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Hydrochemical of Groundwater and the Potential of Sea Water Intrusion in Tanah Laut, South Kalimantan

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Abstract: The Tanah Laut area in South Kalimantan Province is a rapidly developing area, in line with the plan to relocate the country's capital. Therefore, the need for groundwater as a water resource in community life in that area needs to be supported by various studies. This research is intended as a hydrogeological survey in Tanah Laut District, to determine the local groundwater hydrochemistry and its potential for sea water intrusion. The research was conducted in the field by collecting data on the physical properties of groundwater in 155 dug wells and 50 artesian wells. Several groundwater samples representing free and confined aquifers were tested for physical/chemical properties in the laboratory. The analysis was performed based on groundwater table, pH, electrical conductivity (EC) and groundwater facies. The results showed that free groundwater has a pH of 6.1 - 8.4 and a total dissolved solid (TDS) ranged from 20.3 - 964 µS/cm, while the confined groundwater had a pH of 4.01 - 9.95 and a TDS of 28 – 2,670 µS/cm. Groundwater facies vary widely, generally dominated by Na and bicarbonate ions. Brackish groundwater was found in confined aquifers in two locations, namely Asam Jaya and Mekar Sari, indicating that the research area has the potential of sea water intrusion.

Keywords: Groundwater, Hydrochemical, Seawater Intrusion, Potential

Introduction

Many experts have developed hydrochemical studies, including to see the processes that occur during groundwater flow. Hydrochemical indicators can be used to evaluate the quality of water resources as well as helping to develop conceptual hydrogeological models. This model shows the main hydrogeological characteristics and control factors that are useful for a water management program (Mohammadzadeh et al, 2020). Hydrochemical processes as well as various variables that control groundwater quality can also be approached based on hydrochemical characteristics. Geochemical studies by looking at the main variations in the ionic content of groundwater can identify several geochemical processes and the factors that control them (Chandrasekar et al, 2019). Hydrochemical studies can also be used to look at groundwater contamination, in particular base the pH and TDS variables (Listyani & Peni, 2020). The contamination contamination also often occurs because of sea water intrusion.

This article wants to discuss groundwater hydrochemistry in relation to the potential for seawater intrusion in the Tanah Laut area, South Kalimantan. It seems that the sea water intrusion has been done in the research area, therefore the potential of this phenomenon will be important to know. If there is an indication of the potential for seawater intrusion, further prevention is necessary

The hydrochemical study of groundwater was carried out in the Pagatan Groundwater Basin area, especially in Tanah Laut Regency. This district is located in the southeastern part of South Kalimantan Province (Figure 1). The research area has an area of about 159 ha, with an elevation of 0 - 23 m above sea level (asl), consisting of 4 subdistricts, namely Batu Ampar, Panyipatan, Jorong and Kintap. Due to its position on the seashore and along with the increasing population growth, this area has the potential for sea water intrusion. Therefore, hydrochemical and the potential for seawater intrusion studies need to be carried out in this area.

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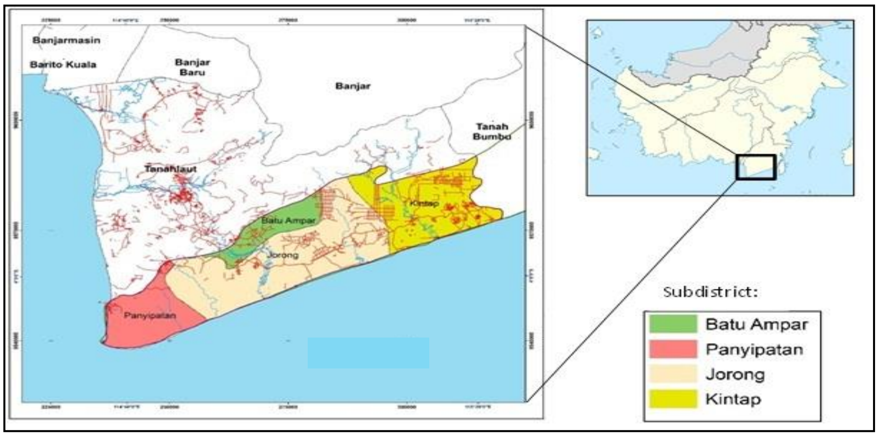


Fig. 1. Research location in Tanah Laut Regency, South Kalimantan.

In facing the plan to move the nation's capital to Kalimantan Island, South Kalimantan Province is the entrance for potential residents or tourists to Kalimantan Island. This of course has an impact on population growth which is also accompanied by increasing water needs. Therefore, a study on the potential of groundwater as an important water resource is very much needed to meet the needs of life and support regional development.

Although brackish groundwater has not been widely found in the research area, groundwater hydrochemical studies are very important to see the quality of water resources. The results of this hydrochemical study can be used as a benchmark for groundwater quality in the initial period. Periodic monitoring is necessary to determine changes in the quality and quantity of groundwater, so that efforts can be made to prevent or control in the phenomenon of pollution.

This hydrochemical study is useful as important information about water resources in Pagatan Groundwater Basin. The results of the study in the Tanah Laut area will later become data that will be combined comprehensively with groundwater data in other areas in the same basin.

Method

Various methods have been developed to determine the origin of salt water. Identification of brine intrusion can be determined based on ion ratio analysis. In a groundwater basin, this process can be a major factor contributing to high salinity and deterioration of groundwater quality (Ebrahimi et al, 2016). Askri et al (2016) investigate the groundwater salinization process in coastal aquifers, and found that there are changes in groundwater along the flow path to the coast from fresh (EC <1,500 µS/cm), brackish (EC: 1,500–3,000 µS/cm) and saline (EC > 3,000 µS/cm). Depletion of Na^+ and K^+ as well as Ca^{2+} and Mg^{2+} enrichment in groundwater can be caused by reverse ion exchange reactions.

