P-ISSN 0216-8138 | E-ISSN 2580-0183
MKG Vol. 23, No.2, Desember 2022 (188 - 197)
DOI: https://doi.org/10.23887/mkg.v23i2.51539

Analysis of Groundwater Potential in the Coastal Area of Parangtritis using Geoelectrical VES Method

La Ode Saleh Isa, Tjahyo Nugroho Adji, Ignasius L. Setyawan Purnama

Received: 19 08 2022 / Accepted: 10 11 2022 / Published: 01 12 2022

Abstract This research was conducted in the coastal area of Parangtritis, Bantul Regency, Special Region of Yogyakarta. This study aims to describe the hydrostratigraphy of aquifers using the Vertical Electrical Sounding (VES) geoelectric method, to calculate the volume of availability and safe yield of groundwater application, and to compare the volume of availability of safe products with the demand for water for domestic and tourism purposes. This study uses a field survey approach and field data analysis. In this study, there were 9 VES measurement points for primary data and 16 VES measurement points from secondary data, five samples of water demand for restaurants, and 74 samples of domestic groundwater needs. The VES point was measured by a purposive random sampling method representing each landform. Hydrostratigraphic analysis and preparation of 2D and 3D cross-sectional models of subsurface lithology were performed on all VES geoelectrical measurement data. The results showed that the aquifer layer is located at varying depths for each landform, with alluvium sand as the constituent material. The most significant potential for groundwater is found in the form of dunes and beach ridges. The second-largest groundwater potential is in fluviomarine landforms, and the most minor is in the alluvial plain. The groundwater availability in each landform is sand dune and beach ridge of 117,776,100 m3; fluviomarine plain (45,422,700) m3; and alluvial plain (25,553,000) m3. Then, the safe yield of groundwater is 3,498,300 m3 in sand dunes and beach ridges, fluviomarine plain (1,566,300 m3), and alluvial plains (580,750 m3). Meanwhile, based on the calculation of the total need for groundwater for domestic and tourism purposes, the availability of safe yield is still in surplus or sufficient for the estimated needs.

Keywords: VES Geoelectric; Groundwater Potency; Domestic Groundwater Need; Tourism Groundwater Need; Geomorphology of Parangtritis

1. Introduction

Coastal areas are often the main choice for people to live in either because of the difficulty of finding a place to live in urban areas or the ease with which people find livelihoods in this area. In addition, coastal areas are also often visited by the community for tours because coastal areas generally provide beach tourist spots that attract tourists to visit. Furthermore, the people who live and visit coastal areas will affect the need and availability of groundwater in this area, so research is needed to examine this so that there is no gap between the availability and the need for groundwater.

The coastal area of Parangtritis has beach and sand dune tourist spots,

---

[1] La Ode Saleh Isa, [1] Tjahyo Nugroho Adji, [1] Ignasius L. Setyawan Purnama
[1] Universitas Gadjah Mada, Indonesia

la.ode.saleh.isa@mail.ugm.ac.id

so this area is the main destination for tourists to vacation. Quoted from Jogja.tribunnews.com (2019), 259,000 tourists visited this area in 2018 A large number of visitors will affect the need and availability of water in this area. This is similar to the research of Koç et al. (2017), which states that increasing tourist visits in tourist areas can increase the amount of groundwater demand.

Furthermore, the large number of visitors increases built-up areas such as hotels and rest areas. LaVanchy (2017) explained that the increasing number of tourist visits in coastal areas led to increased demand for water for consumption and hospitality. In addition, people who live in this area will be stimulated to build restaurants, hotels, and the like. The built-up land also affects the need and availability of groundwater in the Parangtritis coastal area.

Moreover, People in the research area use groundwater for several purposes including for consumption, livestock, and agriculture (Wiyono et.al., 2020). Furthermore, majority of the people in the research area work as a farmer with a large area of farm land. This will lead in to exsecive groundwater use. The increase in the number of tourists, the increase in built-up land, and the presence of community settlements and large area of farm land in the Parangtritis coastal area have led to an increase in the demand for groundwater needs, so there need to be efforts to find groundwater sources so that there is no imbalance between demand for and availability of groundwater in this region.

