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RESEARCH ARTICLE

Groundwater Characteristics Analysis to Identify the Seawater Intrusion in Coastal Deep Aquifer System, Semarang, Central Java, Indonesia

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Abstract

The study area is located in Semarang, representing a coastal and industrial zone where groundwater exploited as main water resources. Seawater instrusion has been identified as a significant issue in coastal regions due to its impact on groundwater quality. The study was conducted using groundwater data from deep aquifers (bore wells). The physical and chemical contents were analyzed to determine the groundwater characteristics and identify the seawater intrusion. Piper and Durov diagram were used to determine the hydrochemical facies and the main processes that influence the chemical content in groundwater. The Cl vs Na/Cl ratio diagram were used to identify the source of Cl and Na ions, determining weather the ions originate from anthropogenic activites or seawater intrusion. The Physical properties of groundwater show that the groundwater in the study area is divided into 2 group: a freshwater group with TDS value <1000 mg/L and a brackish water group with TDS value ranging from 1000 – 4006 mg/L. The results of hydrochemical analysis indicates the occurrence of seawater intrusion in some locations. Seawater intrusion in the study area mainly occurs in the northern part of Semarang city which relatively near with coastal line. The seawater intrusion also occurs in the eastern part of study area (Demak) with a more severe level, reaching areas at a further distance from coastal line compared to Semarang city.

Keywords: Seawater Intrusion, Semarang, Coastal Aquifer, Hydrochemistry

1. Introduction

Groundwater is recognize as a crucial resources for support all the living things in many developing counties (Putra et al., 2019; Taufiq et al., 2018) It is characterized by its naturally renewable properties as part of the hydrological cycle (Asrifah, 2012). Groundwater flows from areas of higher elevation to regions of lower elevation. Within the groundwater system, flow paths are naturally shaped by hilly topography (Toth, 1999). Further research has indicated that the physical and chemical characteristics of groundwater can reveal patterns in groundwater flow, which are essential for understanding groundwater interactions within a system. Groundwater flow tends to alter the chemical composition of groundwater throughout its journey, with dissolved chemical elements evolving through the flow process (Appelo and Postma, 2005; Listiawan et al., 2020).

The study area is located in Semarang areas represent a coastal and industrial zone where groundwater resources have been exploited as a natural resource through the construction of deep wells, shallow well and springs (Ardaneswari et al., 2016; Irawan and Putranto, 2016; Putranto et al., 2017; Putranto and Rüde, 2016) and increased significanly from time to time. One of the important issues regarding groundwater in Semarang is the declining of groundwater level due to groundwater extraction which causes seawater intrusion (Wijatna et al., 2019). Seawater intrusion has been identified as a significant issue in coastal regions due to its potential impact on the quality of freshwater in surrounding areas (Alviyanda et al., 2023; Listiawan et al., 2014; Putra et al., 2019). Seawater intrusion is a phenomenon of increasing groundwater salinity due to mixing with seawater or the dissolution of minerals originating from seawater into groundwater under stagnant conditions (Jiao and Post, 2019). The previous groundwater studies in Semarang conducted by some researcher are stable isotopes study to determine the salinization of shallow groundwater (Satrio et al., 2017), numerical modeling to identify the seawater intrusion (Rahmawati et al., 2013) etc. While, this study analyze groundwater characteristics by using physical an chemical properties of groundwater from deep aquifer system. The groundwater potential and hydrogeological setting of Semarang studied by Putranto and Rüde (2016) and Lubis et al. (2013).

2. Materials and Methods

The study was conducted using 23 borehole data from Center for Groundwater and Enviromental Geology (PATGTL) - Geology Agency, Bandung. The parameters used for analysis are physical properties (pH, EC, TDS and water temperature) and major chemical properties of groundwater i.e. Ca, Mg, Na, K, Cl, HCO_3 and SO_4. The groundwater chemical data were analyzed using several diagrams such as Piper trilinier diagram and Durov diagram to determine the characteristics of groundwater and molar ratio to identify the potential of seawater intrusion.