The research was conducted using the hydrogeological mapping method in the field, by observing several water sources, including 155 dug wells that tapped groundwater in free aquifers and 30 boreholes that tapped groundwater from confined aquifers. The equipment used is geological field equipment (hammer, compass, GPS) and hydrogeological equipment (water static level, pH-meter and EC-meter).

Measurement of the groundwater level and hydrochemical quality was carried out directly in the field. Groundwater sampling was carried out in selected water sources using polyethylene bottles. Furthermore, the groundwater sample is physically / chemically tested in the laboratory.

Testing of the physical / chemical properties of groundwater from selected samples was carried out at the Geological Agency chemical laboratory, Bandung. This testing of the main ion content is carried out using Standard Methods for The Examination of Water and Wastewater 20th Edition 1998 (SMEWW) and Indonesian National Standardization (SNI) 1991.

Hydrochemical analysis was carried out by looking at the distribution of pH, EC and hydrochemical facies. The charge ion balance is calculated before the data were analyzed, with a reference of <5% (Freeze & Cherry, 1979; Yuan et al, 2017). Hydrochemical analysis was assisted by Aquachem 2010.1 software, while the making of illustrations was assisted by ArcGIS 10.3 software.

Result and Discussion

Geological of Research Area

The research area is composed of several rock formations from oldest to youngest, respectively: Ultramafic Rock (Mub), Tanjung Formation (Tet), Berai (Tomb), Warukin (Tmw), Dahor (TQd) and alluvial deposits (Sikumbang, 1994; Figure 2). The sequence from old to young rock units is: Ultramafic Rock serpentinite unit, Tanjung sandstone unit, Berai limestone unit, Warukin sandstone with claystone and coal intercalation unit, Dahor sandstone unit and alluvial deposits.

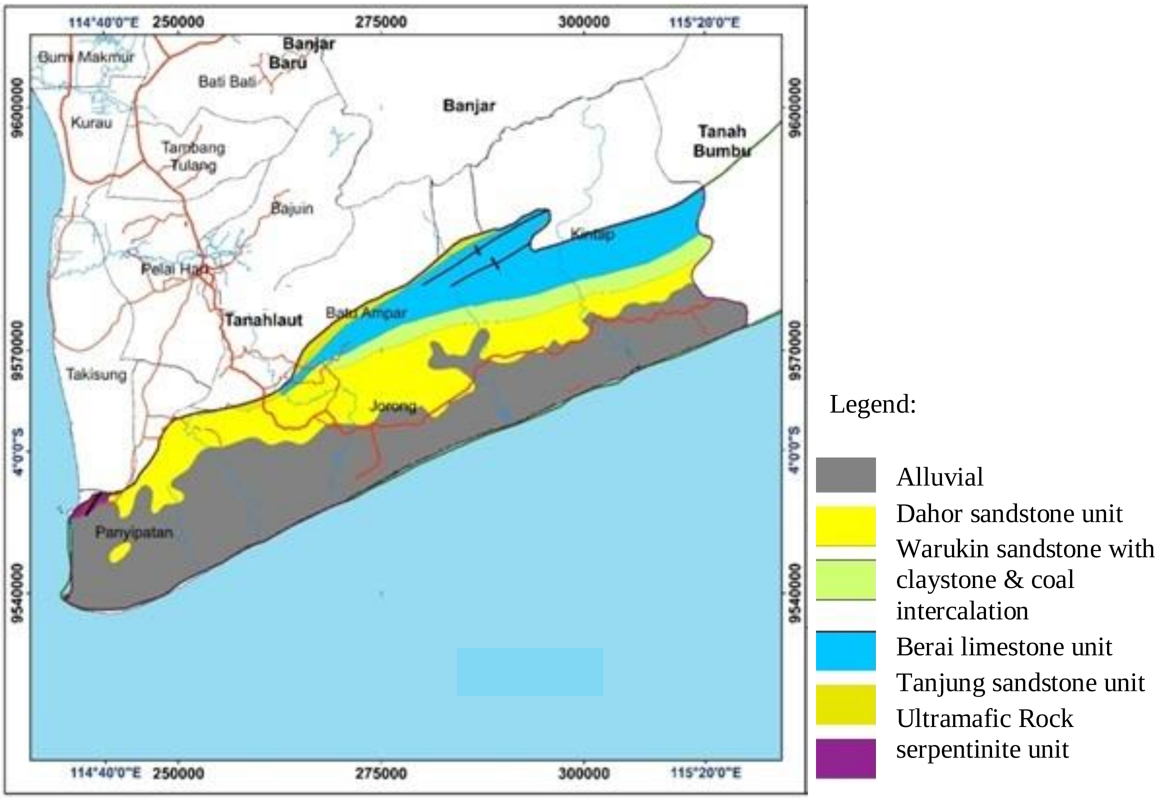


Figure 2. Geological map of research area.

Ultramafic rock serpentinite units have a blackish green color, non-foliation structure, faneric grain size, and euhedral crystal shape. This unit is scattered in the northwestern part of Panyipatan Subdistrict.

The Tanjung sandstone unit is composed of brownish yellow sandstones, medium grain size and massive structure. This formation is spread over Batu Ampar, Jorong, and Kintap Subdistricts.

The Berai limestone unit is mainly composed of yellowish gray limestone and bioclastic limestone. These limestones intersect with marl and sandstones and have a chert composition. This unit is scattered in the central part of Batu Ampar, Jorong, and Kintap Subdistricts.

