussien, G. H. G. (2017). Geoelectrical contribution for delineation the groundwater potential and subsurface structures on Tushka Area, Egypt. *NRIAG Journal of Astronomy and Geophysics*. https://doi.org/10.1016/j.nrjag.2017.10.003.

Anomneze, D. O., Onwuemesi, A. G., Odoh, B. I., Ahaneku, C. V, Okonkwo, C. C., & Oluwajana, O. A. (2014). Reducing Ambiguity with Geoelectric Investigations : Implications for Near-Surface Cavities. J*ournal of Scientific Research & Reports*, 3(5), 675–685.

Ayolabi, E. A., Folorunso, A. F., Odukoya, A. M., & Adeniran, A. E. (2013). Mapping saline water intrusion into the coastal aquifer with geophysical and geochemical techniques: the University of Lagos campus case (Nigeria). *Springer Plus*, 2(1), 433. https://doi.org/10.1186/2193-1801-2-433.

Baiti, H., Siregar, S. S., & Mangkurat, U. L. (2016). *Aplikasi Well Logging untuk Penempatan Pipa Saringan Sumur Bor Air Tanah di Desa Banyu Irang Kecamatan Bati-Bati , Kalimantan Selatan*, 13, 105–110.

Benjumea, B., Macau, A., Gabàs, A., & Figueras, S. (2016). Characterization of a complex near-surface structure using well logging and passive seismic measurements. *Solid Earth*, 7(2), 685–701. https://doi.org/10.5194/se-7-685-2016.

Boubaya, D. (2017). Combining Resistivity and Aeromagnetic Geophysical Surveys for Groundwater Exploration in the Maghnia Plain of Algeria. *Journal of Geological Research,* 2017. https://doi.org/http://dx.doi.org/10.1155/2017/1309053.

Budiono, K., Handoko, Hernawan, u, & Godwin. (2010). Penafsiran Struktur Geologi Bawah Permukaan di Kawasan Semburan Lumpur Sidoarjo , Berdasarkan Penampang Ground Penetrating Radar (GPR). *Jurnal Geologi Indonesia*, 5(3), 187–195.

Dahlin, T., & Bing, Z. (2004). a Numerical Comparison of 2D Resistivity Imaging With Ten. *Geophysical Prospecting,* 52, 379–398.

Darsono. (2016). Identifikasi Akuifer Dangkal dan Akuifer Dalam dengan Metode Geolistrik (Kasus : Di Kecamatan Masaran). *Indonesian Journal of Applied Physics*, 1(April), 40–49.

Eke, K. T., & Igboekwe, M. U. (2011). Geoelectric Investigation of Groundwater in Some Villages in Ohafia Locality, Abia State,Nigeria. British *Journal of Applied Science & Technology,* 1(4), 190–203.

Harjito. (2014). Metode Pumping Test sebagai Kontrol Untuk Pengambilan Airtanah Secara Berlebihan. *Jurnal Sains Dan Teknologi Lingkungan, 6, 1*38–149.

Hector, B., Śeguis, L., Hinderer, J., Descloitres, M., Vouillamoz, J. M., Wubda, M., … Moigne, N. Le. (2013). Gravity effect of water storage changes in a weathered hard-rock aquifer in West Africa: Results from joint absolute gravity, hydrological monitoring and geophysical prospection. *Geophysical Journal International,* 194(2), 737–750. https://doi.org/10.1093/gji/ggt146.

Hodlur, G. K., Dhakate, R., & Andrade, R. (2006). Correlation of vertical electrical sounding and borehole-log data for delineation of saltwater and freshwater aquifers. *GEOPHYSICS*, 71(1), G11–G20.

Jufriadi, A., & Ayu, H. D. (2014). Investigation of Landslide Potential by Using Geolistrik Resistivitas Method in Ampelgading Malang Regency. FOTON, J*urnal Fisika Dan Pembelajarannya,* 18(2), 13–18.

Khan, G. D., Waheedullah, & Bhatti, A. S. (2013). Groundwater Investigation by Using Resistivity Survey in. *Journal of Resources Development and Management,* 2, 9–20.

