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Flux Analysis with the Application of Darcy's Law Based on Borehole Data for Sustainable Groundwater Exploitation

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ABSTRAK

Peta cekungan air tanah Kabupaten Aceh Besar menunjukkan potensi sumber daya air tanah yang sangat besar. Hal ini didukung oleh struktur sedimen yang didominasi oleh kerikil, pasir, dan lempung. Penelitian ini dilakukan untuk mengidentifikasi jenis akuifer dan menghitung besaran debit air tanah yang ada di wilayah Kabupaten Aceh Besar. Perhitungan debit air (*flux*) dilakukan menggunakan persamaan Hukum Darcy lalu dibandingkan dengan data *Pumping Test* (*real* debit). Hasil penelitian menunjukkan bahwa wilayah pesisir Aceh Besar didominasi oleh jenis akuifer tertekan (*Confined Aquifer*) dengan rata-rata kedalaman akuifer 40-120 m dan ketebalan 3-30 m. Hasil perhitungan menggunakan Hukum Darcy pada segmen 1 dan 2 secara berturut-turut diperoleh debit air sebesar 23.93 liter/detik dan 21.88 liter/detik, sedangkan hasil *Pumping Test* (*real* debit) pada segmen yang sama adalah 25.5 liter/detik dan 21 liter/detik. Hasil perbandingan menunjukkan selisih nilai debit sebesar 6,1% dan 4,2%. Hasil perbandingan menunjukkan bahwa perhitungan debit air (*flux*) menggunakan persamaan Hukum Darcy sebanding dengan hasil *Pumping Test* (*real* debit) dengan selisih yang cenderung rendah, sehingga perhitungan debit air (*flux*) menggunakan Hukum Darcy dapat digunakan sebagai acuan dalam eksploitasi awal terhadap sumber air tanah.

***Kata kunci*:** *Borehole*, akuifer, debit (*flux*), *pumping test*, Aceh Besar.

ABSTRACT

The potential for groundwater is very large and widely distributed in Aceh Besar District as indicated by the Groundwater Basin map. This potential is supported by the presence of sedimentary deposits consisting of materials such as gravel, sand and clay. This research was conducted to identify the type of aquifer and calculate the amount of groundwater discharge in the district of Aceh Besar. The discharge calculation is carried out using Darcy's Law where this equation can be used to describe the ability of the aquifer to flow through the rock. This study also compares the results of calculating the water discharge using Darcy's Law with the real Pumping Test data. The results showed that the coastal area of Aceh Besar was dominated by confined aquifers with average depth of 40-120 m and thickness of 3-30 m. The results of calculating the water discharge (flux) in the study area were obtained around 3414.61 m/day or equivalent to 39.51 liters/second. The results of comparison with the real Pumping Tes data in segment 2 found that the results of calculating discharge using Darcy's Law were 23.93 liters/second while the results of real Pumping Test were 25.5 liters/second so that the error value found is 6.1%, and in segment 3 the results of calculating discharge using Darcy's Law is 21.88 liters/second while the results of the real Pumping Test are 21 liters/second so that an error value of 4.2%.. From the results of these two comparisons, it can be seen that the calculation of water discharge using Darcy's Law is comparable and has significant results with the results obtained from the real Pumping Test, so that the calculation of water discharge using Darcy's Law can be used for a reference in the groundwater exploitation.

***Keywords*:** Borehole, Aquifer, Discharge (Flux), Pumping Test, Aceh Besar

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1. INTRODUCTION

Groundwater, as the second largest source of freshwater in the world after ice from polar regions, plays a crucial role in maintaining the availability of clean water. The groundwater could be located in water-saturated pathways, among pores or spaces between grains of bedrock in the soil layer. There are four geological formations of groundwater: aquifers, aquitards, aquicludes, and aquifuges. These four types have unique characteristics in storing and transmitting water (Syukri et al., 2023; Fadhli et al., 2022; Afifuddin et al 2021). Aquifers, especially with sand, gravel and gravel-sand mixtures that have not been further lithified, are recognized as the most efficient layers in storing groundwater. Furthermore, the groundwater potential in an area is heavily influenced by the characteristics of the aquifer layer in that area. Some other important characteristics include types of material, stratigraphy, hydraulic conductivity, specific yield, aquifer thickness, and position of the aquifer from the surface (Fadhli et al., 2019).

