JURNAL geografi

https://jurnal.unimed.ac.id/2012/index.php/geo/article/view/49619
https://doi.org/10.24114/jg.v16i1.49619 - (Vol 16, No 1 – 2024)
available at http://jurnal.unimed.ac.id/2012/index.php/geo
e-issn (2549-7057) & p-issn (2085-8167)

Analysis of Groundwater Salinity Levels in the Lampulo Coastal Area Kuta Alam Sub-District

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ARTICLE INFO
Article History:
Received: August 07, 2023
Revision: January 16, 2024
Accepted: Februari 22, 2024

Keywords:
Salinity
Groundwater
Phreatic Well
Seawater Seepage
Grid Sampling

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ABSTRACT
The problem of seawater seepage in coastal areas can result in a decrease in groundwater quality due to the mixing of seawater and groundwater, so seawater seepage has an impact on increasing salinity, including in the research area. The research location is in the Lampulo beach area, Kuta Alam sub-district. Phreatic well water is generally not liked by residents of this coastal area because it tastes brackish. The high salinity of phreatic groundwater is caused by seawater seepage into alluvial land. The aim of this research is to analyze the level of groundwater salinity in the Lampulo coastal area, Kuta Alam sub-district. This research uses a grid sampling method and criteria for assessing groundwater salinity (°/oo) based on salt content. Groundwater salinity was measured randomly in 50 phreatic wells using a refractometer and marked with sample coordinates using the Avenza Maps application. Field measurement results show that there are variations in salinity values ranging from 0 to 32 ppt. Phreatic well water at the research location based on its salt content is grouped into three groups, namely fresh water, brackish water and salt water. For the freshwater group, a percentage value was obtained with a prevalence of 68%; for the brackish water group, a percentage value was obtained with a prevalence of 26%; and for the salt water group, a percentage value was obtained with a prevalence of 6%.

INTRODUCTION

Groundwater is the world's largest freshwater resource. Almost 50% of drinking and 43% of irrigation water come from aquifer fields (Rojas et al., 2023). However, human dependence on groundwater significantly impacts subsurface water tables and aquifer deviations. Groundwater is classified into two categories, namely shallow and deep. Shallow groundwater is up to 15 meters deep, while deep groundwater is more than 15 meters deep (Riyanti et al., 2022). Between 1960 and 2010, for example, global groundwater depletion was estimated to be no less than 7 trillion m3 due to various factors (Rusli et al., 2023). Climate change and increasing human impacts on the environment are putting pressure on groundwater resources both in quantity and quality. Over the last decade, groundwater extraction has tripled and continues to increase at around 2% per year (Fraser et al., 2020).

This research brings innovation to analyzing groundwater salinity levels in the Lampulo coastal area, Kuta Alam sub-district. Through a new approach, this research tries to respond to the complexity of groundwater quality challenges faced by coastal communities. The update to this research is to introduce an innovative hydrogeology model to analyze the direction of groundwater flow. Involving a more realistic aquifer layer structure, this model provides a deeper understanding of the influence of topography on groundwater flow, which can then be linked to measured salinity levels. By mapping the dynamics of groundwater level changes, this research provides a two-dimensional visual depiction of water flow patterns from high to low points. By involving more comprehensive visualization, this mapping can contribute to understanding changes over time and identifying areas prone to high salinity levels.

Seawater seepage in coastal areas can lead to a decrease in groundwater quality. Due to the mixing of seawater and groundwater, seepage of seawater increases the salinity (salt content) of the groundwater (Muchlis et al., 2021). Seawater seepage in coastal areas may occur due to a decrease in the water table, which results in groundwater extraction. The mixing of seawater, which is quite salty (salt water), with groundwater, occurs in the dispersion zone due to the influence of seawater seepage. Therefore, this zone will impact groundwater availability in the aquifer (Muhardi et al., 2020). Land use, such as ponds, can cause seawater seepage. Because seawater can easily flow ashore through the surface or beneath the surface of the land, ponds in coastal areas significantly impact seawater seepage implementation by causing excessive groundwater salinity (Nurrohim et al., 2012).

The amount of salt dissolved in water is called salinity. The total ion concentration in water is known as salinity. Salinity is expressed in units per mil (°/oo) and parts per thousand fields (Gusman et al., 2020). Salinity can also refer to the salt content of the soil. Effendi (2004) in (Armis et al., 2017) defines salinity as the amount of salt dissolved in water, temperature, pH, and substrate. Salt is one of the physical and chemical properties of water. Salt is a group of ions that dissolve in water, including table salt (NaCl). The seven main ions that produce salt are sodium (Na), chloride (Cl), calcium (Ca), magnesium (Mg), potassium (K), sulfate (SO4), and bicarbonate (HCO3). Most lakes, rivers, and natural streams have very little salt content, so the water in these areas is classified as fresh water.

