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CONTROLLING SEAWATER INTRUSION BENEATH SEMARANG COASTAL URBAN CITY USING GEOPHYSICAL SURVEY AND HYDROGEOCHEMISTRY DATA

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ABSTRACT: As the largest areas in Central Java Province, Semarang has experience coastal inundation from local flood inundation, river flood and sea water tide flood. Moreover, the city experiences long-term seawater intrusion. Investigation of seawater intrusion is a must to control the actual condition. Geophysical survey will provide a subsurface condition that combines the hydrogeochemistry data in controlling seawater intrusion. Resistivity data was collected using the Wenner array. The RMS error computed for iterations of the resistivity value varying from 7.7 to 40.4% with the total depth up to 39.6 m depth in the inverse model resistivity section. Based on the geoelectrical profile, 5 of 10 locations, i.e. SMG-1, SMG-2, SMG-3, SMG-5, and SMG-7 conducted very low resistivity value. The maximum Electrical Conductivity/EC value was 8,810 µS/cm. Integrated Geophysical survey and hydrogeochemical analyses provided the study area into three groups related to the seawater intrusion which are uninfluenced, moderate influenced, and highly influenced.

Keywords: Semarang, Seawater intrusion, Geophysical survey, Wenner array, Hydrogeochemistry

1. INTRODUCTION

Coastal zones often contain some of the most densely populated areas in Indonesia. [1] stated that the availability of flat land, communications arteries, easy sea transportation, permeable soils, and high productivity of organic matter explain this current situation. The coastal zone is subject to more severe complex issues than most other land related to the freshwater demand. The primary use of Semarang coastal areas is housing up to 47% as shown in Table 1.

Table 1. Landuse and the percentage of the area [2]

No	Variable	Area (km^2)	Width (%)
1	Sea water	1.1856	1.02
2	Freshwater	0.6484	0.56
3	Bush	1.3029	1.13
4	Ponds	2.7969	2.42
5	Building	1.1339	0.98
6	Forest	0.0227	0.02
7	Garden	16.121	13.93
8	Housing	54.2003	46.85
9	Swamp	0.0767	0.07
10	Grass	18.3077	15.82
11	Paddy field	11.5	9.94
12	Bare land	0.3202	0.28
13	Moor	8.0817	6.99
	Total	115.698	100

Semarang, as one of the coastal cities in the central north of Java Island, is growing fast, in particular in the industrial and commercial sectors. From a regional development perspective, the position of Semarang is of high strategic value for the economic activities not only for the centre of North Java Island but also for Jakarta as the capital city of Indonesia. This area is supported by an international seaport and a national scale airport (Figure 1). The dynamic condition in Semarang is triggering the increase of economic development for surrounding areas such as from Jakarta in the west to Surabaya in the east.

As the largest areas in Central Java Province, Semarang has experience coastal inundation from local flood inundation, river flood and sea water tide flood. The main factor leading to the land subsidence in Semarang is the groundwater abstraction to fulfil water demands [3]. As population growth and urban development in Semarang City increase, it then leads the clean water quality and its lowering groundwater level [4]. Groundwater conservation zone of unconfined aquifer in Semarang into 4 zones, i.e. secure, vulnerable, critical, and damaged zone based on groundwater quality and its lowering groundwater level was developed by [5]. Moreover, the city experiences long-term seawater intrusion [6-8].

Based on the problem statement, investigation of seawater intrusion is a must to control the actual condition. Geophysical survey will provide a subsurface condition that combines the hydrogeochemistry data in controlling seawater intrusion. Moreover, hydrogeochemistry also will provide the groundwater facies to play a significant role in classifying and assessing water quality.

2. METHODOLOGY

2.1 Geophysical survey

The principle of geophysical survey was to determine, based on measurements taken on the ground, the physical characteristics of the bedrock and to deduce information on its makeup [9]. Geophysical surveys were the most widely used geophysical methods in the island and coastal environments. Electrical methods were usually used to locate brackish or saline waters, although they can yield some geologic information as well [10].

The Wenner array was applied to define profiling resistivity anomalies as an impact of seawater intrusion. The four-point electrodes were arranged constant, 10 m, and moved along profiles up to 180 m length as shown in Figure 1. There were around 10 locations in the Geophysical survey (Figure 2) to address subsurface condition based on resistivity values. The RES2DINV program was applied to provide the two-dimensional (2D) electrical imaging survey. The results from the geoelectrical survey were plotted in the form of inverse model resistivity section which provided an estimated image of the subsurface geology. The data inversion was calculated with the least squares inversion method [11].