Both groundwater exploration and exploitation must be conducted precisely. The balance between the discharge area and the recharge area would be taken into account to prevent negative impacts on the environment. Prior to conducting any activities on groundwater, early detection is needed to evaluate the presence of groundwater, its water potential and water discharge (flux). The discharge is one of the hydrological parameters that is very important for managing water resources and assessing the feasibility of exploitation plans. Therefore, measuring the flow (flux) in water sources beforehand remains a critical step, despite the risk of environmental problems that might occur due to direct measurement methods such as pumping test (Yusra and Afdal, 2023; Darisma et al., 2020)

Darcy's Law is an equation that defines the relationship of fluid flowing in a porous medium (Brown, 2015). Henry Darcy conducted experiments on the flow of water through a porous medium; at that time sand was used as the material. Mathematically, Darcy's Law is formulated as follows:

$$Q = -KA\frac{\Delta h}{L} \qquad (1.1)$$

Where Q is the flow discharge (m^3/s) through a porous medium, A is the cross-sectional area passed through by fluid (m^2), K is the hydraulic conductivity (m/day), L is the length of the cross-sectional distance (m), Δh or $h_m h_{out}$ is the change in water level or hydraulic head (m). Hydraulic head is the height water in a pipe that is in a cross section, the water that comes out and is at the hydraulic head indicates the amount of water at that point. The negative sign (-) in this equation indicates that the fluid flows from high pressure to low pressure (Pangestu and Waspodo, 2019; Syahruddin, 2014). Details of variables for Darcy's Law equation (2.1) can be seen in Figure 1.

Equation (2.1) could be simplified into more general form by changing Δh/L to $\partial h/\partial l$, thus creating a new equation:

$$Q = KA\frac{\partial h}{\partial l} \qquad (2.2)$$

with δh being groundwater depth difference (m) dan δL being groundwater track (m) (Darcy, 1856).

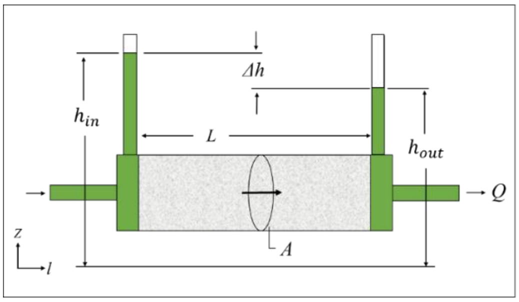

Figure 1. Darcy's Law Illustration (Modified from Fetter,1988)

This research focuses on calculating water discharge (flux) by applying Darcy's Law to determine the amount of discharge that can be pumped, with the main aim of preserving groundwater at the research location. This method is considered an important step in managing groundwater resources optimally. This study was conducted in Aceh Besar, Aceh. Based on the hydrogeological map, this research location is included in the area that has groundwater (Soetrisno, 1993). Aceh Besar has unique groundwater resource potential, mainly due to its extensive coastal area. However, this characteristic also creates a high risk of seawater intrusion into nearshore aquifers (Cahyadi et al., 2013). This research uses secondary data, specifically Borehole data from the Aceh Energy Resources and Minerals (ESDM) Service. The calculation results are then compared with the discharge value obtained from the Pumping Test (actual discharge) carried out by the Aceh ESDM Service. The aim is to evaluate the effectiveness of applying Darcy's Law in calculating groundwater source discharge without the need for additional drilling. Involving data from trusted sources such as the Aceh ESDM Service adds to the validity of this research. Comparison of the calculation results with the actual discharge value from he Pumping Test will provide a deeper understanding of the accuracy of Darcy's Law as a method for measuring groundwater discharge.

This research is expected to study the characteristics of the aquifer in the form of the depth and thickness of the aquifer. The research location near the shoreline is also a concern of this research to study the maximum limit of pumping, which if excessive pumping is carried out, it will cause seawater/saline water intrusion into the aquifer (groundwater) layer (Simpen et al, 2017). in addition, this research can make a significant contribution in understanding the effectiveness of Darcy's Law in the context of practical applications. Thus, the results of this study can serve as a valuable preliminary basis for further groundwater resource exploitation surveys at the study site and can be used as a reference for discharge calculation methods without the need to conduct additional drilling. The analysis of the drill data is in the form of lithological data, well depth, aquifer thickness and water-bearing layers. The characteristics of these layers are analysed to predict the water escape rate and content.

