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STUDY OF COASTAL SEAWATER INTRUSION OF TANGERANG DISTRICT AS A BASIS FOR SUSTAINABLE INDUSTRIAL AREA PLANNING

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Abstract

A decline in groundwater quality in the coastal part of Tangerang Regency, which directly borders the Java Sea, has been identified in recent years. This content analysis research examines the suitability of the coast of Tangerang Regency, especially the Kosambi sub-district, as an industrial area based on the RPIJM of the Tangerang Regency government. Groundwater quality and the impact of intrusion in the study area were analyzed based on secondary data obtained from the Groundwater and Subsidence Monitoring System of the Ministry of Energy and Mineral Resources at 15 water sample points. The parameters analyzed include physical, chemical and inorganic water parameters. The results obtained from the analysis of various parameters show that groundwater in the study area is polluted by seawater. The plan to develop an industrial area in the study area will certainly impact increasingly severe levels of intrusion in the study area if the plan does not pay attention to preserving groundwater resources.

Article History

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Introduction

Water is a very important element of life for living creatures. Earth would never have life like it does today without water. Nowadays, the need for water is increasing along with the population of living things, especially the need for clean groundwater. Groundwater is part of the water system that is located, stored and flows below the surface of the land (Hadimuljono & Kurniawan, 2019). Groundwater has a very important role in many sectors of life. The dynamics of groundwater quality can be influenced by several factors, including the depth of groundwater, rock porosity, human activity and the distance of the groundwater location to the sea (Purnama, 2010). The characteristics of groundwater in coastal areas are brackish to salty as it gets closer to the sea. Besides the factors already mentioned, seasons can also influence the dynamics of groundwater quality in coastal areas (Hounsinou, 2020). The potential for seawater intrusion is greater during the dry season than during the rainy season.

The process of seawater infiltrating rock pores so that it can pollute and even replace the groundwater within it is known as seawater intrusion. The rocks that makeup aquifers in the form of sand in coastal areas can make it easier for seawater to enter groundwater (Nur, 2022). Human activities regarding land and water resources without considering natural sustainability, such as excessive exploitation of groundwater, especially deep groundwater, can also cause seawater intrusion. Sea water intrusion can cause various kinds of losses, one of which is subsidence of the underground surface, land subsidence.

due to excessive exploitation of groundwater and opportunities for land that is intruded by seawater to not provide optimal functions as it should also occur. This, of course, impacts the damage to the construction of buildings built on that land. Uncontrolled land development according to spatial patterns will, of course, also worsen the condition of seawater intrusion in an area.

Indications that groundwater has been polluted by seawater can be determined by observing and measuring several physical, chemical and inorganic water parameters (Sulistyorini et al., 2017). Test parameters include taste, odour, electrical conductivity (EC) and dissolved solids (TDS), which can be correlated with the salinity level of groundwater and the content of main ions, indicating changes in groundwater quality. The main ions include sodium (Na^{+}), chloride (Cl^{-}), calcium (Ca^{2+}), and magnesium (Mg^{2+}). Comparison of the concentration of chloride ions (Cl^{-}) with bicarbonate (HCO_3^{-}) and carbonate (CO_3^{2-}) can also be used to assess the level of seawater intrusion contamination in an area. Chloride ions (Cl^{-}) are the dominant ions in seawater, while total carbonate ions are the dominant ions in groundwater (Sahwilaka & Kustini, 2014).

Sea water intrusion is a major problem in coastal areas, including Tangerang Regency. Geographically, Tangerang Regency is located at coordinates $106^{0}20'$ - $106^{0}43'$ East Longitude and $6^{0}00'$ - $6^{0}20'$ South Latitude, divided into two regional parts, namely the northern part of Tangerang Regency and the central part of Tangerang Regency towards the south (PPID Kabupaten Tangerang, 2022). The geographical position directly adjacent to the capital city influences the high intensity of land use in Tangerang Regency. Land use in Tangerang Regency can be broadly divided into residential, agricultural, pond, and industrial areas. High land use intensity is proportional to the need for clean water. Patterns of exploitation of groundwater resources that do not pay attention to carrying capacity will result in an imbalance in the environmental ecosystem.

Tangerang Regency Government data states a fairly high level of seawater intrusion in several sub-districts located on the coast of the northern part of Tangerang Regency, especially in the research area, namely Kosambi sub-district. Kosambi District is one of the industrial planning areas based on Tangerang Regency Medium Term Investment Program Plan (RIPJM) data (Figure 1) (Komunika Rakyat Indonesia Press, 2021). This fairly high level of seawater intrusion is possible due to the high level of groundwater exploitation. This can occur due to limited surface water sources in the area. Planning it as an industrial area in the research area will certainly exacerbate the seawater intrusion already occurring, considering that the industrial area requires process water, which will be taken from groundwater, especially deep groundwater. In efforts to manage and preserve groundwater resources, it is urgent to follow up on the problem of seawater intrusion in the coastal areas of Tangerang Regency. It is necessary to monitor the conditions of seawater intrusion in the coastal areas of Tangerang Regency from time to time to obtain an idea of the pattern of the seawater intrusion process.

The increasing population and industrial areas in the future will mean that groundwater use in drilled wells will also increase, thus information regarding the level of seawater intrusion in the study area is very necessary. Based on this background, this content analysis research aims to assess the suitability of the coast of Tangerang Regency, especially the Kosambi sub-district, as an industrial area based on a study of seawater intrusion that occurs in the study area.

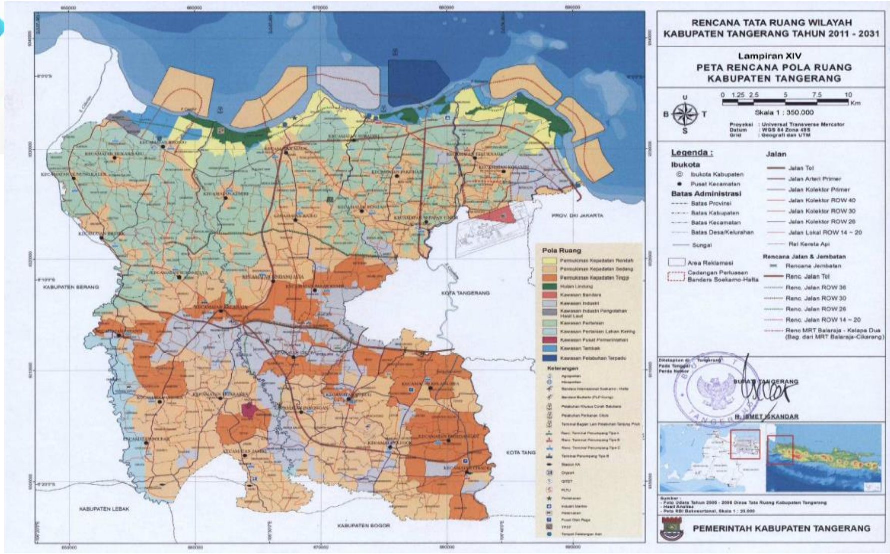

Figure 1. Tangerang regency spatial planning plan for 2011 – 2031

Method

The research method used in this research is the content analysis method which obtained from the Groundwater and Subsidence Monitoring System of the Ministry of Energy and Mineral Resources data. This secondary data consist of testing data related to physical, chemical, and inorganic parameters of groundwater quality in the research focus area that located in coastal areas. Data on groundwater quality parameters was obtained by testing groundwater samples that taken from dug and drilled wells at 15 residents (Figure 2).

