Effect of seawater intrusion on groundwater in the Demak coastal area Indonesia: a review

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Abstract. One of the most complicated areas to repair on the North Shore of Central Java is the beach in the Sayung Demak. More than 300 hectares of land have been flooding in the last five years due to high tides. The erosion area in Sayung area has also been affected by port development activities in the Semarang area, thus changing the hydrodynamic nature of Sayung Demak Waters. Overuse of groundwater has been showing to lead to brine ingress in the coastal region. And long-term groundwater withdrawal forces land subsidence formation. A few waterfront structures in Sayung waters were built as breakwaters to decrease incoming waves. The solution presently used to minimize erosion while catching sediment in the Sayung area is hybrid engineering. The purpose of this study is to review the effectiveness of hybrid engineering in the coastal area of Demak and its relation to seawater intrusion and groundwater based on previous research. Understanding the factors that influence water quality in the source area over time is needed to establish appropriate management plans for the protection of groundwater resources and to ensure the safety and health of the beverage.

1. Introduction

Indonesia is made up of around 17,500 islands with a total coastline of about 80,000 kilometers. The coasts are the most active locations due to their strategic location and abundance of natural resources [1]. Groundwater level change is influenced by population increase, large-scale water consumption, inter-basin water transfer, and the impact of climate change [2]. Excessive groundwater use has been shown to lead to saltwater intrusion into coastal areas [3]. It is impossible to overstate the importance of groundwater resources as the primary supply of fresh water in many countries all over the world. Addiction brings with it the risk of misuse and contamination, resulting in massive water stress - a condition in which local water supplies are insufficient to meet water demands [4].

Extreme groundwater abstraction is the most incredible cause of soil subsidence [5,6,7,8,9]. The extraction of groundwater causes a shift in fluid pressure in the strata, particularly in sedimentary and clayey materials. Excessive pumping of aquifer systems containing rich clay elements can result in persistent compaction that is difficult to undo after stress, resulting in soil subsidence. The subsoil compacts when a big amount of water is pushed out, reducing the size and number of open pores in the soil that previously held water. This could lead to a permanent decline in the aquifer system's overall
storage capacity. These phenomena are seen worldwide in coastal and urban locations with dense housing, buildings, and industrial sites [10].

In the previous six years, Sayung District has experienced severe erosion. In 2002, 145.50 ha of beach in Demak were degraded, and this figure increases to 758.30 ha in 2005 [11]. Another study revealed 2.24 kilometers of shoreline erosion in 2003, 2.58 kilometers in 2009, and 2.24 kilometers in 2013 [12].

In the Sayung sub-region, hybrid engineering is currently being applied to prevent erosion while capturing silt. During the dynamics of tidal phases, hybrid engineering is used to capture land-borne sediment [13]. The notion of Building with Nature is used in this hybrid engineering. Building with Nature is a method of satisfying society's infrastructure needs based on the natural and social systems for which the infrastructure will be implemented [14]. The purpose of this study is to review the effectiveness of hybrid engineering in the coastal area of Demak and its relation to seawater intrusion and groundwater based on previous research. Understanding the factors that influence water quality in the source area over time is needed to establish appropriate management plans for the protection of groundwater resources and to ensure the safety and health of the beverage.

2. Methodology

Based on [12], the following factors influence the hydrodynamic equilibrium between fresh water and seawater, resulting in seawater intrusion in coastal aquifers: geological factors, tidal activity, climate change and sea-level rise, and human-induced factors.

The investigation of seawater intrusion entails assessing the geographical distribution of subsurface physicochemical parameters such as electrical conductivity, salinity, water quality, total dissolving salts, seawater mixing, and so on [15]. The methods used to accomplish this could be divide into two categories: direct approaches and indirect approaches. The direct techniques involve collecting and analyzing water samples for various physiochemical parameters, whereas the indirect method interprets hydrologic attributes based on aquifer material bulk conductivity, bulk resistivity, and seismic velocities. Two popular direct approaches used in seawater intrusion research are groundwater level measurement and geochemical analysis of groundwater samples. Furthermore, remote sensing and GIS have been used in conjunction with direct or indirect methods to supervise coastal aquifers in several cases [12].