2. METHODS

This research was conducted in the Aceh Besar area. Geographically, the Aceh Besar is located at 5°27'10.33"N and 95°28'40.01"E. The geological conditions of this region and its surroundings vary from undulating alluvial plains to lowlands, stretching from the North West to the Southeast, with the height tends to increase towards the South.

The area of study starts from low topographic areas to high topographic areas on a scale of meters above sea level (masl). This research uses Borehole data, where there are 11 borehole data spread randomly throughout the Aceh Besar region. Each of the wells has a distance ranging from 1 - 3 km. The location of the Borehole point in this research area can be seen in Figure 2.

2.1. Segment Split

This research covers a vast area of 7,125 hectares. The flow discharge calculation requires determining the segmentation based on the nearest well point, so that 2 cut-out segments are made according to the design in Figure 3.3. In segment 1 there are 5 well points while in the second segment there are 6 well points.

The well points were created by putting in the coordinates of the aquifer wells using Google earth. There are 11 well points, each of them is separated approximately 1 - 3 km away as shown in Figure 2. The distance between the points is quite far, thus it is necessary to create segments based on the location of the nearest well point. This affects the discharge calculation results, in segment 1 there are 5 well points with an area of 7654, and in segment 2 there are 6 well points with an area of 9333. The division of these segments can be seen in Figure 4.

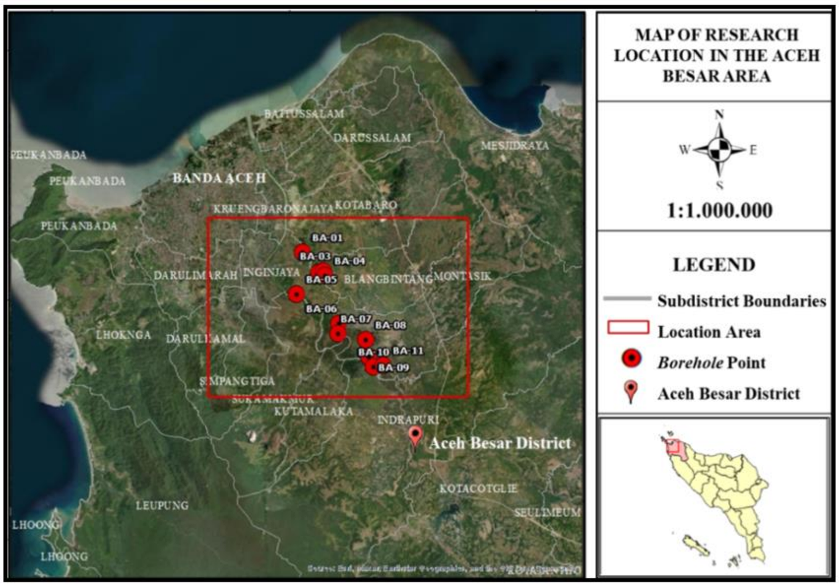

Figure 2. Map of Research Area (Google Earth Satellite Imagery 2022).

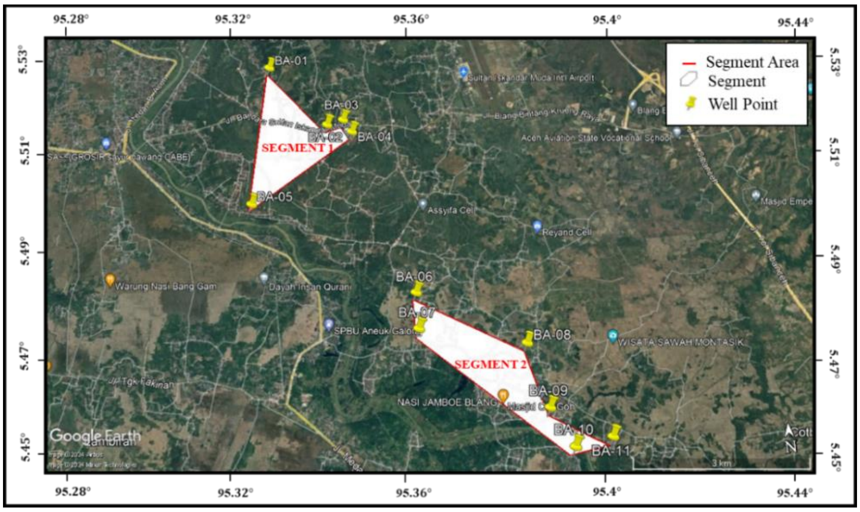

Figure 3. Segmentation Design

After analyzing the lithology of the well layer, the flow (flux) calculation is then carried out using Darcy's Law equation. For the final step, a comparison is made between the results of the discharge (flux) calculation using Darcy's Law and the Pumping Test (real discharge) data.