The amount of salt in one kilogram of water is used to calculate salinity. In real life, fresh water has 0.5 o/o salt, while drinking water has a maximum salt content of 0.2 °/oo. Other sources state that the highest salinity of fresh water is one °/oo, the salinity of drinking water is 0.5 °/oo, and the average salinity of seawater is 35 °/oo (Armis et al., 2017). Factors affecting salinity are evaporation and rainfall. Regarding evaporation, the higher the seawater's evaporation rate in an area, the higher the salinity, and vice versa. In terms of rainfall, the salinity of water in an area of the sea decreases with increasing rainfall, and conversely, with decreasing rainfall, the salinity will increase later (Pasaribu et al., 2023).

Gampong Lampulo is one of the gampongs managed by the city government of Banda Aceh. It is located in the Kuta Alam sub-district and outside the Krueng Aceh route, which is connected to the sea. Land in Lampulo Village is mostly used for shrimp cultivation in the field (Afriyani et al., 2023). One of the villages is Gampong Lampulo, with around 5,583 people. It is divided into four hamlets: Teuku Tuan Dipulo Hamlet, Malahayati Hamlet, Teuku Teungoh Hamlet, and Teuku Disayang Hamlet. On the coast of Lampulo, well water is widely used for daily activities such as bathing, washing, and other needs. Because of its salty taste, phreatic healthy water is generally not liked by residents of this coastal area. The need for groundwater use will increase along with the increase in population and activities in coastal areas (Afriyani et al., 2020).

Fishing ports, limited settlements, ponds, and mangroves are some of the land uses in the coastal area of Lampulo, Kuta Alam sub-district. The groundwater in the coastal area of Lampulo becomes brackish due to ponds that drain seawater to the mainland and accelerate the rate of seawater intrusion. The aims of this study included analyzing the level of groundwater salinity in the coastal area of Lampulo, Kuta Alam sub-district.

RESEARCH METHODS

The research was conducted in the coastal area of Lampulo, Kuta Alam sub-district, Banda Aceh City, and Aceh Province. Geographically, Gampong Lampulo is surrounded by four other villages: Gampong Lamdingin in the east, Gampong Gano in the north, Gampong Mulia in the south, and Gampong Jawa in the west. The research object is devoted to groundwater by collecting samples from phreatic wells to calculate the salinity value using the Grid Sampling method. The Grid Sampling method suits flat topography areas such as coastal areas. The advantage of this Grid Sampling method is localization accuracy, which allows researchers to locate each sample point accurately, providing high precision in the localization of particular objects or phenomena (Afriyani & Gadeng, 2023).

Sampling is used to obtain phreatic well data as basic data for making flow networks and determining groundwater samples to be taken. The research time is June 2023, with groundwater sampling from morning to noon when the weather is sunny. Water salinity was measured using an AMTAST RHS10ATC salt refractometer with a range of weight: 1.000–1.070 and salinity: 0–100 º/oo. The research location is 5° 34′ 44″ N and 95° 19′ 23″ E. The following is a map of where the research can be observed in Figure 1.