The Warukin sandstone with intercalation of claystone and coal unit is composed of brownish yellow sandstones, containing quartz and iron concretions, but so brittle. This unit has alternating claystone with a blackish brown color and coal intercalation with a thickness of 2 - 5 cm.

The Dahor sandstone unit is composed of yellowish brown sandstones with a quartz composition. This unit is easily crushed and is sometimes inserted with clay. These rock units are scattered in the middle of the research area, namely in Panyipatan Subdistrict to Kintap Subdistrict.

Alluvial deposits consist of gravel, sand, silt and clay materials. These deposits are found in coastal and river plains. Alluvial deposits are scattered in the southern part of Panyipatan, Jorong, and Kintap Subdistricts.

Groundwater Table

Observations of shallow groundwater levels in free aquifers were carried out in 155 dug wells, namely in Panyipatan (13 wells), Batu Ampar (16 wells), Jorong (68 wells), and Kintap (58 wells) Subdistricts. The measurement in the field show that the groundwater level is at 2.5 - 37.9 m asl. This very shallow groundwater level occurs because the research area is located near the sea.

The results of the groundwater level mapping are presented in Figure 3. This figure shows that the direction of groundwater flow in the study area generally goes to the coastal area, although in Batu Ampar there is a flow pattern that is locally directed to the northeast.

Meanwhile, the measurement of the deep groundwater level in the confined aquifer was carried out in 30 wells, namely in Panyipatan Subdistrict (3 wells), Batu Ampar (2 wells), Jorong (15 wells), and Kintap (10 wells). From the measurements in the field, it is known that the confined groundwater level is at the highest position of 19 m asl in Batu Ampar and the lowest of -23 m asl in Jorong.

The deep groundwater table map is presented in Figure 4. As in free groundwater, groundwater flow in confined aquifers generally also goes to the coastal area, with variations to the southwest, south and southeast. The flow pattern that leads to the north is found in the middle part of Jorong Subdistrict.

The pH Value

The pH value of groundwater characterizes the degree of acidity. Groundwater is stated to be neutral if it has a pH of around 7, or a pH of 6 - 8 which is the range of water quality standards (Putra et al, 2019). Groundwater with a pH of 5 - 7 is said to be weakly acidic to neutral, which characterizes that dissolved carbonates are predominantly in the form of HCO_3 (Adams et al, 2001, in Ako et al, 2012). Meanwhile, sea flow intrusion often results in the pH of groundwater becoming more alkaline. Salt formed from Ca or Mg can react with carbonic acid to form a strong buffer, forming brackish water (Pryambodo et al, 2016) with a relatively alkaline pH.

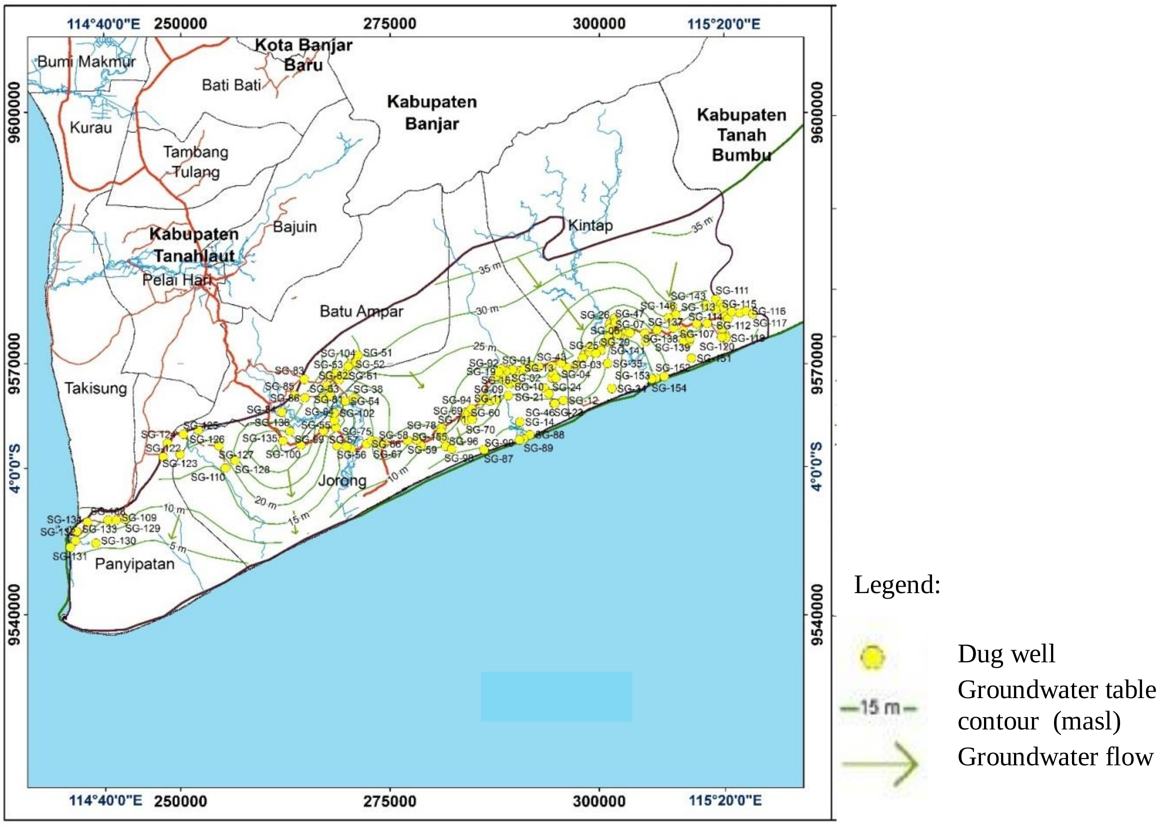


Figure 3. Shallow groundwater table map of research area.