3. RESULT AND DISCUSSION

Borehole data are the primary data used to determine the type of aquifer layer in the Aceh Besar region. This borehole activity was conducted out by the Energy and Mineral Resources Service of Aceh province in 2018 and 2019. The graph of borehole depth and well elevation can be seen in Figure 3. The data shows 11 wells with different elevations, ranging from 4 to 27 meters above sea level. The depth of each well ranges from 70 to 132 meters below sea level. From the results of the graph above, it can be concluded that the lower the topography, the relatively deeper the well will be, and if the topography is higher, the well will be relatively shallow.

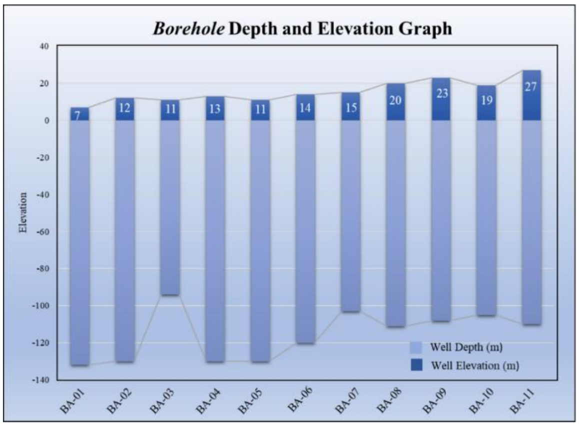

Figure 4. Borehole Depth and Elevation Graphs

3.1. Segment 1

Borehole data in segment 1 shows the potential for aquifers at each well point as listed in Table 1.

Table 1 shows the results of identified boreholes aquifers potential in segment 1 with 5 well points and depths varying from 94 m to 132 m. The characteristics of the aquifer are a layer with high porosity which is dominated by gravel and is bounded by 2 layers (top-bottom) of impermeable material in the form of clay. Therefore, the type of aquifer in segment 1 can be classified as a confined aquifer. The presence of aquifers in segment 1 varies at a depth of around 54 m to 100 m with a thickness of 8 m to 29 m.

3.2. Segment 2

Borehole data in segment 2 shows the potential for aquifers at each well point as listed in Table 2.

Table 2. displays the results of boreholes that have been identified as potential aquifers in segment 2. Segment 2 consists of 6 well points with depths varying between 102 m to 120 m. The potential aquifer in segment 2 is at a depth varying between 67 to 92 m with a thickness of 7 m to 19 m. Similar to segment 1, the characteristics of the aquifer that can be identified from the six wells in segment 2 are the presence of a high porosity layer flanked by 2 layers (top-bottom) of impermeable material in the form of clay; thus it is categorized as a confined aquifer. However, the aquifer layer in segment 2 is dominated by sand.

3.3. Analysis of Aquifers

Differences in geological conditions will determine the type of lithology of the area. The geological condition in the research area is sedimentary rock in the form of alluvium consisting of sand, gravel, clay and mud. These geological conditions will affect the aquifer which is directly related to groundwater availability (Wilopo et al., 2020; Halimi et al., 2018).

Based on rock lithology, aquifers are categorized into unconfined aquifers, confined aquifers, semi-confined aquifers, and drift aquifers. Unconfined aquifer is an aquifer that is only limited by an aquitard layer at the bottom, confined aquifer is an aquifer that is located between layers of impermeable (clay), semi-confined aquifer is an aquifer that is lined by a semi-impermeable layer at the top with a waterproof or impermeable layer at the bottom and floating aquifers where the aquifer is located in the erosion zone and is formed above the impermeable layer.

Table 1. Potential Existence of Aquifers in Segment 1

Well Points	Aquifer Depth (m)	Aquifer Thickness (m)	Lithology
BA-01	72-80	8	Gravel
BA-02	58-76	18	Gravel - sand
BA-03	56-67	11	Gravel
BA-04	54-83	29	Gravel
BA-05	100-120	20	Gravel-sand

Table 2. Potential Existence of Aquifers in Segment 2

Well Points	Aquifer Depth (m)	Aquifer Thickness (m)	Lithology
BA-06	82-95	13	Sand
BA-07	77-92	15	Sand
BA-08	67-86	19	Gravel - sand
BA-09	92-99	7	Gravel - sand
BA-10	72-84	12	Sand
BA-11	89-102	13	Gravel - sand

