E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 8 No 4 2023

RESEARCH ARTICLE

Identification of Saltwater Intrusion Distribution in North Padang Cermin Area, Lampung, Indonesia

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Received: Feb 18, 2023; Accepted: Nov 29, 2023.
DOI: 10.25299/jgeet.2023.8.4.12236

Abstract

The residential areas of North Padang Cermin are mainly located near the coastal area with a high level of groundwater use. Continuous groundwater use could potentially raise saltwater intrusion and lead to a decrease in groundwater quality. The research is conducted to identify the saltwater intrusion spread based on groundwater quality data. Geological observations were carried out to determine the geological conditions of the research area, followed by qualitative and quantitative hydrogeological observations by measuring TDS (Total Dissolved Solid), EC (Electrical Conductivity), pH, temperature, color, and taste. The Herzberg method was used to identify freshwater thickness against seawater intrusion.

Hydrogeologically, the research area has four aquifer systems: aquifers with fissure and intergranular flow, aquifers with intergranular flow and wide-distribution productivity, aquifers with fissure and intergranular flow and local distribution, and aquifers with rare groundwater. Groundwater flow has a radial pattern with the most extensive hydraulic gradient with a value of 0.16 m towards the eastern part of the research area.

The indications of seawater intrusion were found in the water samples measurement located on the east of the research area with water type of brackish–salty with a TDS value of 1,443 – 3,790 ppm and an EC of 3,000 – 7,580 (µS). Based on the Herzberg method, the distribution of seawater intrusion is estimated to occur at a depth of 36.8 m.

Keywords: Groundwater, Saltwater intrusion, Herzberg method, North Padang Cermin

1. Introduction

The existence of groundwater is essential to fulfilling the needs of a residential area. Based on 2018 BPS (Statistics Indonesia) data, 1,543 buildings have not been served by PDAM (Local Government-Owned Water Utility) around the Padang Cermin area. The research area is located in North Padang Cermin, with residential areas generally located on the coast side (Fig. 1). Continuous use of groundwater and the position of the research area near the coast are suspected of causing a decrease in groundwater quality (Maghfiroh & Mutadin, 2021; Herdyansyah & Rahmawati, 2017). One of the impacts is the influence of saltwater intrusion that may appear through rivers, drainage channels, and underground water flow (Setiawan, 2017; Noson, 2002).

From geomorphological perspective, the research area is classified as part of the Barisan Mountains, characterized by the morphology of wavy hills and lowlands, which are influenced by tectonic activity (Mangga et al., 1993; Yudhicara et al., 2017; Radityo et al., 2020). Based on the Regional Geological Map of Tanjungkarang (Mangga et al., 1993), the research area consists of several rock formation units, namely Tarahan Formation (Tpot), Lampung Formation (QTl), and Betung Young Volcanic Deposit (Qhv (b)) which are dominated by Tertiary to Quaternary volcanic products.

From hydrogeological perspective, the research area is located in the Bandar Lampung and Pesawaran Groundwater Basins. Based on the Hydrogeological Map of Tanjungkarang (Setiadi & Ruhijat, 1993), the research area has four types of aquifers with lithology dominated by volcanic deposit products. The aquifers in the research area consist of local aquifers with intergranular flow and medium productivity, productive local aquifers, aquifers with fissure and intergranular flow of medium productivity and wide distribution, and aquifers with rare groundwater productivity.

Within the framework of this research, groundwater quality is identified through the value of TDS (Total Dissolved Solid) and EC (Electrical Conductivity) in the research area. The results of TDS and EC measurements are the main parameters for determining the occurrence of seawater intrusion. The research is conducted to identify the distribution of seawater intrusion based on groundwater quality in the North Padang Cermin area.

2. Research Methodology

Geological observations were carried out in the research area by observing lithology, stratigraphy, and geological structure. Geomorphological observations were also carried out to identify the landforms and the developing geomorphic processes. Hydrogeological observations included measuring water samples from several wells and hot springs in the research area.
Measurements were made at 22 wells and one hot spring, including TDS, EC, color, taste, pH, and temperature.

In addition, two suspected wells samples influenced by seawater intrusion are tested with chemical analysis in the form of ions and cations analysis of Cl, Ca, Mg, and Na elements. The greater the Cl and Na ions content in the well's water samples can provide information about any indication of seawater intrusion. Rainwater and river water samples are used to compare the water value from groundwater wells.