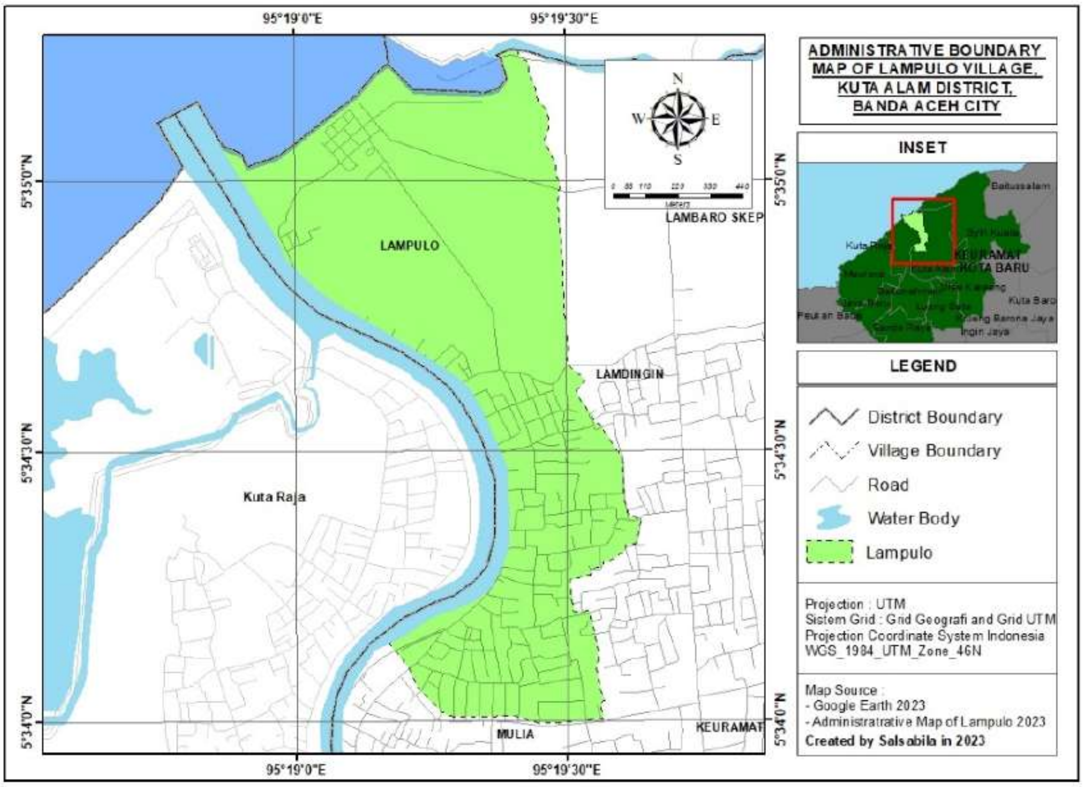

Figure 1. Administrative Map of The Research Location

Research begins with data collection. These include determining phreatic well sampling points, marking the coordinates of wells using Avenza Maps, and measuring phreatic well water salinity values. Sampling points are determined by creating a grid box in ArcGis, which is then determined or sampled based on the grid sampling position. Each grid in the research area is 50 × 50 m^2. To mark coordinate points on the grid that has been sampled, use Avenza Maps. These coordinates are then processed using ArcGIS to map the distribution of salinity values in the field. Processing and analysis of salinity data according to the salinity classification table. As can be seen from Figure 2, a map of the research site using a grid box, Table 1, criteria for assessing groundwater salinity based on salt content.

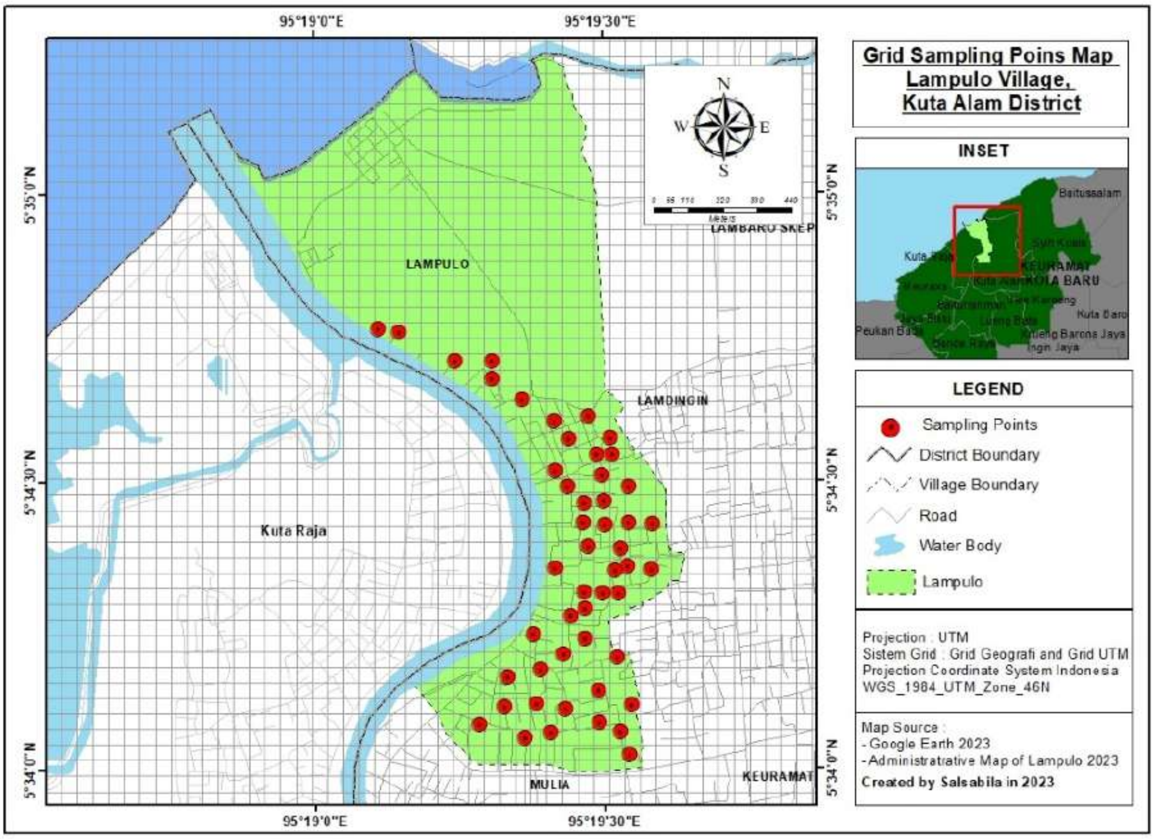

Figure 2. Map of Research Locations with Grid Sampling

Table 1. Criteria for Assessing Groundwater Salinity (o/oo) is Based on Salt Content