Table 4. Result of Water Discharge (Flux) Calculations Based on Darcy's Law

No	Q (m^3/day)	Q (l/sec)	T(m^2/day)
Segment 1	2068.02	23.93	6143.87
Segment 2	1890.77	21.88	5492.17

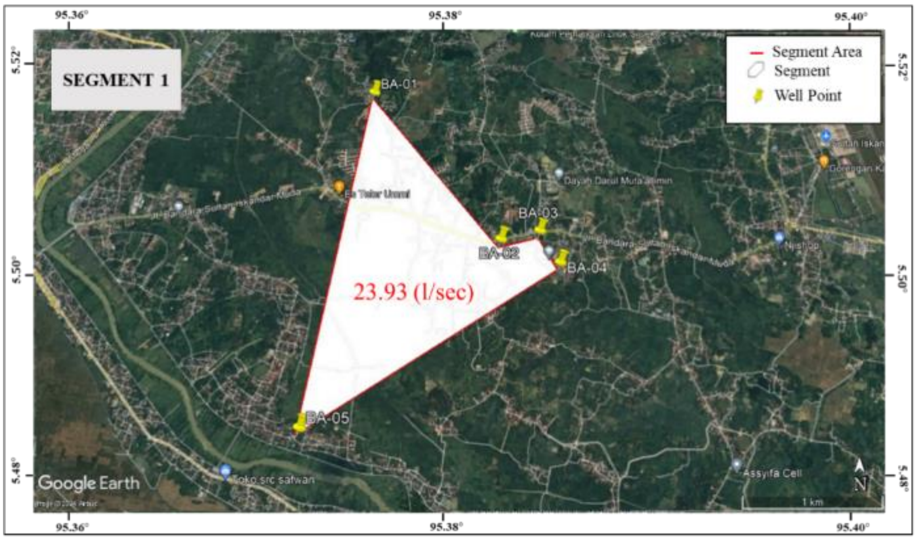

Figure 5. Water Discharge (Flux) Calculation of Segment 1

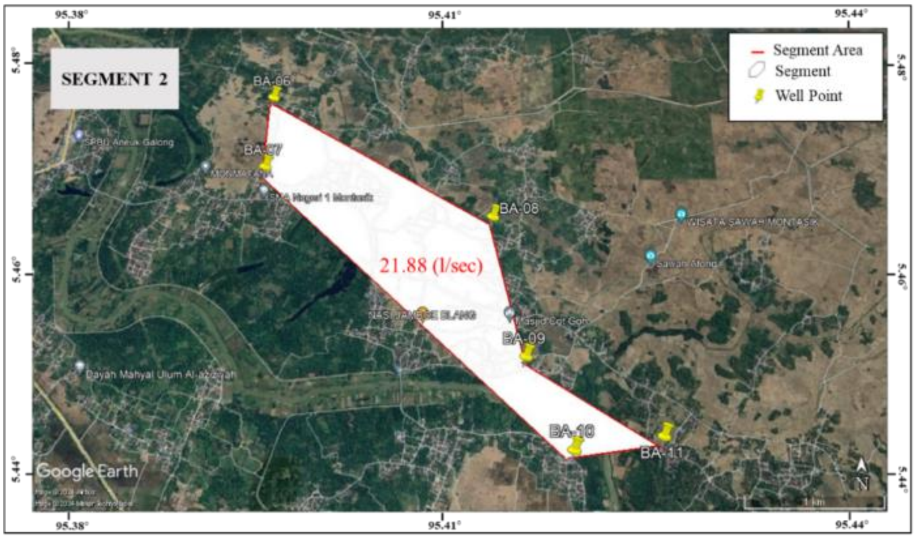

Figure 6. Water Discharge (Flux) Calculation of Segment 2

3.4. Discharge Calculation

Table 4 is the result of water discharge (flux) calculations based on Darcy's Law obtained from 11 well points which have been divided into 2 segments in this research.

3.5. Pumping Test Data

Pumping Test is a real discharge data. The method of measuring water discharges from observing the continuity of the water source and the availability of water from the source itself. Pumping Test data (real discharge) was obtained from the Energy and Mineral Resources Service (ESDM). The Pumping Test (real discharge) data is then validated with the results of discharge calculations based on Darcy's Law in segment 1 and segment 2.