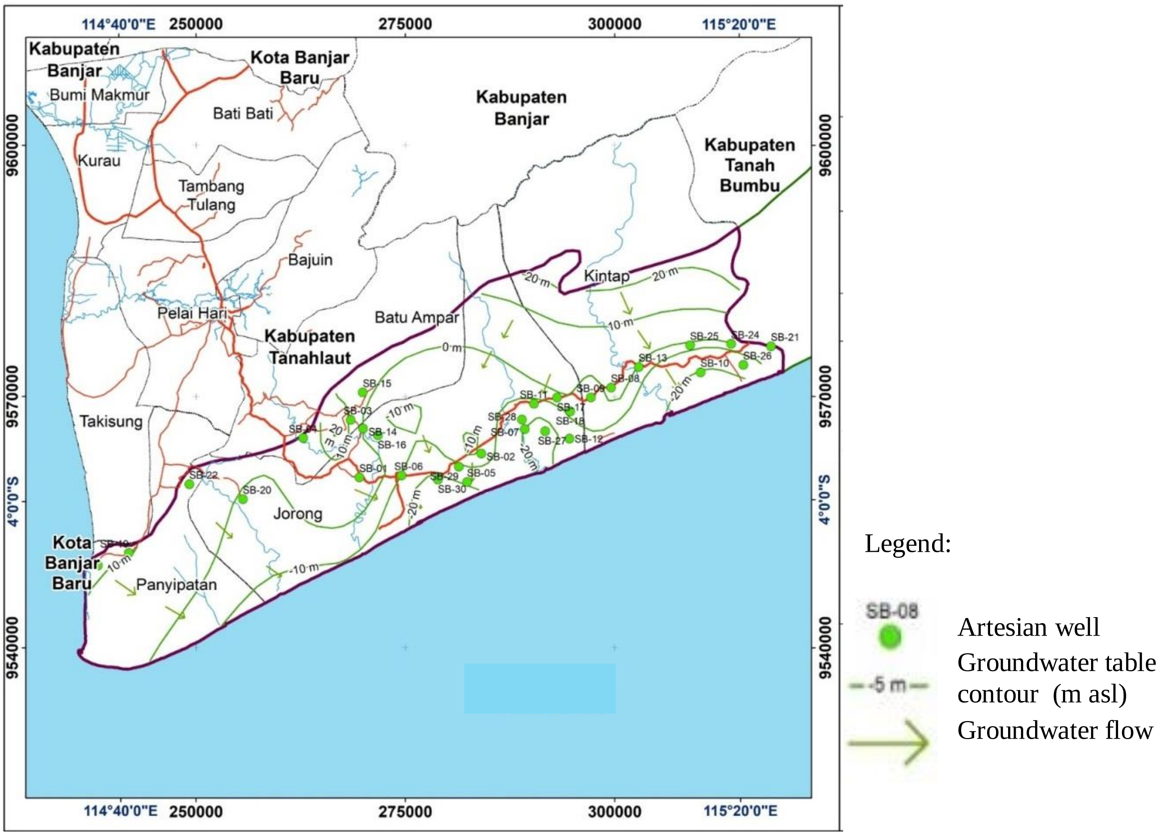


Figure 4. Groundwater table map of confined aquifer

The groundwater in the free aquifer in the study area has a pH of 6.1 - 8.4, while the confined aquifer has a pH of 4.01 - 9.95. This means that the degree of acidity of the groundwater in the study area varies widely, from acidic to alkaline (Table 4; Figures 5 - 6). Groundwater with acidic and alkaline levels shows poor quality, and usually occurs as a result of pollution.

Table l. The pH of groundwater in research area.

Subdistrict	Shallow Groundwater			Deep Groundwater		
	min	max	avg	min	max	avg
Panyipatan	6,8	18	7,4	5,36	6,8	6
Jorong	6,1	28,3	7,6	4,01	58,29	6
Batu Ampar	6,4	38,4	7,5	7,05	69,95	9
Kintap	6,9	48,16	7,49	5,84	7,89	7

[1]SG 129 (Kandangan Lama)
[2]SG 110 (Sabuhur)
[3]SG 106 (Damit)
[4]SG-150 (Sungai Cuka)
[5]SB-05 (Asam Jaya)
[6]SB 23 (Durian Bungkuk)