Data processing is carried out by integrating geological and hydrogeological conditions to analyze the groundwater flow patterns zone, analysis of freshwater thickness, zone of TDS and EC, and the distribution of seawater intrusion analysis. An isophreatic map aims to determine the groundwater flow based on the similarity of the groundwater table height to the topographical elevation. Interaction when the water table in the aquifer is lower than the average sea level could cause seawater to infiltrate the ground (Listiawan et al., 2014). Freshwater thickness analysis was carried out using the Herzberg method. This method is based on groundwater table data assuming that the aquifer is homogeneous. The following calculation can determine freshwater thickness:

$$PA = PB$$
$$\rho S \cdot g \cdot hs = \rho f \cdot g \cdot hf + \rho f \cdot g \cdot hs$$
$$hs = (\rho f)/(\rho s - \rho f) \ hf$$
$$hs = 40hf \quad \ldots (1)$$

Information from Eqn. 1 including P is hydrostatic pressure, ρ_S is the density of seawater (1,025 gr/cm^3), ρ_f is the density of groundwater (1 gr/cm^3), g is gravitational force (9,8 m/s^2), hs is the seawater level, and hf is the freshwater level, counted from the seawater level.

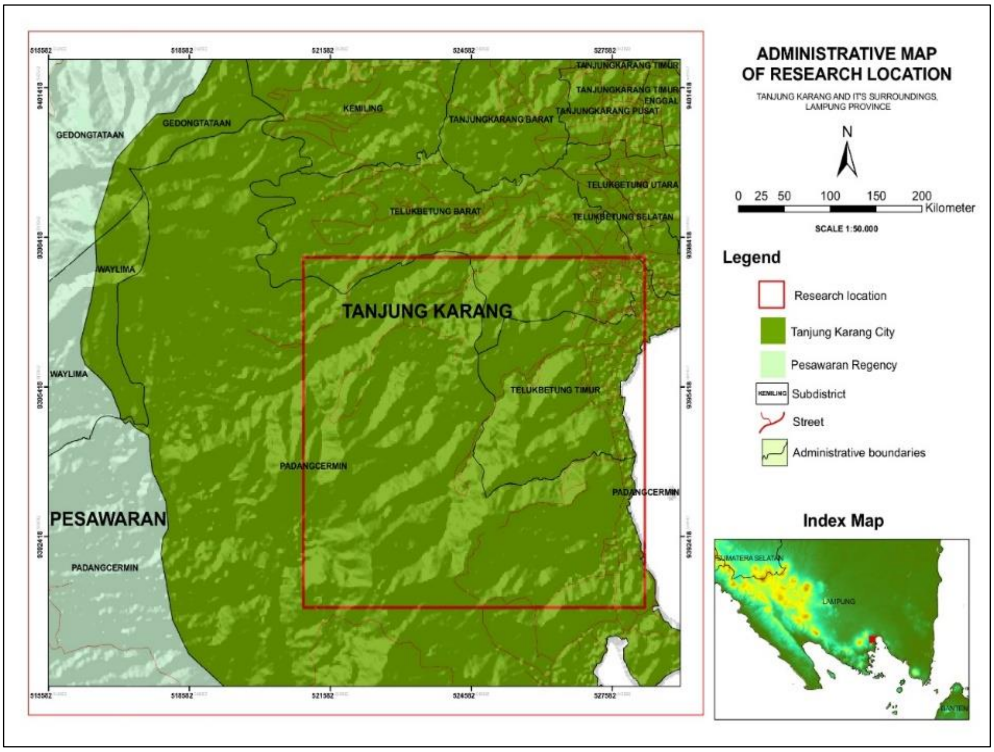

Fig 1. Location of the study area

3. Results and Discussion

3. 1 Geology of the research area

In general, the eastward part of the research area is dominated by the denudational plain. Moderate steep volcanic hills and steep structural hills dominate the western and southern parts of the research area. The young to mature geomorphological stages are observed in the eastern part of the research area, which shows the existence of relatively slight valleys, as seen in the Puri Gading River. The western part of the research area shows relatively steep valleys, as seen in the Ragom Bay River. The geology of the research area is based on outcrops observation, consisting of several lithologies, as shown in Fig. 2.