Figure 8 is a graph of the optimum discharge value based on the Pumping Test (real discharge) in Montasik District. Based on the results, the pumping discharge was 3.5 liters/second. Referring to the map, this well is in segment 2, namely at point BA-07.

From the aquifer analysis, it was found that the geological conditions in the research area were sedimentary rocks in the form of alluvium consisting of sand, clay and gravel. These three types of rocks are classified as aquifers and aquicludes. The sand and gravel in this study area are indicated as aquifers where this layer can store water reserves and can also drain it in sufficient quantities. Clay is indicated as an aquiclude, where this layer consists of water but cannot pass through certain amounts of water.

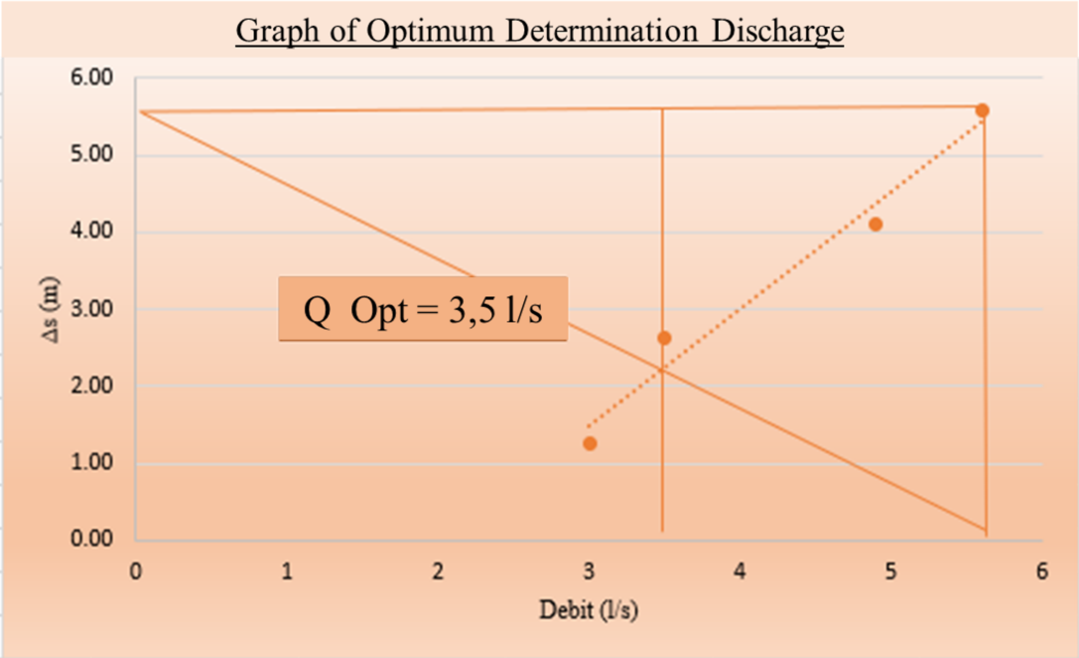

Figure 7. Pumping Test Result of Well 2 (Source. ESDM)

Table 5. Comparison Between Water Discharge (flux) Calculations using Darcy's Law with Pumping Test Data (Real Discharge).

No	Discharge Calculation (Darcy's Law) (l/sec)	*Pumping Test* (l/sec)			Error (%)
		(*Real* Discharge)	Wells	Multiplier	
Segment 1	23.93	5.1	5 points	25.5	6.1
Segment 2	21.88	3.5	6 points	21	4.2

In general, the type of aquifer in the Aceh Besar region can be classified as a confined aquifer, because it is located between layers of clay rock which is an impermeable layer. The aquifer is located at a depth of 54 m – 120 m. It can be concluded that the Aceh Besar region is a very good area for groundwater potential because it has a type of aquifer that is good for storing groundwater. This type of aquifer is a type of groundwater whose quality and quantity are better than shallow groundwater, therefore it is commonly used by industrial activities, including mining areas.

Based on the flow discharge values in the research area, it can be said that the groundwater potential in Aceh Besar in the coastal area is very large, and its availability is still sufficient for sustainable use (Luijendijk, 2020). Sustainable use of groundwater to minimize hazards that threaten human survival and reduce groundwater and environmental problems. The vital role of groundwater and the negative impacts of excessive groundwater extraction, uncontrolled groundwater exploitation can trigger land subsidence. In addition, if excessive exploitation in coastal areas, there is the potential for saltwater intrusion into the aquifer layer. To anticipate these negative impacts, sustainable groundwater management efforts must be able to predict aquifer dimensions and groundwater reserves (Agustin et al, 2023; Shcherbakov et al, 2023; Fang et al, 2023).