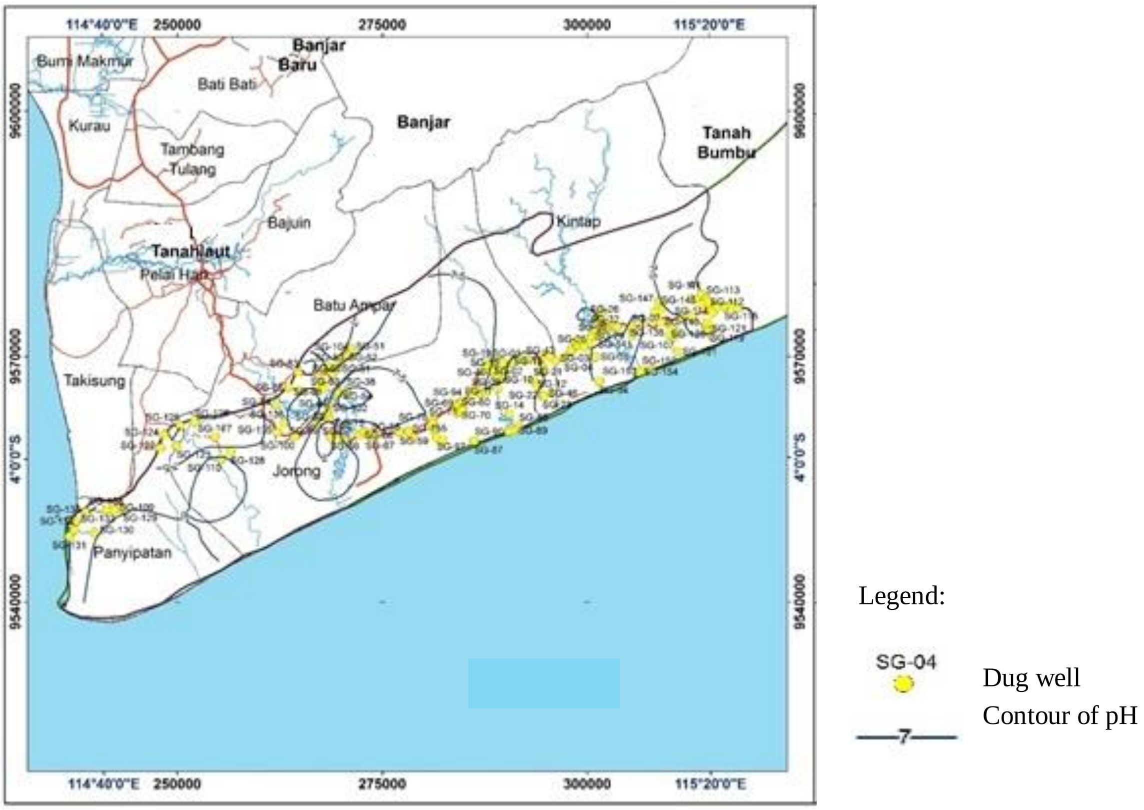
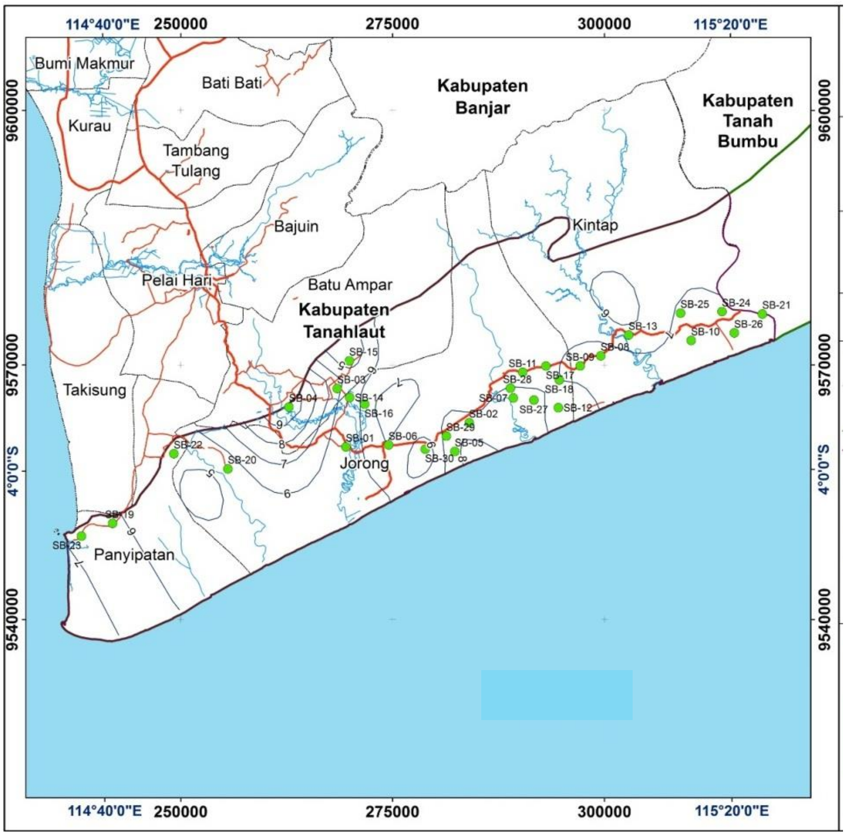


Figure 5. The distribution of pH in free groundwater.

Electrical Conductivity Value

Electrical Conductivity (EC) is a measure of the ability of a substance to conduct electric current (Freeze & Cherry, 1979). The salinity is basically the same as total dissolved solids (TDS) of groundwater (Drever, 1988, in Listyani, 2016). Therefore, the EC and TDS values usually show a similar pattern (Putra et al, 2019). TDS is the amount of all dissolved minerals that are left when all the water is evaporated, or the amount of salt contained in the water (Davis & De Wiest, 1967, in Setiawan et al, 2017).



Legend:

SB-08 Artesian well

—7— Contour of pH

Figure 6. The distribution of pH in confined groundwater.

The EC values of groundwater measured in the field are shown in Table 2. The EC of groundwater values can be used to determine the type and quality of the water, referring to the classification of several previous authors (Table 3).

WHO (2004, in Hadian et al, 2015) provides a limit of EC water of <1500 µmhos/cm as type I water (low salt), and EC of 1500 - 3000 µmhos/cm as type II (medium salt). This means, according to the classification, brackish water has an EC > 1500 µmhos/cm. The TDS limit of 1500 µS/cm can also be used to see the effect of sea water intrusion (Setiawan, 2014)

The results of measurements of EC of groundwater in free aquifers showed a range of values of 20.3 - 964 µS/cm (Figure 7), while the confined aquifer was found to be 28-2,670 µS/cm. Brackish groundwater was found in drilled wells of SB 05 (2,670 µS/cm) in Asam Jaya Village, Jorong Subdistrict and SB 26 (1,820 µS/cm) in Mekar Sari Village, Kintap Subdistrict (Figure 8).

