E-ISSN-2580-7129
Print- ISSN-1978-6107

TECHNO: JURNAL PENELITIAN
Journal homepage: http://ejournal.unkhair.ac.id/index.php/Techno
Volume 13 Number 01 May 2024 DOI: https://doi.org/10.33387/tjp.v13i1.8047

Limitation on the Number of Groundwater Well Pumps in the Coastal Area of Ternate Island

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Received : 22-02-2024
Accepted : 22-04-2024
Available online : 30-05-2024

ABSTRACT

The hydrogeological characteristics of small volcanic islands possess unique attributes. Groundwater flow patterns descend radially and converge in coastal aquifers. The uneven distribution of coastal aquifers sometimes leads communities to extract groundwater from specific points. A notable phenomenon observed in the study area is the presence of dug wells with multiple water pumps. If the combined suction capacity of these pumps exceeds the allowed limit, it has the potential to cause the mixing of saltwater with freshwater. This study utilizes geoelectric methods to delineate the groundwater-saltwater interface beneath the surface. The groundwater-saltwater interface can also be calculated using equations. By knowing the well positions with multiple pumps, it is possible to calculate the allowable number of pumps. The calculations yield a limit of up to 31 pumps per dug well, thereby mitigating the risk of saltwater intrusion. Furthermore, data on the dug well positions within the study area are used to create groundwater table contours and flow models, aiding in the analysis of saltwater pollutant dispersion in the event of intrusion.

Keywords: Well pump quantity, Saltwater intrusion, Coastal area

ABSTRAK

Karakteristik hidrogeologi pulau-pulau vulkanik kecil memiliki keunikan tersendiri. Pola aliran air tanah turun secara radial dan berkumpul di akuifer pesisir. Distribusi akuifer pesisir yang tidak merata menyebabkan masyarakat mengambil air tanah pada titik-titik tertentu. Fenomena penting yang diamati di wilayah studi adalah adanya sumur gali dengan beberapa pompa air. Jika gabungan kapasitas hisap pompa-pompa tersebut melebihi batas yang diperbolehkan, berpotensi menyebabkan tercampurnya air asin dengan air tawar. Studi ini menggunakan metode geolistrik untuk menggambarkan batas kontak air tanah-air asin di bawah permukaan. Batas kontak ini juga dapat dihitung menggunakan persamaan. Dengan mengetahui posisi sumur yang terdapat banyak pompa, maka kita dapat menghitung jumlah pompa yang diperbolehkan. Perhitungan tersebut menghasilkan batas hingga 31 pompa per sumur gali, agar tidak terjadi intrusi air asin. Selain itu, data posisi sumur gali ddalam wilayah penelitian digunakan untuk membuat kontur permukaan air tanah dan model aliran, sehingga membantu dalam analisis sebaran polutan air asin jika terjadi intrusi.

Kata kunci: Jumlah pompa sumur, Intrusi air asin, Daerah pesisir

INTRODUCTION

The unregulated groundwater extraction in small islands can have detrimental effects on the island's hydrological system. Naturally, groundwater can discharge into the sea through runoff or offshore flow (Hughes et al., 2022; Zhou et al., 2019). Cases of saltwater intrusion can occur due to uncontrolled freshwater extraction, consistently posing issues in coastal areas (Alfarrah & Walraevens, 2018; Hussain et al., 2019; Xu et al., 2021). Moreover, there is the global concern of rising sea levels that impact the equilibrium of coastal aquifers (Esteban et al., 2020; Mulyono & Putro, 2019). This condition poses a threat to the coastal aquifers of small islands. When 3% of seawater mixes with freshwater in coastal aquifers, it renders the freshwater unfit for consumption (Sherif & Singh, 2002). This can transpire if coastal water extraction exceeds permissible of 205,000 people on Ternate Island [BPS 2022], it is predicted that the island will limits(de Graaf et al., 2019; Stein et al., 2020). The high demand for water further justifies extensive coastal water extraction. With a population require 1,427 m3/s of raw water by 2039 (Hadi et al., 2019). A case of saltwater intrusion occurred on Ternate Island in 2014, resulting from the extensive coastal groundwater extraction, causing saline water to be drawn into the pumps and contaminating the freshwater (Salam et al., 2018). The issue of saltwater intrusion in coastal regions has garnered significant attention from researchers, particularly concerning groundwater extraction near coastal areas (Sherif & Singh, 2002; de Graaf et al., 2019; Stein et al., 2020; Hadi et al., 2019).

