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Preliminary study of sea water intrusion using geographic information system in Temon, Kulon Progo, Yogyakarta, Indonesia

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Abstract

Temon Sub Districts is an administrative area of Kulon Progo Regency, which borders the South Sea (Indian Ocean). The Temon Sub District is directly adjacent to the waters, so it potentially experiences intrusion like other coastal areas in Indonesia. Therefore, groundwater conditions related to the phenomenon of water intrusion need to be identified. The purpose of this study was to estimate seawater intrusion using a geographic information system (GIS) and water quality variables in the Temon Subs Districts. In this study, we used data on electrical conductivity (EC), total dissolved solids (TDS), and groundwater salinity. The sampling was carried out using a systematic random sampling method. Meanwhile, the data analysis was carried out in a qualitative descriptive manner using the spatial interpolation feature in the Arc GIS 10.8 software. Based on the research results, it is suspected that seawater intrusion has occurred in several locations in Temon Sub Districts. The highest suspected seawater intrusion was found in the vicinity of Jangkaran Village, Kalidengen Village, and Plumbon Village. The EC, TDS, and salinity values suggested that around 26% or 9.68 km^2 of the area has intruded. This research is expected to enrich references regarding the mapping of seawater intrusion in coastal areas.

Keywords: seawater intrusion; groundwater; geographic information system

1. Introduction

Temon Sub-district is one of the administrative areas of Kulon Progo Regency, which directly borders the South Sea (Indian Ocean). Its direct borders with the sea cause various consequences, impacts, and potentials, including potential harms, such as seawater intrusion. Seawater intrusion is the atrocious consequence commonly found in coastal areas.

Seawater intrusion is the entry and mixture of seawater into the freshwater system on the mainland (Purnama, 2020). Further, seawater intrusion occurs in the surface water system (river), as well as in the groundwater aquifer system. The groundwater aquifer system is the layers of rocks below the land surface capable of storing and flowing a sufficient amount of groundwater (Todd & Mays, 2005). The water collected within the aquifer system originates from the reaction between rainwater, sub-soil, and rock layers with the gravity force, land structure, land texture, as well as the permeability and hydraulic conductivity of rock layers below the land surface (Sejati & Prayoga, 2023). Rain is a form of precipitation falling into the earth's surface. The rainwater is permeated into the land lining vertically through the infiltration process. The effects of gravity, permeability, and hydraulic conductivity on the rocks below the land surface pass on the rainwater vertically into the groundwater saturation zone. This process is commonly referred to as percolation. From the saturation zone, the groundwater moves more horizontally than vertically. Within the saturation zone, the groundwater flows following land contour or topography, from the high to the low elevation (Riasasi & Sejati, 2019). Similar to the river water, the groundwater disembogues into the sea.

As reported in the previous study, the outskirt between the groundwater (freshwater) and the seawater (salt water) is named the interface zone (Kodoatie, 2012). In the interface zone, the groundwater and seawater are in the equilibrium position, so they do not get into each other system. The depth of interface zones between the coastal areas is different. A study carried out by Adhiatmi and Santosa (2016) uncovered that a deeper interface zone from the land surface decreased seawater movement into the groundwater and vice versa. The interface zone may vary following the occurrence of water exploitation in the coastal areas. The excessive groundwater anointing without equal groundwater deposition induces shallowing or shift of interface zone moving into the freshwater aquifer system in the mainland. Further, the shift of the interface zone causes seawater movement onto the groundwater system (Adhiatmi & Santosa, 2016; Gusman et al., 2020), commonly known as seawater intrusion. Todd (2005) and Purnama (2020) described that seawater intrusion into the groundwater aquifer system happens due to the massive groundwater usage in the coastal area directly bordering the sea. The extensive use of groundwater should be followed by comparable deposition to maintain the groundwater hydrostatic pressure toward the seawater. The low hydrostatic pressure of groundwater causes seawater entry into the groundwater aquifer.

Previous studies have investigated the seawater intrusion phenomena in the groundwater aquifer system. Several areas have been reported experiencing seawater intrusion, including the areas of North Semarang (Wibowo & Supriyadi, 2014), parts of Tangerang Regency (Waspodo, Kusumarini, & Dewi, 2019), some areas of Kendari City (Kete et al., 2019), some parts of Padang city (Amri & Putra, 2014; Khairunnas & Mulya, 2018), some watersheds in Ciujung and Cidurian (Prihartanto, Naryanto, & Ganesha, 2017), several areas in the Seribu Islands (Cahyadi et al., 2013; Cahyadi, Hidayat, & Fatchurohman, 2017), and some areas of Rembang Regency (Yolanda, 2007). Those studies conclude that seawater intrusion mostly appears due to the massive usage of groundwater, along with ignorance of the safe limit of groundwater deposition.

The seawater intrusion in the Temon Sub-district has been carried out by Wilopo and Welardi (2015), primarily in the areas of Glagah and Congot Beaches. That study uncovered the relatively excellent and decent water in the Temon Sub-district, serving as the fundamental for the YIA Airport construction. However, re-examining the Temon Sub-district's groundwater condition is necessary following the publication of that previous study. Theoretically, groundwater is a hydrosphere object with temporal nature (Sejati, 2021). Therefore, the water content in the past time may differ from its current condition. The water condition relies heavily on the dynamics of land usage and groundwater extraction patterns, especially correlated with the effects of massive constructions.

From the aforementioned discussion, this study identifies the spatial distribution of seawater intrusion using the geographic information system (GIS) with variables of EC, TDS, and salinity in Temon Sub-district, Kulon Progo, Special Region of Yogyakarta. The results of our study are expected to be a reference for the geographic information system (GIS) and geohydrology implementation in seawater intrusion mapping in coastal areas.

2. Method

This study was conducted in Temon Sub-district, Kulonprogo, Special Region of Yogyakarta, Indonesia. Geographically, Temon Sub-district is located at 7°52' 9" SL – 7°54'59" SL and 100°2'1" EL-110°6'30" EL (Progo, 2020). This location is bordered by Kokap Sub-district in the north, Serang River and Wates Sub-district in the east, India Ocean in the south, as well as Bogowonto River and Purwerejo Regency in the west.