The research area is dominated by the Tarahan Formation, which consists of glass tuff, agglomerate, and basalt. The glass tuff is characterized by yellowish white color, fine ash grain size, well sorting, and good porosity. Basalt is relatively dark in color and shows a sheeting joint structure. Agglomerates show weathered appearance, characterized by brown color, and consist of andesite, pumice, tuff, lithic, and basalt. The rock fragments have subrounded-rounded shape, open packed, poorly sorted, compact, tuff matrix, and poor porosity. According to Mangga et al. (1993), Tarahan Formation is a product of volcanic explosive activity in the Early Tertiary. In addition, the Lampung Formation was also found and consisted of pumice tuff with the characteristic of grey color, coarse ash grain size, poorly sorted, and poor porosity.

Lampung Formation is a product of volcanic activity in the Early Pliocene (Mangga et al. 1993). The youngest rocks in the research area are members of the Young Volcanic Deposits, which consists of volcanic breccia and andesitic lava. Volcanic breccia is characterized by greyish-white color, gravel-sized andesite fragments, angular shape, poorly sorted, open packing, tuff matrix, and poor porosity. Andesitic lava is characterized by dark grey color, a porphyritic texture with plagioclase, biotite, quartz mineral phenocrysts, and massive structure with intermediate mineral matrix mass. Based on the outcrop observation, these lithologies are interpreted as Betung Young Volcanic Deposits (Mangga et al., 1993). The geological structure of the research area was identified based on the ridges and valleys lineament and supported by faults and joints measurements in the field.

Data processing of the ridges and valleys lineaments dominantly shows the northwest-southeast trending. Measurements on the fault plane around the Muncak Hills and Ragom Teluk River areas in the central and western parts of the research area show fault movement in a northwest-southeast direction.

The fault indication is also found in the eastern part of the research area, around the Talang Jaya River and Sukajaya River. It shows the movement of the fault plane trending northeast-southwest. It is presumed that this fault is related to the presence of hot spring manifestations in the eastern part of the research area. Data processing of tension joints found in the southern part of the research area shows a northwest-southeast lineament.

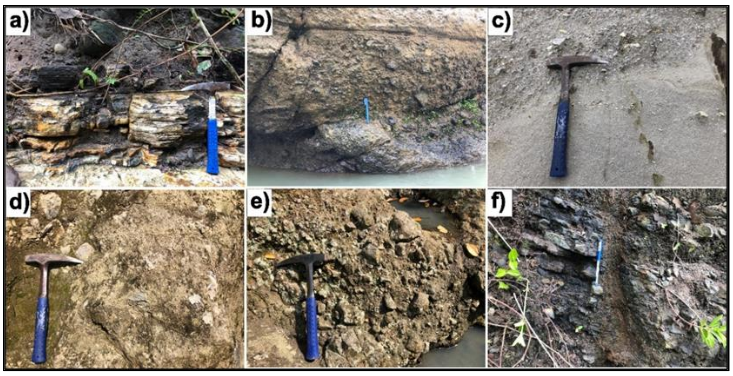

Fig 2. Several outcrops in the research area with lithology of (a) Glass Tuff, (b) Volcanic Breccia (c) Pumice Tuff (d) Agglomerate (e) Andesitic Lava (f) Basalt.

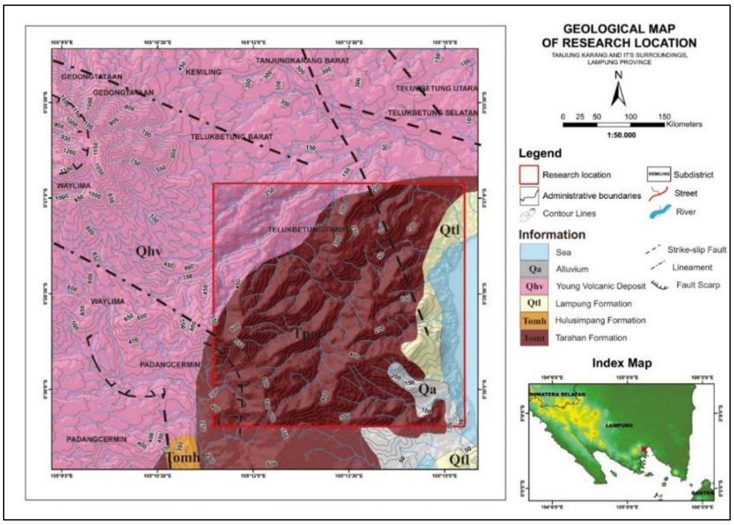

Fig 3. Regional geological map of study area (modification of Mangga et al., 1993)