The occurrence such as in 2014, necessitates us to exercise caution in the coastal groundwater extraction process. The dynamics of the groundwater-seawater relationship must be carefully maintained, particularly in cases of high-volume groundwater extraction (Hussain et al., 2019). Small volcanic island coastal regions exhibit unique hydrological dynamics. The presence of mountains at the center of the island results in radial groundwater flow, implying that it flows downhill towards all coastal areas. This differs from the coastal regions of larger islands or continents (Piscopo et al., 2020; Achmad, 2016). Ternate Island, as a small volcanic island, exhibits a distinctive distribution of coastal aquifers (Salam et al., 2018; Achmad et al., 2016; Achmad, 2016). The productive aquifers on this island are predominantly located in the northeastern to southern regions (Parnadi & Salam, 2022). The geological conditions of Ternate Island's rocks also influence the groundwater quality in the coastal areas (Aryuni et al., 2020). Broadly, the rocks can be categorized into three generations: Old Gamalama Volcano (GmT), Middle Age Gamalama Volcano (GmD), and Young Gamalama Volcano (Gm) (Bronto, S, Hadisantono, and Lockwood, 1982). Due to variations in rock ages, the northern part of Ternate Island, with its younger rocks, is highly susceptible to saltwater intrusion. Some areas in the island's north have groundwater with elevated chloride content and above-average temperatures (Achmad et al., 2016; Aryuni et al., 2020).

The carrying capacity of a small island is inherently static, while the population continually evolves. This becomes especially evident when a small island, serving as a governmental center, surpasses its carrying capacity due to an ever-increasing population (Cashman & Nagdee, 2017). The government should recognize that the relationship between groundwater and population growth (anthropogenic activities) constitutes a socio-ecological entity, where groundwater availability dynamically and non-linearly correlates (Xu et al., 2021; Bouchet et al., 2019).

Based on data from the Central Bureau of Statistics (BPS) for the year 2022, the population of Ternate Island totals of 205.000 individuals. Population distribution primarily occurs in coastal regions. Groundwater originating from mountain peaks ultimately converges and is stored in coastal areas. Generally, the population extracts groundwater in coastal areas, mainly by using water pumps. Additionally, the state-owned Water Company extracts substantial amounts of groundwater from coastal regions (Mulyono & Putro, 2019; Nagu et al., 2018).

An intriguing phenomenon at the core of this research is the abundance of water pumps installed in dug wells by residents (see figure 7.) The overall location of these wells is in close proximity to the coastline. This study aims to demonstrate the potential threat of saltwater intrusion when the number of pumps in a single well is not regulated, and they concurrently extract water.

METHODOLOGY

Unregulated groundwater extraction in coastal areas disrupts hydrostatic equilibrium. Todd and Mays L.W. (2005) and Fetter, C.W. (2004) have elucidated the hydrodynamic relationship between saltwater and freshwater in coastal regions, as originally described by W. Badon Ghijben (1889) and A. Herzberg (1901), as depicted in the figure below (Fetter, 2004; Todd, D. K. and Mays, 2005).

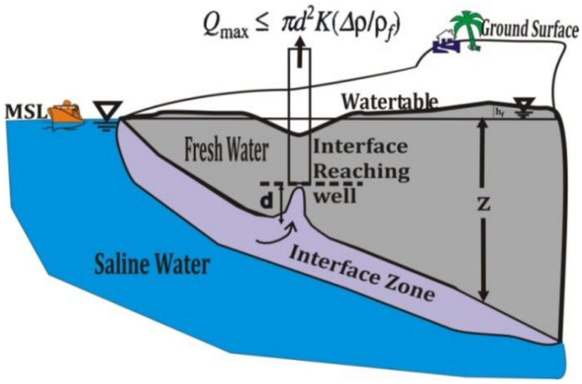


Figure 1. Upconing effects and hydrostatic dynamics in coastal areas

In figure 1, the equations will be applied to constrain the withdrawal rate and the depth of the interface zone, which is given by:

$$Q_{max} \leq \pi d^2 K\left(\Delta\rho/\rho_f\right) \quad (1)$$

$$Z = 40h_f \quad (2)$$

Saltwater within the transition zone or interface may be drawn into the wellbore if its discharge exceeds the equation illustrated in Figure 1. To prevent saltwater intrusion, a geoelectric method needs to be implemented to determine the depth of the interface. In this study, the ARES resistivity meter with a multi-electrode configuration (Wenner-Schlumberger) was employed. Utilizing 24 electrodes with a 5-meter spacing between stick electrodes, a maximum depth of more than 20 meters was obtained. The data acquisition scheme is depicted in the following figure 2.

Groundwater table depth measurements are conducted to create depth contours and groundwater flow direction models. The measurement process is carried out using a scheme as illustrated in the following figure 3.

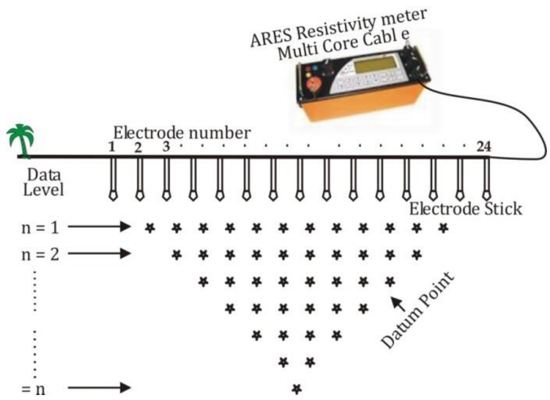


Figure 2. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection

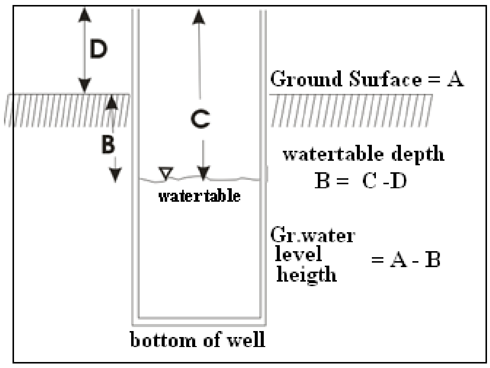


Figure 3. Watertable level measurement

Geological, Geohydrogical Setting and Research Site

Apandi and Sudana (1980) stated that Ternate Island is composed of Holocene volcanic rocks (Qhv), including andesitic breccia and basalt (Apandi, T., and Sudana, 1980). Boronto et al. (1982) divided the rocks of Ternate Island into three generations: Old Gamalama Volcano (Gt), Middle Age Gamalama Volcano (Gd), and Yuong Gamalama Volcano (Gm), based on their eruption periods (Bronto, S, Hadisantono, and Lockwood, 1982). This classification is founded on the eruption history. These sediment layers significantly influence the hydrogeological system of Ternate Island.