The groundwater sampling was conducted in the entire area of Temon Sub-district, Kulonprogo, Indonesia using the grid sampling method. The imaginary line (grid) with the determined distance in the research map was used as the sampling framework. The sampling coordinate points were selected randomly following the grid. This grid approach was chosen due to the variation of geomorphological conditions in our research location. According to the available geomorphological map of the Special Region of Yogyakarta (Husein & Srijono, 2010), the geomorphological condition of our research location is relatively uniform as it only consists of only two classes, namely the *flood plains* and *saturated dune fields*. Due to its fairly similar geomorphology condition, the grid sampling can better represent the groundwater condition in our research location. In spatial pattern research, the grid approach has been frequently adopted as it facilitates the construction of a map and prevents the pilling of sampling in a single location, producing more representative data. The grid sampling was arranged with a 1 km^2 × 1 km^2 interval, as illustrated in Figure 1.

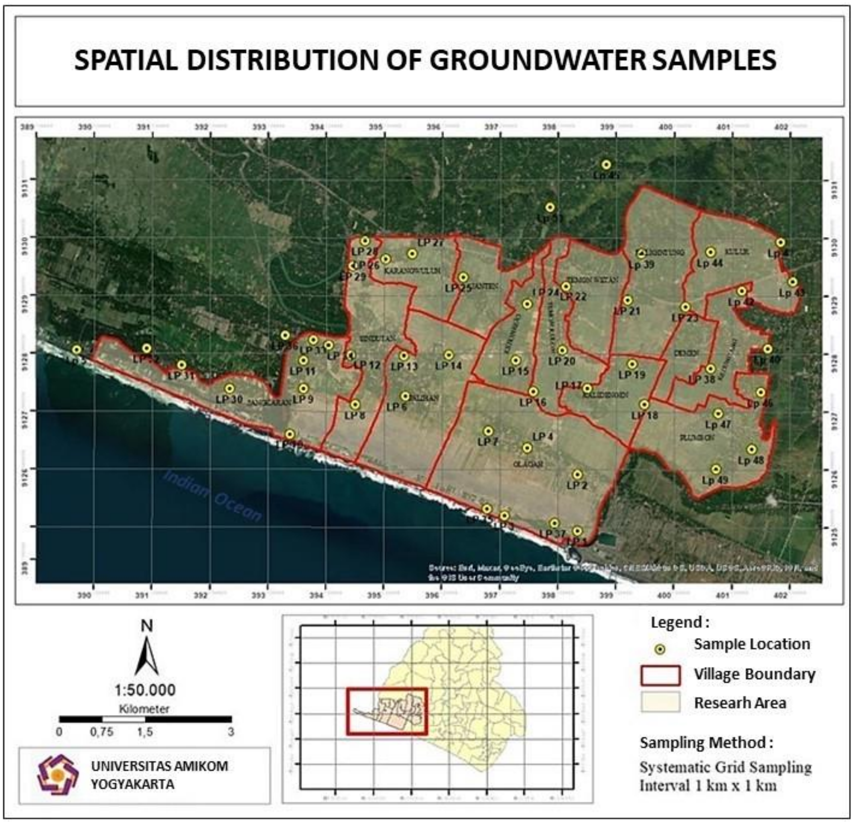

Figure 1. Map of Sampling Location

The obtained data were analyzed in situ, using parameters of electrical conductivity (EC), total dissolved solids (TDS), and salinity. These parameters are commonly used in seawater intrusion identification research (Gusman et al., 2020; Salem, Mountasir, & Shames, 2018; Simuningkalit & Lumbantoruan, 2016; Yang, Jeong, Agossou, Sohn, & Lee, 2022). The in-situ analysis was carried out directly in the field. Further, the samples were tested using the portable water quality tester type Hanna Instrument HI 9812-5 straight in the field to lower damages on the water sampling. The obtained levels on each parameter were later categorized, showing the water condition in the research areas. Then, the spatial data distribution was identified using the geographic information system (GIS) software through the spatial interpolation technique. The interpolation was carried out using the *inverse distance weighted* (IDW) method. The IDW method offers higher accuracy as all values from the IDW method are close to the minimum and maximum values from the sample data (Balakrishnan, 2019; Seyedmohammadi, Esmaeelnejad, & Shabanpour, 2016).

In addition, the interpolation results were classified using the manual and equal interval classification method integrated with the GIS software. The manual classification method was used to examine the level of seawater intrusion. It was conducted based on the standard values used by the previous research. Meanwhile, the equal interval method was adopted to present the research results in the form of a representative and easily comprehended map. The equivalent interval classification method divides the equally same amount of interval on each class that is compatible with familiar scopes, such as percentage (Longley et al., 2015). This classification emphasizes the total relative amounts of attributes toward the other values. This method was selected due to its understandable information presentation for the non-technical users. Systematically, the research scheme is illustrated in Figure 2.