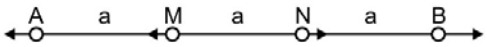

Fig. 1 Electrode configuration in Wenner array [11]

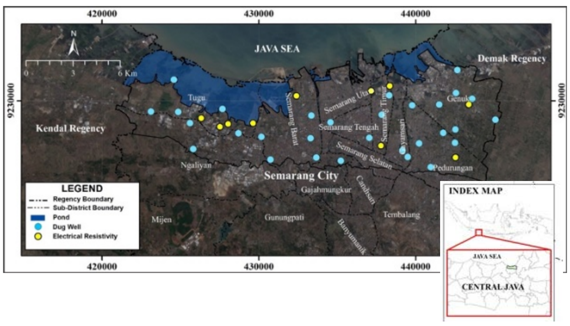

Fig. 2 Geophysical survey (yellow dots) and hydrogeological mapping points (blue dots).

2.2 Hydrogeochemistry analysis

The hydrogeochemistry analysis was one of the most fundamental aspects of groundwater studies. Knowledge of processes that control natural water composition was needed for groundwater management [12]. The assessment of groundwater quality is possible to understand the change in quality due to rock-water interaction or impacts of anthropogenic influence [13].

There were thirty (30) groundwater samples were analysed to define hydrogeochemistry characteristics in the study area. The field campaign was accomplished in July 2017. The pH and electrical conductivity of groundwater sample values were measured by using WtW profile pH 3210 and Cond 3310 during the field campaign respectively. While the major of cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) and anions (Cl^-, SO_4^{2-}, and HCO_3^-) were analysed in the Indonesian Geological Agency laboratory. The major cations were analysed using Atomic Absorption Spectroscopy. Chloride and sulphate were evaluated using argentometric and turbidimetric respectively. Meanwhile, bicarbonate was examined using titrimetric. Indeed, pH and EC value were employed to assess groundwater quality. The Stiff and Piper diagrams were applied. The Stiff system showed the differences or similarities in water and changes in water composition. Piper diagram depicted the groundwater facies as well as identified the hydrochemistry composition in different classes.

3 RESULTS AND DISCUSSION

3.1 Results of the Geophysical survey

A geophysical survey using Wenner array conducted the distribution of seawater intrusion based on the very low resistivity values [14-19]. Lowering the resistivity value as indicating of seawater intrusion also stated by some researchers on worldwide using geophysical survey. The RMS error computed for iterations of the resistivity value is varying from 7.7 to 40.4% with the total depth up to 39.6 m in the inverse model resistivity section.

Based on the geoelectrical profile (Figure 3), 5 of 10 locations, i.e. SMG-1, SMG-2, SMG-3, SMG-5, and SMG-7 conducted very low resistivity value. SMG-1 which is located in the north of Semarang was showing a very low resistivity range 0.702-1.26 Ωm up to 25 m depth. The second level of low resistivity below 1 Ωm was up to 7.5 m depth which is located in the distance around 125 m. Meanwhile, in SMG-2, the profiling resistivity provided the resistivity range between 0.195-1.05 Ωm. The seawater intrusion occurred starting in the depth of 2.5 m. Image SMG-3 is indicating very low resistivity, 0.00863-0.457 Ωm, starting the depth of 18.5 m. This situation is likely similar to the location of SMG-5 which is indicating seawater intrusion in the depth of 18.5 with the range of resistivity value around 0.0593-0.787 Ωm. SMG-7 has two level of seawater intrusion, i.e. the first level, the resistivity showed below 1 Ωm and around 20 m depth. Furthermore, in the distance of around 120 m, seawater intrusion occurs in the depth of starting 2.5 m with the resistivity value of a range of 0.194-0.661 Ωm.