Freshwater	**Brackish**	**Saline**	**Brine**
< 0,5	0,5 – 30	30 – 50	> 50

Source: Prihartanto, 2017

RESULTS AND DISCUSSION

The increase in salinity values in groundwater occurs due to pollutants entering and mixing with fresh groundwater (Todd & Mays, 2005). According to Geyben-Herzberg's law, underground water in coastal areas does not mix with seawater under natural conditions. According to this law, an interface (border zone) is formed when underground freshwater meets seawater in a coastal aquarium (Musnawir, 2001; Indahwati et al., 2012). The difference in specific gravity between salt water (1.025 g/cm^3) and freshwater (1,009 g/cm^3) is due to the formation of an interface (Purnama, 2010; Todd & Mays, 2005 in (Maulana, 2016).

Judging from hydrogeological conditions, Gampong Lampulo has fresh, brackish, and salty groundwater. Gampong Lampulo is one of the villages in the Kuta Alam sub-district, which has two geological formations, namely the alluvium rock formation and the tuffa muria rock formation. Salinity in phreatic well water in coastal areas is used to assess groundwater salinity. Field measurements are carried out in alluvial rock formations, free aquifers directly adjacent to the sea, where the soil material is sandy clay. Salinity testing was carried out at 50 observation points in Gampong Lampulo, as in Table 2.

Table 2. Groundwater Salinity Values on the Lampulo Coast, Kuta Alam Sub-District

Sample	Coordinate		High Groundwater Level	Salinity (o/oo)	Elevation	Information
	X	Y				

1	95.323996	5.571128	1,42 m	0,1	3m	Freshwater, clear, doesn't smell
2	95.324404	5.571798	3,61 m	0	5m	Freshwater, clear, doesn't smell
3	95.324949	5.571771	1,75 m	0	3m	Freshwater, clear, doesn't smell
4	95.325371	5.571765	1,06 m	0	2m	Freshwater, clear, doesn't smell
5	95.325663	5.572545	3,66 m	0,1	5m	Freshwater, clear, doesn't smell
6	95.326347	5.572444	1,97m	0	3m	Freshwater, clear, doesn't smell
7	95.326363	5.573756	3,99 m	0,2	5m	Freshwater, clear, doesn't smell
8	95.325288	5.572427	3,07 m	0	4m	Freshwater, clear, doesn't smell
9	95.324420	5.571318	2,68m	0	4m	Freshwater, clear, doesn't smell
10	95.323858	5.568411	6,37m	0	7m	Freshwater, clear, doesn't smell
11	95.324818	5.568037	4,2m	0	5m	Freshwater, clear, doesn't smell
12	95.325413	5.567764	6,03m	0	7m	Freshwater, clear, doesn't smell
13	95.325751	5.568523	6,78m	0	8m	Freshwater, clear, doesn't smell
14	95.325703	5.567099	6,31m	0	7m	Freshwater, clear, doesn't smell
15	95.322184	5.569370	4,47m	0	5m	Freshwater, clear, a little smell
16	95.324545	5.576882	4,15m	2	5m	Brackish, clear, doesn't smell
17	95.325157	5.576249	4,83m	0,5	6m	Brackish, clear, doesn't smell
18	95.325206	5.575781	6,14m	0,6	7m	Brackish, clear, doesn't smell
19	95.324785	5.575779	4,99m	1	6m	Brackish, clear, doesn't smell
20	95.322621	5.577364	3,3m	1	4m	Brackish, clear, doesn't smell
21	95.321757	5.577979	6,24m	0,5	8m	Brackish, turbid, doesn't smell
22	95.321770	5.578488	4,92m	1	7m	Brackish, turbid, doesn't smell
23	95.320700	5.578486	3,72m	31	5m	Saline, clear, doesn't smell
24	95.319070	5.579320	2,36m	32	4m	Saline, clear, doesn't smell
25	95.318477	5.579408	1,67m	31	3m	Saline, clear, a little yellow, doesn't smell

