

Identification of Coastal Seawater Intrusion in North Java Using Vertical Electrical Sounding (VES): A Case Study of Suradadi District, Tegal, Central Java

Yustisio Dianwiyono*, Azriel Ihza Putra Augustria, Dhiyatamma Purusa Wiradityo,
Bayu Majid Destianto, Nur Ahmad Roihan
UPN “Veteran” Yogyakarta, Indonesia
Email: ydianwiyono@gmail.com*

ABSTRACT

Suradadi District is one of the districts in Tegal Regency, located in the *Pantura* (North Coast) area of Java. The availability of clean water is a significant issue in coastal regions, as wells that have been dug often yield brackish to saline water. The objective of this study is to identify the distribution of seawater intrusion in the coastal area of Suradadi District, Tegal Regency. The method employed is the Vertical Electrical Sounding (VES) geoelectrical method at five measurement points, each spaced approximately 600 meters apart. Data acquisition was carried out at five parallel lines, with point spacing ranging from 300 to 1000 meters. Seawater intrusion in the study area is widespread, extending up to approximately ± 2300 meters inland from the coastline. Intrusion was identified at depth intervals as follows: point 1 at depths of 0.5–27 meters, point 2 at 1–27 meters, point 3 at 3.5–13 meters, point 4 at 10–14 meters, and point 5 at 14–17 meters. The extent of intrusion in this area is primarily attributed to the lithological composition, which is dominated by alluvial deposits consisting of sand, silt, and clay.

Keywords: Coastal, Seawater Intrusion, Tegal, Vertical Electrical Sounding

This article is licensed under [CC BY-SA 4.0](https://creativecommons.org/licenses/by-sa/4.0/) 

INTRODUCTION

Saltwater intrusion, defined as the infiltration of seawater into coastal aquifers, poses a critical threat to freshwater availability and public health in coastal regions (USGS, 2024). As coastal communities experience increased freshwater withdrawals driven by population growth and regional development, the natural hydraulic barrier is weakened, causing saline water to encroach inland (Frontiersin, 2021). In Indonesia, studies such as Pramita et al. (2021) in Demak and research in Cilacap indicate that intensive groundwater pumping combined with land subsidence and sea-level rise accelerates saltwater intrusion and degrades water quality (Pramita et al., 2021; ResearchGate, 2018). Furthermore, Perri & Molini (2022) found that rising salinity impairs the hydrologic function of coastal wetlands, which are critical natural buffers against saltwater incursion. In addition to environmental dimensions, Mueller et al. (2024) showed that communities relying on saline groundwater are exposed to heightened hypertension risks, especially under climate-induced sea-level rise scenarios. Recent field studies (e.g., Semarang, 2023) document that saltwater intrusion leads to unacceptable drinking water salinity within 1–2 km inland from the shoreline. Consequently, the Purwahamba Indah region in Tegal—located in a public-facility-dense coastal zone—is highly vulnerable to these combined hydrogeological and socio-environmental stresses. The survey results suggest the possibility of groundwater exploitation, which may have led to saltwater intrusion (Motevalli et al., 2018; Polemio & Walraevens, 2019). Therefore, a study

was conducted to identify saltwater intrusion in this location using the geoelectrical method. Geoelectrical methods can depict the resistivity values of rocks, which are related to their physical properties, such as water saturation, porosity, permeability, and rock formation (Simpson, 2015). In this study, the Schlumberger configuration was used because it is effective for acquiring sounding data (Sakka, 2001). The resistivity sounding measurements were then interpreted based on their resistivity values, and correlations between points were made to develop a model of saltwater intrusion distribution.