The EC value has a very strong correlation to the total dissolved solid (TDS) value. High TDS can result from mixing or saltwater intrusion. High total dissolved solids levels in saline springs are significantly related to salt-bearing strata. Saline springs may originate from the evaporites (Bo et al, 2015). Meanwhile, in coastal areas, high TDS can indicate sea water intrusion.

Table 2. The EC value of groundwater in research area (µS/cm).

Subdistrict	Shallow Groundwater			Deep Groundwater		
	min	max	avg	min	max	avg
Panyipatan	26,7	555	132,04	46	225	164
Jorong	23,1	492	144,51	28	2670*	494
Batu Ampar	52,4	368	120,62	106	196	151
Kintap	20,3	964	175,77	37	1820**	535

*SB 05 Asam Jaya Village

**SB 26 Mekar Sari Village

Table 3. The water classification based on TDS and EC.

Water type	TDS mg/L			EC (µS/cm) equivalence*
	Freeze & Cherry, 1979	USGS (Hem, 1970 in Setiawan, 2014)	Carroll (1962, in Todd, 1980)	Todd, 1980
Fresh water	< 1,000	< 1,000	0 - 1,000	0 - 1,560
Brackish water	1,000 – 10,000	1,000 - 3,000 (slightly saline)	1,000 - 10,000	1,560 - 15,600
Saline water	10,000 – 100,000	3,000 - 10,000 (moderately saline)	10,000 - 100,000	15,600 - 156,000
		10,000 - 35,000 (very saline)		
Brine	> 100,000	> 35,000	> 100,000	> 156,000

* TDS of 1 mg/L ~ EC of 1,56 µS/cm

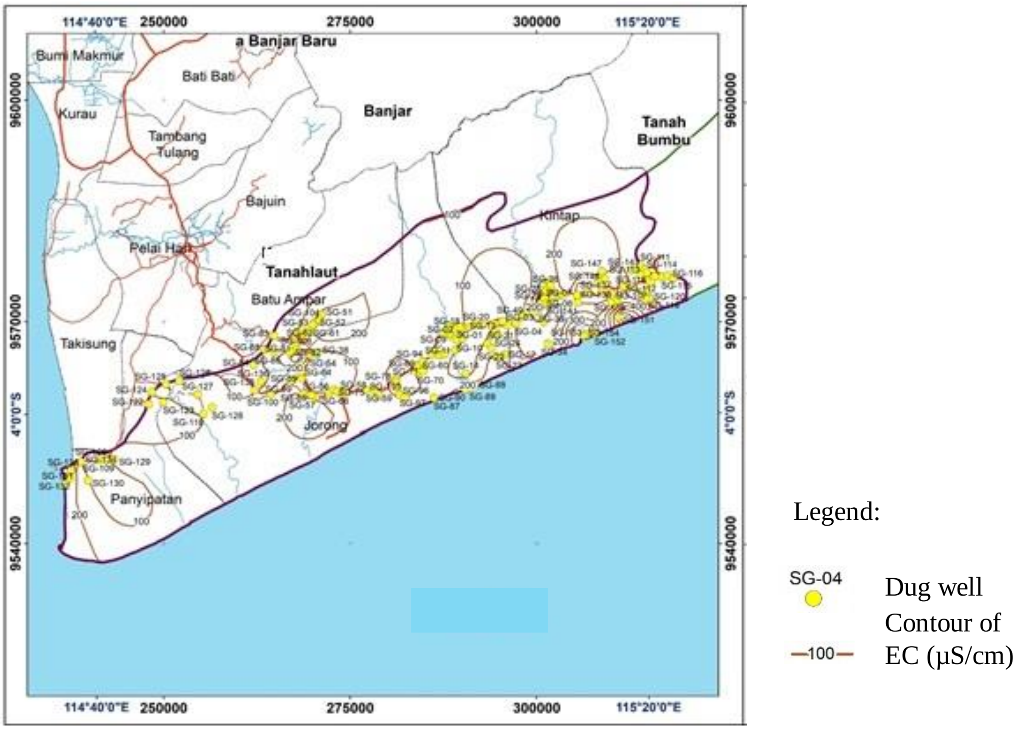


Figure 7. Iso-EC map of free groundwater in research area.

Hydrochemical Facies of Groundwater

The chemical type or groundwater facies characterizes the processes that occur in groundwater flow below the surface. Analysis of the groundwater ion content can show the processes that occur in the groundwater flowpath. The results of hydrochemical analysis of ionic composition, organic matter and mineralization show low ionic content in lake water and possible hydrochemical enrichment associated with seawater (Onishchuk et al, 2020).