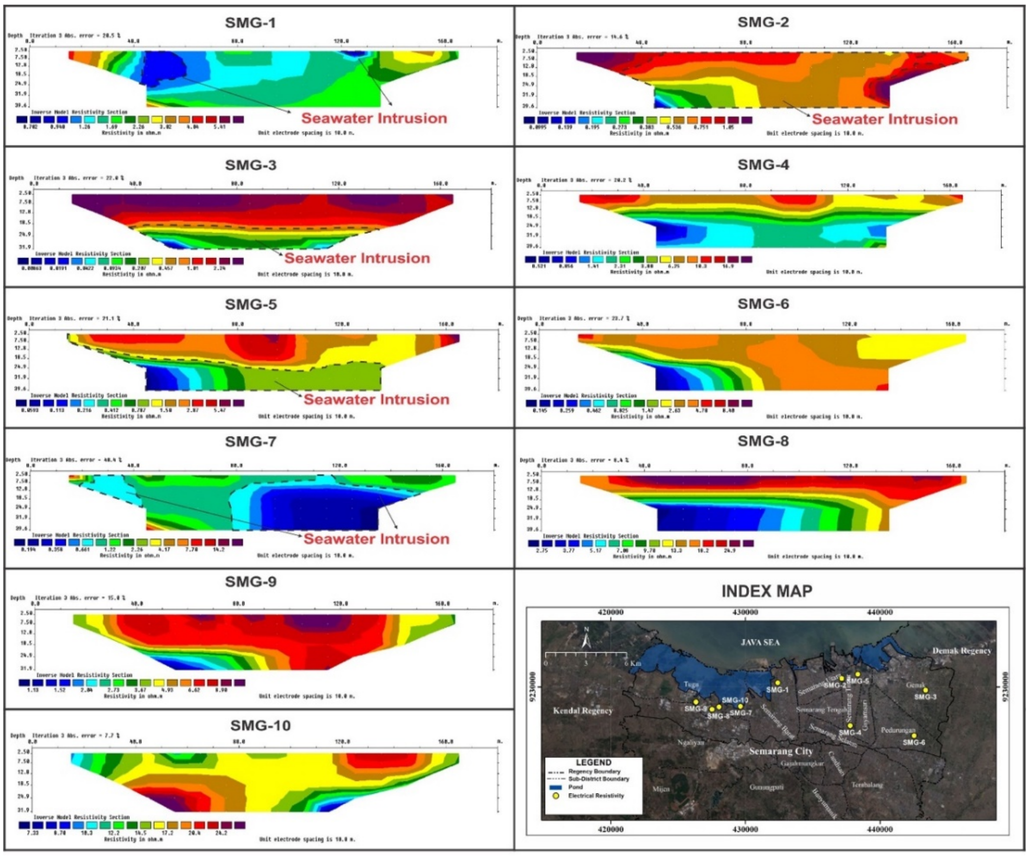

Fig. 3 Inverse model resistivity section of Geophysical survey.

3.2 Hydrogeochemistry analyses

The hydrogeochemistry content was analysed to define the groundwater quality as well as groundwater facies. The maximum Electrical Conductivity/EC value was 8,810 µS/cm as shown in Table 2. It is located in SG-25 (Genuk Sub-District) around 3 km from the Java Sea coastline in the northeast of Semarang. A higher value of EC indicates unsuitable for drinking water. Water has a salty taste and indicates there was seawater intrusion occurred in this area.

Table 2. Summary statistics of ions content

Variable	EC (µS/cm)	pH	DO (mg/L)	Salinity (mg/L)
Min	458	6.22	0.28	100
Ave	1,637	7.19	0.71	803
Max	8,810	8.02	1.07	4,900
SD	1,606	0.34	0.19	916

Moreover, the values of Na^{+1} and Cl^{-1} are around 1,555.6 mg/L and 2,374.2 mg/L respectively. Table 3 shows the value of both physical and chemical content of groundwater sample analyses. Those are obviously the highest values. Another indication of seawater intrusion in this area is the value of Salinity which was up to 4,900 mg/L. In the north of Semarang, EC values resulted above 2,000 µS/cm. While in the centre of Semarang, the range of EC values was 750-1,500 µS/cm. In this region, groundwater from dug wells was still possible for consuming. Meanwhile, in the south, the EC values are up to 1,500 µS/cm. It means groundwater is visible as drinking water resources. Moreover, pH value is the range of 6.22-8.02. These values are acceptable for standard water drinking.