Groundwater in coastal areas is the main water source that supplies water needs in this area. In some countries (Sappa et al., 2015; Comte et al., 2016), aquifers in coastal areas supply fresh water for industrial, agricultural and drinking water for the community, so aquifers in these areas have an important role in supporting sustainable livelihoods. In maintaining its sustainability, groundwater monitoring in coastal areas needs to be carried out. Liu (2008) stated that it is necessary to have good management and monitoring of groundwater aquifers in coastal areas to maintain groundwater quality. One of the efforts to monitor groundwater aquifers in coastal areas is to conduct studies on the potential of groundwater sources in coastal areas.

The hydrostratigraphic cross-section is arranged based on the stratigraphic order of the rocks below the surface. Porous materials with good permeability can become aquifers in certain stratigraphic sequences. Hydrostratigraphic cross-section can provide an overview of the depth and thickness of the aquifer, the type of aquifer, whether it is a free or confined aquifer, and the movement of groundwater below the surface (Åberg et al., 2021). Furthermore, the geophysical method provides convenience in compiling a hydrostratigraphic cross-section, with the method commonly used being the VES geoelectric method (Eluwole et al., 2018). The injection of electric current to the subsurface in this method is polarized through layers of different materials. It brings information about the type of material, depth, thickness, and direction of layer distribution based on the resistivity value of the material obtained.

The VES geoelectric method is one of the effective methods used in groundwater exploration in coastal areas. Adadzi et al. (2018) stated that the VES geoelectric method is easy to use and the costs incurred are quite low in operation. Furthermore, the research results by Khalil et al. (2020) also show that the VES geoelectric method can describe the presence of groundwater aquifer layers in coastal areas. In addition, the results of VES data processing can provide hydrostratigraphic information on the research location. In addition, the results of research conducted by Santosa and Adji (2007) showed significant results using the VES geoelectric method in the bay area. This research aims: 1) to describe the hydrostratigraphy of aquifers using the Vertical Electrical Sounding (VES) geoelectric method; 2) to calculate the volume of availability and safe yield of groundwater application, and 3) to compare the volume of availability of safe yields with the demand for water for domestic and tourism purposes.

2. Methods

The method applied in this research is a field survey and analysis of field data. Field surveys were conducted to collect VES geoelectric data and groundwater requirements for domestic and tourism purposes. The VES points were determined by purposive sampling technique. The research area consits of several landforms with varying composing materials which form different characterstic of groundwater aquifer. In order to obtain targeted results, the ves points were setted in the field based on characteristics of the landform. VES geoelectrical data consists of 9 primary data points and 16 secondary data points with a target polarization depth of >150 meters below the earth's surface. Field data analysis was carried out on groundwater demand, quantity, and safe yields. The groundwater quantity is calculated using the static method with the following formula (Todd and Mays, 2005).

$$Vat = Sy \times Vak \text{ atau } Vat = A \times Da \times Sy \quad (1)$$

where:

Vat = groundwater volume (m3);

Sy = specific yield (%);

Vak = volume of the aquifer is the area of the aquifer x aquifer thickness (m3);

A = surface area (m2);

Da = aquifer thickness (m);

$$\text{Water daily need} = \frac{\text{Amount of daily water need}}{\text{Number of family members}} \quad (2)$$

The water requirement per year can be calculated by the following equation:

$$\text{Yearly water need} = \text{Amount of daily water need} \times \sum \text{people} \times 365 \text{ days} \quad (3)$$

The VES geoelectrical data collection was carried out through field measurements using a set of geoelectrical types with a Schlumberger configuration. This configuration is often used in geoelectric sounding methods because it displays vertical variations of material layers below the earth's surface. The determination of the VES point in this study used a purposive sampling technique with the aim of obtaining the desired measurement results (Figure 2).