Piper diagram is more commonly used to determine hydrochemical facies of groundwater compared to other diagrams because it allows for more precise identification of samples and dominant processes in water chemistry. Most natural waters contain cations and anions in chemical equilibrium (Piper, 1994). This statement assumes that the most abundant cations are Ca, Mg, K and Na, while the most abundant anions consist of HCO_3, SO_4, and Cl. The hydrochemical properties of groundwater reflect the residence time or groundwater circulation distance within the aquifer (Chebotarev, 1955; Hutabarat et al., 2023; Trisnadiansyah et al., 2022).

Chloride is the dominant ion in seawater and normally occurs in small concentration in groundwater while HCO_3 typically the most abundant ion in groundwater present in small concentration in seawater (Pradesh, 2014). The effect of seawater intrusion and anthropogenic activities on groundwater can be analyzed using Na/Cl ratio vs Cl diagram, Na/Cl ratios ≤ 0,86 indicates seawater intrusion while Na/Cl ratios ≥1 indicates the anthropogenic sources (Sudaryanto and Naily, 2018; Sunkari et al., 2021).

3. Results

3.1. Geology and Hydrogeology

From regional geological map (Thanden et al., 1996), the geological condition of the research area consist of alluvium (Qa) and Damar Formation (Qtd). The alluvium consist of river and delta deposit such as silt, sand, gravel, pebbles and boulder. The aquifers and aquitards distribution is inhomogeneous, with each aquifer layer separated by lower permeability layer. In general, the aquifers are composed of clayey sand, sand and gravel with depth range from 30 – 90 meter below ground surface. The alluvium aquifers are categorized into two groups: the Garang aquifer and the Quaternary marine sediment aquifer. The lithologic characteristics of these aquifers are similar; however, the groundwater quality differs. The Garang aquifer contains fresh water, whereas the Quaternary marine aquifer contains brackish or salt water (Sihwanto et al., 1988; Haryadi et al., 1991; Mulyana et al., 1994; Wahid & Hendra, 1998; Pasaribu, 2003; Susana & Harnadi, 2007; Putranto and Rüde, 2016) Damar Formation (Qtd) consist of tuffaceous sandstone, conglomerate and volcanic breccia. The aquifer of this Formation consist of tuffaceous sand, sand and conglomerate with depth range from 30 – 100 meter below ground surface.

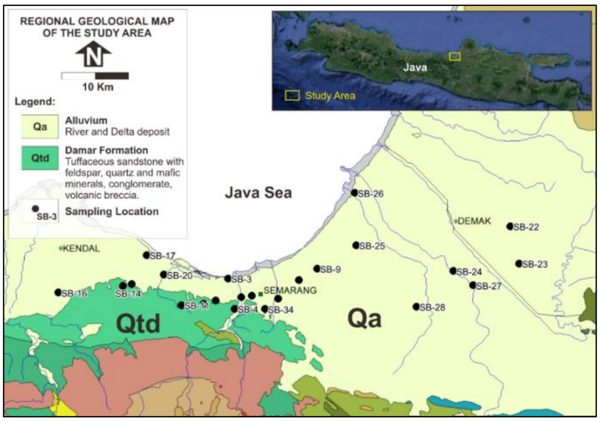

Fig 1. The geological map of the study area (Thanden et al., 1996) and the distribution of sampling locations

3.2. Physical Properties of Groundwater

The physical properties of groundwater shows heterogeneous characteristics. Total dissolved solids (TDS) value range from 259 – 4006 mg/L, electrical conductivity (EC) value range from 387 – 5980 µS/cm, pH value range from 6,23 – 8,06 and water temperature range from 25^{o} – 34^{o} C. Based on physical properties, the groundwater in the study area divided into 2 group. The freshwater with TDS value <1000 mg/L and brackish water with TDS value 1000 – 10.000 (Freeze and Cherry, 1979). The majority of groundwater are classified as freshwater and 7 locations classified as brackish water, namely SB-22, SB-23, SB-24, SB-25, SB-27, SB-28 and SB-33.