3. Results and discussion

3.1. Sea water intrusion problem

Due to their richness of natural resources and maritime amenities, most coastal areas are economic centers around the world and today support two-thirds of the population. Natural resources in coastal areas, especially groundwater, are typically overexploited due to industrialization and development. The indiscriminate removal of groundwater for various reasons leads to a decline of the level of the barometer, which causes intrusion of sea waters. Around the world, seawater intrusion has been found to decrease groundwater quality and salinity [16,17]. That renders groundwater supplies extremely susceptible, especially in dry and semi-arid regions where groundwater is the main supply of potable drinking water within the coastal areas due to the scarcity of surface water. Salinization also affects agricultural production and restricts crop selection [18,19].

Coastal topography, aquifer lithology, the sea-to-inland hydraulic gradient, and groundwater recharge and withdrawal rate all influence the degree of saltwater intrusion in coastal locations [20]. Change in sea level and aquifer recharge control processes at the freshwater-seawater interface. There are ion-exchange and dissolution/precipitation reactions that occur when interface sites change [21,22]. In limited aquifers, groundwater is usually isolated from seawater by depositions of quartz deposits, often deposited during the latest transgression, because of such isolation, contamination salinization of water in more complex limited aquifer systems [23]. The major economic and environmental repercussions of saltwater intrusion into freshwater aquifers and drainage basins are natural ecosystem degradation and pollution of municipal and industrial water sources, agriculture, and industry [24].
Saltwater infiltration into groundwater and estuaries: Saltwater from the coastlines will begin to flow into the wells with a consistent flow velocity from groundwater wells and after a specific rise in sea levels. Saltwater intrusion affects groundwater salinity, necessitating desalination at treatment plants. Because groundwater supplies over 80% of the water supply in coastal areas [25], saltwater intrusion poses serious problems. The infiltration of salt water into groundwater systems elevates the height of the freshwater–saltwater interface, affecting coastal ecosystems like marshes. The presence of saltwater in the water elevates the chloride concentration, which, if consumed, can result in high blood pressure. Furthermore, higher chloride concentrations may cause pipe corrosion at the drinking water facility. Furthermore, according to [26], seawater intrusion into water treatment facilities could harm the bacteria used in the biological treatment of water.

3.2. Demak coastal permeable dams

Permeable dams are based on the idea of restoring mangrove environment by restoring the net sediment stability. Sediment dynamics restoration is increasingly being recommended as a precondition for ecological restoration [27,28]. By trapping sediment-laden streams in the sedimentation cavity, permeable dams increasing enormous sedimentation rates while lowering wave-induced erosion and reducing wave activity. Dams are only temporary, and following mangrove recovery, they may become outdated. This nature-based adaptive strategy could see as an example of how natural forces are intercorporate within the framework of Nature and Structure [29,30], through collaboration with local populations, to fulfill their socioeconomic requirements.

According to the Indonesian Ministry of Maritime Affairs and Fisheries, quite 80% of mangrove forests in North Java have been impacted, affecting coastal security: nearly 750 km of the 1,690 km of coastline is eroding, and nearly 130 km² of mangrove habitat was probably lost in 2014, affecting quite 30 million people in Java. Even though the majority of coastal erosion happens in rural areas, annual economic losses are estimated to be USD 2.2 billion [31,32]. The losses are due to urbanization, industry, aquaculture pond conversion, and subsidence [34].