The results of field data measurements are then processed into MS-excel to obtain the apparent resistivity value (ρa). Furthermore, the true resistivity value was obtained using the IP2WIN software application, while for compiling 3D hydrostratigraphic cross-sections assisted by Rockwork 16 software.

The safe yield of groundwater use is obtained based on data on annual groundwater level fluctuations, specific yield, and aquifer surface area calculated using equation (4). Furthermore, tourism groundwater needs are calculated based on the water needs of hotel guests by following SNI (2002), which shows that the water requirement per hotel room is 90 litres/day multiplied by the number of days in a year. In addition, the need for groundwater for tourism purposes is also obtained from the use of groundwater in restaurants Estimating groundwater needs in restaurants refer to equations (2) and (3).

$$HA = F \times A \times Sy \qquad (4)$$

where :

HA = safe yied (m3)

F = annual groundwater flutuation (m);

A = aquifer surface area (m2)

Sy = spesific yield (depending on the type of aquifer material).

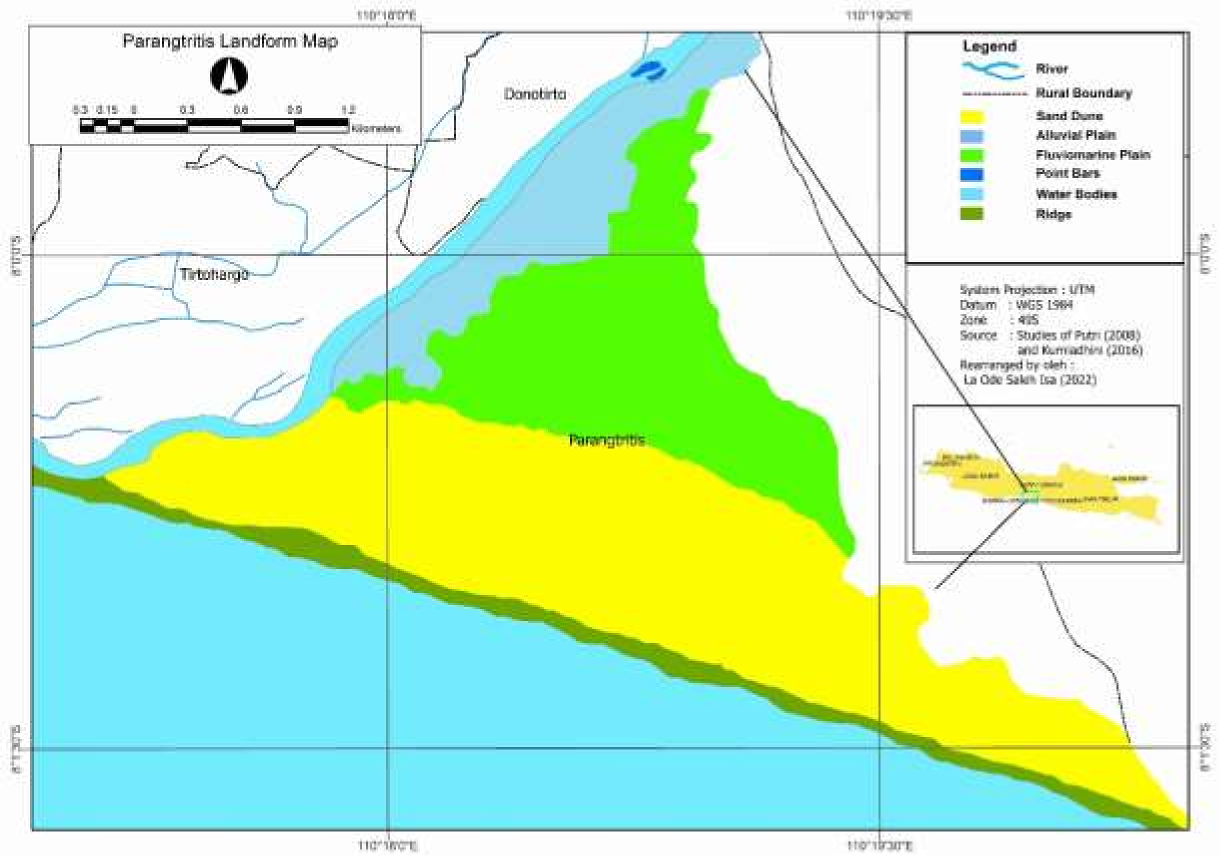

Figure 1. Landform at the research site

3. Results and Discussion

Combination of VES one dimension profile with 2D and 3D models showed a clear image of subsurface layers. Therefore, these methods combinations are the best compared with a single VES method.