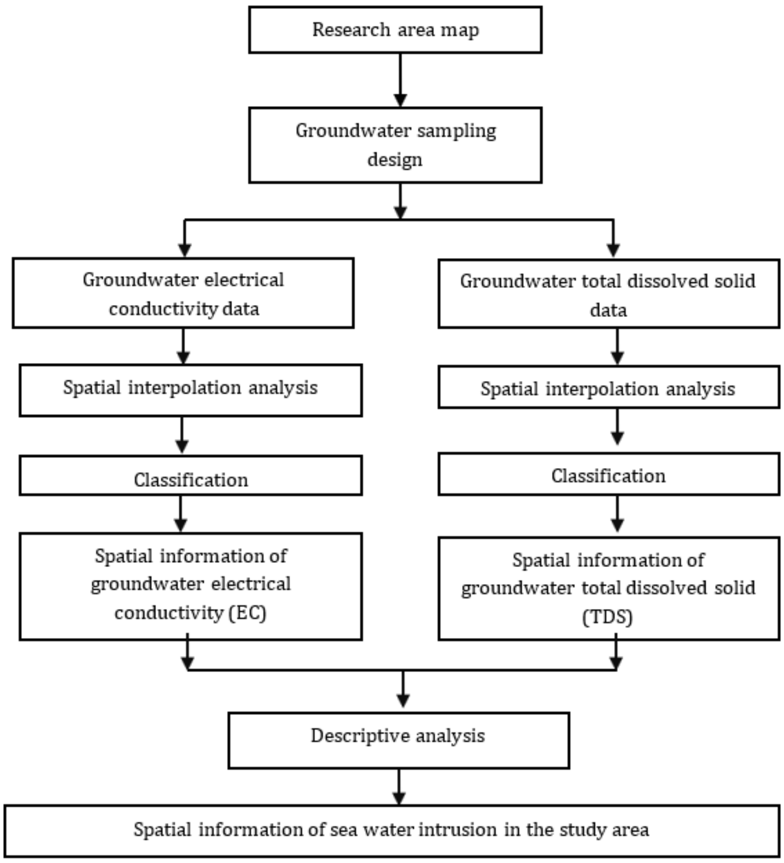

Figure 2. Flowchart of Research Procedures

3. Results and Discussion

3.1. Conjecture of Seawater Intrusion Based on the Groundwater's Electrical Conductivity Spatial Pattern in Temon Sub-district

The results of the electrical conductivity measurement are shown in Table 1. We obtained variation in electrical conductivity, with the lowest electrical conductivity at 217 µS/cm detected from (LP) 1 research location in Glagah Sub-district. Meanwhile, the highest electrical conductivity was observed from the observation site in Kalidengen Sub-district (3101 µS/cm). The majority of groundwater in our research location has low EC, below 1000 µS/cm, with the lowest EC from Sindutan Sub-district, at an average of 324 µS/cm EC. The highest EC was found in Kalidengen Sub-district, with an average of 2032 µS/cm EC. These measurement results were interpolated and classified. The classification was carried out at around 250 µS/cm intervals on data with high variations, resulting in representative data.

Figure 3 illustrates the highest EC (more than 2000 µS/cm) was identified on LP (research point) 18, widening into LP 19, LP 20, and LP 47. Administratively, these four locations are in Kalidengan, Plumbon, and Temon Sub-districts. Figure 3 also presents that LP 18, 19, 20, and 47 are far from the sea areas. The high EC from these locations can be caused by its close proximity to the Serang River (on the east side of the research location). Further, Jeen, Kang, Jung, & Lee (2021) proposed that the river canal affects the seawater intrusion pattern. The river water contaminated with seawater can get into the freshwater aquifer system due to groundwater exploitation (Jeen et al., 2021). According to the available theory, the EC level on the Serang River is above the freshwater. The river water intrudes into the freshwater aquifer system. Following the spatial interpolation pattern presented in Figure 3, the outset of intrusion is around the LP 18 research location, dispersing into the surrounding area.

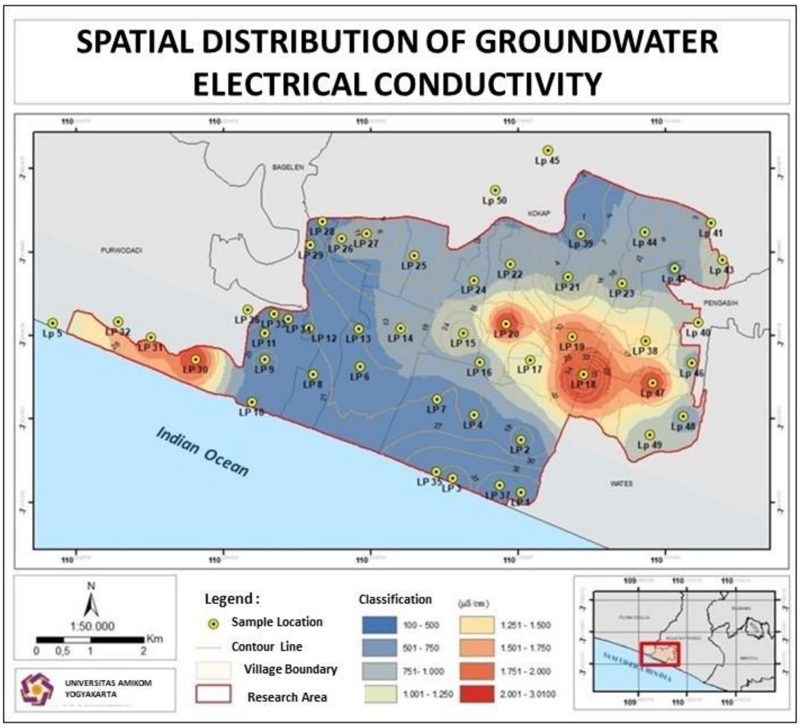

Figure 3. Distribution of Groundwater Electrical Conductivity

Table 1. Measurement Results on Groundwater Electrical Conductivity

Sub-district	Observation Location	EC (µS/cm)
Jangkaran	5	1025
	30	2345
	31	2015
	32	1527
	34	249
	33	454
	9	253
	10	351
	11	279
	36	337
Sindutan	8	285
	12	317
	28	291
	29	402
Palihan	6	347
	13	404
	14	763
Karangwuluh	26	588
	27	530
Janten	25	503
Kebonrejo	50	307
	15	894
	24	512
Kulur	41	727
	43	890
	44	608
Temon	20	2391
	16	596
	22	576
Glagah	4	245
	2	311
	7	277
	1	217
	35	365
	3	385
	37	207
Kalidengen	18	3101
	17	998
	19	1995
Kaligintung	21	611
	39	381
Kedundang	38	1380
	40	753
	42	454
Plumbon	46	611
	47	2315
	48	578
	49	723

The seawater intrusion is fathomed from the Serang River, as exhibited by the EC level of the Serang River. Meanwhile, Figure 4 shows the measured locations, as marked by numbers 1, 2, and 3.