Khumaedi, Supriyadi, Pradana, A., Imam, S., Yusuf, M., & Sarkowi, M. (2015). Application of Vertical Gradient Methods of Microgravity Time Function to Determine Ground Water Reduction in Semarang Period of 2013. *Jurnal Pendidikan Fisika Indonesia,* 11(2), 142–147. https://doi.org/10.15294/jpfi.

Kitila, G., Lemessa, G., Gebrekidan, H., & Alamirew, T. (2013). Identification of Groundwater Level by Using Geoelectrical Resistivity Method at Fincha'a Sugar Estate, Blue Nile Basin, Western Ethiopia. *STAR Journal,* 2(3), 114–125.

Laxmi, G., & Ramadass, G. (2012). Ground Water Contamination in Granitic Terrain – A Case Study from Katedan , Greater Hyderabad , A . P ., Introduction : *International Journal of Pure and Applied Sciences and Technology,* 8(1), 15–25.

Loke, M. H., & Barker, R. D. (1995). Least-squares deconvolution of apparent resistivity pseudosections. *Geophysics,* 60(6), 1682. https://doi.org/10.1190/1.1443900.

Loke, M. H., & Dahlin, T. (2002). A comparison of the Gauss-Newton and quasi-Newton methods in resistivity imaging inversion. *Journal of Applied Geophysics*, 49(3), 149–162. https://doi.org/10.1016/S0926-9851(01)00106-9.

Manna, F., Walton, K. M., Cherry, J. A., & Parker, B. L. (2017). Mechanisms of recharge in a fractured porous rock aquifer in a semi-arid region. *Journal of Hydrology*, 555, 869–880. https://doi.org/10.1016/j.jhydrol.2017.10.060.

Maria, R., Rusydi, A. F., Lestiana, H., & Wibawa, S. (2018). Hidrogeologi dan potensi cadangan airtanah di dataran rendah indramayu. *RISET Geologi Dan Pertambangan*, 28(2), 181–192. https://doi.org/10.14203/risetgeotam2018.v28.803.

Maryanto, S., Suciningtyas, I. K. L. N., Dewi, C. N., & Rachmansyah, A. (2016). Integrated Resistivity and Ground Penetrating Radar Observations of Underground Seepage of Hot Water at Blawan-Ijen Geothermal Field. *International Journal of Geophysics,* 2016. https://doi.org/10.1155/2016/6034740.

Metwaly, M., & Alfouzan, F. (2013). Application of 2-D geoelectrical resistivity tomography for subsurface cavity detection in the eastern part of Saudi Arabia. *Geoscience Frontiers*, 4(4), 469–476. https://doi.org/10.1016/j.gsf.2012.12.005.

Millah, N., Khumaedi, & Supriyadi. (2011). Monitoring Daerah Resapan Air Dengan Metode Geolistrik Semarang. *Jurnal Pendidikan Fisika Indonesia*, 7, 33–37. Retrieved from https://journal.unnes.ac.id/nju/index.php/JPFI/article/view/1066.

Pranata, K. B., Jufriadi, A., Ayu, H. D., & Wahyuningsih, D. (2016). Penerapan Metode Resistivitas Untuk Identifikasi Penyebab Rawan Longsor Pada Daerah Aliran Sungai Brantas Kecamatan Sukun Kota Malang. *Jurnal Neutrino*, 8(2), 67–72. https://doi.org/10.18860/neu.v8i2.3311.

Ronczka, M., Hellman, K., Günther, T., Wisén, R., & Dahlin, T. (2017). Electric resistivity and seismic refraction tomography: A challenging joint underwater survey at Äspö Hard Rock Laboratory. *Solid Earth*, 8(3), 671–682. https://doi.org/10.5194/se-8-671-2017.

Susilo, A., Sunaryo, & Fitriah, F. (2018). Groundwater investigation using resistivity method and drilling for drought mitigation in Tulungagung , Indonesia, (April). https://doi.org/10.21660/2018.47.98784.

Wiyono, Lailatin, N., & Jufriadi, A. (2019). Interpretation Patterns for The Distribution of The Turbidity of Soil Water Around TPA Supit Urang (Final Removal of Garbage) Using Geoelectric Resistivity Methods Interpretation Patterns for The Distribution of The Turbidity of Soil Water Around TPA Su. *In 9th Annual Basic Science International Conference 2019 (BaSIC 2019)*. Malang. https://doi.org/10.1088/1757-899X/546/2/022037.