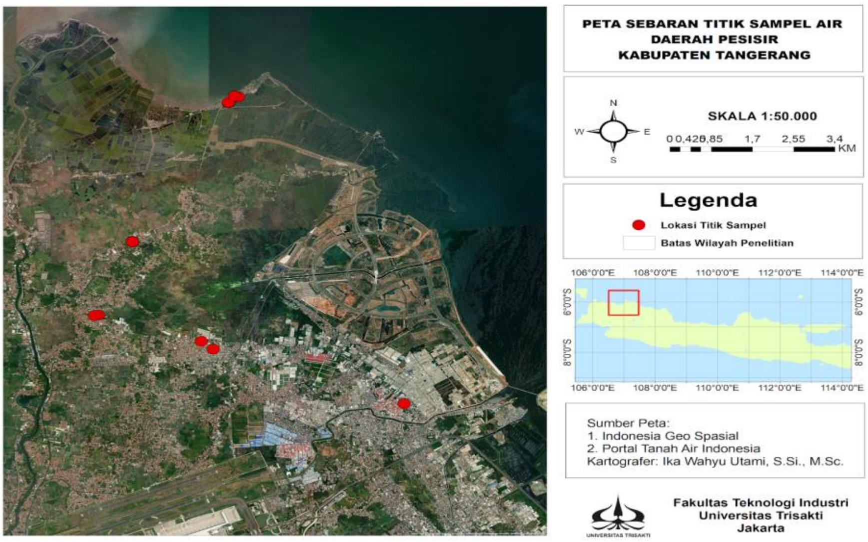

Figure 2. Water sampling point

Geological Setting of Study Area

The geological structure of the study area belongs to the northern zone, which is built by low mountains from folded tertiary layers and quaternary coastal lowlands bordering the Java Sea (Kastowo, 1975). Based on the Geological Map Sheet of Jakarta and the Kepulauan Seribu, the geological formations of the study area, if sorted by period from oldest to youngest, are the Banten Tuff (QTvb), which is composed of pumice tuff, tuff and tuff sandstone, Alluvial Fan (Qav) consisting of layered fine tuff, sandy tuff alternating with conglomerate tuff; Pematang Pantai deposits (Qbr) which are composed of fine-coarse sand with a good level of sorting and mollusc shells can be found and Alluvial deposits (Qa) which are composed of clay, silt, sand, gravel, gravel and boulders.

The structure of the study area is slightly wavy. The study area, ± 30 km^2, comprises alluvial clay, gravel and gravel deposits. This type of soil is brown alluvial with a medium grain texture consisting of clay, sand and gravel resulting from the transport and erosion of rocks in the upstream area of the river (Komunika Rakyat Indonesia Press, 2021). The following geological map of the Tangerang district area is shown in Figure 3. Based on the topographic conditions, the study area includes a low and flat elevation coastal plain with an average land slope of 0 - 8%, decreasing to the north. The topographic conditions of the northern part of Tangerang Regency cause groundwater resources to be vulnerable to damage due to seawater intrusion. In other hand, a fresh groundwater qualities turn salty due to seawater intrusion.

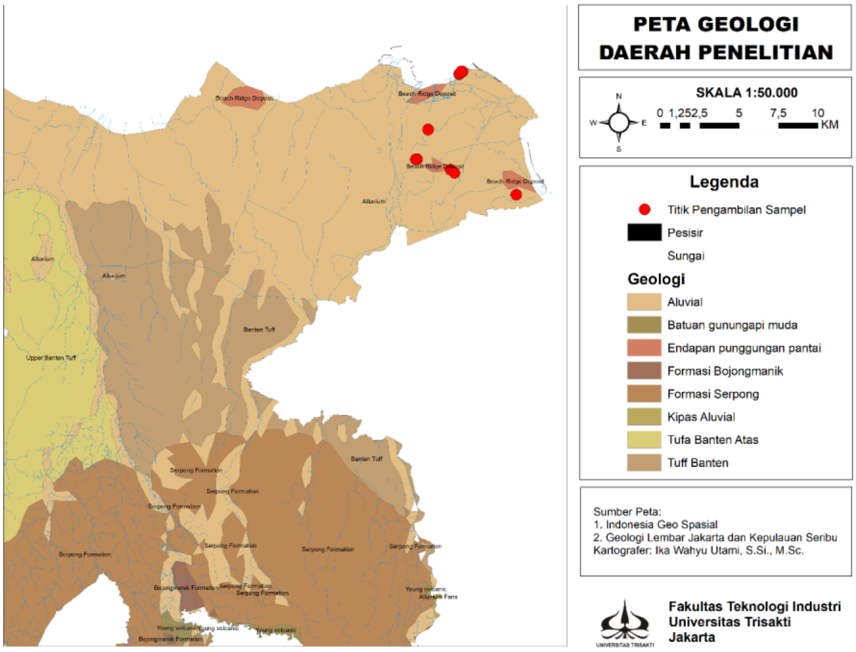

Figure 3. Geological map of the study area

Analysis of Electrical Conductivity (EC) and Total Dissolved Solid (TDS)

In groundwater quality assessment, the ability of water to conduct electric current is measured by a physical property called electrical conductivity (EC) (Ruseffandi & Gusman, 2020). There exists a correlation between salinity levels and dissolved salt ions, which is responsible for the creation of electrical conductivity values. The amount of salt dissolved in water is known as salinity (Ruseffandi & Gusman, 2020). The water quality of a groundwater source can be ascertained by examining the correlation between the salinity parameter and the electrical conductivity value. Total Dissolved Solids (TDS), often known as dissolved solids, is a physical characteristic used to assess the quality of groundwater. It encompasses all dissolved salts, metals, minerals, cations, and anion in water (Tameno et al., 2020). TDS readings can also reveal groundwater quality, in accordance with EC. Table 1 presents the classification of water salinity based on EC and TDS levels (Kustiyaningsih & Irawanto, 2020)(Sihombing, 2016). The distribution of seawater intrusion in a region can thereafter be examined using the parameters provided by the distribution of EC and TDS measurements. Equation (1) can be used to calculate the TDS value (Ifmalinda et al., 2019).

$$\text{TDS (mg/l)} = 0{,}64 \times \text{EC } (\mu\text{S/cm}) \ldots (1)$$

Table 1. Water quality classification based on EC and TDS

No.	**Water Quality**	**Electrical Conductiviy (EC) (µS/cm)**	**Total Dissolved Solids (TDS) (mg/l)**
1	Bid	< 1.500	< 1.000
2	Slightly brackish	> 1.500 – 5.000	> 1.000 – 3.000
3	Brackish	> 5.000 – 15.000	> 3.000 – 10.000
4	Salty	> 15.000 – 50.000	> 10.000 – 35.000
5	Brine (Connate)	> 50.000	> 35.000

Water Quality Analysis

Tests on water quality were also carried out in the study area. The parameters used to test water quality in the research area include inorganic, physical and chemical parameters. The quality standard values and elemental units of the water quality parameters tested refer to the quality standard values based on Indonesian Government Regulation No. 22 of 2021 concerning the implementation of environmental protection and management and also refer to the Todd and Mays quality standard values presented in Table 2 (Pradhan, 2011).

Table 2. Water quality standard testing

Parameter	**Elements**	**Quality Standard**	**Unit**	
Inorganic	Nitrite	0,06	mg/l	PP RI No. 22 Tahun 2021 concerning Implementation of Environmental Protection and Management
	Nitrate	10	mg/l	
Physical	Odor	Odorless	-	
	TDS	1.000	mg/l	
	Taste	Tasteless	-	
	EC	1.000	µS/cm	
Chemical	Iron (Fe)	0,3	mg/l	
	Chloride (Cl)	300	mg/l	
	Sulphate (SO_4)	300	mg/l	
	pH	6 – 9	mg/l	
	Hardness ($CaCO_3$)	500	mg/l	(Todd & Mays, 2004)
	Sodium (Na)	200	mg/l	

Kalium (K)	50	mg/l
Bicarbonate (HCO_3)	500	mg/l
Magnesium (Mg)	50	mg/l
Calcium (Ca)	100	mg/l

Ravelle Index

Seawater intrusion will certainly impact changes in groundwater composition, especially the composition of chloride ions. The Ravelle Index (RI) is a method that can be used to determine the level of seawater infiltration in an aquifer by using a comparison of the concentrations of chloride ions (Cl) with bicarbonate (HCO_3) and carbonate (CO_3) (Todd & Mays, 2004). The classification of seawater intrusion into groundwater based on the Ravelle Index value can be seen in Table 3 (Wijatna et al., 2019). The Ravelle Index equation can be formulated with equation (2) as follows:

$$RI = \frac{Cl}{CO_3 + HCO_3} \ldots (2)$$

Table 3. Seawater contamination levels based on Ravelle Index

No.	Intrusion Levels	Ravelle Index (RI)
1	Fresh water	< 0,5
2	Slightly	> 0,5 – 1,3
3	Medium	> 1,3 – 2,8
4	Slightly high	> 2,8 – 6,6
5	High	> 6,6 – 15,5
6	Seawater	> 15,5

Research and Discussions

Groundwater Quality Analysis

The results of measuring and mapping physical parameters include EC, odour, taste and TDS values from 15 sample points in the study area. All samples tested showed odourless elements, but some tasted salty in the groundwater. The test results for the EC and TDS can be seen in Figure 4. The results of the research show that there are five well water samples in the research focus area which are below the groundwater quality standard in terms of EC parameters of < 1.000 µS/cm and seven samples of well water are below the groundwater quality standard from the TDS aspect of < 1.000 mg/l. The graph shows that the water sample point with the highest EC and TDS values is at sample point 7, with a EC value of 25.000 µS/cm and TDS of 16.664 mg/l.