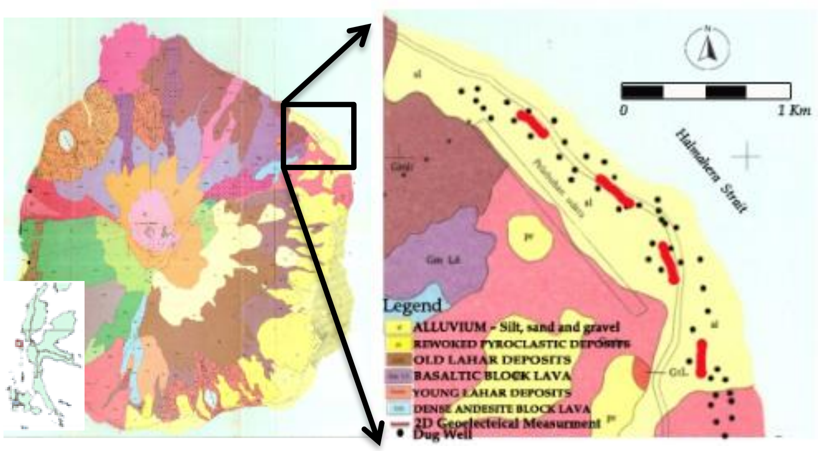


Figure 4. Geological map and research site

In the hydrogeological system of Ternate Island, there are also surface deposits, namely Alluvium (Al) and Pyroclastic Breakdown Deposits (Pr). Both of these deposits (Al and Pr) are derived from the three age categories of Gamalama rocks (Gt-Gd-Gm). The presence of Mount Gamalama in the center of Ternate Island contributes to orographic factors that affect rainfall. Salam et al. (2018) calculated rainfall over a span of 22 years and classified Ternate Island as having a type-B climate (tropical rainforest) (Salam et al., 2018). Besides orographic factors, the presence of volcanoes also creates a radial groundwater flow pattern that spreads throughout the coastal regions, including the study area. As seen in Figure 4, the study area is predominantly composed of Alluvium (Al) deposits. Both of these deposits are productive in storing groundwater, particularly unconfined groundwater.

RESULTS AND DISCUSSION

Based on the geological map of Ternate Island (Bronto, S, Hadisantono, and Lockwood, 1982), the rocks in the northern region are classified as Yuong Gamalama Volcano (Gm), resulting in the presence of surface aquifer layers primarily distributed along the coastal areas. The depth to the groundwater table, measured from community wells, ranges from 2.3 to 15 meters. Figure 4 illustrates that the study area is dominated by alluvial deposits (Al). Contour maps of groundwater table depths and groundwater flow direction models were developed from measurements taken from 54 well samples, as presented in Figure 5