Based on water discharge (flux) calculations using Darcy's Law, the water discharge value in segment 1 is 23.93 liters/second while the value obtained from the Pumping test (real discharge) is 5.1 liters/second/well, so that a total of 5 well points will be obtained the result is 25.5 liters/second which is comparable to the calculation results based on Darcy's Law. Likewise, the results of water discharge (flux) calculations using Darcy's Law obtained in segment 2 are 21.88 liters/second and the results from the Pumping test (real discharge) are 3.5 liters/second, which if multiplied by 5 well points, the result is 21 liters/second. second.

From these two data comparisons, the error value between the two data was found. This could possibly be caused by determining the aquifer layer, aquifer thickness, aquifer depth, as well as data used in calculating water discharge (flux).

The error results from the comparison in Table 5 are obtained using the following formula:

$$\text{Error percentage } \% = \frac{\text{Estimated value} - \text{Real value}}{\text{Real value}} \times 100\ \%$$

Based on Table 5, the error value obtained in segment 1 is 6.1% and in segment 2 is 4.2%. This shows a small error value between the calculation results and pumping test data, so it can be said that water discharge (flux) calculations using Darcy's Law can be used as a reference for groundwater exploitation. According to (Fadhli et al., 2024), in the coastal area of Southwest Aceh found that the level of discrepancy between the pumping test method and

Darcy's calculation was 5%. The dimensions of aquifer in the study were estimated from the results of 2D geoelectric method. However, both the calculation results and the pumping test show that the water discharge is higher in segment 1 than segment 2. This can not only be caused by differences in the depth and thickness of the aquifer, but also due to differences in the materials that make up the aquifer (Devy et al., 2018; Fadhli et al., 2019). Where the aquifer in segment 1 is dominated by gravel, while the aquifer in segment 2 is dominated by sand. Gravel has a higher porosity so the water holding capacity is higher, this ultimately affects the water discharge in the area.

4. CONCLUSIONS

Based on the analysis of aquifer types from 11 wells, it showed that the aquifer on each point had an average depth of 54 m to 120 m, with the average thickness of 15 meters. The type of aquifer found in the area is a confined aquifer which has good groundwater quality and potential. The calculations based on Darcy's Law gave the water discharge (flux) value of 23.93 liters/second in segment 1 and 21.88 liters/second in segment 2. It could be concluded that the groundwater potential of Aceh Besar Regency's coastal area is quite enormous, and its availability is still very valuable economically. The water discharge (flux) value calculated using Darcy's Law were quite similar to the measurement result with Pumping Test data (real discharge), as the differences in segment 1 and segment 2 were 6.1% and 4.2%, respectively. This small margin shows that the calculation of water discharge (flux) using Darcy's Law could be comparable and have significant accuracy to the results obtained from the Pumping Test (real discharge), thus Darcy's Law could be implemented as a reference in groundwater exploitation.

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REFERENCES

Afifuddin, I., Rustan, and Restianingsih, T. 2021. Identifikasi Lapisan akuifer Menggunakan Metode Geolistrik Konfigurasi Achlumberger di Perumahan Arza Griya Mandiri Jambi. Jurnal Komunikasi Fisika Indonesia, 18(3), 173-178.

Agustin, F., Abdullah, C.I., Herlina, D., Akhyar, M. F., Amukti, R., Himawan, B., and Adiputra, R. N. 2023. Aquifer Geometry Identification and Determination of Aquifer Storage and Recovery (ASR) in Bandung. IOP conf. Series: Earth and Environmental Science. The 2nd International Conference on Mining and Environmental Technology.

Cahyadi, A., Hidayat, W. dan Wulandari. 2013. *Adaptasi Masyarakat Terhadap Keterbatasan Sumberdaya Air di Pulau Pramuka, Kepulauan Seribu, DKI Jakarta*. Jurnal Penelitian Kesejahteraan Sosial, 12 (2): 207 – 213.

Darcy, H. (1856). Les Fountaines publiquea de la Ville de Dijon. Paris: Dalmont.

Darisma, D., Fernanda, F., and Syukri, M. 2020. Investigation of Groundwater Potential Using Electrical Resistivity Method and Hydraulic Parameters in lam Apeng, Aceh Besar, Indonesia. Jurnal of Geoscience, engineering, environtment, and Technology, 5(4), 185-190.

