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Analysis of Shallow Groundwater Quality as an Indicator of Seawater Intrusion in the Northern Coast of Java

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Abstract

This study investigates the quality of shallow groundwater as an indicator of seawater intrusion in Yosorejo Village, Batang Regency, located on the northern coast of Java. This study evaluates physicochemical parameters for Total Dissolved Solids (TDS), Electrical Conductivity (EC), and pH, incorporating geological factors to investigate preliminary indicators of saline intrusion. Groundwater sampling and analysis took place in September-October 2023 using seven domestic wells distributed at various distances from the coastline (0-4 km) and topographic elevations (0-10 meters above sea level). GIS mapping of TDS and Electrical Conductivity revealed peaks for TDS with a maximum reading of 1400 ppm and Electrical Conductivity with a maximum reading of 1970 µS/cm, indicating that saline intrusion is well under way. It also confirmed increasing tendencies towards decreasing elevations nearshore. Groundwater pH varies between 7 to 8.4, within tolerable standards but slightly basic inland along hydrolysis and lithological reactions. Geologically, this site is primarily covered by very porous layers of alluvial deposit silt sand, representing aquifers amenable to saline waters. This work presents its originality by doing integrated spatial hydrogeological analyses to identify saline intrusion affected areas within 0-500 meters onshore. This work contributes to the development of environmental physics and hydrogeological research by confirming empirically for the imbalanced interface between seawater and groundwaters on tropical low-lying areas, pressing for alleviating strategies to secure groundwaters' sustainability.

Keywords: Coastal Sediment; Groundwater Quality; Seawater Intrussion

Cite This Article

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INTRODUCTION

Groundwater is a very important natural resource that plays a crucial role in our day to day needs. Factors such as sustainability, availability, and simplicity in management characterize groundwater as very important to various sectors [1,2]. Groundwater usage is also determined by climatic factors or human practices in terms of various habits and patterns entailing our day to day usage of this important substance [3,4]. Moreover, availability is also dependent on factors including vegetation, topography, porosity, intensity of rainfall, and permeability of rock formations in our environment [5,6].

Natural environment factors, whether geographical or geological, are also important elements in determining the availability of groundwater resources. Especially on the northern part of Java, where it directly faces the sea, this region is most exposed to seawater intrusion causing remarkable variation in terms of groundwater quality [7-9]. Geological factors also contribute to groundwater availability, especially for areas near the shores where intrusion can occur frequently [10-12]. In general, for the complicated geological structure on the northern part of Java, geological formations are composed of various layers of sediments and are stated to contribute to underground flow resulting in fresh to brackish or saltwater environments using infiltration processes on the shores [13].

Groundwater usage variation is established on both the volume and quality of groundwater [14]. This is threatened by human induced over extraction, pollution, and disruptions to the balance between groundwater and saltwater interfaces [15,16]. The determination of degraded quality in groundwaters near coastal areas, specifically those with degradation from saltwater interfaces, can be established using TDS, conductivity, and pH measurements [17]. Groundwater usage can therefore be classified according to its variation on physical properties established on geological investigations.

Cases of change in groundwater quality in Java's northern coastal areas are directly observed by local residents, showing that they can taste salt in traditional sources of fresh groundwater. It is important to identify areas where the intrusion of seawater into groundwater has occurred to ensure sustainability in accessing groundwater. To this end, research must determine variables showing signs of intrusion into low lying areas around the coastline on the basis of geological assessments to identify susceptibility to intrusion.

METHODS

The study was carried out in Yosorejo Village, Gringsing District, Batang Regency, Central Java, which is on Java's Northern Coast. Groundwater physical parameters, including TDS, electrical conductivity, and pH, were measured during field observations conducted in September and October of 2023. Additionally, geographic data was recorded, including sample coordinates, local elevation, and distance from the shoreline. While the identified groundwater quality was further discussed in relation to local geological features, the TDS, electrical conductivity, and pH data were spatially analyzed based on their distance from the coastline.