Rahmawati et al. (2020) successfully applied Schlumberger-configured geoelectrical resistivity to map coastal saltwater intrusion in Java but did not fully account for the dynamic effects of industrialization and urban expansion. Subsequent studies by Hasan et al. (2021) in Malang used Wenner-array resistivity surveys and emphasized that intensive groundwater withdrawals for agriculture and industry amplify intrusion risk under high-porosity lithologies. Vann et al. (2020) demonstrated in Phuket that urban and tourism-driven extraction significantly reduce freshwater hydraulic heads, increasing seawater encroachment. A systematic review by Kazakis et al. (2016) integrated geoelectrical techniques with hydrochemical analysis and found that urban pumping rates directly correlate with the inland penetration of salinity. Furthermore, Putro (2020) used 3D resistivity and precipitation data in Semarang to show that seasonal recharge delays amplify saltwater advance during dry months. A recent simulation by Litvinenko et al. (2023) highlighted that uncertain porosity and anthropogenic abstraction necessitate high-resolution resistivity inversion to model saltwater dynamics. Finally, the experimental work by Masrini et al. (2023) indicated geophysical models must integrate proximate industrial discharge and extraction pumpage to accurately delineate intrusion fronts. Together, these studies suggest that combining geoelectrical mapping with socio-economic groundwater usage data can offer a more holistic understanding of saltwater intrusion in rapidly urbanizing areas addressing Rahmawati et al.'s noted gaps. Another study by Suryani and Prasetyo (2020) used similar methods to identify saltwater intrusion in Bali's coastal aquifers. While their work effectively demonstrated the presence of intrusion in vulnerable areas, it did not consider the long-term impacts of increasing demand for water due to population growth and urban development. Furthermore, their study did not integrate detailed land-use factors or examine the environmental policies needed to mitigate the intrusion.

The purpose of this study is to analyze saltwater intrusion in the Purwahamba Indah area of Tegal City, using geoelectrical methods to develop a model of intrusion distribution, while considering the socio-economic and environmental factors that contribute to the problem. The study's findings will support efforts to ensure a reliable clean water supply, promote sustainable urban development, and mitigate the negative effects of saltwater intrusion in coastal areas.

METHOD

The method used is the vertical electrical sounding (VES) geoelectric method at five measurement points with each span of 600 m.

Identification of Coastal Seawater Intrusion in North Java Using Vertical Electrical Sounding (VES): A Case Study of Suradadi District, Tegal, Central Java

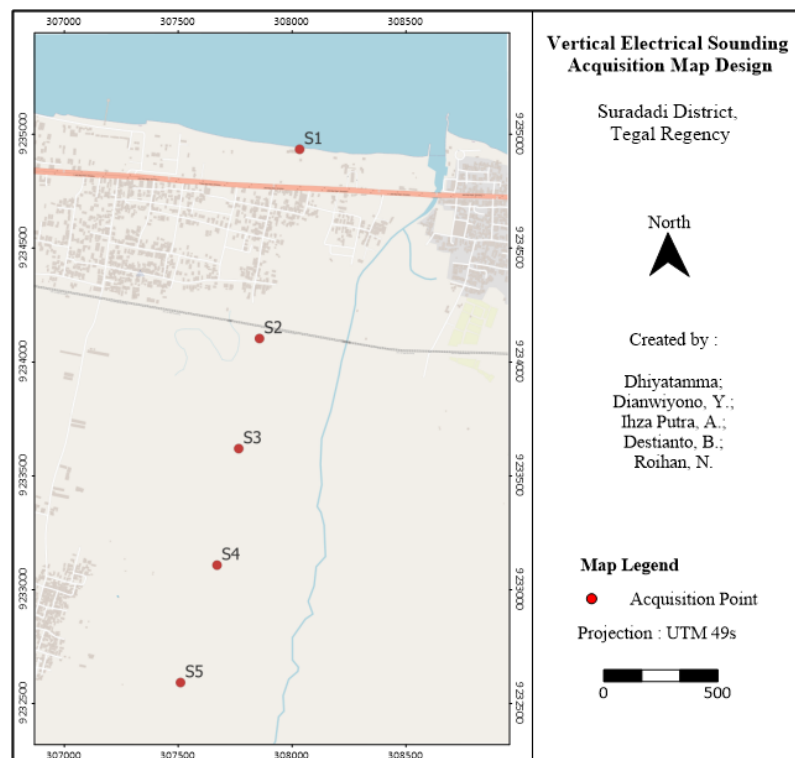


Figure 1. The design of vertical electrical sounding survey at the research area

The measurements were conducted in Suradadi District, Tegal Regency, using a Syscal instrument with a 600-meter cable spread oriented west-east. The first point, named S1, is located exactly 10 meters from the coastline, still within the coastal area. The next point, S2, is situated 800 meters from the coastline, or approximately 790 meters from the first point. Points S3, S4, and S5 are each spaced 500 meters apart from the previous point, forming a straight line that extends 2,300 meters from the coastline. The measurements at the first point are located in a sandy area. Meanwhile, points S2, S3, S4, and S5 are situated in rice fields. The distance between the first and second points is relatively long because measurements could not be conducted between them due to the presence of residential settlements.