In 2013, the first BwN pilot for coastal restoration using permeable dams in Indonesia was taken out in Bogorame, a tiny town near Demak. Demak's coastal erosion is significant, with land losses of up to 100 meters per year due to widespread aquaculture in the once dense mangrove woods, as well as subsidence. This coastal scheme has a diurnal tide with a tidal range of around 0.1 to roughly 1 m, with a modest semi-diurnal element. Wind, rain, and waves obey seasonal trends with the northwest monsoon from November to April, with the wettest months being December through February. During these months, waves of about 5 s with heights off the coast of about 1.5 m destroy the susceptible coast even more. In Demak's waters, this monsoon generates a counterclockwise residual current of 0.1 to 0.2 m/s [34].

The seepage dams must remain in situ for a period dictated by the sedimentation rate and the mangrove regeneration rate. The involvement of local stakeholders in construction, inspection, maintenance, and repair is critical. Horizontal support beams are utilized to stabilize the structure as well as to transmit hydrodynamic loads to it. They are found in the HW, LW, and sometimes the third row of the MSL. As a result, waterproofing dams are constructed to MHW, however, in practice, they are a little lower because the broom wood coating looks to shrink/lower over time [33].

The building cycle outlined below is based on a substantial incident in Demak. The buildings should be built through the monsoon season, which runs from November to March. It is efficient because coastal erosion and sediment redistribution occur during this time. The whole process, including site selection, contractor option, material selection, construction, inspection/monitoring, and maintenance, must be engaging with stakeholders/local communities. The long-term vision specifies the dam's required lifespan. As a result, regular inspection is critical for prompt maintenance [33].

3.3. Groundwater quality

One of the most significant effects of sea-level rise is the intrusion of saltwater into groundwater. As a result, saltwater infiltration might create substantial disruptions to water supply networks. These
occurrences get the potential to have devastating effects on coastal communities, destroying critical infrastructure, disruption of economic activity, and contamination of water by saltwater [35].

Semarang's coastal areas, in general, are under tremendous pressure due to coastal vulnerability. It is showed by the flood induced by high tide, which is currently flooding 7 out of 16 districts and affecting 3,915.16 acres [36]. From 1985 to 2008, one of the increases in intertidal areas owing to sea-level rise was up to 5,536 cm per year, whereas land subsidence in the port region was 5-7.5 cm per year [38]. According to [37], Semarang is the most substantial erosion process.

In Bandarharjo Village, the water supply systems begin with the water supplier, the upper reservoir, and the distribution is then used by the customer. The bulk of the water reserves in Bandarharjo are deep groundwater well. Water was pumped 85 meters underground to the higher reservoir. The water tank maintains adequate pressure to provide water to clients. Waters was delivering to customers via 4-6 inch PVC pipes. The observations revealed that the pipeline distribution was commonly drowning out by rob. This strategy has the potential to improve the government's beverage supply system [38].

3.4. Coastal damage in coastal area

The coastal area may be a key location for a range of activities such as port, recreation, fishing, agriculture, industry, settlement, and so on. However, coastal areas are also prone to change induced by activity within the coastal areas and other activities upstream. Residents are especially vulnerable because they assume natural resources are abundant in the coastal's areas. If the world has degenerated, it will have a significant economic and social impact on them. Tidal floods are based on the effects of rising sea levels and exacerbate by land subsidence. Causes of land subsidence by the density of built-up areas and the extraction of spring water. When PDAM (local water firm) doesn’t work, people can readily use groundwater as an alternative water system. Land subsidence exacerbates by urban development. Seawater rushes to land subsidence, inundating places. During the season, the inundated region worsens [39].

Central Java Province's coastal area runs over kilometers of shoreline, comprising the cities of Kendal, Semarang, Demak, and Jepara, and consists of low mud and sandy beaches less than 5 m high. The plain area is subject to geomorphological processes such as erosion-sedimentation, land subsidence, and tidal flooding [40]. As a consequence of groundwater depletion, land subsidence is common in areas of Central Java Province's coastal region. It is also inducing by the natural consolidation of alluvial soil and construction loads. Diverse points in Semarang's low-lying zone have subsidence rates of moreover 10 cm per year [41].