The results of processing geoelectrical data at the research site are compiled into 3D models to facilitate the calculation of layer thickness and depth, calculate the specific yield (Sy) value and make it easier to interpret the distribution of aquifers at the study site. The study area's 3D lithology models show the thickness and depth of the aquifer layers that vary in each landform. The materials that make up the aquifer at the study site determine the type of aquifer found in the study site. Overall, there are two types of storage media, namely the main aquifer and aquitard. The main aquifer is medium to fine sand, alluvium sand, and sandy material, while the aquitard is alluvium clay material.

The alluvial plain landform has the main aquifer layer spread throughout the study site with varying depths (Figure 3). The main aquifer with the constituent material in the form of sand material is at a depth of 129–180 meters and has a layer thickness of about 51 meters. Furthermore, the main aquifer with medium sand constituent material is at a depth of 10–127 meters. The thickness of this aquifer layer is 110 meters and 40 meters in different distribution directions. The aquitard layer in this formation is at a depth of 0–36 meters with a fairly thin layer.

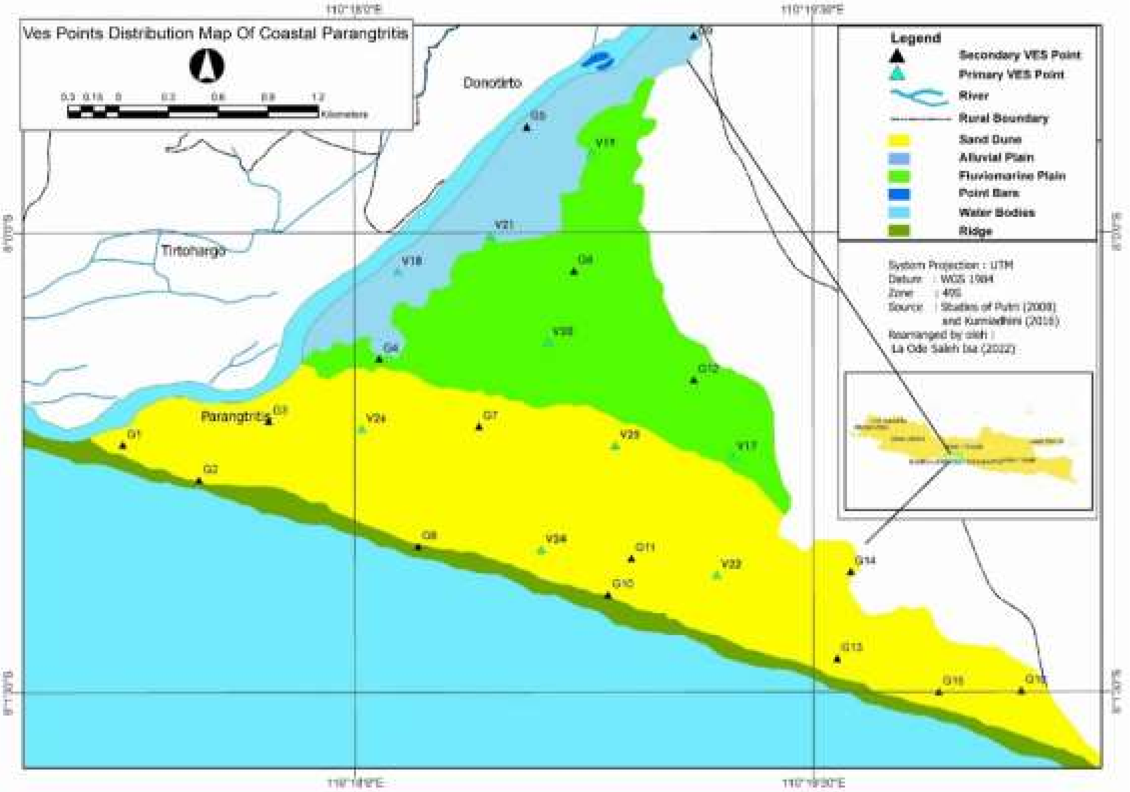

Figure 2. Location of the distribution of VES measurement points

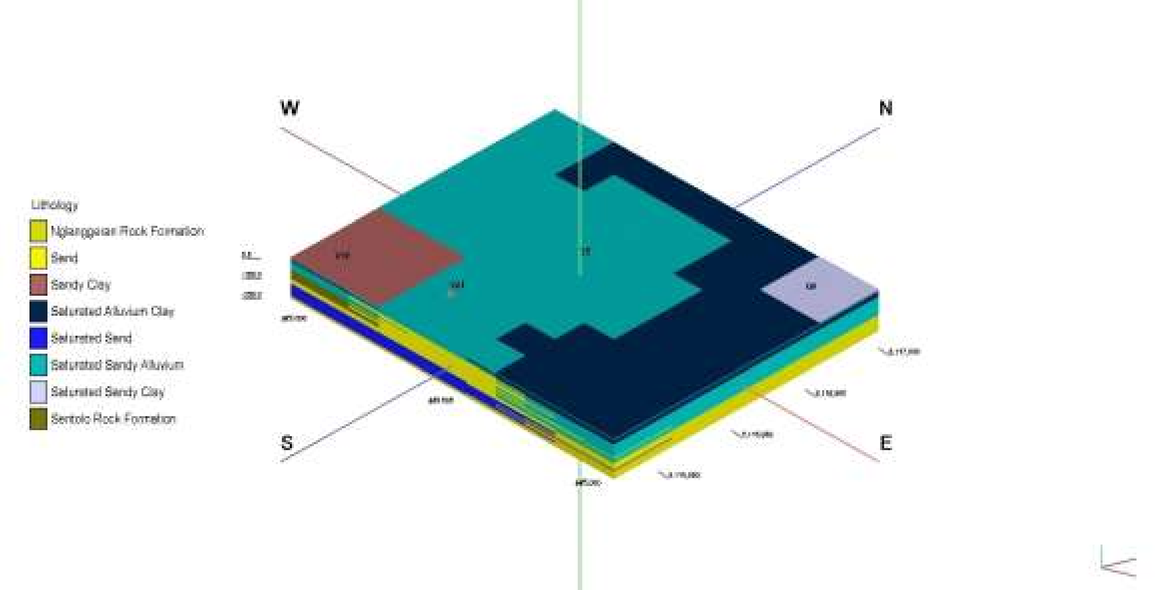

Figure 3. 3D model of subsurface hydrostratigraphy in the alluvial plain

Sand and alluvial sand, as the main aquifers in sand dunes and beach ridges, have varying depths and thicknesses (Figure 5). Sandstone is at a depth of 29–120 meters with a layer thickness of 44 and 91 meters in different distribution directions. Furthermore, alluvium sand is located 1–105 meters below the ground surface with a layer thickness ranging from 58 to 104 meters. The aquitard layer in this landform has a depth of about 1–180 meters below the ground surface and has a layer thickness of about 179 meters.