3. 2 Analysis of Groundwater Flow Patterns

The groundwater flow pattern in the North Padang Cermin area was obtained based on observations of several wells found in the research area (Table 1). From 22 wells measurement, the Ground Water Table (MAT) is located at 0 – 10.7 m depth. Wells elevation varies from 4 m to 410 m above sea level. Based on isophreatic data, the groundwater flow pattern flows radially with gradient variations. The northern part has a gradient of 0.1 meters; the west side 0.08 meters; the south side 0.01 meters; and the eastern part 0.16 meters. Based on the distribution of these gradient values, the research area has a hydraulic gradient trending from west to east (Fig. 4).

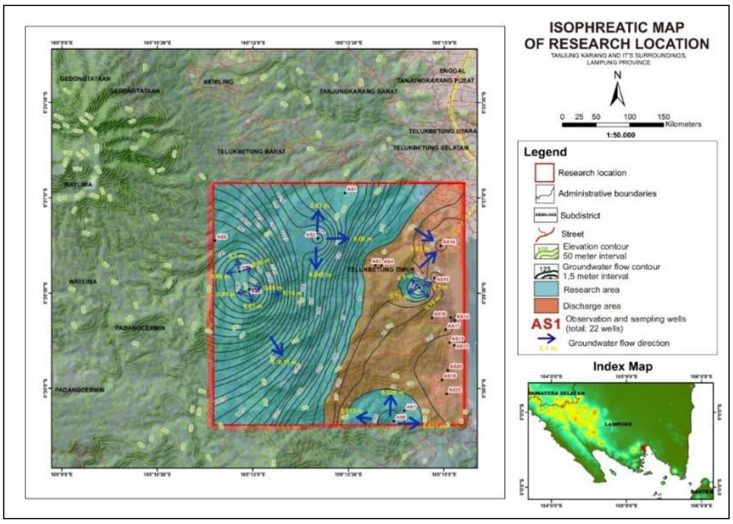

Fig 4. Isophreatic map of the study area

The type of aquifer found in the research area is unconfined aquifer, while the aquifer system found in the coastal region of the research area. The lithology of the study area is dominated by products volcanoes and some alluvial deposits, so the study area potentially has a typology of volcano aquifer systems and alluvial aquifer systems (Irawan & Puradimaja, 2013). According to the aquifer typology of Puradimaja (1993), study area is classified as the Coastal Alluvial Deposit aquifer system.

Based on the groundwater flow direction in Fig. 4, the main catchment area is located in the western part and the discharge area is located in the eastern of the research area. The discharge area is directly adjacent to the sea and has a low hydraulic gradient. Therefore, seawater can potentially enter existing wells, especially in coastal areas and the environment. Based on the isophreatic map of the research area, wells located in residential areas in the eastern part of the research area have the potential for seawater intrusion.

Table 1. Quantitative data on well measurements in the research area

Sample	Elevation (m)	MAT (m)	H (m)	Sample	Elevation (m)	MAT (m)	H (m)
AS1	157	1,95	155,05	AS12	8	0,92	7,08
AS2	238	9,7	228,23	AS13	6	1,2	4,8
AS3	49	6,73	42,27	AS14	13	2,27	10,73
AS4	48	7	41	AS15	8	2,2	5,8
AS5	383	13,5	369,5	AS16	16	1,8	14,2
AS6	410	28	382	AS17	18	3,6	14,4
AS7	37	2,7	34,3	AS18	10	4,8	5,2
AS8	48	1,5	46,5	AS19	12	2,3	9,7
AS9	320	10,7	309,3	AS20	10	1,6	8,4
AS10	100	2,25	97,75	AS21	4	2,3	1,7
AS11	20	1,66	18,34	AS22	7	2,4	4,6

3. 3 Comparative Analysis of TDS and EC Values to the Shoreline

The results of TDS and EC values measurements on 22 wells in the research area were used to see the relationship between groundwater in residents' wells and seawater intrusion. In the graphic (Fig. 5), the comparison between elevation and the TDS and EC values shows a relatively similar distribution of values and patterns.