Devy, S. D. and Sarungallo, C. 2018. Groundwater Aquifer Study on Coal Mining Area: a case of North Samarinda, Indonesia. Jurnal of Degraded and Mining Lands Management. 6(1), 1483-1493. Doi: 10.15243/jdmlm.2018.061.1483.

Fadhli, Z., Syukri, M., Anda, s. T., Marvita, Y., Karmel, M. E. R., Alfaiz, K., and Embara, P. 2024. The Calculation of Saltwater Discharge at Ahrimp Pond, Soutwest Aceh, Based on Geoelectrical Data. AIP Publishing. 12th Annual International Conference (AIC) 2022: On Sciences and Engineering.

Fadhli, Z., et al. 2022. Ground Surface Quality Assesment using P-wave Velocity from 2-D Seismic Refraction method. Aceh International Journal of Science and Technology. 11(3), 258-263. Doi: 10.13170/aijst.11.3.28818.

Fadhli, Z., Syukri, M., and Marwan. (2019). Identification of Aquifer Layer Based on 2D Resistivity Data in Lhokseumawe Aceh-Indonesia. Journal Aceh Physics Society, 8(3), 78-83. doi: 10.24815/jacps. v8i3.14518.

Fang, Y., Qian, J., Zheng, T., Wang, H., Zheng, X., and Walter, M. 2023. Submarine Groundwater Discharge in Response to The Construction of Subsurface Physical Barries in Soastal Aquifers. Journal of Hydrogeology. 617(B).

Fetter, C.W. 1988. *Applied Hydrogeology*. New York: Macmillan Publishing Company.

Halimi, S., Rechachi, H., Bahroun, S., Mizane, N.E., and Daifallah, T. 2018. Assesment of Groundwater Salinity and Risk of Soil Degradation in Quaternary Aquifer System. Example: Annaba Plain, Algeria N-E. Journal of Water and Land Development. 36(I-III), 57-65. Doi: 10.2478/jwld-2018-0006.

Luijendijk, E., Gleeson, T., and Moosdorf, N. 2020. Fresh Groundwater Discharge Insignificant for The World's Oceans but Important for Coastal Ecosystems. Nature Communications. https://doi.org/10.1038/s41467-020-15064-8.

Pangestu and Waspodo, R. S. B. 2019. Prediksi Potensi Cadangan Air Tanah Menggunakan persamaan darcy di Kecamatan Dramaga, kabupaten Bogor. Jurnal Teknik Sipil dan Lingkungan, 04(01), 59-68.

Shcherbakov, A. and Baramykov, M. 2023. Calculation of Water Flow Discharge Using The Truncated Triangular Prisms Method. IOP conf. Series: Earth and Environmental Science. 1206012032.

Simpen, I. N., Redana, I. W., Pujianiki, N. N., and Umratul, I. 2017. Aquifers Selection to Ais Geoelectitical Methods on Drilled Well Building Near to Beach. International Journal of Physical Sciences and Engineering. 1(3), 41-50.

Soetrisno, S (t.t). 1993: Hydrogeological Map of Indonesia Scale 1:250.000. Directorate of Environmental Geology, Bandung.

Syahruddin, M. H. 2014. Persamaan aliran Air dalam media berpori sebagai Aliran Air Tanah (Groundwater). Simposium Fisika Nasional 2014 (SFN XVVII). Denpasar-Bali.

Sykri, M., Fadhli, Z., Amsir., Anda, S. T., and Safitri, R. 2023. Sedimentary Aquifer Accessing Using 2-D Resistivity

Imaging, Case Study: Blang Bintang, Aceh Besar. AIP Publishing. 11th Annual International Conference (AIC) 2021: On Sciences and Engineering. 2613(1). https://doi.org/10.1063/5.0121564.

Wilopo, W., Putra, D. P. E., and Susatyo, R. 2020. Aquifer Distribution and Groundwater Geochemistry in Bojonegoro Sub-district, Bojonegoro District, East Java Province, Indonesia. Jurnal of Degraded and Mining Lands Management. 7(4), 2327-2335. Doi: 10.15243/jdmlm.2020.074.2327.

Yusra, R. D. and Afdal. 2023. Pendugaan Intrusi Air Laut terhadap Air Tanah Dangkal di kecamatan Pariaman Utara Kota Pariaman. Jurnal Fisika Unand, 12(1), 35-41