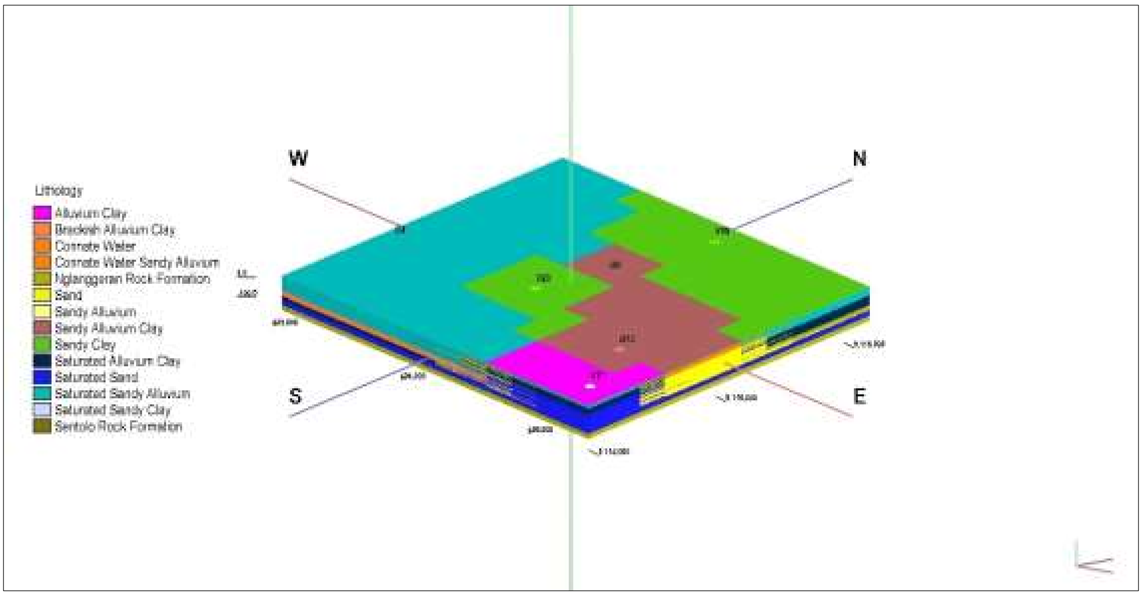

Figure 4. 3D model of subsurface hydrostratigraphy in the fluviomarine plain

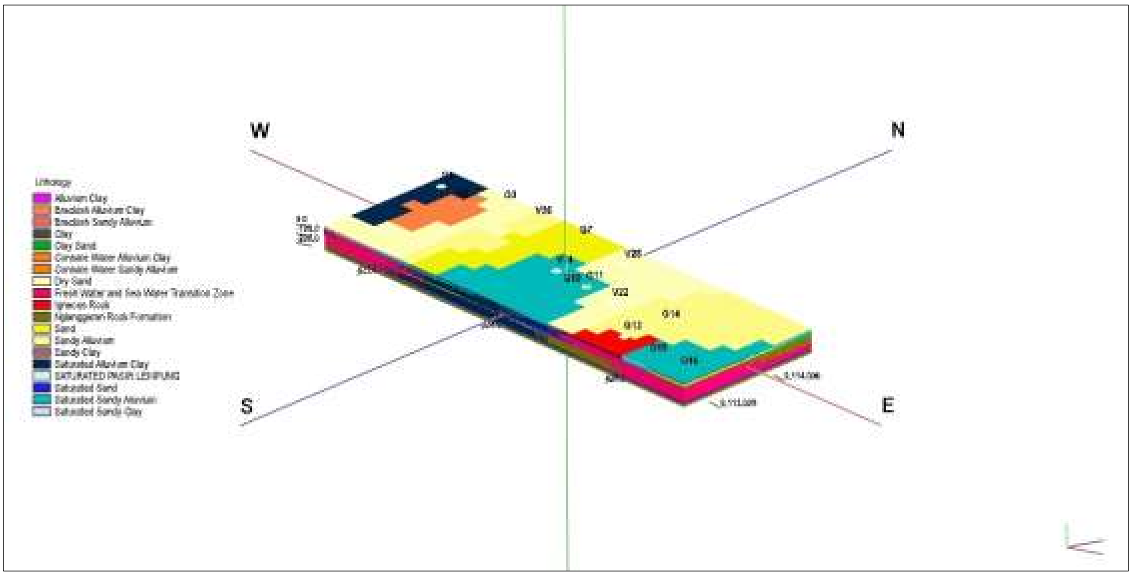

Figure 5. 3D model of subsurface hydrostratigraphy in the sand dunes and beach ridges

The specific yield value is determined based on the aquifer constituent materials found at the research site. Alluvium sand has a Sy value of about 0.23. The groundwater availability at the research site is then calculated using equation (1). The total availability of water in alluvial plains is 25,553,000 m^3; fluviomarine plains (45,422,700 m^3), and the availability of water for sand dune and beach ridge landforms is 117,776,100 m^3. Based on the characteristics of the aquifer and the amount of available water obtained, sand dunes and beach ridges are the areas with the best groundwater potential. The fluviomarine plain is the area with the second-best groundwater potential, and the alluvial plain is the area with the least groundwater potential.