Table 1. The physical and chemical properties of groundwater in the study area

Location Code	pH	T_{water} (^{o}C)	TDS (mg/L)	EC (µS/cm)	HCO_3	Ca	Mg	K	Na	Cl	SO_4	Type
SB-3	6,9	33	803	1199	231.8	33.4	28.6	21.9	179.6	258.3	32.8	Freshwater
SB-4	6.4	31	496	740	189.1	43.7	42.7	15.1	34.9	92.3	40.0	Freshwater
SB-9	8.1	30	453	676	137.3	6.0	2.1	7.3	135.4	106.9	55.8	Freshwater
SB-10	7.2	32	720	1074	310.9	14.3	12.3	18.1	191.6	159.2	48.9	Freshwater
SB-12	6.4	25	329	491	244	51.0	15.6	11.6	27.9	25.4	11.4	Freshwater
SB-22	7.3	27	4007	5980	6.1	33.7	12.3	22.1	866.8	1594.8	29.9	Brackish
SB-23	7.1	26	1380	2060	134.2	16.8	6.8	8.6	634.6	895.0	23.8	Brackish
SB-24	7.1	26	1012	1511	237.9	13	4.4	5.7	315.5	319.4	53.3	Brackish
SB-25	7.1	32	1722	2570	292.8	32.6	14.8	16.8	570.7	678.7	49.0	Brackish
SB-26	7.5	32	876	1307	274.5	7.1	1.7	6.7	259.7	248.3	54.1	Freshwater
SB-27	6.5	30	2030	3030	359.5	52.3	35.4	18.3	571.4	788.4	42.8	Brackish
SB-28	6.6	31	1106	1650	335.5	30.3	11.7	17.5	321.4	297.3	47.7	Brackish
SB-32	6.7	31	877	1309	536.8	43.9	37.3	13.1	258.8	182.2	42.7	Freshwater
SB-33	6.5	34	1008	1504	152.5	61.8	20.2	20.8	227.6	414.0	18.5	Brackish
SB-34	7.0	31	688	1027	542.9	36.6	13.4	13.6	254.3	89.6	52.7	Freshwater
SB-35	7.5	34	480	717	237.9	6.3	2.4	8.9	131.9	76.1	22.7	Freshwater
SB-37	6.8	33	693	1034	274.5	37.5	16.0	25.5	161.9	173.2	51.3	Freshwater
SB-11*	6.2	31	259	387	147.8	36.4	11.3	10.1	15.9	36.4	7.1	Freshwater
SB-14*	6.3	25	340	507	274.5	36.4	10.8	10.4	53.5	16.8	11.9	Freshwater
SB-16*	6.3	25	644	961	579.5	77.6	26.6	15.2	76.7	16.0	16.1	Freshwater
SB-17*	7.0	25	491	733	122	3.8	2.1	11.9	157.2	179.2	4.6	Freshwater
SB-19*	6.9	25	747	1115	134.2	24.7	18.4	5.1	200	270.3	45.5	Freshwater
SB-20*	6.5	25	986	1472	183	34.7	14.0	21.5	259.2	369.9	16.2	Freshwater

* From Virgianty et al. (2021); chemical data present in Mg/L

3.3. Chemical Properties of Groundwater

3.3.1 Piper Diagram

The hydrochemical facies concept was developed to understand and categorize water composition in different classes (Talabi and Tijani, 2013). According to Freeze and Cherry (1979), changes in ion concentration due to the length of distance in groundwater circulation affect the solubility of a substance. Hydrochemical facies consist of different zones that process the concentration of cations and anions. According to Domenico and Schwartz (1990), in a large system, the evolution of dominant anion facies in a groundwater flow system changes from HCO_3 in the upper region, to SO_4 in the middle region, and to Cl in the lower region.