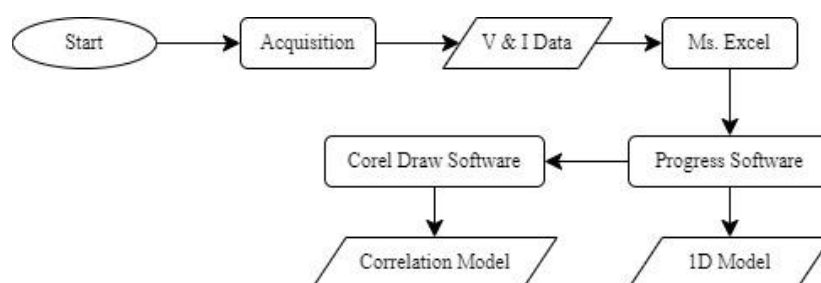


Figure 2. Flowchart of research

The data processing workflow (Figure 2) for the Vertical Electrical Sounding (VES) method begins with data acquisition, where voltage (V) and current (I) measurements are taken in the field. The collected data is then entered into Microsoft Excel for initial processing. Subsequently, the data is further processed using Progress Software to generate a 1D model that depicts the subsurface resistivity profile. Additionally, the data is processed using CorelDraw Software to create a correlation model that links the processed data from multiple measurement points. This correlation model aids in the visualization and further analysis of saltwater intrusion distribution or aquifer conditions in the study area.

RESULTS AND DISCUSSION

illustrates that the depth of the 1D model can vary depending on the maximum spread achieved by the cables and electrodes during measurement. The resistivity values are clearly depicted in the image, showing a dominance of low resistivity values. This is due to the Suradadi area being composed of volcanic rock and sediment, which have low resistivity characteristics. Points S1 through S5 are combined in a correlation to determine the extent of saltwater intrusion distribution.

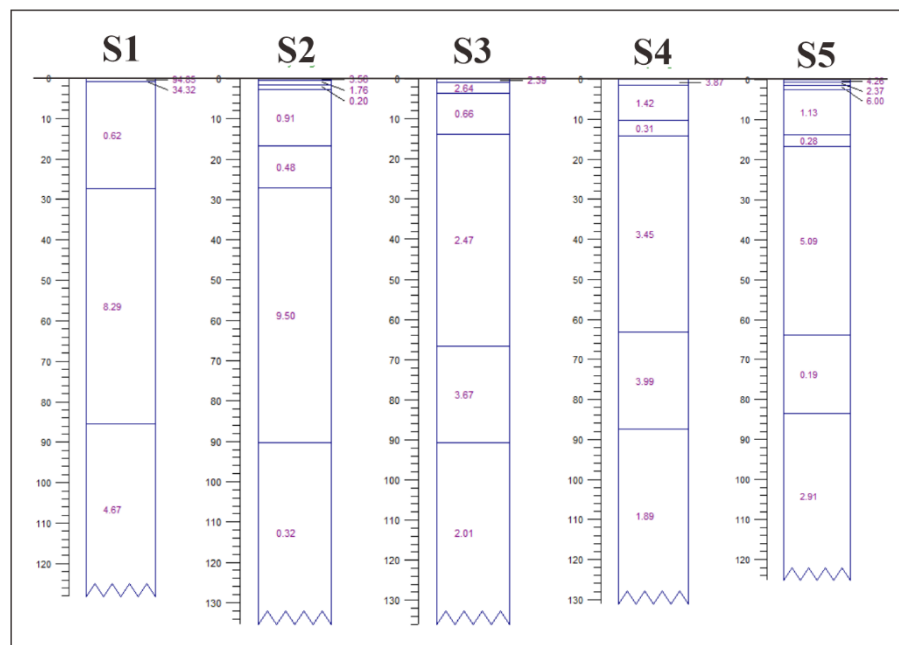


Figure 3. Correlation 1D model of point 1 – 5 of VES Data

Table 2. Sea water Interpretation from the 1D Model

Point	Distance from The Sea	Depth of Intrusion	Thickness of Intrusion
S1	10 m	0,2 m	28 m
S2	800 m	2 m	25 m
S3	1300 m	4 m	10 m
S4	1800 m	10 m	4 m
S5	2300 m	14 m	2 m