The fast conversion of mangroves into fish and shrimp ponds is among the most significant challenges to coastal security [42,43]. Such a change across the entire tidal zone has cascade consequences that lead to increase coastal subsidence and erosion. Mangrove forest destruction limits its ability to dampen waves, retain silt, and accumulate organic matter. Furthermore, rivers are separated from the natural floodplain in aquaculture pond systems, depriving the floodplain of new sediment input. Furthermore, sinking raises wave heights by increasing sea depths, making shorelines more prone to erosion. That enhances the erosive force of the waves in muddy coastal areas, which increases with the formation of pond embankments, creating wave reflection [44].

3.5. Climate change

Indonesia's marine continent is one of the locations most susceptible to the impacts of climate change. Temperature differences, precipitation changes, sea-level rise, enhanced hydrometeorological catastrophes, robustness, destruction of infrastructure, enhanced fire risk, damage to ecosystems, health issues, and enhanced discomfort for inhabitants are all factors that have an impact on the economy, whether directly or indirectly [45-48]. In Indonesia, changes in the patterns and intensity of temperature and precipitation indices are becoming the primary indicators of climate change. Climate change can be detected using time series data, which provide long-term information about changes, cycle analysis, or movements around the estimate [49].
Climate change and sea-level rise are the two most major climatic elements influencing seawater intrusion in coastal areas. The primary source of groundwater recharge is atmospheric precipitation; nevertheless, its quantity varies across time and space. Furthermore, inter-annual variability in atmospheric precipitation is significant. During the rainy season, groundwater level rises in proportion to precipitation, but, in the summer, a multiplication of evapotranspiration combined with a drop in precipitation leads to a fall in groundwater level [50].

Climate change has a substantial impact on coastal population settlement and livelihoods all over the world [51,52,53]. Drought losses, environmental degradation, food instability, water-borne infections, and a shortage of energy and sufficient water supplies have all been reported in coastal areas as a result of climate change's consequences. Changes in precipitation patterns and extended droughts have also intensified disasters, with negative consequences for humanity, natural ecosystems, and human well-being [54]. The disruption of saltwater and drought as a result of climate change and rising sea levels has an impact on coastal settlements in terms of social upheaval and local economic collapse [55].

Many studies have identified adaptation as a strategy for mitigating the effects of climate change-induced sea-level rise [56,57,58]. This study [57] investigated how coastal communities in Semarang, Indonesia, responded to the vulnerability of their socioeconomic activity. Natural resource-related economic and social livelihoods, as well as other variables, demonstrated adaptation. Five strategies for adapting to climate change to reduce vulnerability are building artificial boundaries, shielding deltas from saline intrusion using underwater barriers, elevating ground levels, generating dunes and natural beach obstacles, and moving people [59].

Adapting developed infrastructure systems is critical to mitigating the negative effects of sea-level rise on coastal cities. Rising sea levels have a significant impact on water and wastewater systems. Saltwater intrusion into groundwater aquifers is one of the most serious consequences of sea-level rise. As a result, brine penetration can create primary interruptions in water supply systems. In the case of wastewater infrastructure, increasing sea levels can result in sewage backups owing to septic tank failure and transmission pipe failure due to rising water tables. Furthermore, wastewater network pumping stations and water treatment facilities are vulnerable to flooding and storm surges [26].

3.6. Strategic plans
3.6.1. Hybrid engineering. Several different forms of coastal constructions can help to prevent coastal morphodynamics [63]. The fencing structures are built along the coasts to defend the beaches from direct wave attacks. Breakwaters protect the beach from erosion and also have a lower impact on water quality and the environment [64]. Offshore breakwaters are widespread to use as coastal erosion protection by destroying wave energy before it reaches the shore, while a breakwater connecting the beach and the beach serves to protect port waters from wave disturbances so that ships can be moor [61,63].