(2024), 2 (2): 152–164 Scientica 3021-8209
Jurnal Ilmiah Sain dan Teknologi

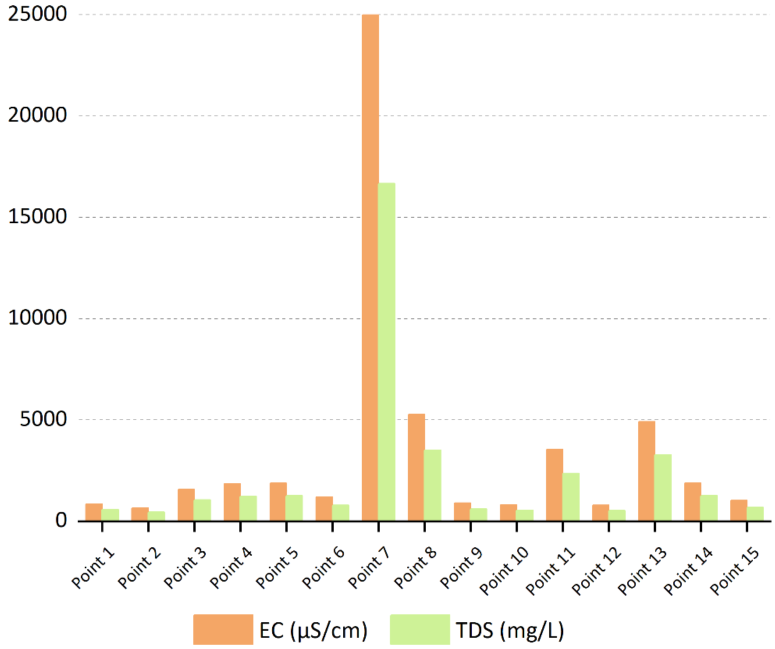

Figure 4. EC and TDS levels in study area

Several substances, including organic and inorganic chemicals, fine solids from weathering rocks, and other dissolved solid waste elements, can contribute to the elevated TDS levels in eight well water samples (Klassen et al., 2014). The high TDS figures in the study area may also be attributed to the impact of human activity on it, such as the presence of industrial and domestic trash.

The EC parameters, which were quite high at the 10 sample points, could be caused by the large number of metal ions dissolved in the groundwater. The more metal ions dissolved, the greater the potential for seawater intrusion. Seawater intrusion can create opportunities for the movement of water containing salt elements to fill groundwater so that the groundwater level begins to be replaced by water with a high salt content. The more dissolved salt elements are ionized, the higher the EC value, which will also have a worse impact on groundwater quality. Based on the scattered TDS and EC values, the study area can be classified as brackish to salty water quality.

Groundwater with high TDS and EC values is very dangerous if consumed by humans. Minerals and inorganic elements contained in groundwater will settle in the human body over a long period to trigger the emergence of kidney stones (Setioningrum et al., 2020). The parameters EC and TDS are closely correlated with salinity. Salinity is the level of saltiness or dissolved salt content in water. Water salinity shows the amount of salt in certain waters. Groundwater salinity levels indicate seawater intrusion parameters. Based on EC and TDS test data, most groundwater in study area has brackish to salty water quality.

The chemical parameter test consists of the elements calcium (Ca), magnesium (Mg), potassium (K), chloride (Cl), sodium (Na), sulfate (SO_4), hardness ($CaCO_3$), and bicarbonate (HCO_3). Based on laboratory test results, several water samples have concentration values for the elements calcium (Ca), magnesium (Mg) and potassium (K) that exceed the quality standards (figure 5). The calcium content in groundwater in the study area ranges between 15,5 and 713,14 mg/l. The magnesium content ranged between 1,88 and 664,16 mg/l, and the potassium content ranged between 0,03 and 98 mg/l. Sample point 7 has the highest potassium, calcium and magnesium contents of all samples. The presence of high concentrations of calcium and magnesium ions in water can cause the water to become hard. Water with a high hardness level is very dangerous since it can cause blockages in blood vessels and kidney stones.

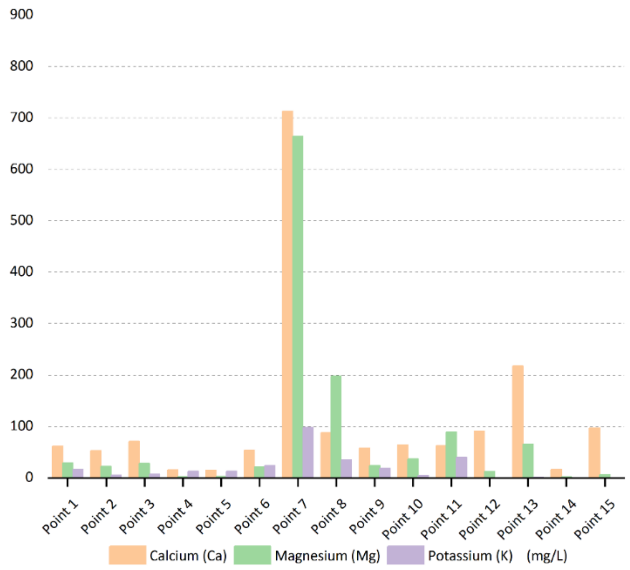

Figure 5. Calcium, magnesium and potassium levels in study area

One of the groups of alkali metals consists of sodium. Sedimentary and igneous rocks contain much sodium. The element sodium is most often found in seawater due to the weathering of soluble igneous rocks, which are then carried to the sea and accumulate there. Another source of elemental sodium is seawater intrusion. A sodium concentration of less than 200 mg/l in water is permitted. The sodium content in the research area ranges from 62,8 mg/l to 4771,5 mg/l, as shown in Figure 6. The highest sodium content is found in sample 7. Considering that the research location is close to seawater, it is necessary to be wary of excessive sodium concentrations. The dominant ions Na^+ and Cl^- exist in seawater, and sediments that come into contact with seawater will absorb Na^+ significantly.

The sulfate element (SO_4) has the same source as sodium, predominantly from seawater. Based on laboratory test results, sulfate levels are below quality standards except at sample point 8, where the value exceeds 300 mg/l. The concentration of the hardness element ($CaCO_3$) shows values that exceed the quality standard, that is 500 mg/l at several sample points such as 7, 8 and 13, at which point the groundwater has a salty taste. Meanwhile, the bicarbonate element (HCO_3) from several laboratory test samples showed above the quality standard, that is > 500 mg/l.