Research Design

This study applies a quantitative descriptive design to analyze groundwater salinity using in-situ measurements of TDS, EC, and pH from domestic wells in Yosorejo Village, Batang, Central Java. Data collection was conducted during the dry to wet transition period with stable climatic conditions (no rainfall for ±7 days). Geological interpretation is integrated through literature review and geomorphological analysis.

Research Target/Subject

The research targets groundwater from household wells located in Yosorejo Village, Batang Regency, a low elevation alluvial plain on the northern coast of Java. The area was selected due to indications of increasing groundwater salinity. The indications of sea water intrusion imaged by TDS, EC, and pH value. A total of 7 wells were sampled, distributed across various distances from the shoreline range 0 – 4 km and different local topographic positions range form 0 – 10 mdpl.

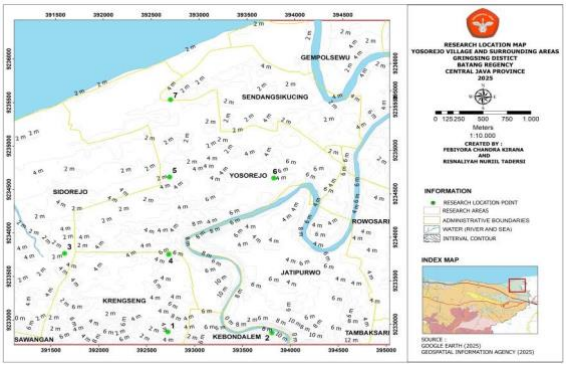

Figure 1. Sampling Locations in Yosorejo Village

Research Procedure

Preliminary study of geological maps and geomorphological conditions; site selection and determination of sampling points, in-situ measurement of TDS, EC, pH, and recording well depth, coordinates, and elevation, documentation of local landform characteristics, compilation of geological information from published sources, integration of field and geological data for interpretation of saline intrusion mechanisms.

Instruments, and Data Collection Techniques

Groundwater quality was measured using a portable TDS meter, electrical conductivity (EC) meter, and digital pH meter. Sampling followed a purposive method based on well accessibility, distance to coastline, and spatial distribution across the village. All measurements were taken directly in the field (in-situ) after purging stagnant water from the wells. Each point's coordinates, elevation, and well depth were recorded using GPS and field notes.

Data analysis technique

The data were analyzed using descriptive statistics to identify the distribution of TDS, EC, and pH. The results of data analysis are used to identify distribution patterns of TDS, EC, and pH in coastal areas. Spatial analysis was conducted by plotting EC values on coordinate based distribution maps. Geological and geomorphological interpretation was carried out by integrating field observations with literature data on local lithology.

RESULTS AND DISCUSSION

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is a physical parameter that is highly sensitive to changes in hydrogeological conditions, particularly in dynamic coastal environments. TDS can change from fresh to brackish as influenced by certain factors. [18] stated that TDS in lower areas increases with distance from the shore. This TDS gradient exists as a result of pressures between inland groundwaters and saltwater, resulting in saltwater infiltration into coastal aquifers [19]. The TDS increases with distance inland, reflecting reduced hydraulic pressures

or increased abstraction of groundwaters, resulting in a transition boundary between fresh and brackish aquifers moving inland.

Table 1. TDS Examination Results in Yosorejo Village

No	Sample Points	TDS (ppm = 1 mg/L)	EC (µS/cm)	pH
1	Well Point 1	172	262	7,1
2	Well Point 2	384	566	8,4
3	Well Point 3	476	704	7,2
4	Well Point 4	371	548	7,5
5	Well Point 5	413	615	7,3
6	Well Point 6	354	523	7,6
7	Well Point 7	1400	1970	7

The mention of TDS in ppm expression reveals that certain aquifers can either be fresh or brackish (Freeze and Cherry, 1979). Large TDS content refers to ionization or rather ionization of certain ions including Na+, Cl-, SO4 -2, and NO3- ions [20]. Furthermore, TDS contents are directly proportional to the degree or nature of groundwater hardness [21]. Additionally, [22] assert that TDS contents are affected by transport processes within lithological formations.