26	95.324927	5.575168	6,13m	1	7m	Brackish, a little yellow, doesn't smell
27	95.323979	5.576242	2,24m	0,5	4m	Brackish, a little yellow, doesn't smell
28	95.323538	5.576733	3,66m	1	5m	Brackish, clear, doesn't smell
29	95.323573	5.575294	2,59m	0,5	5m	Brackish, clear, doesn't smell
30	95.323923	5.574867	3,385m	0,6	5m	Brackish, clear, doesn't smell
31	95324411	5.574374	4,9m	0,2	6m	Freshwater, clear, doesn't smell
32	95.324978	5.574423	3,55m	0	5m	Freshwater, clear, doesn't smell
33	95.325684	5.574834	4,72m	0	6m	Freshwater, clear, doesn't smell
34	95.325702	5.573798	2,09m	0	3m	Freshwater, clear, doesn't smell
35	95.325454	5.573043	3,53m	0,4	5m	Freshwater, clear, doesn't smell
36	95.324375	5.573794	4,205m	0	6m	Freshwater, clear, doesn't smell
37	95.324995	5.573744	3,42m	0	5m	Freshwater, clear, doesn't smell
38	95.324528	5.573131	5,34m	0	7m	Freshwater, clear, doesn't smell
39	95.323576	5.572506	3,51m	0,6	6m	Brackish, clear, doesn't smell
40	95.322920	5.570567	2,26m	0,3	4m	Freshwater, a little yellow, doesn't smell
41	95.323146	5.569557	4,54m	0,4	5m	Freshwater, clear
42	95.322669	5.567597	5,92m	0	7m	Freshwater, clear
43	95.325335	5.569925	2,16m	0	3m	Freshwater, clear
44	95.324432	5.570457	2,38m	0	4m	Freshwater, turbid, doesn't smell
45	95.322083	5.568498	4,81m	0,1	6m	Freshwater, clear, doesn't smell
46	95.321357	5.567987	3,74m	0	5m	Freshwater, clear
47	95.323011	5.568561	5,06m	0	6m	Freshwater, clear
48	95.323422	5.567750	5,92m	0	7m	Freshwater, clear, doesn't smell
49	95.323780	5.570007	3,67m	0,1	5m	Freshwater, clear, doesn't smell
50	95.324809	5.568954	4,07m	0	5m	Freshwater, clear, doesn't smell

Source: Result of groundwater salinity measurements in the field, 2023

According to (Purnomo & Hakim, 2013), the requirements for clean water will increase when land use changes, especially in communities or industries. If the level of intrusion rises to the point where soil degradation occurs, this condition will be threatened. Settlements in the south and fish auction places in the north continue to dominate land use in the study area. The standard urban areas need around 120 liters per person per day of water, while rural areas need around 60 liters per person per day of water (Fazillah, 2023).

Phreatic well water salinity is a parameter used in research as a phreatic well water quality value. For this study, 50 phreatic wells were taken randomly, with one phreatic well sample point in each grid sampling box. Salinity measurements are prohibited in cloudy or rainy weather because the refractometer cannot read salinity without receiving direct sunlight. Even if it rains, it is not permissible to calculate the salinity of the water because groundwater mixes with rainwater through seepage. This is also related to the varying salinity of tides mixing with rainwater.

The level of groundwater salinity can also be affected by the direction of groundwater flow. Where groundwater concentrated at one point has a high salinity value. The dynamic nature of groundwater in coastal areas is influenced by various elements such as rock porosity, sea distance, groundwater depth, and human activity above (Febriarta, 2020). According to (Indriatmoko, 2018), the structure of the aquifer layer, which becomes relatively flat along the coast, greatly affects the hydrostatic balance of fresh and saltwater flows and underground water flows. There is a dynamic hydrostatic balance between the two groundwater flows, meaning that fresh groundwater from the land can push the salty groundwater out to sea if the flow pressure is higher, and vice versa. Higher seawater pressure combined with a decrease in the balance of fresh underground water flows will cause a push of saltwater into inland aquifer systems.

The flow net map is a picture of groundwater flow in two dimensions. Groundwater forms flow patterns that describe the contour of the groundwater surface as it flows. Gravitational attraction influences the flow of groundwater from high points to low points (Noval et al., 2023). Areas with higher groundwater levels become recharge areas, while areas with lower groundwater levels become runoff areas (Afriyani, 2019). The results of measuring the groundwater level in the study area indicate that the groundwater level is in the range of 1.42 mdpl to 6.78 mdpl. The free groundwater flow direction always corresponds to an area's topography. Groundwater in the study area flows from south to north, starting from settlements (the recharge area) to coastal areas (the discharge area), as shown in Figure 3.

One of the primary sources of saltwater intrusion is groundwater exploitation. Groundwater is the primary source of drinking water in most coastal locations, and extraction has expanded in tandem with the growth of coastal towns. Saltwater intrusion only reaches certain locations in basic conditions because it is limited by the pressure from the freshwater column, which is larger due to its higher position than sea level. Groundwater extraction lowers groundwater column pressure, allowing seawater to flow further inland.