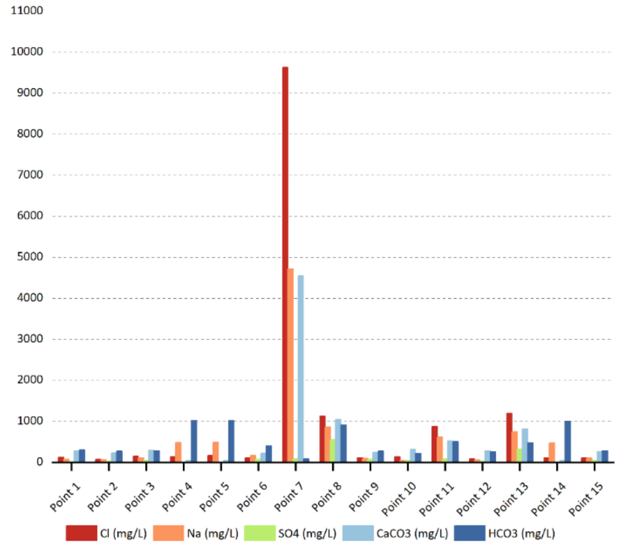

Figure 6. Levels of Cl^-, Na^+, SO_4^{2-}, $CaCO_3^-$ and HCO_3^- ions in study area

Analysis of the influence of intrusion can also be seen from the Ravelle Index (RI) value. Ravelle Index compares the concentration of chloride ions with bicarbonate and carbonate. Mineral levels usually increase with chloride levels; high chloride levels can be accompanied by high calcium and magnesium levels, which can increase the corrosivity of the water. The results of the Ravelle Index calculation can be seen in Table 4. Sample points 7, 8, 11, and 13 can be classified as points with moderate to high intrusion levels. There is an anomaly in the research results; the sample with the greatest level of intrusion is shown by sample point 7, where sample point 7 is located less close to the coast than the other points. The very sharp increase in the Ravelle Index value at sample point 7 compared to samples at other points indicates that groundwater movement is influenced by seawater and seawater intrusion.

Tabel 4. Ravelle Index (RI) in study area

No	Point	RI
1	Point 1	0,401188
2	Point 2	0,255782
3	Point 3	0,535490
4	Point 4	0,139419
5	Point 5	0,162734
6	Point 6	0,278593
7	Point 7	116,3627
8	Point 8	1,234453
9	Point 9	0,409855
10	Point 10	0,618345
11	Point 11	1,741911
12	Point 12	0,332382
13	Point 13	2,484636
14	Point 14	0,113179
15	Point 15	0,373372

The elements of inorganic parameters consist of nitrite (NO_2) and nitrate (NO_3). Based on laboratory test results, it is known that nitrite (NO_2) levels for several samples from water intake points (Points 3, 7 and 13) have values that exceed the threshold limit, that is > 0.06 mg/l (Figure 7). The source of nitrite can come from household activity waste or domestic waste. 7 water sample points had nitrate (NO_3) content exceeding the threshold limit, that is > 10 mg/l. The high nitrate value probably comes from agricultural waste, considering that the research location comprises alluvial rocks whose soil is very good for developing the agricultural sector.

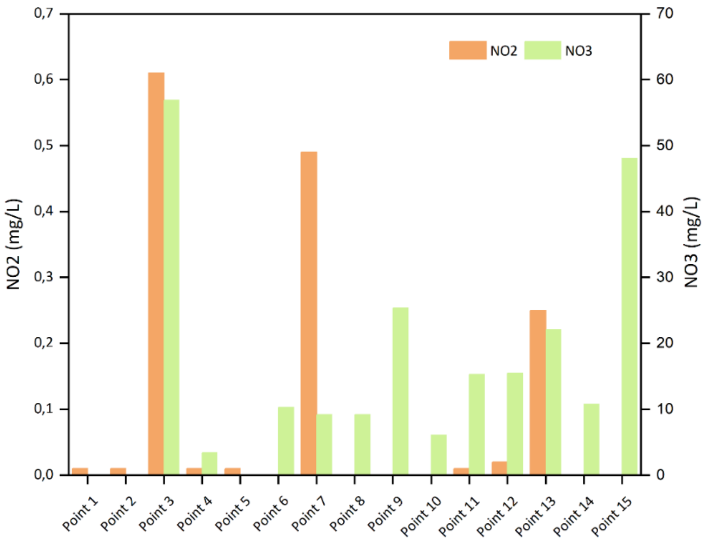

Figure 7. NO_2 and NO_3 ion levels in study area

Feasibility of Industrial Area Development Plan based on Sea Water Intrusion Data on the Coast of Tangerang Regency

Based on the analysis of physical, chemical, and inorganic water parameters, several parameters indicate a high level of seawater intrusion in the study area, which is planned as an industrial area by the Tangerang Regency government. High levels of TDS, EC, chloride ions, sulfate ions and other ions in groundwater due to seawater intrusion can have several impacts on industrial areas located on the coast. High levels of water's physical, chemical and inorganic parameters can indicate pollution by soluble substances, such as salt and other chemicals. This pollution can harm groundwater quality, which industry may use as a water source. Decreased groundwater quality can certainly limit the availability of clean water for industry. In addition, groundwater with high TDS and EC levels can increase the risk of metal corrosion in industrial equipment and infrastructure that uses water and can cause corrosion in building structures in coastal industrial environments.

Based on the content analysis results regarding physical, chemical and inorganic water parameters, of course, the development of industrial areas could have serious consequences for the severity of seawater intrusion that has occurred in the Tangerang Regency area. One of the main impacts is changes in soil structure, which can increase the risk of seawater intrusion into groundwater. Building infrastructure, such as factories, can disrupt the natural barrier that prevents seawater intrusion by altering the flow patterns of groundwater and causing damage to the soil layer. Furthermore, falling groundwater levels could result from increased groundwater extraction to suit industrial needs.

The intrusion conditions in the Tangerang Regency require integrated attention from various stakeholders. The industrial sector's contribution to the economic growth of Tangerang Regency, especially in coastal areas, plays a very important role in controlling the level of seawater intrusion in the study area. Its strategic location, directly adjacent to the country's capital, will result in a fast agglomeration process. The number of industries in study area continues to increase. The ever-increasing development of the industrial sector also impacts the growth of new settlements in the study area. This will result in increased exploitation of groundwater without paying attention to the existing carrying capacity to meet water needs in the production process of an industry or to meet the daily water needs of the population.

Based on secondary data analyzed in this research, the coast of Tangerang is starting to be polluted by seawater. It is feared that development plans and industrial development in coastal areas will further worsen seawater intrusion. Sea water intrusion is a natural phenomenon that cannot be avoided. However, this condition can be minimized by development efforts in areas with coastal areas. Several factors that can contribute to the rate of seawater intrusion must be analyzed further, especially industrial development in the study area, to reduce the rate of intrusion on the coast of Tangerang Regency. Planning is needed in coastal areas that also support environmental interests, not just economic aspects. Actions that can be taken include:

- Enforcing regional regulations related to coastal area spatial planning,
- Continuously optimizing water catchment areas in upstream areas to maintain groundwater reserves so that groundwater potential is maintained,
- Limiting the excessive groundwater exploitation in coastal industry areas by strictly implementing groundwater use permit regulations
- Optimizing the function of mangrove areas on the coast as a buffer zone, which can be an effective barrier to the penetration rate of seawater intrusion.

Conclusion

Based on the analysis and discussion carried out, it can be concluded that based on the physical, chemical, and inorganic parameters tested, the Tangerang coast has begun to be intruded on by seawater. The groundwater quality in the study area can be classified as brackish to salty water. If implemented in accordance with the Tangerang Regency RPIJM, the ever-increasing development of the industrial sector will result in increased exploitation of internal groundwater, which is already occurring now. It is feared that development plans and industrial development in coastal areas will further worsen seawater intrusion. In Tangerang Regency, the causes of seawater intrusion are mostly caused by population activities such as land conversion, deep water well drilling not supervised by the industrial sector, and the lack of buffer zones to prevent seawater intrusion.

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STUDY OF COASTAL SEAWATER INTRUSION OF TANGERANG DISTRICT AS A BASIS FOR SUSTAINABLE INDUSTRIAL AREA PLANNING

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STUDY OF COASTAL SEAWATER INTRUSION OF TANGERANG DISTRICT AS A BASIS FOR SUSTAINABLE INDUSTRIAL AREA PLANNING

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Abstract

A decline in groundwater quality in the coastal part of Tangerang Regency, which directly borders the Java Sea, has been identified in recent years. This content analysis research examines the suitability of the coast of Tangerang Regency, especially the Kosambi sub-district, as an industrial area based on the RPIJM of the Tangerang Regency government. Groundwater quality and the impact of intrusion in the study area were analyzed based on secondary data obtained from the Groundwater and Subsidence Monitoring System of the Ministry of Energy and Mineral Resources at 15 water sample points. The parameters analyzed include physical, chemical and inorganic water parameters. The results obtained from the analysis of various parameters show that groundwater in the study area is polluted by seawater. The plan to develop an industrial area in the study area will certainly impact increasingly severe levels of intrusion in the study area if the plan does not pay attention to preserving groundwater resources.