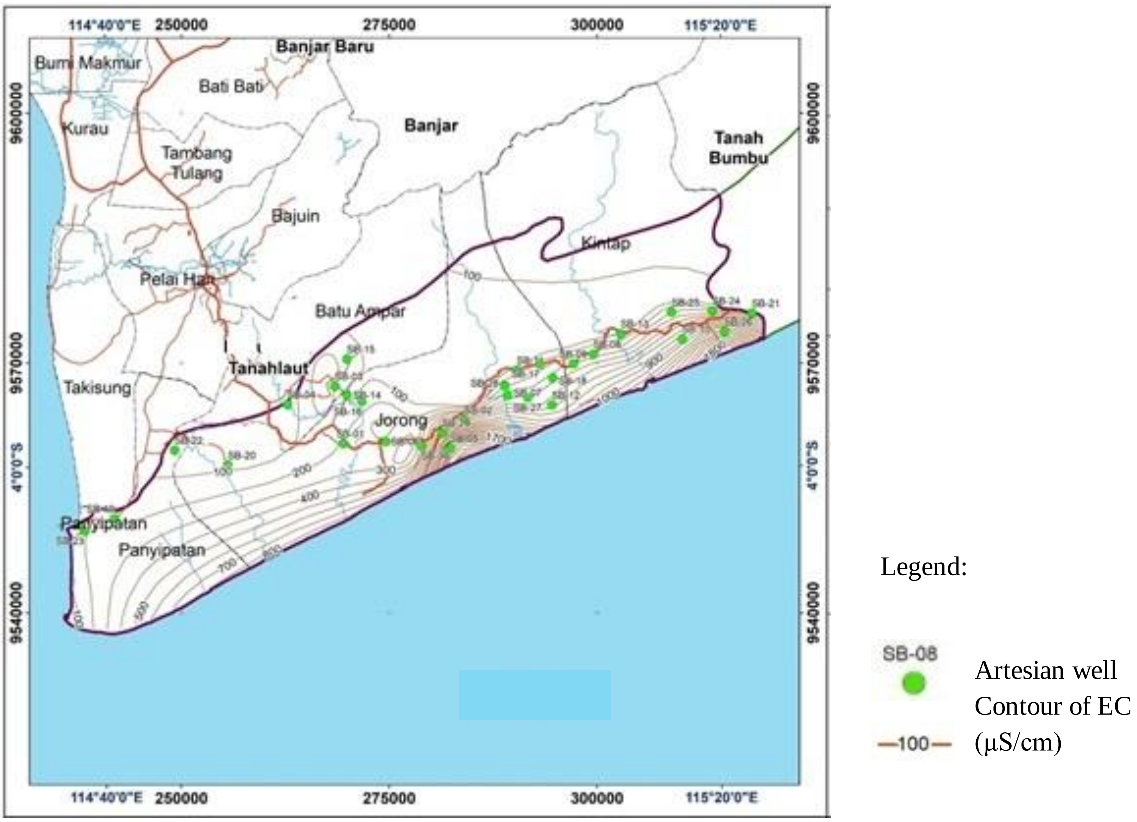


Figure 8. Iso-EC map of confined groundwater in research area.

The USGS classification (Hem, 1970 in Setiawan et al, 2017) states that fresh water usually has a Ca-HCO_3 facies, whereas the Na-HCO_3 facies indicate fresh to slightly salty water, and the Na-Cl facies indicate salty - very salty water. Groundwater which is classified as Na-HCO_3 is mostly found in free and confined groundwater, but based on its TDS value, the groundwater is still fresh. The facies that are close to Na-Cl are found in SB 05, although there is also still a predominance of bicarbonate ions.

The results chemical laboratory tests of free groundwater in the study area have many variations of chemical types, with different predominance of main ions (Table 4). Sodium is the dominant cation in some shallow groundwater samples, while the dominant anion is bicarbonate (HCO_3^-).

The Potential of Seawater Intrusion

The hydrochemical processes can be interpreted from the chemical facies of the groundwater. The type of process that often occurs in coastal areas is mixing. The content of major ions in mine water is enriched by mixing processes with saline waters from deep rock layers. Meanwhile, the hydrochemical effects of diluting rainwater can occur in springs and small rivers (Bozau et al, 2017). The mixing process can also take place in the mine and geothermal area. In mine area, both surface water and groundwater vary in its geochemical. Before and after the remediation, surface water and groundwater have an acid-to-alkaline pH, which decreased with the remediation, whereas Eh increased (Neiva et al, 2015). The mixing process affects the chemical type of cold water. Cold water was Na-K-HCO_3 type, indicating the influence of deep groundwater by iron exchange, while non mixing cold water was type Ca-HCO_3. In general, the hydrochemistry of cold water close to hot water changes significantly due to the direct mixing of hot and cold water (Jayawardana et al, 2016). Meanwhile, ion exchange processes often occur in coastal aquifers.

Table 4. Chemical facies of groundwater in research area.

Subdistrict	Shallow Groundwater		Deep Groundwater	
	Sample Code	Chemical Type	Sample Code	Chemical Type
Panyipatan	SG-108	Na, K – Cl, HCO_3	SB-19	Ca, Na - HCO_3
	SG-122	Na,Ca – Cl, HCO_3	SB-22	Na, Ca – Cl, HCO_3
	SG-131	Ca - HCO_3	SB-23	Na, Ca, Mg - HCO_3
Jorong	SG-09	Na,Ca - Cl	SB-01	Na, Ca – Cl, HCO_3
	SG-11	Na, Ca, Mg – Cl, HCO_3	SB-02	Na, Ca - HCO_3
	SG-14	Mg, Na – Cl, HCO_3	SB-05	Na – Cl, HCO_3
	SG-21	Ca – Cl, HCO_3	SB-06	Na, K, Mg - HCO_3
	SG-44	Ca, Mg - HCO_3	SB-07	K, Na - HCO_3
	SG-62	Ca, Mg - HCO_3	SB-11	Na, K - HCO_3, Cl
	SG-65	Na, Ca – Cl, HCO_3	SB-12	Ca, Na, Mg - Cl
	SG-68	Na, Ca, Mg – Cl, Ca, Mg - HCO_3, SO_4	SB-14	Na, K – Cl, HCO_3
	SG-77	Na, Ca - Cl	SB-15	Na, Ca - Cl
	SG-87	Na, Ca – Cl, SO_4	SB-16	Ca, Na, Mg - HCO_3
	SG-92	Na, Ca – Cl, HCO_3	SB-17	Na, Ca - HCO_3, Cl
	SG-93	Na, Ca – Cl, HCO_3	SB-18	Na - HCO_3
	SG-95	Na, Ca, Mg – Cl, HCO_3	SB-20	Na, Ca – Cl, HCO_3
	SG-102	Na, Cl - HCO_3	SB-27	Na - HCO_3
	SG-110	Na, Ca – Cl, HCO_3	SB-28	Na - HCO_3
			SB-29	Na - HCO_3
			SB-30	Na, Ca – Cl, HCO_3
Batu Ampar	SG-63	Na, Ca – Cl, HCO_3	SB-03	Ca, Cl - HCO_3
	SG-84	Na, Ca, Mg – Cl, HCO_3	SB-04	Na, Ca - HCO_3
Kintap	SG-08	Na, Cl - HCO_3	SB-08	Na - HCO_3
	SG-25	Ca, Mg - HCO_3, SO_4	SB-09	Na, Ca - HCO_3
	SG-27	Na, Ca - HCO_3, Cl	SB-10	Na - HCO_3
	SG-31	Na, Ca – Cl, HCO_3	SB-13	Na, Ca – Cl, HCO_3
	SG-36	Na, Ca - Cl	SB-21	Na - HCO_3
	SG-111	Na, Ca - HCO_3	SB-24	Na - HCO_3
	SG-139	Na, Ca – Cl, HCO_3	SB-25	Na, K, Mg - HCO_3
	SG-146	Na, Ca - Cl, HCO_3	SB-26	Na, Ca - HCO_3
	SG-151	Na, Ca – Cl, HCO_3, SO_4		
	SG 153	Na - HCO_3, Cl		