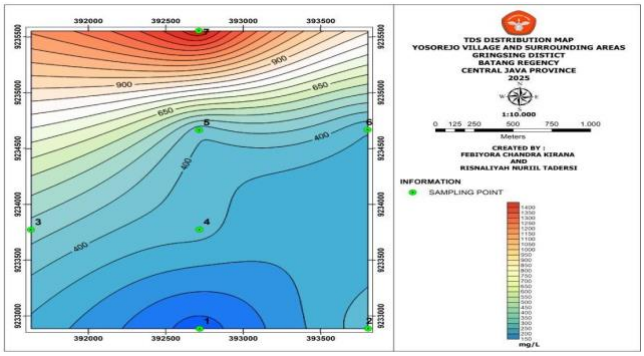

Figure 2. TDS Distribution Map of Yosorejo Village

The distribution pattern of shoreline distance and elevation (Figure 2) matches the result obtained by [18], showing TDS increasing towards the shoreline and also increasing where elevation is lower. The highest TDS, at 1400 ppm, was measured 200 meters inland from the shoreline, while the lowest TDS, at 172 ppm, was measured 4 km inland. This data also indicates a shifting hydraulic gradient [19]. This verifies that the balance between groundwater and saltwater interfaces has also shifted, meaning that seawater intrusion has already occurred in Yosorejo coastal areas [15,16].

Electric Conductivity (EC)

The Electrical Conductivity (EC) measurements within the research site varied between 262 µS/cm and a highest value of 1970 µS/cm, with an average EC of 741 µS/cm in Yosorejo Village (Table 1). With respect to the classification described by [11] it can be identified that the highest conductivity belongs to brackishwater, while the other six data belong to freshwater. Higher EC can act as an index to identify large chloride ion contents in water mixtures between seawater and freshwater within coastal areas [8,23,18].

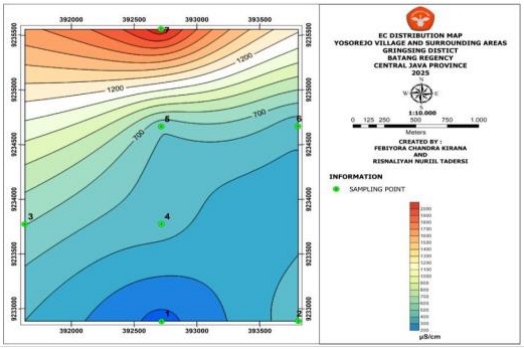

Figure 3. EC Distribution Map of Yosorejo Village

The existence of a mixture of seawater and fresh water, forming brackish water with positive chloride ion content, proves that seawater intrusion has occurred in the coastal region of Yosorejo Village [24]. The highest EC levels are distributed in the coastal areas and low-lying regions, making it unsuitable for drinking purposes [16]. However, for areas with higher topography, they contain EC levels within the range of 200-500 µS/cm, showing that they are not affected by groundwater quality deterioration. Analysis on the spatial mapping of EC (Figures 3) shows that areas where water quality has been strongly affected by intrusion are between 0-500 meters from the coastline. [18] reported that areas impacted by intrusion are typically within 500 meters of the coastline, which is consistent with this observation. In contrast to Pekalongan Regency, where saltwater intrusion extends up to 6.52 km inland from the coastline, Yosorejo Village's coastal area is therefore thought to be relatively low risk of saltwater intrusion [25].

Potential of Hydrogen (pH)

Groundwater pH can also relate to its suitability for general domestic uses. As stated by [26] hydrogen ion presence is related to its acidity, but pH is usually steady in tropical areas [24].