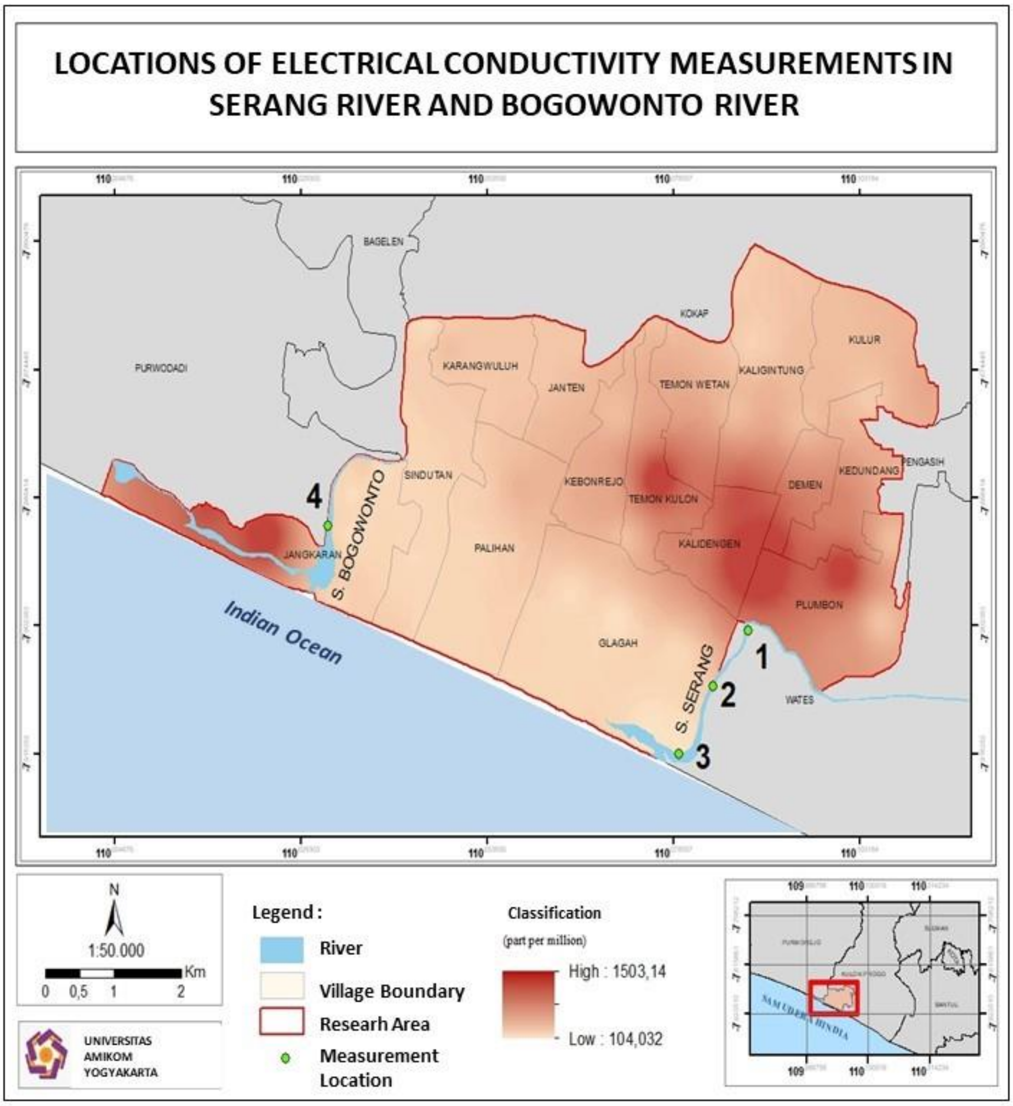

Figure 4. EC Measurement Location in Serang and Bogowonto Rivers

The location LP 1 in Figure 4, shows EC of 8777 µS/cm with a salinity percentage of 0.45%. Meanwhile, location 2 presents an EC of 12703 µS/cm with a salinity percentage of 0.62%, and location 3 has an EC of 14306 µS/cm with 0.76% salinity. The high EC level has also been observed in the Temon Sub-district, the West of Jangkaran Sub-district. This location is bordered by the Bogowonto River. This river was identified as having a high EC level in its west area and low EC in its east area. Therefore, the high EC level in this sub-district originates from the Bogowonto River. The EC measurement for the Bogowonto River was carried out in research location number 4, as shown in Figure 4. From our measurement process, we found that Bogowonto River has an EC of 6180 µS/cm (0.30%). Additionally, the seawater intrusion is also possibly caused by the intrusion around the LP 30 research location, as presented in Figure 3. The west side of Bogowonto River has a 1250–3000 µS/cm EC level, while in its east, the EC level ranges between 300–750 µS/cm. A low EC level of <500 µS/cm has also been reported in the north of Temon Sub-district, in Kaligintung Sub-district, especially in the Astana Girigondo area, the cemetery in the hill areas. In this hilly area, there is dense vegetation with no housing. Another relatively extensive area with low EC is also found in the south and west areas of the Temon Sub-district. The EC level of 200–750 µS/cm is identified in various regions of the East Jangkaran Sub-district, along with the Sindutan, Palihan, and Glagah Sub-districts. In these coastal areas, primarily in the Jangkaran and Glagah Sub-districts, the majority of people use artesian well since the dug well cannot operate maximumly. Further, the obtained EC values were classified to find the spatial distribution of groundwater types in the research location using the EC-based water type classification proposed by Todd (2005). The classification results are presented in Figure 5.