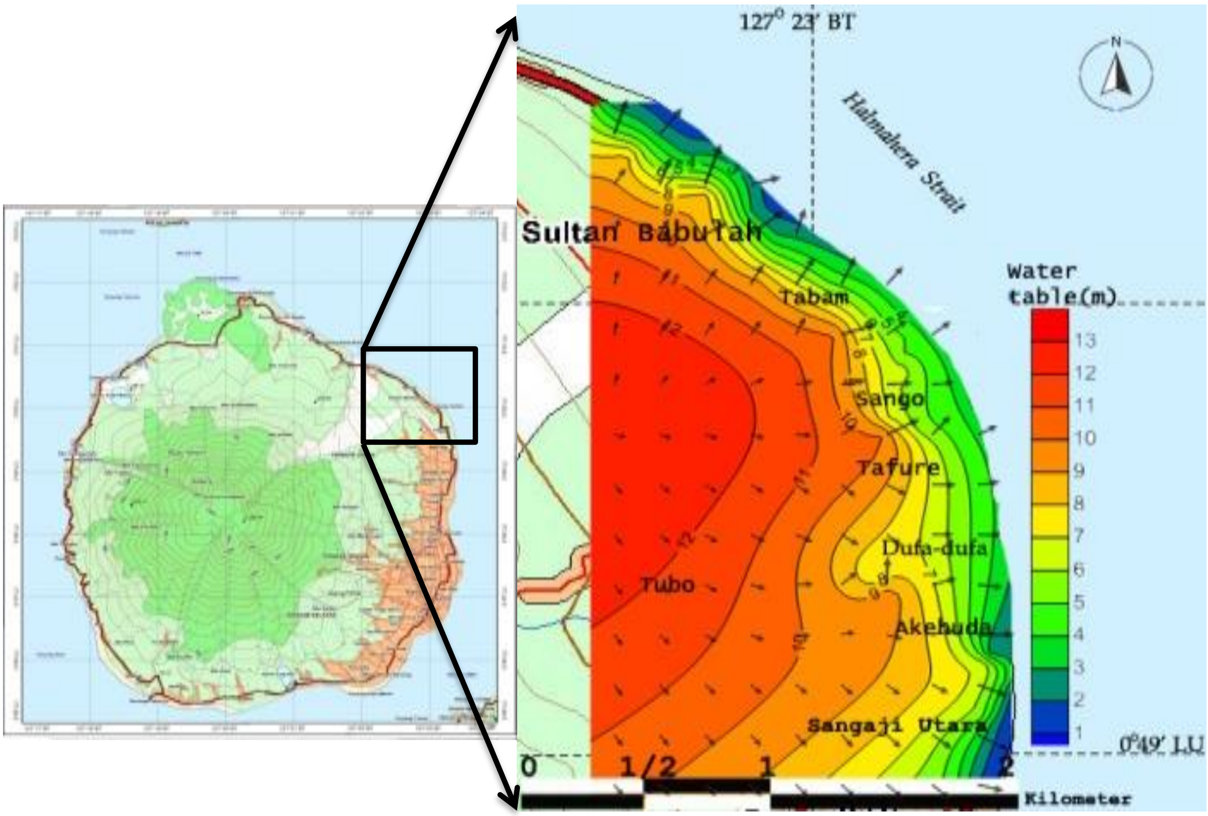
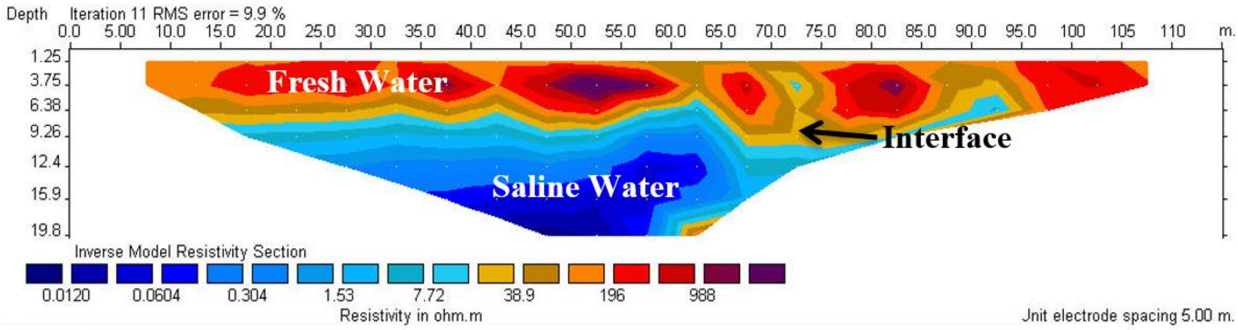
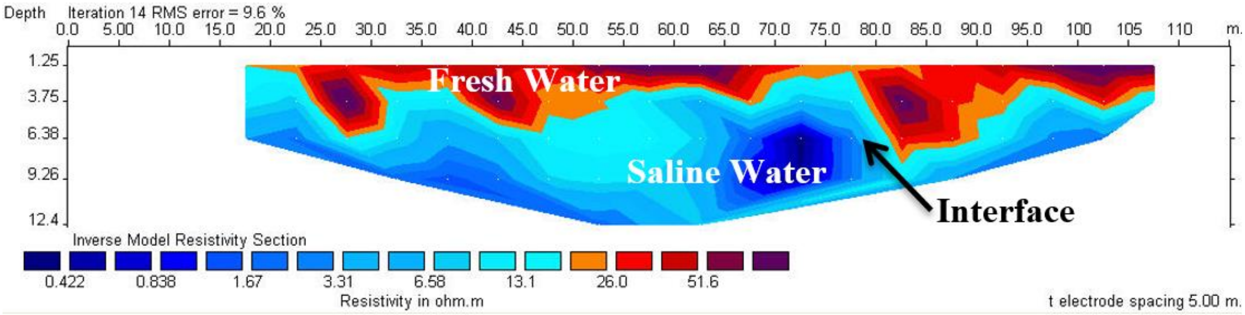