Based on Fig. 5, it can be interpreted that the closer location of the test well to the coastline, the greater the value of TDS and EC. The closer to the shoreline, the TDS and EC contour values will be higher due to the continuously increasing salinity. TDS and EC values significantly affect the salinity level of the water tested because the higher TDS and EC value will affect the higher NaCl (dissolved salt) level. TDS and EC measurements result from resident's wells in samples AS1 to AS10 ranged from 14–303 ppm and 22–603 µS, respectively.

Based on the TDS (Freeze & Cherry, 1979) and EC (Rhodes, 1992) classification in Table 2, groundwater samples from AS1 to AS10 are classified as freshwater. Meanwhile, the results of TDS and EC measurements from residents' wells with AS11–AS22 samples had a TDS value range of 263–3,790 ppm and an EC value range of 572–7,580 µS. Based on the TDS and EC classification in Table 2, the samples were classified as freshwater to brackish water. In addition, measurements were also made on several rainwater, river water, seawater, and hot springs to compare TDS and EC values. Almost all of the TDS values in the Padang Cermin Utara area are still below quality standards by Regulation of the Minister of Health No. 23 concerning Clean Water Quality Standards 2017, which is <1.500 ppm, included in the category of clean water. Except for AS21, located in Sukajaya Lempasing village, AS12 and 13 in Sukamaju Village, Bandar Lampung city is below the quality standard.

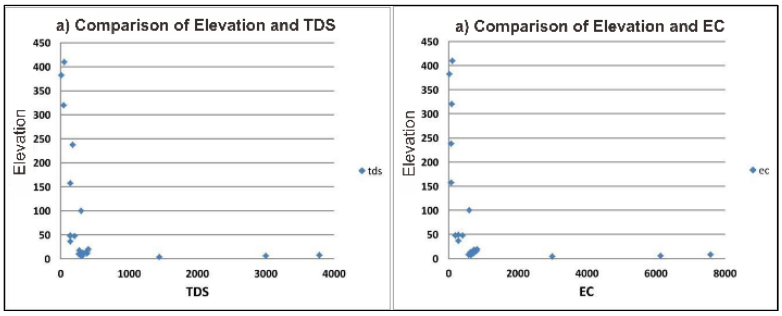

Fig 5. Comparison of elevation, TDS, and EC

3. 4 Seawater Intrusion Analysis

Seawater intrusion can be identified based on TDS and EC measurement results from 22 water samples obtained in the research area. Analysis of seawater intrusion was identified based on TDS and EC values that exceeded the standard value of fresh water according to Freeze & Cherry (1979) and Rhoades (1992), namely 0 –1,000 mg/l for TDS and <700 µS/cm for EC (Table 3). Todd & Mays (2005) has also classified TDS into four types: type I is freshwater with TDS < 1,000 mg/L; type II is brackish water with TDS between 1,000 and 10,000 mg/L; type III is saline water with TDS from 10,000 till 100,000 mg/L; and type IV is brine water with TDS > 100,000 mg/L

Three water test samples have higher TDS and EC values, namely AS12, AS13, and AS21 (Table 2). The TDS values for AS12, AS13, and AS 21 are 3,790 mg/l, 3,000 mg/l, 1,443 mg/l, respectively. While the EC values for AS12, AS13, and AS21 are 7,580 µS/cm, 6,135 µS/cm, and 3,000 µS/cm, respectively.