To maintain the sustainability of the amount of groundwater available, it is necessary to know the availability in terms of the safe yield of groundwater. The safe yield of groundwater is calculated based on the value of groundwater fluctuations at the study site, the area of each landform, and the specific yield value of the aquifer constituent materials. These parameters are then calculated based on equation (4). The safe yield for alluvial plains is 580,750 m3; fluviomarine plains of 1,566,300 m3; and the safe yield for sand dune and beach ridge landforms is 3,498,300 m3.

Furthermore, a comparison between the safe yield of groundwater and the total water demand (domestic + tourism) is carried out to determine or evaluate whether the total demand for clean water has exceeded the available safe yield (deficit) or is still below the available safe yield (surplus). Table 1 compares the amount of groundwater demand, the availability of groundwater, and the availability of safe yields at the study site.

Table 1. Comparison between static goundwater availability, total groundwater needs, and safe yields of groundwater in each landform

No	Landforms	Static groundwater availibility (m^3/year)	Total demand (domestic and tourism) of groundwater (m^3/year)	Groundwater safe yield (m^3/year)
1	Alluvial plain	25,553,000	187,821,7	580,750
2	Fluviomarine plain	45,422,700	171,712,06	1,566,300
3	Sand dunes and beach ridges	117,776,100	184,013,37	3,498,300

Table 1 shows that the use of groundwater by the community for meeting domestic and tourism needs does not exceed the safe yield found in the research location (still in surplus). This indicates an excess of groundwater that can still be used for other purposes (e.g. agriculture). However, in using groundwater for other purposes, it is still necessary to pay attention so that it does not exceed the safe yield of groundwater potential.

4. Conclusions

Hydrostratigraphically, in the study area, there are two layers that store groundwater reserves, namely (a) the primary aquifer, which contains medium to fine sand, alluvium sand, and sandy material, and (b) alluvium clay material as an aquitard. The largest groundwater reserves are usually found in sand dunes and beach ridges, followed by fluviomarine plains, while alluvial plains have the least groundwater volume. Overall, safe yield reserves in all landforms are still greater than the total water demand for domestic and tourism purposes. Local government should take action to form regulations about groundwater pumping in research area to avoid cone of depression and intrusion of saltwater. The research results could be used to establish development planning programs based on grondwater approach.

ACKNOWLEDGEMENT

Incessant gratitude is addressed to Allah Subhanahu wa Ta'ala, who always makes it easy in all affairs. The authors would like to thank our parents who support this research. Furthermore, we would like to thank all parties that we cannot mention one by one who has assisted, especially during the field survey.

REFERENCES

Åberg, S. C., Åberg, A. K., & Korkka-Niemi, K. (2021). Three-Dimensional Hydrostratigraphy and Groundwater Flow models in Complex Quaternary Deposits and Weathered/Fractured Bedrock: Evaluating Increasing Model Complexity. *Hydrogeology Journal, 29,1043–74*.

Adadzi, P., Coffie, H., Afetorgbor, E., & Takase, M. (2018). Vertical Electrical Sounding Survey for

Groundwater Exploration for Rural Water Supply in Parts of Ketu South in the Volta Region of Ghana. *Journal of Hydrogeology & Hydrologic Engineering, 7(1), 1–8*. https://doi.org/10.4172/2325-9647.1000166.