Figure 5. Watertable contours and its flow model

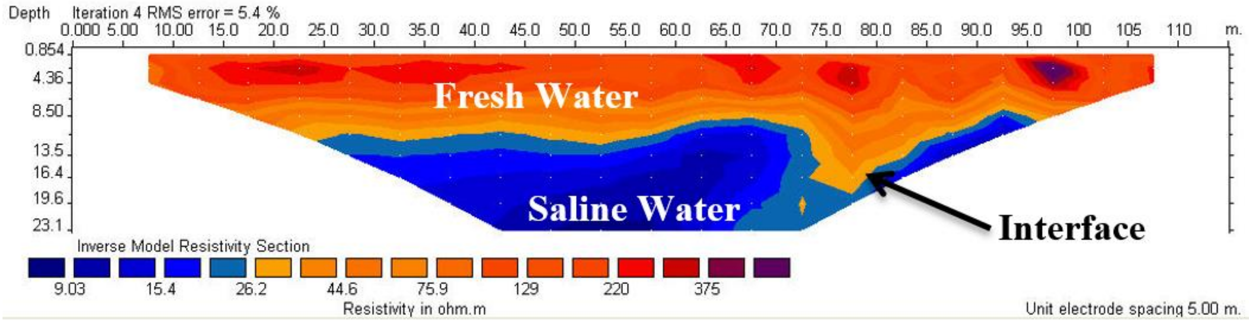
The above Figure 5, illustrates the groundwater flow direction within the study area, following the principles of groundwater flow in small volcanic islands. The groundwater eventually flows towards the coastal regions of the island. The elevation of the groundwater table also conforms to the island's morphology, becoming shallower as one approaches the coastline. To determine the depth of the interface, a 2D multi-electrode geoelectric measurement was conducted between residential areas and the coastline. The results of the 2D geoelectric measurements can provide information about the depth of the saltwater-freshwater contact boundary (interface zone).



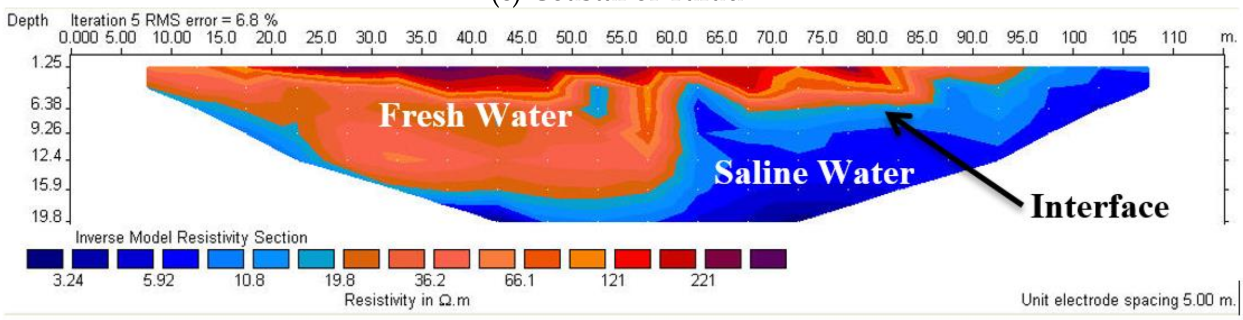
(a) Coastal of Dufa-dufa



(b) Coastal of Sango



(c) Coastal of Tarau



(d) Coastal of Tabam

Figure 6. 2-D geoelectrical resistivity images with interpretation from coastal area

The average depth from the 2D geoelectric measurements ranges between 13 to 23 meters, with an electrode spacing of 5 meters. The determination of the depth of the interface zone serves as a reference for analyzing groundwater pump extraction limitations from well sources. The results of the 2D geoelectric measurements at four locations within the study area are presented in the figure 6.

The depth of the interface zone varies at each measurement location. When averaged, it is estimated that the depth of the interface zone ranges between 6 to 13 meters from the ground surface. The average well positions are located at elevations ranging from 15 to 45 meters above sea level. By applying equation (2), it can be estimated that the depth of the interface (Z) ranges from 80 to 100 meters below the well's base.

The average well pumps used by residents have a suction capacity of 29 liters per minute or 0.483 liters per second. Typically, the suction pipe is inserted between 1 to 1.5 meters from the groundwater surface (d). From equation (1), by taking the values of Z = 80 meters and d = 79 meters, the pump discharge limit (Q) should not exceed 14.729 liters per second. This discharge rate will be exceeded if there are more than 31 pumps in a single well. Based on observations in residential areas, the most common pipe size used is ½ inch (22 mm) PVC pipe, and the maximum number of pumps found in a single well is usually 12 to 15 pumps. With the calculations above, it can be considered safe from the threat of saltwater intrusion.