Tanah Laut Regency is an area located on the seashore bordering the Java Sea, therefore the potential for seawater intrusion is easily occur. The phenomenon of seawater intrusion is characterized by the presence of brackish water. Although the presence of brackish water is not common, seawater intrusion must be monitored and anticipated because this process results in groundwater contamination.

The presence of seawater intrusion will increase the salinity of fresh groundwater on land. This salinity can be measured from the variable TDS or EC of groundwater. The presence of brackish groundwater can indicate seawater intrusion. However, high salinity of groundwater may also be formed prior to human or fossil water (Iwaco et al, 1994 in Listyani, 2016). Therefore, the study of the potential for seawater intrusion needs to be studied from various aspects. The potential for seawater intrusion may also be seen from the main ion content in groundwater, for example by looking at the Na-Cl ion ratio (Bear et al, 1999, in Putra et al, 2020).

The potential for seawater intrusion in groundwater aquifers in the study area is indicated by the presence of brackish water in the confined aquifer as shown in Table 5.The results of the field survey showed that there was brackish water in two bore wells, namely in Asam Jaya Village, Jorong Subistrict (SB 05) and Mekarsari, Kintap Subdistrict (SB 26). Brackish groundwater is only found in confined aquifers, while groundwater in free aquifers in all locations is still fresh.

One indication of seawater intrusion is the pH of alkaline groundwater, as shown in groundwater of SB 05 (pH 8.29) and SB 26 (pH 7.8). The pH value of seawater is generally alkaline (7.6 - 8.3) (Brotowidjoyo et al, 1995, in Pryambodo), therefore, groundwater that experiences seawater intrusion tends to be more alkaline than freshwater.

The potential for intrusion is also indicated by the presence of brackish water, which is indicated by a fairly high TDS value. The TDS value of groundwater in SB 05 is known to be 2,670 µS/cm, while in SB 26 it is 1,820 µS/cm. Thus, based on the TDS value, the two wells showed brackish groundwater in the confined aquifer. This is also supported by the groundwater facies in SB 05 where chloride ion is the dominant anion. The groundwater facies at SB 26 are still dominated by bicarbonate ions, so the indication of sea water intrusion is less strong. However, because the Tanah Laut area is a rapidly developing area, the potential for seawater intrusion must still be noticed. Moreover, the Asam Jaya region is an industrial area which of course needs a lot of groundwater, so the potential for seawater intrusion in this area is quite large and needs to be anticipated.

Table 5. The presence of brackish water is an indication of potential seawater intrusion in the study area.

Location	Well number	pH	TDS (µS/cm)	Chemical Type	Landuse
Asam Jaya, Jorong	SB 05	8.29	2,670	Na - Cl, HCO_3	Industrial
Mekar Sari, Kintap	SB 26	7.8	1,820	Na, Ca - HCO_3	Fishery cultivation area

Conclusion

Tanah Laut Regency has the potential for groundwater that develops in both free and confined aquifers. In all of these aquifers, groundwater generally flows towards the coast. This groundwater has a wide variety of hydrochemical properties. This variation is shown from several aspects, including pH, EC and groundwater facies.

The groundwater in the free aquifer shows a pH of 6.1 - 8.4, while the confined aquifer shows a pH value of 4.01 - 9.95 which means that the groundwater in all aquifers is acidic to alkaline. Meanwhile, the TDS of groundwater in the free aquifer is known to be 20.3 - 964 µS/cm and in the confined aquifer is 28-2,670 µS/cm.

From the TDS value, it is known that there is brackish groundwater in confined aquifers, namely in the Asam Jaya and Mekar Sari areas. Groundwater facies in the study area developed with various variations, with the dominance of Na and bicarbonate ions. The presence of brackish groundwater in Asam Jaya with Na - Cl and HCO_3 facies indicates that the research area has the potential for seawater intrusion, especially because the area is developing as an industrial area.

The numerous data of groundwater hydrochemistry will be better to collect in periodical time to anticipate sea water intrusion in the research area. In addition, population growth and land use development also need to be controlled to prevent sea water intrusion.

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