The essential feature of a breakwater is that waves can pass through it without affecting their profile, and wave diffraction is independent of whether or not the structure is permeable [63,64,65]. Breakwater orientation can be constructed or adjusted to transport sediments in the desired direction, and wave energy can affect sediment transport and coastal alterations [66]. The geometric shape and configuration of the breakwater location, as well as the water depth, height, and period of the wave, influence the efficacy of the construction type in decreasing wave energy. Changes in coastline and sediments gathered behind the relevant breakwater construction are determined by the length of the breakwater and its distance from the shore [67].

Wave Breaker in Bedono Waters (in Demak Coastal) experiences overtopping in each season, this will affect the ability of buildings to reduce incoming waves [68]. While, waves that existed across the breakwater in the Sayung Waters did not encounter overtopping waves through the East, Transition I and Transition II, overtopping did occur during the season, where the building elevation is 2.5 m (1.8 m from MSL) and run-up height between 0.6 and 1.8, measured from the water depth at the foot of the building based on 1.24 m HHWL. As a result, because the waves do not pass through it, the system is incredibly effective as a breakwater [69].
3.6.2. **Mangrove ecosystems.** The presence of the breakwater caused silt to be deposited on the beach, and the substrate's elevation was raised to a level ideal for mangrove establishment. On the exposed coast, the tranquil region protected by the breakwater was also ideal for restoration work. The method created favorable conditions for coastal rehabilitation, allowing the coastal ecology to recover naturally [70].

When these valuable mangrove forests were removed for development, erosion became an issue. As a result, restoring mangrove forests is the most acceptable and long-term solution to the coastal erosion of most tropical coasts inhabited by mangroves all around the world. To avoid further degradation of coastal habitats, it is also necessary to put limits on coastal development. To safeguard the coastal environment and deteriorated mangrove forests, detached breakwaters can be created offshore instead of dikes on the beaches [71].

The mangrove ecosystem's purpose is to reduce the risk of vulnerability in coastal areas. Mangroves are, in fact, the most common habitat along tropical coasts around the world. The mangrove habitat provides numerous benefits. Mangroves, for example, can absorb the energy of large waves that have formed on the high seas, particularly during tropical storms. Furthermore, over time, mangroves resist erosion produced by waves [72].

3.6.3. **Adaptation and mitigation.** Meanwhile, based on the literature review/theory about alternative strategies for handling sea level rise and the results of vulnerability assessments in the Coastal Area of Semarang, it can be concluded that alternative strategies that can be carried out to minimize the impact of sea level rise in the Coastal Area of Semarang City are as follows:

1) In areas that have low vulnerability, the strategies used include providing a no physical development policy, withdrawing subsidies and applying high taxes for physical and community development, increasing or establishing retreat/moving areas, providing easy licensing for investors/communities who will and have self-supporting elevation of area-scale land and providing an overview of existing vulnerabilities, moving buildings and threatened people, estimating the movement of rising sea levels, regulating coastline realignment, creating buffers/green lines in upland areas and converting inundated land functions into aquaculture areas, forests mangroves and tourism areas [72].

2) In areas that have moderate vulnerability, the strategies used include changes in land use and space use, planning and providing evacuation and emergency routes, increasing disaster preparedness institutions, strict regulations and regulations in regional development, providing easy licensing for investors/communities who raise the area/land independently and estimate the movement of sea level rise [72].

4. **Conclusion**

Based on the results of previous research, wave breaker in Bedono Waters experiences overtopping in each season, and conditions will affect the ability of buildings to reduce incoming waves. Whereas, waves that existed across the breakwater in the Sayung Waters, the structure is extremely effective as a breakwater.

Saltwater intrusion into the coastal aquifers is a very famous problem all over the world, but it has not been addressed in practice. Strategies are required to close significant gaps in local people's knowledge and management practices, although for land-use organizers. Some examples of adaptation strategies for coastal communities include purveying of safe drinking water, securing environmental river flow at the lowest flowability to maintain freshwater ecosystems, protection from climatological disasters and settlements in high-risk areas, expanding education access, building capacity for climate change readiness, and also innovative thinking.

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