Table 2. Measurement of 22 qualitative groundwater data of resident's wells

Sample	Coordinates X	Coordinates Y	Sampling Location	Elevation (m)	EC (µS)	TDS (ppm)	pH	Temperature (°C)	Color	Water Taste	Weather
AS1	524812	9397729	Well water	157	71	142	7,12	27,2	Clear	None	Sunny
AS2	524030	9396414	Well water	238	80	175	7	26	Clear	None	Sunny
AS3	525696	9395637	Well water	49	283	141	6,8	28,7	Yellowish	None	Sunny
AS4	525873	9395625	Well water	48	186	146	6,73	29	Clear	None	Sunny
AS5	521757	9395456	Well water	383	22	14	7,14	26,6	Clear	None	Rainy
AS6	522035	9394933	Well water	410	98	54	7	26,5	Clear	None	Rainy
AS7	526532	9391414	Well water	37	278	139	6,5	27,2	Clear	None	Sunny
AS8	526230	9391114	Well water	48	403	201	6,55	26,6	Clear	None	Sunny
AS9	521046	9396348	Well water	320	83	41	7,21	25,4	Clear	None	Rainy
AS10	526978	9394977	Well water	100	603	303	7,05	29,1	Clear	None	Sunny
AS11	527870	9394119	Well water	20	814	406	7,03	29,8	Clear	None	Overcast
AS12	527988	9394036	Well water	8	7580	3790	7	31,1	Cloudy	Salty	Sunny
AS13	527973	9393306	Well water	6	6135	3000	8	28,8	Cloudy	Salty	Sunny
AS14	527584	9396197	Well water	13	635	326	7	28,3	Clear	None	Overcast
AS15	527403	9395267	Well water	8	572	294	6,8	29,2	Clear	None	Overcast
AS16	527328	9394108	Well water	16	805	388	6,7	28,2	Clear	None	Overcast
AS17	527727	9393762	Well water	18	740	273	7,04	27,6	Clear	None	Sunny
AS18	527620	9392317	Well water	10	586	263	6,9	27,8	Clear	None	Sunny
AS19	527841	9393396	Well water	12	734	388	7,6	29,2	Clear	None	Sunny
AS20	527792	9392588	Well water	10	628	314	6,5	28,6	Clear	None	Rainy
AS21	528119	9392012	Well water	4	3000	1443	7	28,3	Cloudy	Brackish	Heavy rain
AS22	527760	9391905	Well water	7	642	318	7,3	28	Clear	None	Rainy
S1	525741	9395579	River water	30	190	97	5	27,1	Cloudy	None	Rainy
S2	526232	9391116	River water	130	90	45	6	26	Brownish	None	Rainy
S3	526996	9394974	River water	37	115	57	5	29	Brownish	None	Sunny
AL	527798	9395273	Seawater	0	8528	4073	8,3	29,7	Cloudy	Salty	Slight rain
AH	527798	9394765	Rainwater	60	34	17	6,5	26	Clear	None	Rainy
MP	527937	9393893	Hotspring	3	452	251	7,2	45	Clear	None	Heavy rain

Table 3. Groundwater classification EC (Rhoades, 1992) and TDS (Freeze & Cherry, 1979)

No	EC (µS/cm)	Type of water	TDS (mg/l or g/m-3)	Type of water
1	<700	Non-saline	0 – 1.000	Freshwater type
2	700 – 2.000	Slightly saline	1.000 – 10.000	Brackish water type
3	2.000 – 10.000	Moderately saline	10.000 – 100.000	Saline water type
4	10.000 – 25.000	Highly saline	>100.000	Brine water type
5	25.000 – 45.000	Very highly saline		
6	>45.000	Brine water		

In determining the quality of groundwater, it is necessary to examine the physical and chemical parameters of the water. Physical parameters of water quality include color and Total Dissolved Solids (TDS) and chemical parameters include iron, total hardness, chloride, manganese, nitrate as N, nitrite as N, pH, sulfate and organic matter (Munfiah et al., 2013). In this study, chemical analysis of groundwater was also carried out to determine the composition of the significant groundwater ions, such as Na, Cl, Mg, and Ca.

Groundwater chemical tests were conducted on the AS21 sample with TDS and EC values that exceeded the freshwater limit. The groundwater chemical test aims to identify the effect of seawater intrusion on the groundwater chemical composition based on the effective ion content of groundwater. The analysis results showed that Na ions' content was 335.34 mg/L, and Cl ions were 848.67 mg/L.

Table 4. Groundwater chemical test results on the AS21 sample.

Sample	Parameter	Result (mg/L)
AS21	Cl	848,67
	Ca	238,95
	Mg	125,82
	Na	335,34

The content of Na and Cl ions in AS21 has exceeded the maximum limit for the content of the ions in clean water (Millah & Satyanto, 2019). Based on the data, it is interpreted that AS21 has shifted in the main ion content due to mixing with seawater because of its high salinity properties (Table 4). The content of Na and Cl ions exceeding the maximum limit of clean water has impacted the decreasing groundwater quality (Indriastoni & Kustini, 2014).