Stiff diagram (Figure 4) shows the dominant cations and anions distribution with concentration represented in electrical equivalent (meq/L). The major cations concentration in groundwater are in the decreasing order as $Na^{+1} > Ca^{+2} > Mg^{+2} > K^{+1}$. The major anions concentration is in the decreasing order as $HCO_3^{-1} > Cl^{-1} > SO_4^{-2}$. Sodium ($Na^{+1}$) was predominant cation in the north (SG-16) and the north-east of Semarang (SG-24 and SG-25) while the chloride was the predominant anion in those regions. Seawater intrusion in the coastal plains dominates the chloride ion concentration. It can be concluded that the most predominant water type in the north-east and the north of Semarang areas was the Na-Cl water type. While Ca^{+2} was distributed predominant cation of the groundwater samples in the south of Semarang (SG-12, SG-13, SG-18, SG-19). While HCO_3^{-1} was the predominant anion in the south of Semarang, it means that the most predominant water type in the south of Semarang was Ca-HCO_3 water type. HCO_3^{-1} ion is mainly derived from the CO_2 present in the atmosphere. The dominantly chemical parameter contents in this study are similar to some studies of seawater intrusion in the coastal area [18,20-21]

The Piper diagram shows the electrical equivalent percentage (meq%) composition of different ions to define the groundwater facies and to determine the water type. The Piper diagram displays in three parts: two trilinear diagrams along the bottom and one diamond-shaped diagram in the middle. The trilinear diagrams show the percentage concentration of cations (Na^{+1} + K^{+1}, Ca^{+2}, Mg^{+2}) and anions (HCO_3^{-1}, Cl^{-1}, SO_4^{-2}) of each sample. The data points of the two trilinear diagrams are extended onto a diamond-shaped which lie perpendicular to the third axis in each triangle. According to the Piper diagram (Figure 5), there are five groups: alkaline earth water predominantly hydrogencarbonate (SG-12), alkaline earth water with higher alkaline content predominantly hydrogencarbonate (SG-2, SG-5, SG-6, SG-7, SG-9 SG-10, SG-11, SG-14, SG-15, SG-18, SG-19, SG-23 and SG-30), alkaline earth water with higher alkaline content predominantly sulphate/chloride (SG-4), alkaline water predominantly (hydrogen) carbonate (SG-1, SG-3, SG-8, SG-20, SG-21, SG 22, SG-26, SG-28 and SG-29) and alkaline water predominantly sulphate-chloride or predominantly chloride (SG-16, SG-17, SG-24, SG-25 and SG-27).

Table 3. Major ions content in the groundwater of Semarang coastal urban city

Code	EC (μS/cm)	pH	DO (mg/L)	Salinity (mg/L)	Na^{+1} (mg/L)	K^{+1} (mg/L)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	Cl^{-1} (mg/L)	HCO_3^{-1} (mg/L)	SO_4^{-2} (mg/L)
SG-01	2,460	7.57	0.55	1,300	387	53.1	83.8	49.6	452	826	6.30
SG-02	1,079	6.84	0.43	500	91.3	22.1	96.8	31.5	99.8	469	14.5
SG-03	1,359	7.35	0.58	600	261	21.0	50.6	6.50	115	681	12.8
SG-04	2,340	6.96	0.54	1,200	241	21.8	251	20.9	333	514	274
SG-05	751	6.77	0.78	300	40.7	11.3	84.0	24.3	87.8	270	22.0
SG-06	679	6.85	0.89	300	40.4	17.1	79.7	15.8	53.5	311	15.2
SG-07	747	6.78	0.63	300	72.5	8.20	66.1	15.3	91.4	259	19.7
SG-08	845	7.16	0.91	400	123	18.7	49.2	13.1	87.4	431	24.1
SG-09	681	7.17	0.49	300	53.6	11.4	48.7	14.2	62.2	312	21.4
SG-10	491	6.22	0.68	200	43.5	8.40	40.5	10.9	45.5	162	17.5
SG-11	622	7.46	0.54	200	53.9	2.60	60.4	9.80	49.1	321	6.50
SG-12	728	7.18	0.74	300	32.1	3.70	102	19.9	29.5	415	17.8
SG-13	568	6.92	0.70	200	47.9	4.50	52.2	16.0	48.7	271	15.5
SG-14	458	7.37	0.97	100	30.1	7.60	59.0	10.6	23.5	262	11.1
SG-15	906	7.76	1.07	400	83.4	12.2	47.1	47.0	67.0	449	19.8
SG-16	3,900	7.31	0.96	2,100	653	57.9	84.3	45.0	934	521	37.3
SG-17	2,680	7.37	0.74	1,400	400	24.4	110	39.7	633	402	46.2
SG-18	1,002	7.23	0.89	400	82.1	6.90	84.9	42.9	59.5	530	27.7
SG-19	834	7.18	0.84	300	70.3	11.1	96.8	18.1	40.7	460	23.6
SG-20	1,530	7.17	0.28	700	156	28.6	68.5	31.2	117	780	19.5
SG-21	1,890	7.61	0.91	900	353	20.3	37.0	56.3	176	948	22.5
SG-22	1,203	7.13	0.34	600	145	24.0	99.0	18.1	82.6	610	0.0
SG-23	956	6.98	0.87	400	85.9	10.5	105	12.9	55.1	488	0.0
SG-24	2,720	8.02	0.66	1,400	489	27.9	59.0	45.9	533	726	0.0
SG-25	8,810	7.23	0.66	4,900	1,556	63.5	168	135	2,374	1,041	0.0
SG-26	1,006	7.51	0.74	400	189	8.80	46.2	1.60	53.5	524	0.0
SG-27	3,710	7.32	0.83	2,000	747	25.6	57.9	37.0	701	907	57.9
SG-28	1,456	7.01	0.48	700	178	46.3	113	23.2	84.2	745	32.3
SG-29	1,448	7.26	0.91	700	200	9.30	97.4	23.2	148	531	68.9
SG-30	1,248	7.07	0.68	600	105	10.7	114	33.8	87.8	523	61.9