Keywords: coast; intrusion; ground water; water quality; industry

Introduction

Water is a very important element of life for living creatures. Earth would never have life like it does today without water. Nowadays, the need for water is increasing along with the population of living things, especially the need for clean groundwater. Groundwater is part of the water system that is located, stored and flows below the surface of the land (Hadimuljono & Kurniawan, 2019). Groundwater has a very important role in many sectors of life. The dynamics of groundwater quality can be influenced by several factors, including the depth of groundwater, rock porosity, human activity and the distance of the groundwater location to the sea (Purnama, 2010). The characteristics of groundwater in coastal areas are brackish to salty as it gets closer to the sea. Besides the factors already mentioned, seasons can also influence the dynamics of groundwater quality in coastal areas (Hounsinou, 2020). The potential for seawater intrusion is greater during the dry season than during the rainy season.

The process of seawater infiltrating rock pores so that it can pollute and even replace the groundwater within it is known as seawater intrusion. The rocks that makeup aquifers in the form of sand in coastal areas can make it easier for seawater to enter groundwater (Nur, 2022). Human activities regarding land and water resources without considering natural sustainability, such as excessive exploitation of groundwater, especially deep groundwater, can also cause seawater intrusion. Sea water intrusion can cause various kinds of losses, one of which is subsidence of the underground surface, land subsidence due to excessive exploitation of groundwater and opportunities for land that is intruded by seawater to not provide optimal functions as it should also occur. This, of course, impacts the damage to the construction of buildings built on that land. Uncontrolled land development according to spatial patterns will, of course, also worsen the condition of seawater intrusion in an area.

Indications that groundwater has been polluted by seawater can be determined by observing and measuring several physical, chemical and inorganic water parameters (Sulistyorini et al., 2017). Test parameters include taste, odour, electrical conductivity (EC) and dissolved solids (TDS), which can be correlated with the salinity level of groundwater and the content of main ions, indicating changes in groundwater quality. The main ions include sodium (Na^+), chloride (Cl^-), calcium (Ca^{2+}), and magnesium (Mg^{2+}). Comparison of the concentration of chloride ions (Cl^-) with bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) can also be used to assess the level of seawater intrusion contamination in an area. Chloride ions (Cl^-) are the dominant ions in seawater, while total carbonate ions are the dominant ions in groundwater (Sahwilaka & Kustini, 2014).

Sea water intrusion is a major problem in coastal areas, including Tangerang Regency. Geographically, Tangerang Regency is located at coordinates $106^0 20'$ - $106^0 43'$ East Longitude and $6^0 00'$ - $6^0 20'$ South Latitude, divided into two regional parts, namely the northern part of Tangerang Regency and the central part of Tangerang Regency towards the south (PPID Kabupaten Tangerang, 2022). The geographical position directly adjacent to the capital city influences the high intensity of land use in Tangerang Regency. Land use in Tangerang Regency can be broadly divided into residential, agricultural, pond, and industrial areas. High land use intensity is proportional to the need for clean water. Patterns of exploitation of groundwater resources that do not pay attention to carrying capacity will result in an imbalance in the environmental ecosystem.

Tangerang Regency Government data states a fairly high level of seawater intrusion in several sub-districts located on the coast of the northern part of Tangerang Regency, especially in the research area, namely Kosambi sub-district. Kosambi District is one of the industrial planning areas based on Tangerang Regency Medium Term Investment Program Plan (RIPJM) data (Figure 1) (Komunika Rakyat Indonesia Press, 2021). This fairly high level of seawater intrusion is possible due to the high level of groundwater exploitation. This can occur due to limited surface water sources in the area. Planning it as an industrial area in the research area will certainly exacerbate the seawater intrusion already occurring, considering that the industrial area requires process water, which will be taken from groundwater, especially deep groundwater. In efforts to manage and preserve groundwater resources, it is urgent to follow up on the problem of seawater intrusion in the coastal areas of Tangerang Regency. It is necessary to monitor the conditions of seawater intrusion in the coastal areas of Tangerang Regency from time to time to obtain an idea of the pattern of the seawater intrusion process.

The increasing population and industrial areas in the future will mean that groundwater use in drilled wells will also increase, thus information regarding the level of seawater intrusion in the study area is very necessary. Based on this background, this content analysis research aims to assess the suitability of the coast of Tangerang Regency, especially the Kosambi sub-district, as an industrial area based on a study of seawater intrusion that occurs in the study area.

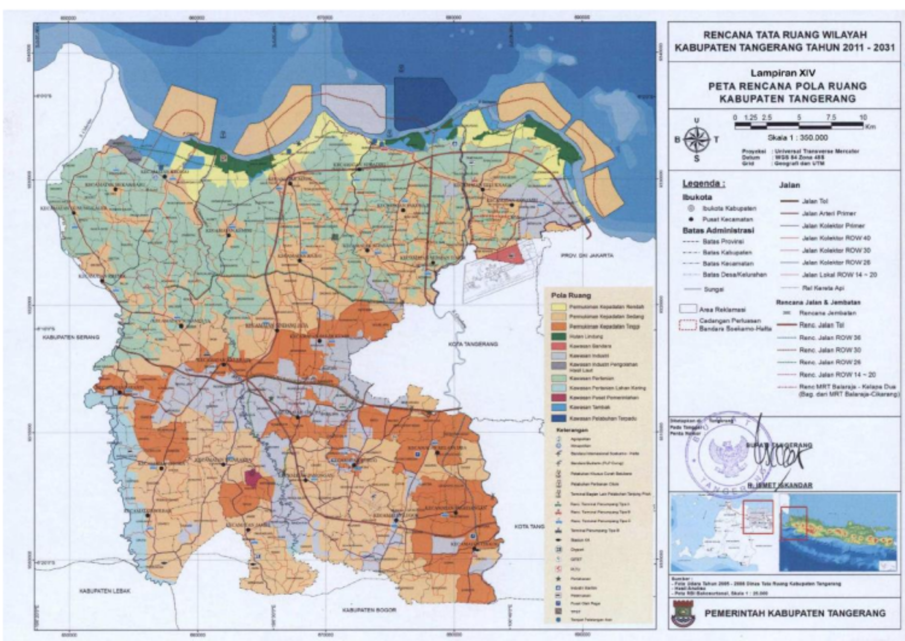

Figure 1. Tangerang regency spatial planning plan for 2011 – 2031

Method

The research method used in this research is the content analysis method which obtained from the Groundwater and Subsidence Monitoring System of the Ministry of Energy and Mineral Resources data. This secondary data consist of testing data related to physical, chemical, and inorganic parameters of groundwater quality in the research focus area that located in coastal areas. Data on groundwater quality parameters was obtained by testing groundwater samples that taken from dug and drilled wells at 15 residents (Figure 2).