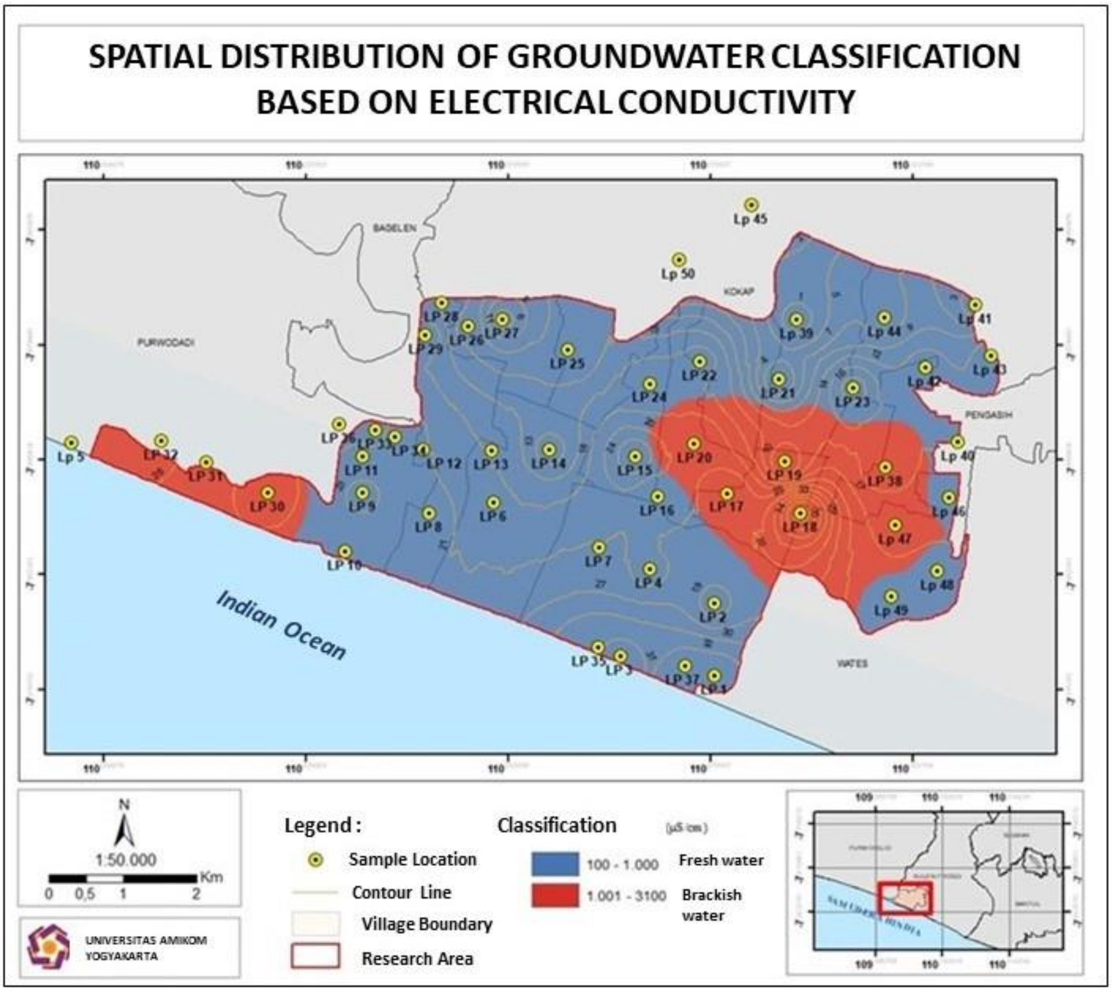

Figure 5. Groundwater Distribution based on Electrical Conductivity

As illustrated in Figure 5, we located two types of water according to the obtained EC data, namely the freshwater with EC 100–1000 µS/cm and brackish water with 1001–3100 µS/cm. In general, Temon Sub-district is dominated by relatively excellent fresh water, with the alleged intrusion in the brackish water. The brackish water has been identified in the research areas of LP 5, 30, 31, and 32, located around the west side of Bogowonto (Jangkaran Sub-district), with a total area of 1.5 km^2. Besides, we also found brackish water in the LP 17, 18, 19, 20, 38, and LP 47 research locations, with a total area of 7.4 km^2 in the Kalidengen Sub-district. Therefore, the total area of seawater intrusion is 8,9 km^2. Simultaneously, the freshwater was also uncovered in some areas of the Temon Sub-district, specifically in the north and some east points of its coastal areas. The fresh groundwater was found in the 28,1 km^2 area of Temon Sub-district. As the total area of Temon Sub-district is 37 km^2, 76 and 24% of areas have fresh water and brackish water simultaneously, based on the electrical conductivity.

3.2. Conjecture of Seawater Intrusion Based on Spatial Pattern of Total Dissolved Solids and Groundwater Salinity in Temon Sub-district

Total dissolved water is one of the water quality parameters representing the salinity level of the water area (Rusydi, 2018). This total dissolved solids (TDS) parameter correlates with the electrical conductivity (EC) and salinity parameters. The high EC level represents the high TDS and salinity. TDS is measured using the ppm (part per million*)* unit that is equal to milligrams/liter (mg/L). The field measurement results on TDS are presented in Table 2, showing the total dissolved solid ranging from 103 ppm to 1504 ppm. The lowest TDS of 103 ppm was found in LP 37, research location in Glagah Sub-district, while the highest TDS was in the LP 18, research location in the Kalidengen Sub-district.

The groundwater in the Temon Sub-district is dominated by low TDS, below 500 ppm. The lowest TDS was found in the Sindutan Sub-district, with an average TDS of below 162 ppm, while the highest TDS was from Kalidengen Sub-district, with a TDS average of 1062 ppm. These measurement results were interpolated and classified. The classification process was completed using a 250 ppm interval for representative data representation, as illustrated in Figure 6.