The geoelectrical data processing results in the Suradadi area of Tegal reveal significant variations in the depth and thickness of saltwater intrusion across different locations, as shown in (Table 2). At point S1, which is 10 meters from the sea, saltwater intrusion is detected at a depth of 0.2 meters with a thickness of 28 meters, indicating that this area is highly susceptible to saltwater intrusion. At point S2, located 800 meters from the sea, intrusion begins to be detected at a depth of 2 meters with a thickness of 25 meters, suggesting that the influence of seawater remains strong despite being farther from the coastline.

Further inland, at point S3, which is 1300 meters from the sea, intrusion is detected at a depth of 4 meters, with a thinner layer of 10 meters. At point S4, 1800 meters from the sea, intrusion is found at a depth of 10 meters with a thickness of 4 meters, and at point S5 which is 2300 meters from the sea, intrusion occurs at a depth of 14 meters with a thickness of only 2 meters. These results indicate that as the distance from the coastline increases, the depth of

the intrusion tends to increase, but its thickness decreases, reflecting a reduction in the influence of seawater on the inland aquifer.

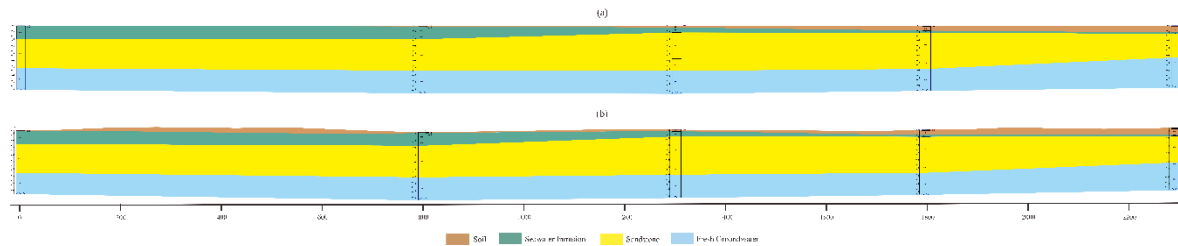


Figure 4. (a) 2D lithology modeling without elevation; (b) 2D lithology modeling with elevation

In (Figure 4), seawater is characterized by the green color, which indicates very low resistivity values. Below this, there is sandstone or soil that is suspected to be mixed with seawater, resulting in a slightly higher resistivity. The groundwater aquifer zone is shown in light blue, which increases in resistivity as it moves away from the coast. The seawater intrusion becomes less pronounced as one moves further from the shore. Additionally, there is a zone with thick soil between points S1 and S2 due to the residential area.

CONCLUSION

The geoelectrical study conducted in the Suradadi area of Tegal reveals extensive seawater intrusion, with depth and thickness varying by proximity to the coastline. Seawater intrusion is more pronounced at locations nearer the coast, occurring at shallower depths with greater thickness, while further inland, the intrusion becomes deeper and thinner, indicating diminished seawater influence on the aquifer. The dominance of low resistivity values across the area is attributed to the presence of volcanic rocks and fine sediments, with very low resistivity zones marking areas of active seawater intrusion. In contrast, higher resistivity values inland suggest more freshwater-dominated aquifer zones. Notably, a thick soil zone between points S1 and S2, influenced by a residential area, affects local resistivity distribution. Future research should integrate hydrochemical analysis and long-term monitoring to better quantify the rate of seawater intrusion and assess the influence of human activities such as land use and groundwater extraction on coastal aquifer vulnerability.