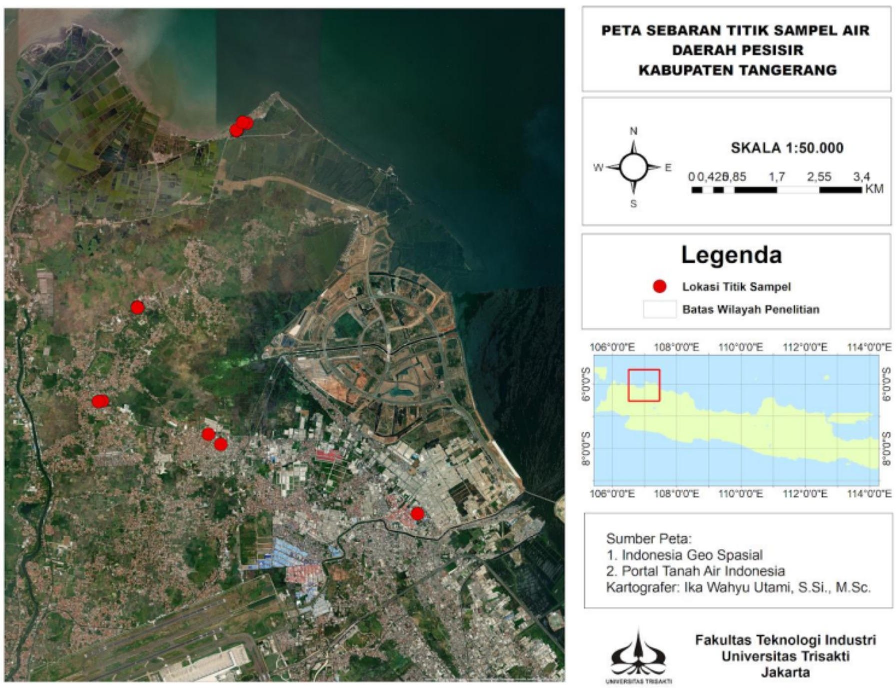

Figure 2. Water sampling point

Geological Setting of Study Area

The geological structure of the study area belongs to the northern zone, which is built by low mountains from folded tertiary layers and quaternary coastal lowlands bordering the Java Sea (Kastowo, 1975). Based on the Geological Map Sheet of Jakarta and the Kepulauan Seribu, the geological formations of the study area, if sorted by period from oldest to youngest, are the Banten Tuff (QTvb), which is composed of pumice tuff, tuff and tuff sandstone, Alluvial Fan (Qav) consisting of layered fine tuff, sandy tuff alternating with conglomerate tuff; Pematang Pantai deposits (Qbr) which are composed of fine-coarse sand with a good level of sorting and mollusc shells can be found and Alluvial deposits (Qa) which are composed of clay, silt, sand, gravel, gravel and boulders.

The structure of the study area is slightly wavy. The study area, ± 30 km^2, comprises alluvial clay, gravel and gravel deposits. This type of soil is brown alluvial with a medium grain texture consisting of clay, sand and gravel resulting from the transport and erosion of rocks in the upstream area of the river (Komunika Rakyat Indonesia Press, 2021). The following geological map of the Tangerang district area is shown in Figure 3. Based on the topographic conditions, the study area includes a low and flat elevation coastal plain with an average land slope of 0 - 8%, decreasing to the north. The topographic conditions of the northern part of Tangerang Regency cause groundwater resources to be vulnerable to damage due to seawater intrusion. In other hand, a fresh groundwater qualities turn salty due to seawater intrusion.

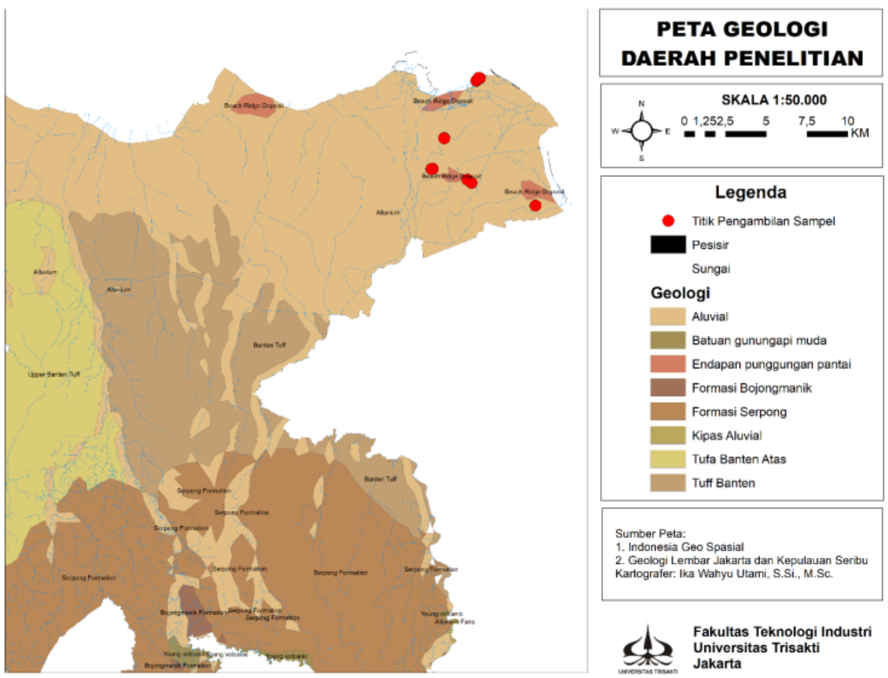

Figure 3. Geological map of the study area

Analysis of Electrical Conductivity (EC) and Total Dissolved Solid (TDS)

In groundwater quality assessment, the ability of water to conduct electric current is measured by a physical property called electrical conductivity (EC) (Ruseffandi & Gusman, 2020). There exists a correlation between salinity levels and dissolved salt ions, which is responsible for the creation of electrical conductivity values. The amount of salt dissolved in water is known as salinity (Ruseffandi & Gusman, 2020). The water quality of a groundwater source can be ascertained by examining the correlation between the salinity parameter and the electrical conductivity value. Total Dissolved Solids (TDS), often known as dissolved solids, is a physical characteristic used to assess the quality of groundwater. It encompasses all dissolved salts, metals, minerals, cations, and anion in water (Tameno et al., 2020). TDS readings can also reveal groundwater quality, in accordance with EC. Table 1 presents the classification of water salinity based on EC and TDS levels (Kustiyaningsih & Irawanto, 2020)(Sihombing, 2016). The distribution of seawater intrusion in a region can thereafter be examined using the parameters provided by the distribution of EC and TDS measurements. Equation (1) can be used to calculate the TDS value (Ifmalinda et al., 2019).

$$\text{TDS (mg/l)} = 0{,}64 \times \text{EC } (\mu\text{S/cm}) \; \ldots \; (1)$$

Table 1. Water quality classification based on EC and TDS

No.	Water Quality	Electrical Conductiviy (EC) (µS/cm)	Total Dissolved Solids (TDS) (mg/l)
1	Bid	< 1.500	< 1.000
2	Slightly brackish	> 1.500 – 5.000	> 1.000 – 3.000
3	Brackish	> 5.000 – 15.000	> 3.000 – 10.000
4	Salty	> 15.000 – 50.000	> 10.000 – 35.000
5	Brine (Connate)	> 50.000	> 35.000

Water Quality Analysis

Tests on water quality were also carried out in the study area. The parameters used to test water quality in the research area include inorganic, physical and chemical parameters. The quality standard values and elemental units of the water quality parameters tested refer to the quality standard values based on Indonesian Government Regulation No. 22 of 2021 concerning the implementation of environmental protection and management and also refer to the Todd and Mays quality standard values presented in Table 2 (Pradhan, 2011).

Table 2. Water quality standard testing

<table>
<tr><th>Parameter</th><th>Elements</th><th>Quality Standard</th><th>Unit</th><td rowspan="7">PP RI No. 22 Tahun 2021 concerning Implementation of Environmental Protection and Management</td></tr>
<tr><td rowspan="2">Inorganic</td><td>Nitrite</td><td>0,06</td><td>mg/l</td></tr>
<tr><td>Nitrate</td><td>10</td><td>mg/l</td></tr>
<tr><td rowspan="4">Physical</td><td>Odor</td><td>Odorless</td><td>-</td></tr>
<tr><td>TDS</td><td>1.000</td><td>mg/l</td></tr>
<tr><td>Taste</td><td>Tasteless</td><td>-</td></tr>
<tr><td>EC</td><td>1.000</td><td>µS/cm</td></tr>
</table>

Chemical	Iron (Fe)	0,3	mg/l	
	Chloride (Cl)	300	mg/l	
	Sulphate (SO_4)	300	mg/l	
	pH	6 – 9	mg/l	
	Hardness ($CaCO_3$)	500	mg/l	(Todd & Mays, 2004)
	Sodium (Na)	200	mg/l	
	Kalium (K)	50	mg/l	
	Bicarbonate (HCO_3)	500	mg/l	
	Magnesium (Mg)	50	mg/l	
	Calcium (Ca)	100	mg/l	