The hydrochemical facies of groundwater in the research area dominated by Na-Cl facies found in 15 sampling locations. Natrium and cloride are abundant ion of seawater. The samples with Na-Cl facies indicating the occurance of seawater instrusion into freshwater aquifer, as evidenced by high electrical conductivity values in SB-22, SB-23, SB-25, SB-27, and SB-33. Another possible source of chloride is water-rocks interaction in groundwater with long circulation time. Na-Cl facies samples with low electrical conductivity influenced by water-rocks interaction while higher electrical conductivity with Na-Cl facies indicated the source of Na and Cl ions are from seawater.

The Na-HCO_3-Cl facies found in SB-32 and SB-35 samples. The presence of HCO_3 and Cl type in this facies might be caused by ion exchange during water-rocks interaction. In the table 1, it shows that SB-32 and SB-35 had higher HCO_3 values compared to Cl, indicated the SB-32 and SB-35 water originated from freshwater aquifer.

The Mg-Cl facies found in sample SB-4. The presence of this ion might be caused by the interaction of water and rocks with ferromagnesian minerals such as olivine, pyroxene, amphibole and biotite. Based on the geological map, these mafic mineral found in Damar Formation. The Na-HCO_3 facies found in sample SB-34. The HCO_3 ion generally originates from the shallow groundwater, with CO_2 is the primary source.

The Ca-Mg-HCO_3 facies in SB-11 and SB-12, as well as the Ca-Na-HCO_3 facies in SB-14 and SB-16, were likely caused by ion exchange in rocks during groundwater flow processes. The Mg type in the Ca-Mg-HCO_3 facies indicated that the groundwater had a longer circulation compared to the Ca type. Similarly, the Na type in the Ca-Na-HCO_3 facies indicated that the groundwater had a longer circulation compared to the Ca type. According to geology regional map, the Damar Formation (Qtd) has a lithology consisting of tuffaceous sandstone, conglomerate and volcanic breccia, with sandstone composed of mafic minerals, feldspar and quartz. This suggests that the Ca type in the facies originated from Ca-Plagioclase minerals, which are part of the feldspar group.