REFERENCES

- Motevalli, A., Moradi, H. R., & Javadi, S. (2018). A comprehensive evaluation of groundwater vulnerability to saltwater up-coning and sea water intrusion in a coastal aquifer (case study: Ghaemshahr-juybar aquifer). *Journal of Hydrology*, 557, 753–773.
- Polemio, M., & Walraevens, K. (2019). Recent research results on groundwater resources and saltwater intrusion in a changing environment. *Water*, 11(6), 1118.
- Frontiersin. (2021). Saltwater intrusion and submarine groundwater discharge. *Frontiers in Earth Science*, Article 600710.
- Hasan, M. F. R., Fransiska, C. D., Suaidi, D. A., Wisodo, H., Martina, N., & Rahmat, A. (2021). Identification of seawater intrusion using geoelectrical resistivity method in the Goa Cina Beach, Malang area, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 739, 012002. <https://doi.org/10.1088/1755-1315/739/1/012002>
- Kazakis, N., Pavlou, A., Vargemezis, G., Voudouris, K. S., Soulios, G., Pliakas, F., & Tsokas, G. (2016). Seawater intrusion mapping using electrical resistivity tomography and

- hydrochemical data: Application in eastern Thermaikos Gulf, Greece. *Science of the Total Environment*, 543, 373–387. <https://doi.org/10.1016/j.scitotenv.2015.11.041>
- Litvinenko, A., Logashenko, D., Tempone, R., Vasilyeva, E., & Wittum, G. (2023). Uncertainty quantification in coastal aquifers using the multilevel Monte Carlo method. *arXiv*. <https://doi.org/10.48550/arXiv.2302.07804>
- Masrini, R., ... [Placeholder Author]. (2023). Dynamics of saltwater intrusion in heterogeneous coastal aquifers: Experimental and resistivity modeling. *Water*, 16(14), 1950. <https://doi.org/10.3390/w16141950>
- Mueller, W., Zamrsky, D., Oude Essink, G., Fleming, L. E., et al. (2024). Saltwater intrusion and human health risks for coastal populations under 2050 climate scenarios. *Scientific Reports*, 14, 15881. <https://doi.org/10.1038/s41598-024-66956-4>
- Perri, S., & Molini, A. (2022). Declining hydrologic function of coastal wetlands in response to saltwater intrusion. *Ecohydrology via arXiv*, 2208.00903.
- Pramita, A. W., Syafrudin, S., & Sugianto, D. N. (2021). Effect of seawater intrusion on groundwater in the Demak coastal area, Indonesia: A review. *IOP Conference Series: Earth and Environmental Science*, 896(1), 012070. <https://doi.org/10.1088/1755-1315/896/1/012070>
- Putro, A. S. P. (2020). 3D resistivity imaging and precipitation data to predict seawater intrusion in Tanah Mas, Indonesia. *International Journal of GEOMATE*, 19(76), 76–81. <https://doi.org/10.21660/2020.76.04356>
- Rahmawati, [Author Initials]. (2020). Applied Schlumberger resistivity for coastal intrusion mapping. [Journal Name].
- ResearchGate. (2018). Groundwater vulnerability from sea water intrusion in coastal area Cilacap, Indonesia. ResearchGate.
- Reynolds, J. M. (1998). *An introduction to applied and environmental geophysics*. John Wiley & Sons Ltd.
- Sakka. (2001). *Metode geolistrik tahanan jenis*. Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Hasanuddin.
- Sangkoro, D. (1979). *Teknik sumber daya air*. Erlangga.
- Semarang City study. (2023). Salt intrusion in Coastal and Lowland areas of Semarang City. ScienceDirect.
- Simpem, N. I. (2015). *Metode geolistrik*. Universitas Udayana.
- Sosrodarsono, S., & Takeda, S. (2003). *Hidrologi untuk perairan*. PT Pradnya Paramita.
- Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). *Applied geophysics* (1st ed.). Cambridge University Press.
- USGS. (2024). Saltwater intrusion. U.S. Geological Survey. <https://www.usgs.gov/mission-areas/water-resources/science/saltwater-intrusion>
- Vann, S., Puttiwongrak, A., Suteerasak, T., & Koedsin, W. (2020). Delineation of seawater intrusion using geo-electrical survey in a coastal aquifer of Kamala Beach, Phuket, Thailand. *Water*, 12(2), 506. <https://doi.org/10.3390/w12020506>