Ravelle Index

Seawater intrusion will certainly impact changes in groundwater composition, especially the composition of chloride ions. The Ravelle Index (RI) is a method that can be used to determine the level of seawater infiltration in an aquifer by using a comparison of the concentrations of chloride ions (Cl) with bicarbonate (HCO_3) and carbonate (CO_3) (Todd & Mays, 2004). The classification of seawater intrusion into groundwater based on the Ravelle Index value can be seen in Table 3 (Wijatna et al., 2019). The Ravelle Index equation can be formulated with equation (2) as follows:

$$RI = \frac{Cl}{CO_3 + HCO_3} \ldots (2)$$

Table 3. Seawater contamination levels based on Ravelle Index

No.	Intrusion Levels	Ravelle Index (RI)
1	Fresh water	< 0,5
2	Slightly	> 0,5 – 1,3
3	Medium	> 1,3 – 2,8
4	Slightly high	> 2,8 – 6,6
5	High	> 6,6 – 15,5
6	Seawater	> 15,5

Research and Discussions

Groundwater Quality Analysis

The results of measuring and mapping physical parameters include EC, odour, taste and TDS values from 15 sample points in the study area. All samples tested showed odourless elements, but some tasted salty in the groundwater. The test results for the EC and TDS can be seen in Figure 4. The results of the research show that there are five well water samples in the research focus area which are below the groundwater quality standard in terms of EC parameters of < 1.000 µS/cm and seven samples of well water are below the groundwater quality standard from the TDS aspect of < 1.000 mg/l. The graph shows that the water sample point with the highest EC and TDS values is at sample point 7, with a EC value of 25.000 µS/cm and TDS of 16.664 mg/l.

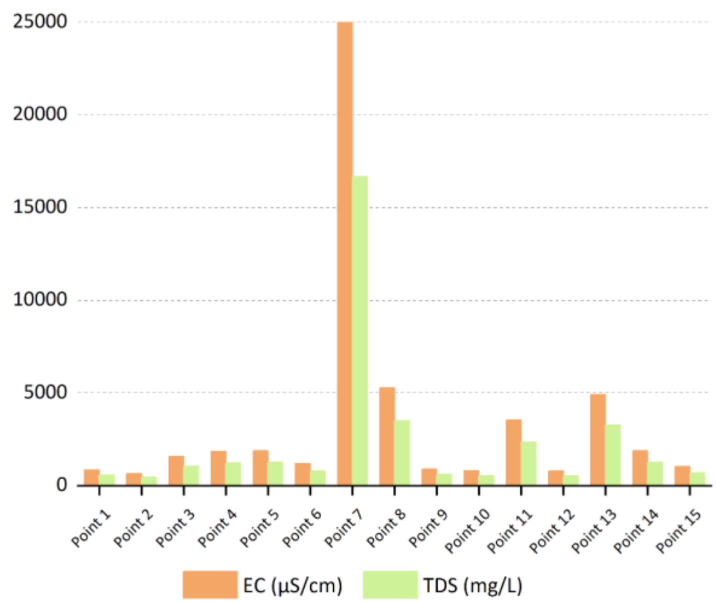

Figure 4. EC and TDS levels in study area

Several substances, including organic and inorganic chemicals, fine solids from weathering rocks, and other dissolved solid waste elements, can contribute to the elevated TDS levels in eight well water samples (Klassen et al., 2014). The high TDS figures in the study area may also be attributed to the impact of human activity on it, such as the presence of industrial and domestic trash.

The EC parameters, which were quite high at the 10 sample points, could be caused by the large number of metal ions dissolved in the groundwater. The more metal ions dissolved, the greater the potential for seawater intrusion. Seawater intrusion can create opportunities for the movement of water containing salt elements to fill groundwater so that the groundwater level begins to be replaced by water with a high salt content. The more dissolved salt elements are ionized, the higher the EC value, which will also have a worse impact on groundwater quality. Based on the scattered TDS and EC values, the study area can be classified as brackish to salty water quality.

Groundwater with high TDS and EC values is very dangerous if consumed by humans. Minerals and inorganic elements contained in groundwater will settle in the human body over a long period to trigger the emergence of kidney stones (Setioningrum et al., 2020). The parameters EC and TDS are closely correlated with salinity. Salinity is the level of saltiness or dissolved salt content in water. Water salinity shows the amount of salt in certain waters. Groundwater salinity levels indicate seawater intrusion parameters. Based on EC and TDS test data, most groundwater in study area has brackish to salty water quality.

The chemical parameter test consists of the elements calcium (Ca), magnesium (Mg), potassium (K), chloride (Cl), sodium (Na), sulfate (SO_4), hardness ($CaCO_3$), and bicarbonate (HCO_3). Based on laboratory test results, several water samples have concentration values for the elements calcium (Ca), magnesium (Mg) and potassium (K) that exceed the quality standards (figure 5). The calcium content in groundwater in the study area ranges between 15,5 and 713,14 mg/l. The magnesium content ranged between 1,88 and 664,16 mg/l, and the potassium content ranged between 0,03 and 98 mg/l. Sample point 7 has the highest potassium, calcium and magnesium contents of all samples. The presence of high concentrations of calcium and magnesium ions in water can cause the water to become hard. Water with a high hardness level is very dangerous since it can cause blockages in blood vessels and kidney stones.

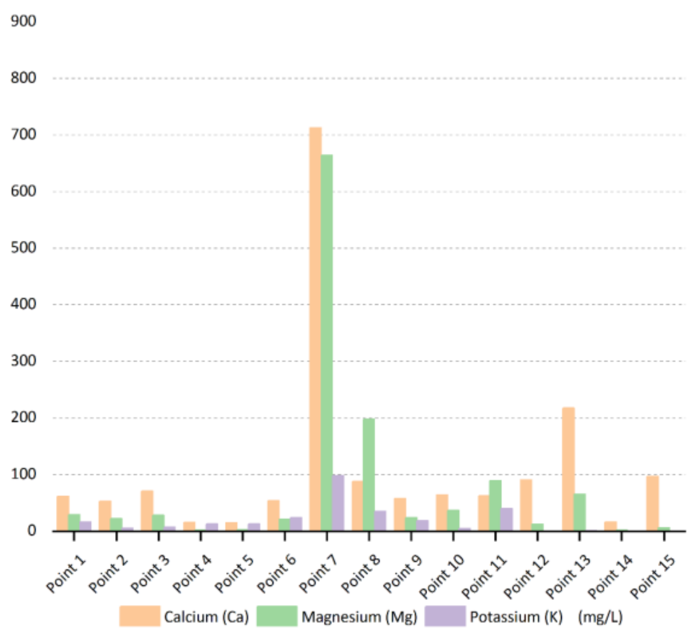

Figure 5. Calcium, magnesium and potassium levels in study area

One of the groups of alkali metals consists of sodium. Sedimentary and igneous rocks contain much sodium. The element sodium is most often found in seawater due to the weathering of soluble igneous rocks, which are then carried to the sea and accumulate there. Another source of elemental sodium is seawater intrusion. A sodium concentration of less than 200 mg/l in water is permitted. The sodium content in the research area ranges from 62,8 mg/l to 4771,5 mg/l, as shown in Figure 6. The highest sodium content is found in sample 7. Considering that the research location is close to seawater, it is necessary to be wary of excessive sodium concentrations. The dominant ions Na^+ and Cl^- exist in seawater, and sediments that come into contact with seawater will absorb Na^+ significantly.

The sulfate element (SO_4) has the same source as sodium, predominantly from seawater. Based on laboratory test results, sulfate levels are below quality standards except at sample point 8, where the value exceeds 300 mg/l. The concentration of the hardness element ($CaCO_3$) shows values that exceed the quality standard, that is 500 mg/l at several sample points such as 7, 8 and 13, at which point the groundwater has a salty taste. Meanwhile, the bicarbonate element (HCO_3) from several laboratory test samples showed above the quality standard, that is > 500 mg/l.