The distribution of seawater intrusion in the research area was identified using the Herzberg method by assuming a homogeneous aquifer. The groundwater thickness calculation is carried out in the interface zone using cross-section A-B that crosses through the research area (Fig. 6). The Herzberg method used intruded groundwater values, while cross-sectional lines are drawn from the well closest to the shoreline, namely AS12 to identify the thickness of the fresh water in the research area. Using Herzberg equation, the groundwater table (MAT) of AS12 or hf is 0,92 m and calculated with 40. From the calculation results, the thickness of the groundwater from the AS12 test well sample was 36.8 meters (Fig. 7).

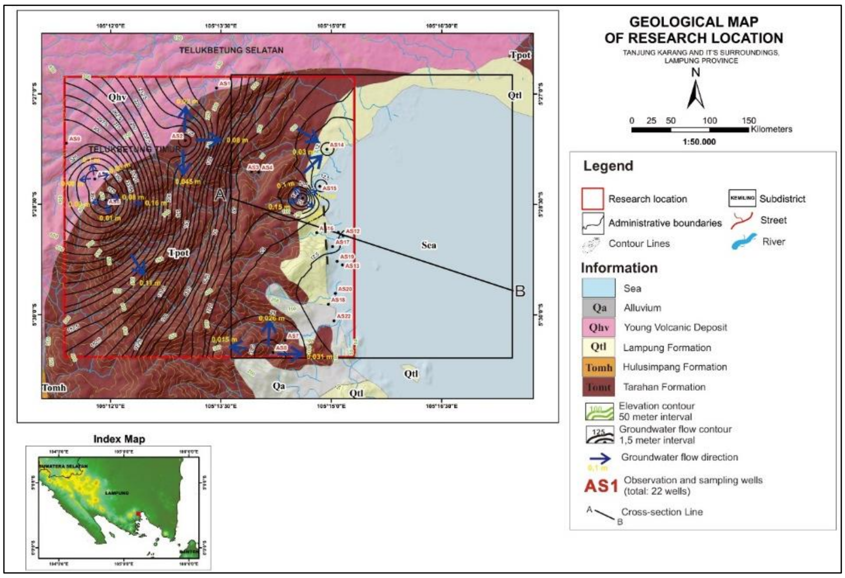

Fig 6. A-B cross-section line in the research area

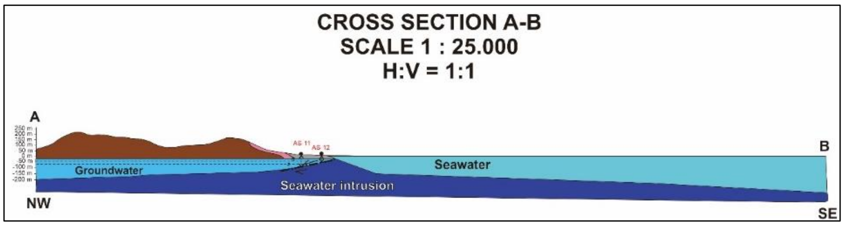

Fig 7. A-B cross section of seawater intrusion

4. Conclusions

1) The geology of the research area is composed of volcanic products consisting of glass tuff, agglomerates, and basalt as the members of the Tarahan Formation. In addition, pumice tuff was also found and interpreted as a member of the Lampung Formation. The youngest rocks are volcanic breccias and andesitic lava, which are the member of Betung Young Volcanic Deposits.
2) Based on isophreatic data, the groundwater flow pattern is radial with a hydraulic gradient value of 0.16 meters with a flow direction from west to east in the research area.
3) There is an increase in the TDS and EC measurement results that are getting closer to the shoreline. Based on the results of TDS and EC measurements and groundwater chemical tests, there was sea intrusion in the eastern part of the research area, namely the test wells AS12 and AS13, which belong to the Sukamaju Village, and AS21, which belong to the Sukajaya Lempasing area.
4) The thickness of fresh water in seawater intrusion identified using the Heizberg method shows a thickness of 36.8 meters of fresh water.

Acknowledgments

We would like to thank all of the ITERA Geological Engineering Study Program lecturers who helped complete this paper. We also thank the regional government of Padang Cermin Utara and the community members who have assisted in collecting data for this research.

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