Badan Standardisasi Nasional (BSN). (2002). Standar Nasional Indonesia (SNI) no.19 6728.1-2002, Tentang Penyusunan Neraca Sumber Daya - Bagian 1: Sumber Daya Air Spasial. Jakarta: Badan Standardisasi Nasional (BSN).

Comte, J. C., Cassidy, R., Obando, J., Robins, N., Ibrahim, K., Melchioly, S., & Mjemah, I. (2016). Challenges in Groundwater Resource Management in Coastal Aquifers of East Africa: Investigations and Lessons Learnt in the Comoros Islands, Kenya and Tanzania. *Journal of Hydrology: Regional Studies, 5(March), 179–99*. https://doi.org/10.1016/j.ejrh.2015.12.065.

Eluwole, A. B., Olorunfemi, M. O., & Ademilua, O. L. (2018). Soil Horizon Mapping and Textural Classification Using Micro Soil Electrical Resistivity Measurements: Case Study from Ado-Ekiti, Southwestern Nigeria. Arabian *Journal of Geosciences,11(12).* https://doi.org/10.1007/s12517-018-3652-x.

Jogja.tribunnews.com. (2019). Libur Lebaran 260,000 wisatawan ditargetkan kunjungi pantai selatan bantul. Diakses dari halaman. https://jogja.tribunnews.com/2019/05/28/libur-lebaran-260000-wisatawan-ditargetkan-kunjungi-pantai-selatan-bantul.

Khalil, M., Ibrahim, S.M., Didar-Ul Islam, Uddin, M. J., & Majumder, R. K. (2020). Coastal Groundwater Aquifer Characterization from Geoelectrical Measurements- A Case Study at Kalapara, Patuakhali, Bangladesh. *Journal of Applied Geology, 5(1), 1-10*. https://doi.org/10.22146/jag.55009.

Koç, C., Bakış, R., & Bayazıt, Y. (2017). A Study on Assessing the Domestic Water Resources, Demands and Its Quality in Holiday Region of Bodrum Peninsula, Turkey. *Tourism Management, 62(October), 10–19*. https://doi.org/10.1016/j.tourman.2017.03.024.

Kurniadhini, F. (2016). Analisis Potensi Airtanah Untuk Kebutuhan Air. *Skripsi*. Yogyakarta: Universitas Gadjah Mada.

LaVanchy, G. T. (2017). When Wells Run Dry: Water and Tourism in Nicaragua. *Annals of Tourism Research, 64(May), 37–50*. https://doi.org/10.1016/j.annals.2017.02.006.

Liu, J., Rich, K., & Zheng, C. (2008). Sustainability Analysis of Groundwater Resources in a Coastal Aquifer, Alabama. *Environmental Geology, 54(1), 43–52.* https://doi.org/10.1007/s00254-007-0791-x.

Putri, F. W. (2008). Potensi Airtanah Desa Parangtritis Kecamatan Kretek Bantul DIY. *Tesis*. Yogyakarta: Universitas Gadjah Mada.

Santosa, L. W., & Adji, T. N. (2007). The Investigation of Groundwater Potential By Vertical Electrical Sounding (Ves) Approach In Arguni Bay Region, Kaimana Regency, West Papua. *Forum Geografi, 21(1): 43–56.*

Sappa, G., Sibel E., Flavia F., Lukuba N. S., & Giulia L. (2015). Effects of Seasonal Change and Seawater Intrusion on Water Quality for Drinking and Irrigation Purposes, in Coastal Aquifers of Dar Es Salaam, Tanzania. *Journal of African Earth Sciences, 105(May): 64–84.* https://doi.org/10.1016/j.jafrearsci.2015.02.007.

Todd, D. K., & Mays, L. W. (2005). *Groundwater Hydrology, Third Edition. Edited by Jennifer Welter. Third*. Danvers, Massachusetts: John Wiley & Sons, Inc.

Wiyono, M. B., Adji, T. N., & Santosa, L. W. (2020). Analisis Ketersediaan Airtanah dengan Metode Statis di Pulau Pasaran, *Media Komunikasi Geografi, 21(2), 223-233.* https://doi.org/10.23887/mkg.v21i2.30259