4 CONCLUSION

Semarang Coastal Urban City which is directly adjacent to the Java Sea resulted that this area is potentially experiencing the seawater intrusion. The intrusion of seawater resulted in the decrease in groundwater quality. Integrated Geophysical survey and hydrogeochemical analyses provided the study area into three groups related to the seawater intrusion which are uninfluenced, moderate influenced, and highly influenced as shown in Figure 6.

The uninfluenced areas to seawater intrusion are depicted by the lowering EC value below 1,500 μS/cm as shown in Table 4, the water type both alkaline earth water and alkaline water with predominantly hydrogencarbonate and resistivity value above 5 Ωm. These areas are mainly located in the south, west, and south-east of Semarang.

The moderately influenced areas have EC value in the range of 1,500-2,500 μS/cm. The water type is alkaline water predominantly hydrogencarbonate, and indicating seawater to intrusion in depth from 2.5-25 m widespread in the city centre and the north of Semarang urban coastal city.

The high influenced areas of seawater intrusion show that EC value above 2,500 μS/cm while the water type is alkaline water predominantly chloride, and seawater occur in starting depth of 2.5 m in the north and the north-east of Semarang.

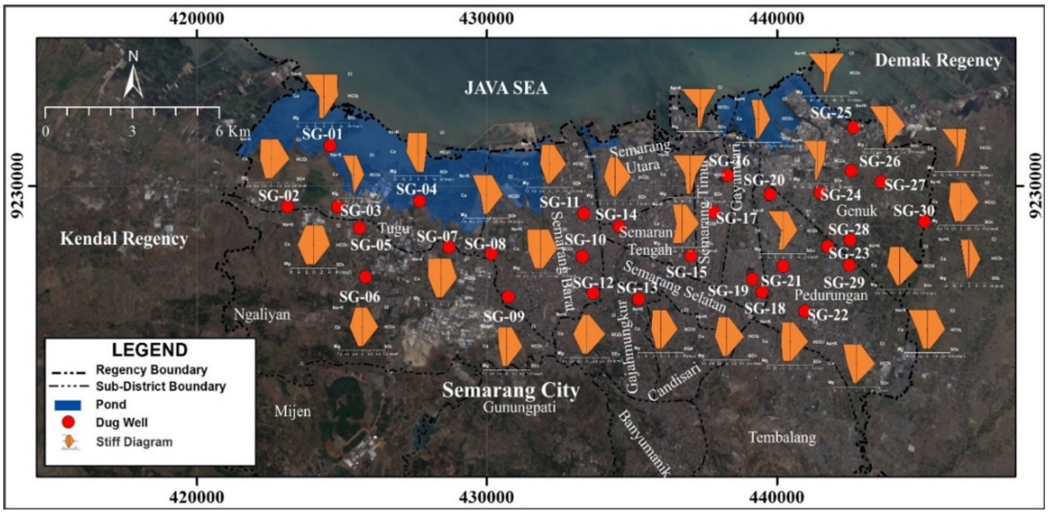

Fig. 4 Stiff diagram showing the distribution of major cations and anions content.