Based on the results of measurements of groundwater samples in the field, it shows that there are variations in salinity values; the salinity measured at 50 phreatic well points in the coastal area of Lampulo ranges from 0 to 32 ppt. The lowest salinity values are found in densely populated residential areas. Groundwater salinity values that are quite high are concentrated close to coastal areas, where there are interactions between land and sea, such as tides. The highest salt content is spread unevenly towards the south. This indicates that there is a suspicion of seepage of seawater on the alluvial land, which causes a high salinity value of 20 ppt.

Higher salinity was found in areas in the north towards the sea compared to areas in the south towards settlements. However, in the south, there is one well near the river bank with a salinity value of 0,6 ppt; the water from this well is classified as brackish water. This can be explained by the fact that the aquifer that carries air is most likely a closed aquifer that still carries sea air traps. If you look at the rock under the tuff alluvial deposit, chances are that it has nothing to do with high salinity because of the rock's influence.

Seawater seepage is seawater subsurface (lateral and vertical) movement onto land towards coastal freshwater aquifers (Benaafi et al., 2023). Seawater seepage in the south is relatively low compared to the north because it does not affect seawater seepage into the groundwater. When viewed from the perspective of the type of rock, which is volcanic rock, namely tufa, this rock factor does not affect the condition of groundwater salinity. Data from salinity measurements in phreatic wells in the coastal area of Lampulo can be grouped into three categories: freshwater, brackish water, and salt water. As can be seen from Table 2 and Figure 4, the results from the analysis of the salinity of well water according to the salt content.

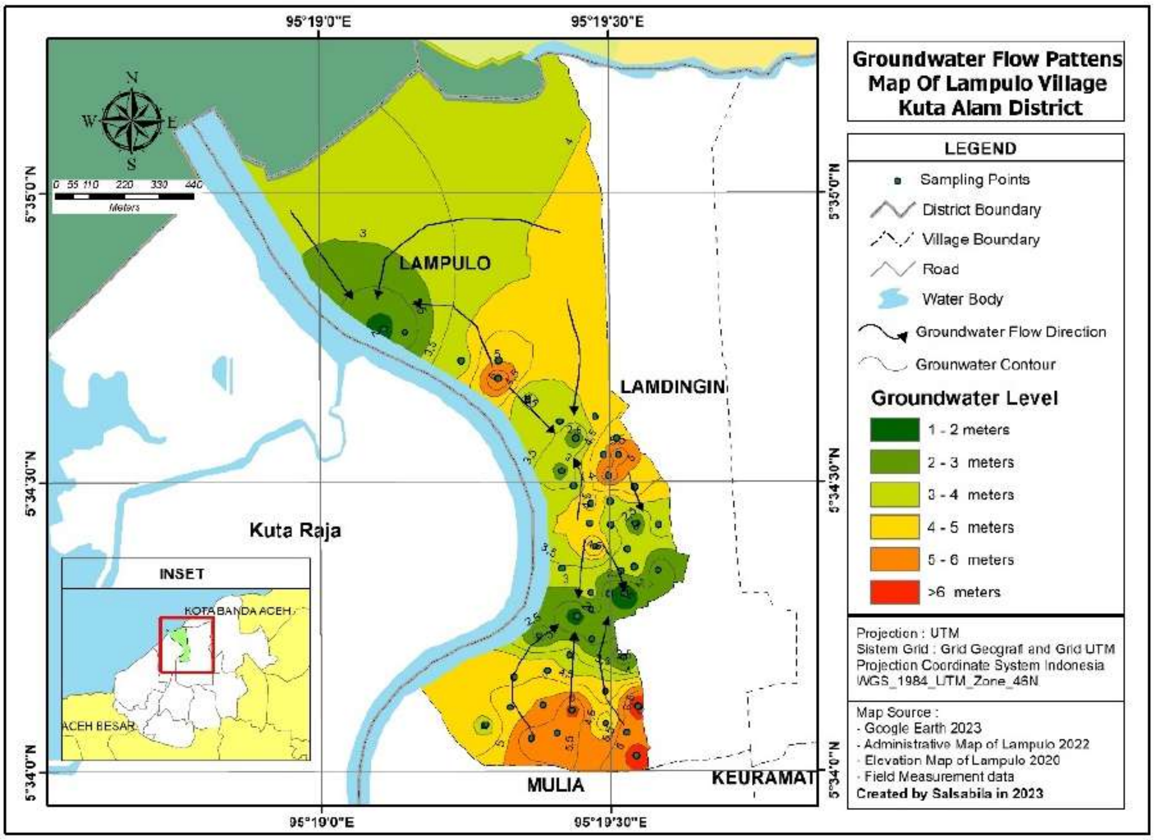

Figure 3. Groundwater Flow Pattern Map

Table 3. Analysis of Phreatic Well Water Salinity Based on Salt Content

Salinity Category (ppt)	Number of Wells	Color Description
Freshwater (< 0,5)	34	
Brackish (0,5 – 30)	13	
Saline (30 - 50)	3	
Brine (> 50)	0	