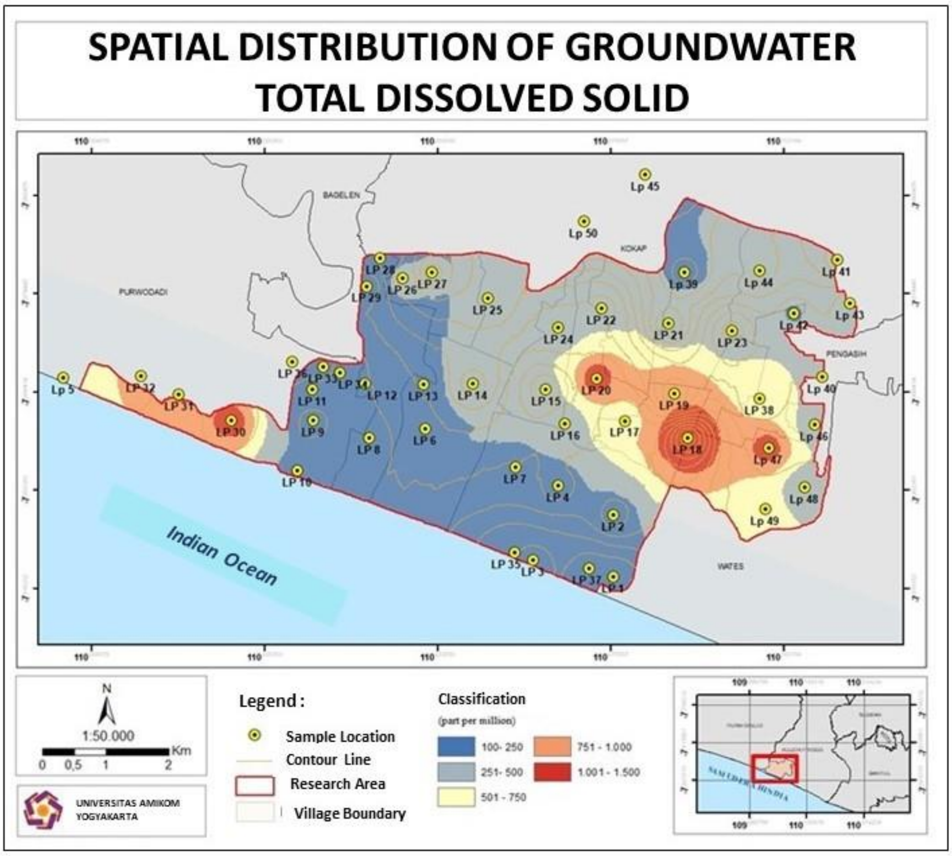

Figure 6. Distribution of Groundwater Total Dissolved Solid

Table 2. Results of Groundwater Total Dissolved Solid

Sub-district	Observation Location	TDS (ppm)
Jangkaran	5	511
	30	1171
	31	1023
	32	804
	34	123
	33	226
	9	131
	10	181
	11	137
	36	161
Sindutan	8	150
	12	157
	28	141
	29	200
Palihan	6	172
	13	198
	14	379
Karangwuluh	26	293
	27	257
Janten	25	251
Kebonrejo	50	151
	15	445
	24	312
Temon	20	1198
	16	295
	22	433
Glagah	4	121
	2	154
	7	143
	1	106
	35	175
	3	194
	37	103
Kalidengen	18	1504
	17	688
	19	995
Kaligintung	21	303
	39	191
	45	232
	23	296
Kedundang	38	687
	40	378
	42	233
Kebonrejo	50	151
	15	445
	24	312
Kulur	41	352
	43	443
	44	302
Plumbon	46	305
	47	1156
	48	276
	49	556

The highest TDS of >1000 ppm was identified on LP 18, 47, and LP 20 research locations. However, the TDS value decreased to 500-750 ppm in the LP 17, 38, and LP 49 research locations. These areas are located in the Kalidengen Sub-district and some parts of the Plumbon and Temon Sub-districts. The lowest TDS of 100-250 ppm was discovered on the north side of Temon Sub-district, in the Kaligintung Sub-district. Aside from those areas, we also found low TDS values in the South and West areas of the Temon Sub-district, particularly the east areas of the Jangkaran Sub-district, along with the Sindutan, Palihan, and some areas of the Glagah Sub-districts. The high TDS was also found in the most western region of the Temon Sub-district, within the Jangkaran Sub-district. This area is adjacent to the Bogowonto Riveer, with high TDS in the west of the river, while the eastern river area presents the lowest TDS. The west area of the river has 750–1000 ppm TDS which continuously reduces on its west, while the east part of the river has <250 ppm, on average.

Salinity closely correlates with TDS as their calculation are based on water conductivity. The correlation between salinity and TDS is directly proportional, so high salinity represents high TDS levels. This correlation is induced by the salt, which is one of the solids dissolved within the water. Their correlation is presented in Figures 7 and 8. Figure 7 presents a linear and positive connection between TDS and salinity, signifying that high TDS shows a great salinity level. The positive slope indicates the linear and positive relationship between salinity and TDS, thus, the increase in the TDS variable is directly proportional to higher salinity. Therefore, greater TDS also depicts higher salinity. In addition, the graphic also shows that the 1 ppm greater value of TDS shows a 0.998 increase in salinity, which is close to 1. The results of the salinity analysis are summarized in Table 3.