Figure 7. Number of pumps that are still allowed

CONCLUSION

The distribution of aquifers in the coastal areas of a small volcanic island is highly productive in groundwater storage. This is substantiated through 2D geoelectric measurements conducted between the coastline and residential wells. Coastal regions also serve as groundwater discharge areas, attracting numerous settlements. The looming threat is the intrusion of seawater resulting from uncontrolled extraction. This event has occurred previously on Ternate Island The Regional Water Company employed high-capacity pumps to draw groundwater near the freshwater springs, not far from the coastline, leading to saltwater intrusion in the vicinity of the springs. Densely populated coastal communities that install too many water pumps in a single dug well also face the risk of seawater intrusion. When considering the pump capacity used in relation to the distance of the well from the coastline and the number of pumps in the well, the situation remains safe. The calculations indicate that no more than 30 water pumps should be installed in a single dug well, assuming all pumps are activated simultaneously. In reality, not all pumps are always in operation. Each household activates the pump as needed, and some households have water storage. In such a scenario, the threat of saltwater intrusion remains distant, even with multiple pumps in a single dug well.

ACKNOWLEDGEMENTS

This work was supported by research grants and fellowships from PKUPT. The author is grateful to Lab. Of Science Education Faculty of Khairun University for loaning the ARES Resistivitymeter and for assistance in fieldwork are also acknowledged.

REFERENCES

Achmad, R. (2016). *Kajian Hidrogeologi Pulau Ternate* (Doctoral dissertation, Universitas Gadjah Mada).

Achmad, R., Hadi, M. P., & Purnama, S. (2016). Kerentanan Penyusupan Air Laut di Pesisir Utara Pulau Ternate (Vulnerability of Sea Water Intrusion in Northern Coastal of Ternate Island). *Jurnal Manusia* dan *Lingkungan*, *23*(2), 163-168. https://doi.org/10.22146/jml.18787

Alfarrah, N., & Walraevens, K. (2018). Groundwater Overexploitation and Seawater Intrusion in Coastal Areas of Arid and Semi-Arid Regions. *Water*, *10*(2), 143:1-24. https://doi.org/10.3390/w10020143

Apandi, T., & Sudana, D. (1980). *Peta Maluku Utara, Geologi Lembar Ternate, (1980).* Bandung: Pusat Penelitian dan Pengembangan Geologi.

Aryuni, V., Salam, R., & Achmad, R. (2020). *Coastal Groundwater Quality Identification of Ternate City*. *Ictl 2018*, 25–29. https://doi.org/10.5220/0008896800250029

Bouchet, L., Thoms, M. C., & Parsons, M. (2019). Groundwater as a Social-Ecological System: A Framework for Managing Groundwater in Pacific Small Island Developing States. *Groundwater for Sustainable Development*, *8*, 579-589. https://doi.org/10.1016/j.gsd.2019.02.008

Bronto, S, Hadisantono, & Lockwood, J. (1982). *Peta Geologi Gunungapi Gamalama, Ternate Maluku Utara*. Bandung: Direktorat Volkanikologi.

Cashman, A., & Nagdee, M. R. (2017). Impacts of Climate Change on Settlements and Infrastructure in The Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS). *Science Review*, *2017*, 155-173.

De Graaf, I. E., Gleeson, T., Van Beek, L. P. H., Sutanudjaja, E. H., & Bierkens, M. F. (2019). Environmental Flow Limits to Global Groundwater Pumping. *Nature*, *574*(7776), 90-94. https://doi.org/10.1038/s41586-019-1594-4

Esteban, M., Takagi, H., Jamero, L., Chadwick, C., Avelino, J. E., Mikami, T., ... & Shibayama, T. (2020). Adaptation to Sea Level Rise: Learning from Present Examples of Land Subsidence. *Ocean & Coastal Management*, *189*, 104852. https://doi.org/10.1016/j.ocecoaman.2019.104852

Fetter, C. (2004). *Applied Hydrogeology, 4 edition.* New York: Mac Millan Publishing.