Source: Annam, 2023

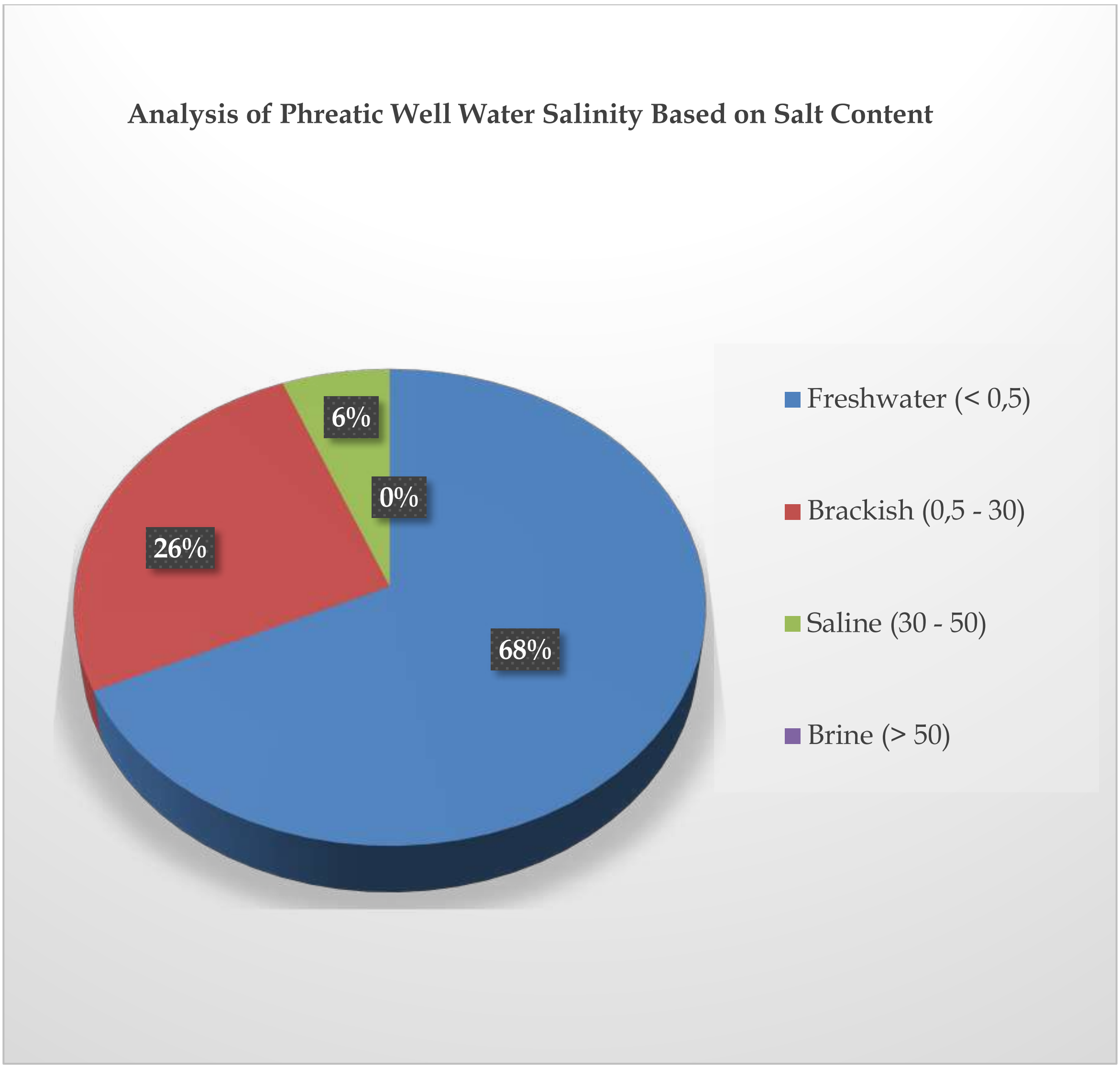

Figure 4. Phreatic well water salinity level based on salt content

According to the results of the analysis of phreatic well water salinity research, such as in the coastal area of Lampulo, Kuta Alam sub-district, no wells are categorized as very salty (brine). So, the results of the explanation table for the analysis of the salinity of well water according to the salt content are categorized into three groups: freshwater, brackish water, and salt water. The measurement results explained that the freshwater group obtained a percentage value with a prevalence of 68%, the salty water group had a percentage value of 26%, and the saltwater group had a percentage value of 6%.