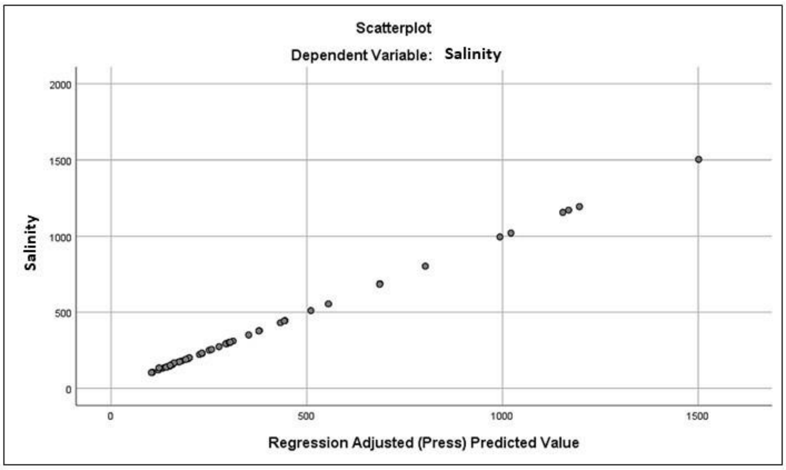

Figure 7. Correlation between Salinity and TDS

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.303	.521		.581	.564
	TDS	.998	.001	1.000	981.321	.000
a. Dependent Variable: Salinity						

Figure 8. Results of Correlation Test between Salinity and TDS

Table 3. Results of Groundwater's Total Dissolved Solid

Sub-districts	Observation Location	Salinity (ppm)
Jangkaran	5	511
	30	1171
	31	1020
	32	803
	34	135
	33	223
	9	132
	10	181
	11	138
	36	168
sindutan	8	147
	12	157
	28	140
	29	201
palihan	6	173
	13	196
	14	379
karangwuluh	26	293
	27	256
Janten	25	251
Kebonrejo	50	152
	15	445
	24	311
Kulur	41	351
	43	443
	44	301
Temon	20	1194
	16	295
	22	431
Glagah	4	121
	2	154
	7	141
	1	106
	35	175
	3	194
Kalidengen	37	104
	18	1504
	17	688
	19	995
Kaligintung	21	302
	39	190
	45	232
Kedundang	23	293
	38	684
	40	377
	42	230
Plumbon	46	304
	47	1156
	48	274
	49	555

The obtained salinity data are similar to the TDS data. The data are directly proportional with the average difference of <5 ppm. The obtained salinity ranges between 104 to 1504 ppm. The lowest salinity of 104 ppm was identified in the LP 37 research location in the Glagah Sub-district. Meanwhile, the highest salinity was found in the LP 18 research location in the Kalidengen Sub-district, similar to the obtained TDS data. The majority of groundwater in the Temon Sub-district has low salinity, below 500 ppm. The lowest salinity was found in the Glagah Sub-district, with an average salinity of 142 ppm. Meanwhile, the highest average salinity of 1504 ppm was identified in the Kalidengen Sub-district. The obtained salinity data were interpolated and classified. The classification was carried out at 250 ppm intervals for generating representative data presentation. The spatial distribution of the salinity is presented in Figure 9.

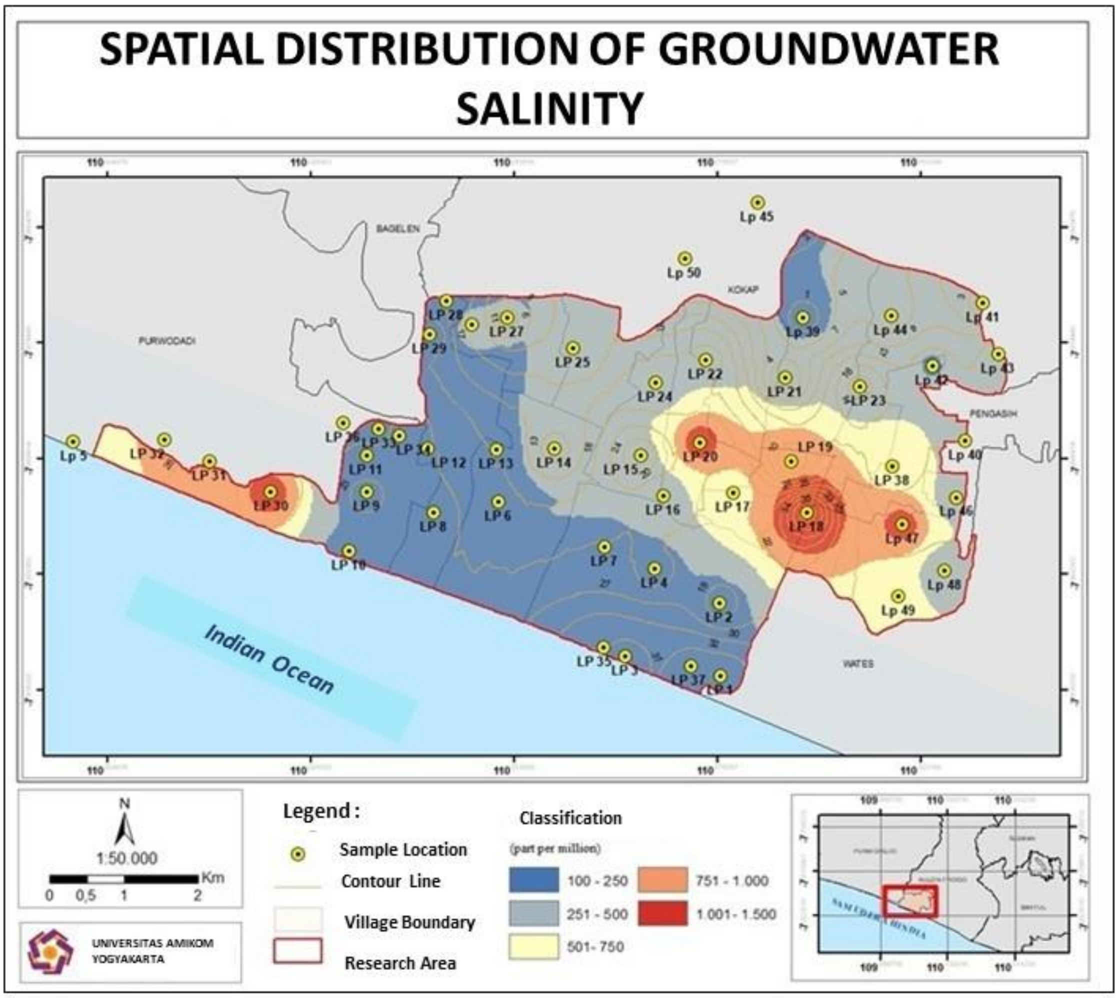

Figure 9. Distribution of Groundwater Salinity

The spatial salinity pattern was further classified to find the conjecture of seawater intrusion using the salinity classification from Goetz (1986). In the collected data, we used (%) unit, where the 0.1% salinity is equal to 1000 ppm. The classification results are illustrated in Figure 10.