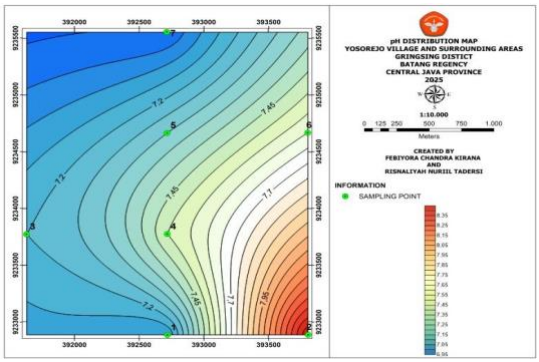

Figure 4. pH Distribution Map of Yosorejo Village

Groundwater characterization in Yosorejo Village demonstrated pH levels between 7 and 8.4, classified within the valid range for drinking purposes (Table 1). The spatial variation in pH levels, flagged according to distance and topographic elevation, reveals a trait to approach neutral pH near the shore but slightly basic at points measured 4 km inland from the shore (Figure 4). These observations are in line with [22], concluding that the pH in Jakarta's coastal aquifers was largely neutral, even though very high chloride ion (Cl-) content was identified to penetrate into the aquifers. The basic pH environment sampled 4 km inland from the shore can be indicated to contain hydrolysis reactions for bicarbonate ions (HCO_3 -) and hydroxide ions (OH-) [22]. Additionally, this indication points to the presence of dissolution processes in the groundwater aquifer [27].

Coastal Lithology of Yosorejo Village

The research area is situated in a coastal environment where there are units of alluvial deposit geological formations (Figure 5). Additionally, based on geological and topographic mapping, it can be concluded that this research area has flat to very gentle topographic features, measuring between 0 to 10 meters above sea level, where areas near the coastline are only about 2-4 meters above sea level, making it very prone to saltwater intrusion from a hydrogeological standpoint.

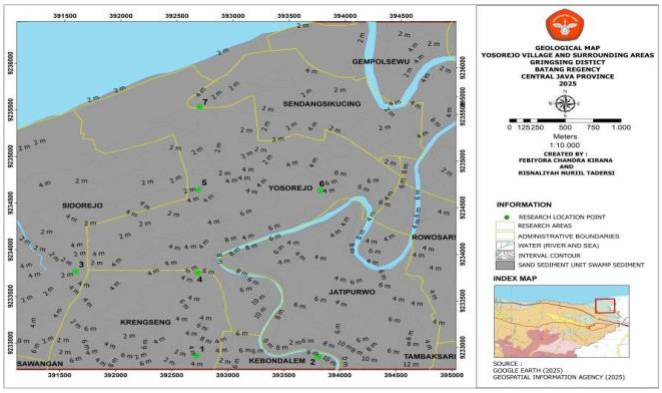

Figure 5. Geological Map of Yosorejo Village

Setyanto et al. (2022) found that the sediments deposited in the Batang coastal area are mostly composed of silt fractions to about ±96.4%, with clays at 3.1% and only 0.5% sands. The study was done on the coastal region at Sigandu Beach, Batang Regency. The silty and fine sand materials are relatively more porous and permeable so that they can function as subsurface fluids, including the flow of saltwater from the sea. Relative to topographic mapping data and well points in the research location, the flat-low topographic features and lithography with large porosity are more predisposed to seawater invasion, especially those areas near the coastline.

CONCLUSIONS

This study can conclude several points, including: 1. The distribution of TDS and EC values shows an increasing pattern towards the coast, especially at low elevations. This indicates the influence of seawater on shallow groundwater quality at several observation points. 2. The geological environment that consists of sandy to silty materials of high porosity, as well as flat- low topography, contributes to the inland migration of seawater. The combination of these factors adds strength to the notion that the shallow aquifer within the studied environment is prone to saltwater invasion, particularly in areas close to the coastline. 3. Mostly, Yosorejo Village, Batang Regency's shallow groundwater exhibits characteristics that make it susceptible to seawater intrusion, necessitating mitigation measures.

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AUTHOR CONTRIBUTIONS

For this research articles contributed by Merisa R. Mawaddah from Environment Engineering focused on the identify the groundwater quality in Yosorejo Village. Risnaliyah Nuriil Tadersi and Febiyora Chandra Kirana from Geology Engineering contributed on identify the lithology of groundwater aquifer in the coastel of Yosorejo Village. Andicho Haryus Wirasapta from Electrical Engineering contributed as editors.

CONFLICT OF INTEREST

The authors declare no conflict of interest. The funding sponsor (RTA Universitas Gadjah Mada) had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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