In the Regulation of the Minister of Health of the Republic of Indonesia Article No. 492 of 2010 regarding drinking water quality standards, such as being suitable for direct consumption without further processing and meeting health standards, phreatic well water in the study area, especially in the coastal area of Lampulo, Kuta Alam sub-district, has not met good water quality standards according to the Minister of Health Regulation because it has a high salt content value, even though in the south area the salt content value is lower. However, groundwater in phreatic wells in the study area cannot be used directly by the community. It must first undergo water treatment to determine whether it should be used as drinking or raw drinking water. As can be seen in Figure 5, the results of the analysis of shallow well salinity values according to salt content.

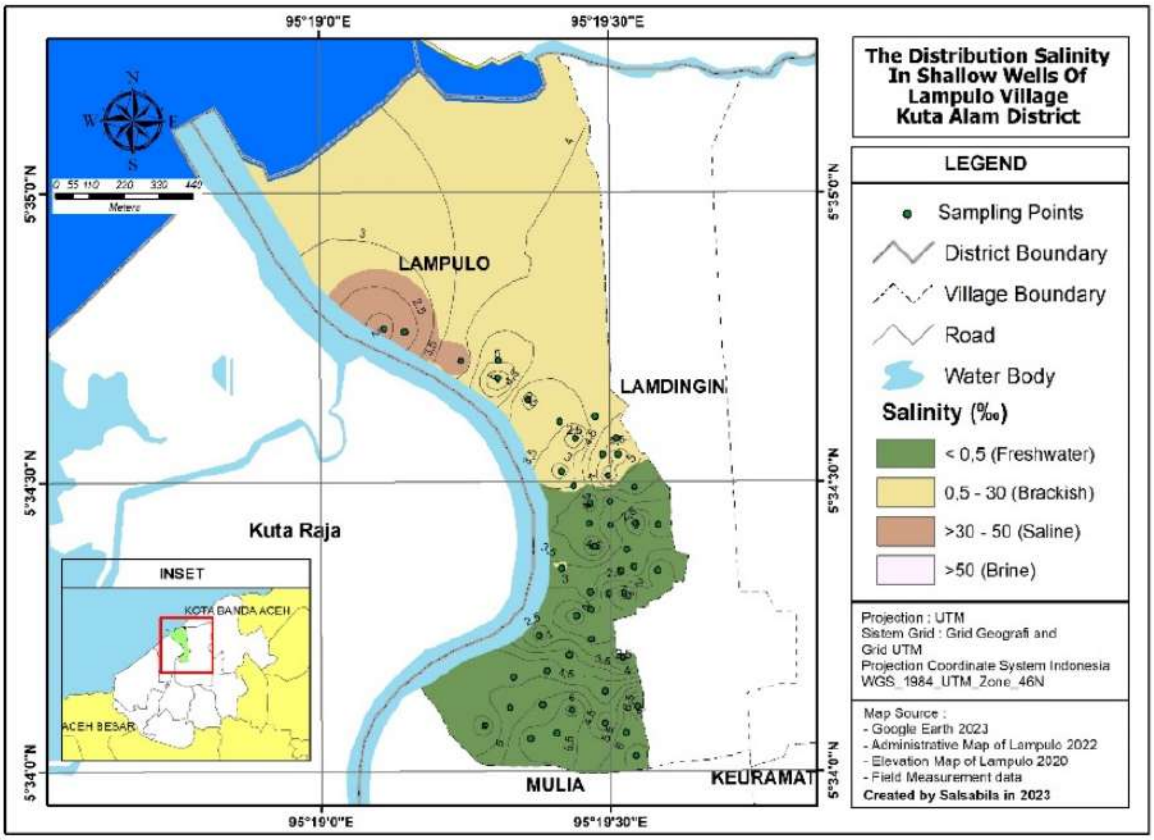

Figure 5. Map the distribution of salinity in phreatic wells Lampulo village Kuta Alam sub-district

CONCLUSION

The results showed that the groundwater salinity in the coastal area of Lampulo ranged from 0 to 32 ppt. The direction of phreatic groundwater flow in the study area flows from the south-north, starting from settlements (recharge areas) towards coastal areas (discharge areas). The high salinity value measured in coastal areas is 32 ppt compared to residential areas, with a low salinity value.

According to the study results, it was measured by proper salt content so that drinking water could be consumed. A total of 50 phreatic wells were obtained in three groups: the freshwater group with a percentage value of 86%, the salty water group with a percentage value of 26%, and the salt water group with a percentage value of 6%. Phreatic groundwater (wells) in the coastal area of Lampulo, Kuta Alam sub-district, are in the categories of fresh water, brackish water, and salt water, so they do not meet the quality and health standards of water according to the regulations drawn up by PERMENKES No. 492 of 2010 Article 1 regarding good water quality and fulfilling health requirements so that it can be drunk directly without any processing mechanism.

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