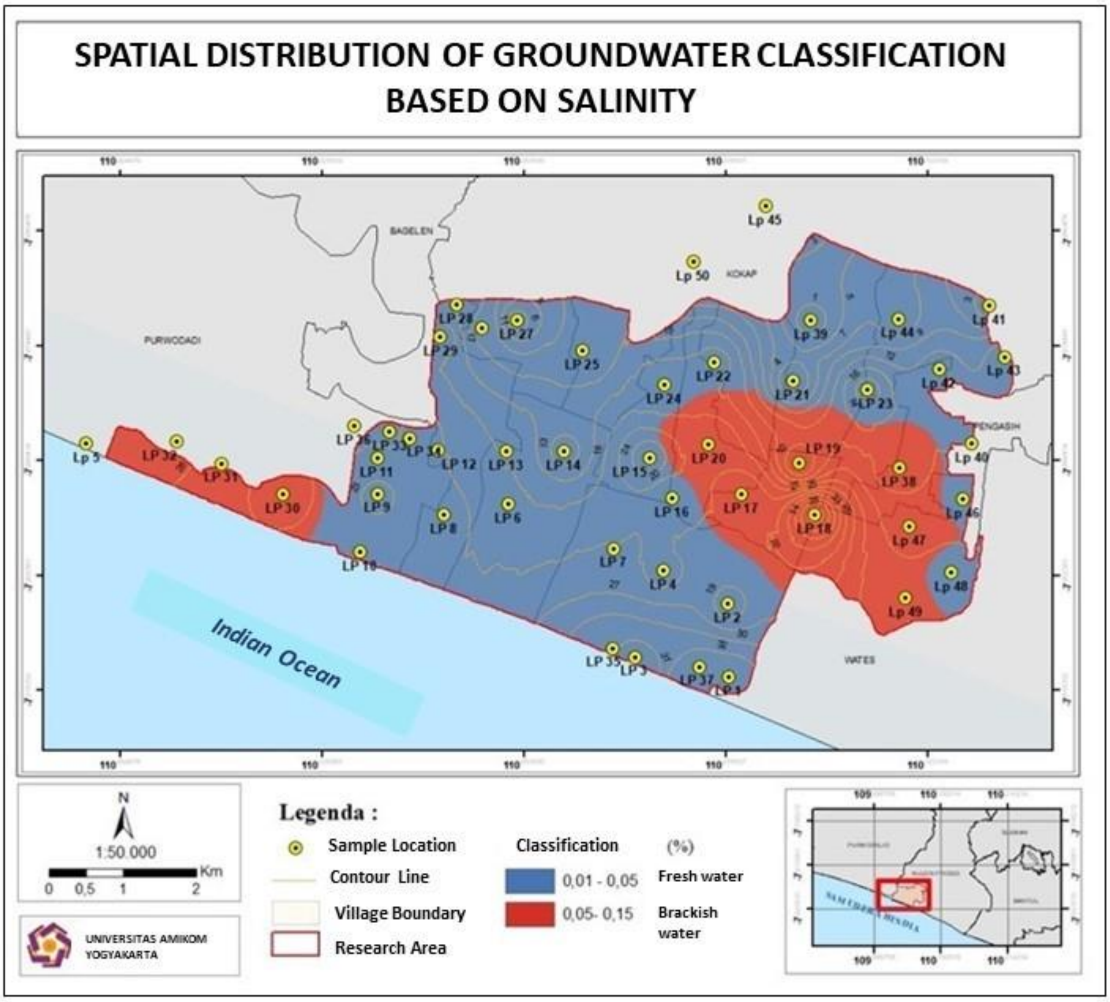

Figure 10. Distribution of Groundwater based on Salinity

The classification of salinity indicated that the groundwater in Temon Sub-district is dominated by acceptable quality. The brackish water was identified in LP 5, 30, 31, and LP 32 observation locations in the entire west areas of Bogowonto River, with a total area of 1.5 km^2. Additionally, the brackish water was also found in LP 17, 18, 19, 20, 28, and LP 37 research locations, in the Kalidengen Sub-district, with a total area of 8.18 km^2. Therefore, the total research area experiencing seawater intrusion is 9,68 km^2. Meanwhile, the freshwater area dominating the research location is 27.8 km^2. On the whole, from Temon Sub-district's total area of 37 km^2, we identified 26 and 74% of brackish and freshwater, respectively.

4. Conclusion

Our analysis results suggested that seawater intrusion has occurred in several areas of Temon Sub-district. Spatially, the highest seawater intrusion was around the Jangkaran, Kalidengen, and Plumbon Sub-districts. The conjecture of intrusion is formulated based on the water quality test based on the electrical conductivity (EC), total dissolved solids (TDS), and salinity. The areas being intruded with seawater scored EC, TDS, and salinity of 1001-3100 µS/cm, 1001-1500 ppm, and 0.05-0.15%, respectively. The total area suspected to be experiencing seawater intrusion is 9.68 km^2 (26% of the total research area). Generally, the seawater intrusion was identified in the areas with close proximity to the downstream of the

Serang and Bogowonto Rivers. The seawater intrusion is fathomed due to the excessive usage of groundwater around the Serang and Bogowonto downstream. Further, the brackish water in the Serang and Bogowonto Rivers intrudes the groundwater system, resulting in high levels of EC, TDS, and salinity. The groundwater condition should be monitored periodically, primarily the groundwater in the areas of Jangkaran, Kalidengen, and Plumbon Sub-districts. The determination of safe groundwater deposition and detailed interface zone mapping is also necessary to be conducted in the Jangkaran, Kalidengen, and Plumbon Sub-districts to anticipate the widened seawater intrusion zone.

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