Hadi, M. P., Salam, R., & Achmad, R. (2019). Groundwater Resources Mapping for Small Island using Geoelectrical Technique. *The Indonesian Journal of Geography*, *51*(1), 49-53. https://doi.org/10.22146/ijg.41242

Hughes, J., Petheram, C., Taylor, A., Raiber, M., Davies, P., & Levick, S. (2022). Water Balance of a Small Island Experiencing Climate Change. *Water*, *14*(11), 1771.1-26 https://doi.org/10.3390/w14111771

Hussain, M. S., Abd-Elhamid, H. F., Javadi, A. A., & Sherif, M. M. (2019). Management of Seawater Intrusion in Coastal Aquifers: A Review. *Water*, *11*(12), 2467.1–20. https://doi.org/10.3390/w11122467

Mulyono, P. F., & Putro, H. (2019). Analisis Ketahanan Air di Kota Ternate Provinsi Maluku Utara. *Jurnal Teknik Pengairan*, *10*(2), 120-125. https://doi.org/10.21776/ub.pengairan.2019.010.02.05

Nagu, N., Lessy, M. R., & Achmad, R. (2018). Adaptation Strategy of Climate Change Impact on Water Resources in Small Island Coastal Areas: Case Study on Ternate Island-North Maluku. *KnE Social Sciences*, 424-441. https://doi.org/10.18502/kss.v3i5.2347

Parnadi, W. W., & Salam, R. (2022). Identifikasi Akuifer Air Tanah di Kaki Gunung Api Gamalama Pulau Ternate Menggunakan Data Geolistrik Tahanan Jenis 2-Dimensi. *JFT: Jurnal Fisika dan Terapannya*, *9*(2), 65-78. https://doi.org/10.24252/jft.v9i2.33725

Piscopo, V., Lotti, F., Formica, F., Lana, L., & Pianese, L. (2020). Groundwater Flow in The Ischia Volcanic Island (Italy) and its Implications for Thermal Water Abstraction. *Hydrogeology Journal*, *28*(2), 579-601. https://doi.org/10.1007/s10040-019-02070-4

Salam, R., Nagu, N., Lessy, M. R., & Achmad, R. (2018). Gambaran Resistivitas Batuan Bawah Permukaan Daerah Intursi Air Laut (Studi Kasus Pulau Ternate). *Geosains Kutai Basin*, *1*(1). https://doi.org/10.30872/geofisunmul.v1i1.165

Sherif, M. M., & Singh, V. P. (2002). Effect of Groundwater Pumping on Seawater Intrusion in Coastal Aquifers. *Journal of Agricultural and Marine Sciences [JAMS]*, *7*(2), 61-67. https://doi.org/10.24200/jams.vol7iss2pp61-67

Stein, S., Sola, F., Yechieli, Y., Shalev, E., Sivan, O., Kasher, R., & Vallejos, A. (2020). The Effects of Long-Term Saline Groundwater Pumping for Desalination on The Fresh–Saline Water Interface: Field Observations And Numerical Modeling. *Science of The Total Environment*, *732*,139249. https://doi.org/10.1016/j.scitotenv.2020.139249

Todd, D. K., & Mays, L. W. (2004). *Groundwater Hydrology*. John Wiley & Sons.

Xu, X., Xiong, G., Chen, G., Fu, T., Yu, H., Wu, J., ... & Shi, X. (2021). Characteristics of Coastal Aquifer Contamination by Seawater Intrusion and Anthropogenic Activities in The Coastal Areas of The Bohai Sea, Eastern China. *Journal of Asian Earth Sciences*, *217*, 104830. https://doi.org/10.1016/j.jseaes.2021.104830

Zhou, Y., Sawyer, A. H., David, C. H., & Famiglietti, J. S. (2019). Fresh Submarine Groundwater Discharge to The Near-Global Coast. *Geophysical Research Letters*, *46*(11), 5855-5863. https://doi.org/10.1029/2019GL082749