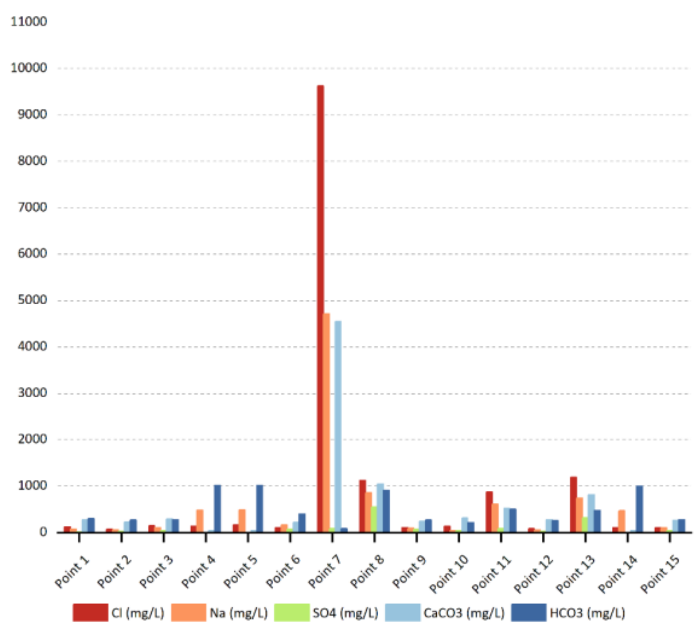

Figure 6. Levels of Cl^-, Na^+, SO_4^{2-}, $CaCO_3^-$ and HCO_3^- ions in study area

Analysis of the influence of intrusion can also be seen from the Ravelle Index (RI) value. Ravelle Index compares the concentration of chloride ions with bicarbonate and carbonate. Mineral levels usually increase with chloride levels; high chloride levels can be accompanied by high calcium and magnesium levels, which can increase the corrosivity of the water. The results of the Ravelle Index calculation can be seen in Table 4. Sample points 7, 8, 11, and 13 can be classified as points with moderate to high intrusion levels. There is an anomaly in the research results; the sample with the greatest level of intrusion is shown by sample point 7, where sample point 7 is located less close to the coast than the other points. The very sharp increase in the Ravelle Index value at sample point 7 compared to samples at other points indicates that groundwater movement is influenced by seawater and seawater intrusion.

Tabel 4. Ravelle Index (RI) in study area

No	Point	RI
1	Point 1	0,401188
2	Point 2	0,255782
3	Point 3	0,535490
4	Point 4	0,139419
5	Point 5	0,162734
6	Point 6	0,278593
7	Point 7	116,3627
8	Point 8	1,234453
9	Point 9	0,409855
10	Point 10	0,618345
11	Point 11	1,741911
12	Point 12	0,332382
13	Point 13	2,484636
14	Point 14	0,113179
15	Point 15	0,373372

The elements of inorganic parameters consist of nitrite (NO_2) and nitrate (NO_3). Based on laboratory test results, it is known that nitrite (NO_2) levels for several samples from water intake points (Points 3, 7 and 13) have values that exceed the threshold limit, that is > 0.06 mg/l (Figure 7). The source of nitrite can come from household activity waste or domestic waste. 7 water sample points had nitrate (NO_3) content exceeding the threshold limit, that is > 10 mg/l. The high nitrate value probably comes from agricultural waste, considering that the research location comprises alluvial rocks whose soil is very good for developing the agricultural sector.

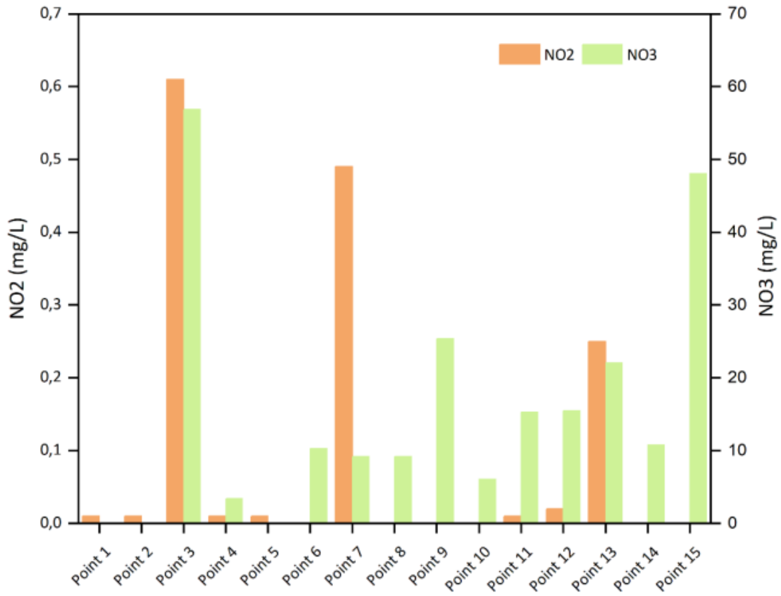

Figure 7. NO_2 and NO_3 ion levels in study area

Feasibility of Industrial Area Development Plan based on Sea Water Intrusion Data on the Coast of Tangerang Regency

Based on the analysis of physical, chemical, and inorganic water parameters, several parameters indicate a high level of seawater intrusion in the study area, which is planned as an industrial area by the Tangerang Regency government. High levels of TDS, EC, chloride ions, sulfate ions and other ions in groundwater due to seawater intrusion can have several impacts on industrial areas located on the coast. High levels of water's physical, chemical and inorganic parameters can indicate pollution by soluble substances, such as salt and other chemicals. This pollution can harm groundwater quality, which industry may use as a water source. Decreased groundwater quality can certainly limit the availability of clean water for industry. In addition, groundwater with high TDS and EC levels can increase the risk of metal corrosion in industrial equipment and infrastructure that uses water and can cause corrosion in building structures in coastal industrial environments.

Based on the content analysis results regarding physical, chemical and inorganic water parameters, of course, the development of industrial areas could have serious consequences for the severity of seawater intrusion that has occurred in the Tangerang Regency area. One of the main impacts is changes in soil structure, which can increase the risk of seawater intrusion into groundwater. Building infrastructure, such as factories, can disrupt the natural barrier that prevents seawater intrusion by altering the flow patterns of groundwater and causing damage to the soil layer. Furthermore, falling groundwater levels could result from increased groundwater extraction to suit industrial needs.

The intrusion conditions in the Tangerang Regency require integrated attention from various stakeholders. The industrial sector's contribution to the economic growth of Tangerang Regency, especially in coastal areas, plays a very important role in controlling the level of seawater intrusion in the study area. Its strategic location, directly adjacent to the country's capital, will result in a fast agglomeration process. The number of industries in study area continues to increase. The ever-increasing development of the industrial sector also impacts the growth of new settlements in the study area. This will result in increased exploitation of groundwater without paying attention to the existing carrying capacity to meet water needs in the production process of an industry or to meet the daily water needs of the population.

Based on secondary data analyzed in this research, the coast of Tangerang is starting to be polluted by seawater. It is feared that development plans and industrial development in coastal areas will further worsen seawater intrusion. Sea water intrusion is a natural phenomenon that cannot be avoided. However, this condition can be minimized by development efforts in areas with coastal areas. Several factors that can contribute to the rate of seawater intrusion must be analyzed further, especially industrial development in the study area, to reduce the rate of intrusion on the coast of Tangerang Regency. Planning is needed in coastal areas that also support environmental interests, not just economic aspects. Actions that can be taken include:

- Enforcing regional regulations related to coastal area spatial planning,
- Continuously optimizing water catchment areas in upstream areas to maintain groundwater reserves so that groundwater potential is maintained,
- Limiting the excessive groundwater exploitation in coastal industry areas by strictly implementing groundwater use permit regulations
- Optimizing the function of mangrove areas on the coast as a buffer zone, which can be an effective barrier to the penetration rate of seawater intrusion.

Conclusion

Based on the analysis and discussion carried out, it can be concluded that based on the physical, chemical, and inorganic parameters tested, the Tangerang coast has begun to be intruded on by seawater. The groundwater quality in the study area can be classified as brackish to salty water. If implemented in accordance with the Tangerang Regency RPIJM, the ever-increasing development of the industrial sector will result in increased exploitation of internal groundwater, which is already occurring now. It is feared that development plans and industrial development in coastal areas will further worsen seawater intrusion. In Tangerang Regency, the causes of seawater intrusion are mostly caused by population activities such as land conversion, deep water well drilling not supervised by the industrial sector, and the lack of buffer zones to prevent seawater intrusion.

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GENERAL COMMENTS

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15