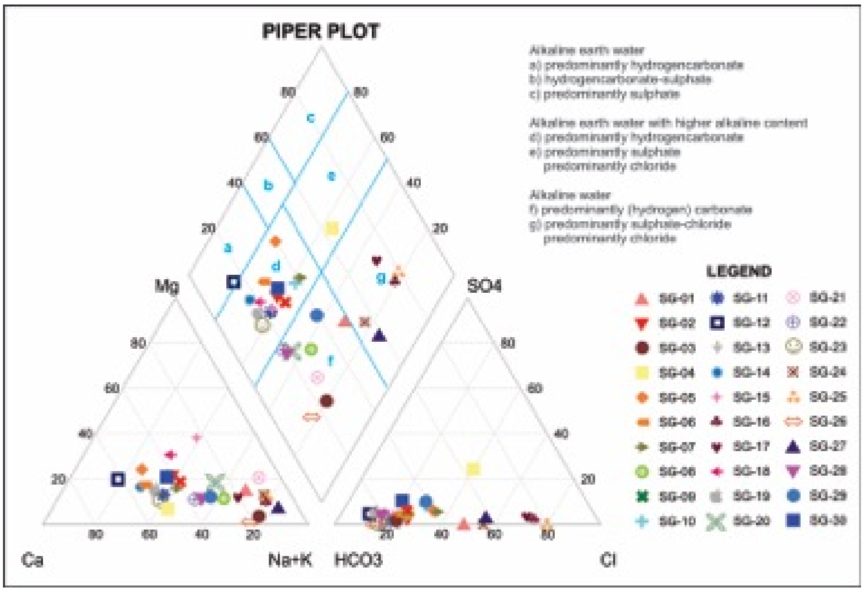

Fig. 5 Piper plot showing the groundwater facies.

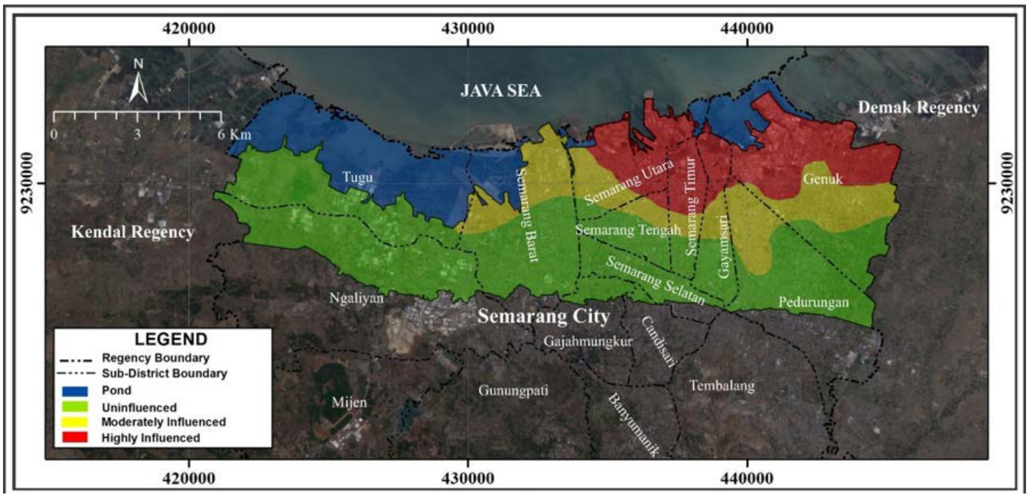

Fig. 6 Seawater intrusion zones

Table 4. Parameters of seawater intrusion in Semarang coastal urban area

Parameters	Seawater Intrusion Zones		
	Uninfluenced	Moderately Influenced	Highly Influenced
EC	< 1,500 µS/cm	1,500-2,500 µS/cm	>2,500 µS/cm
Water type	Alkaline earth water (predominantly hydrogencarbonate) Alkaline earth water with higher alkaline content (predominantly hydrogencarbonate and predominantly sulphate/ chloride) Alkaline water (predominantly (hydrogen) carbonate)	Alkaline water (predominantly hydrogen) carbonate)	Alkaline water (predominantly sulphate-chloride/predominantly chloride)
Depth of Seawater Intrusion	-	2,5-25 m (SG-1), >20 m(SG-3), and >2.5 m(SG-7)	>2.5 m (SG-2 and SG-5)

5. ACKNOWLEDGEMENT

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