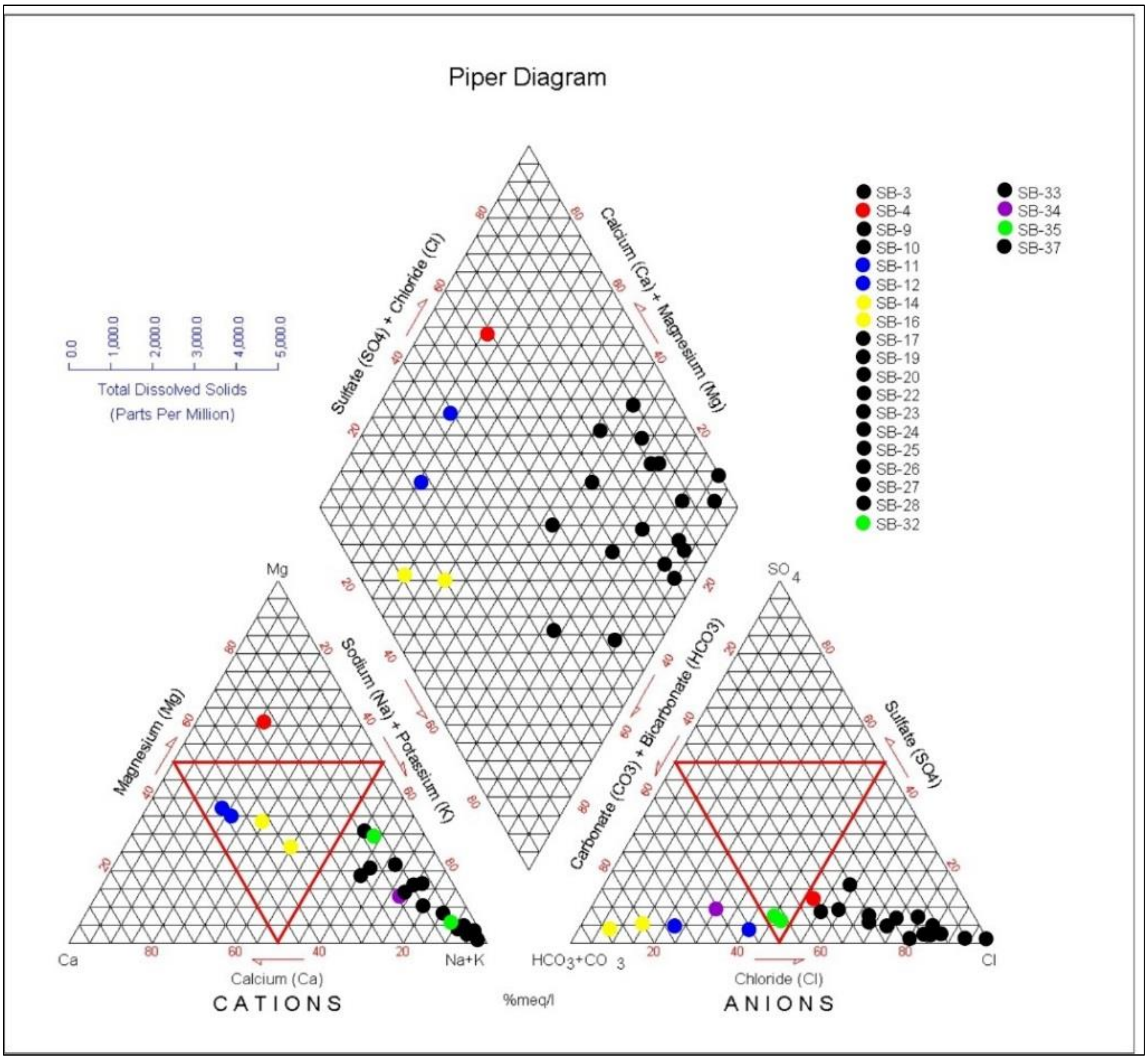

Fig 2. Result of Piper diagram analysis

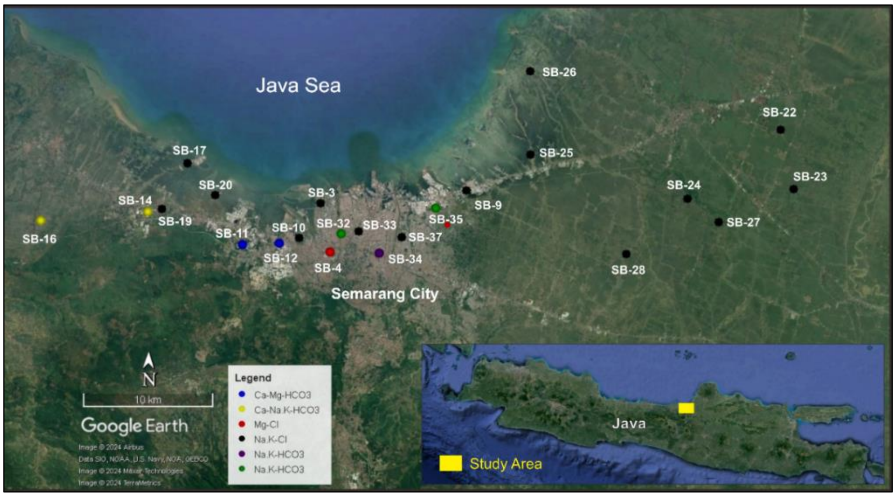

Fig 3. The distribution of hydrochemical facies in the study area

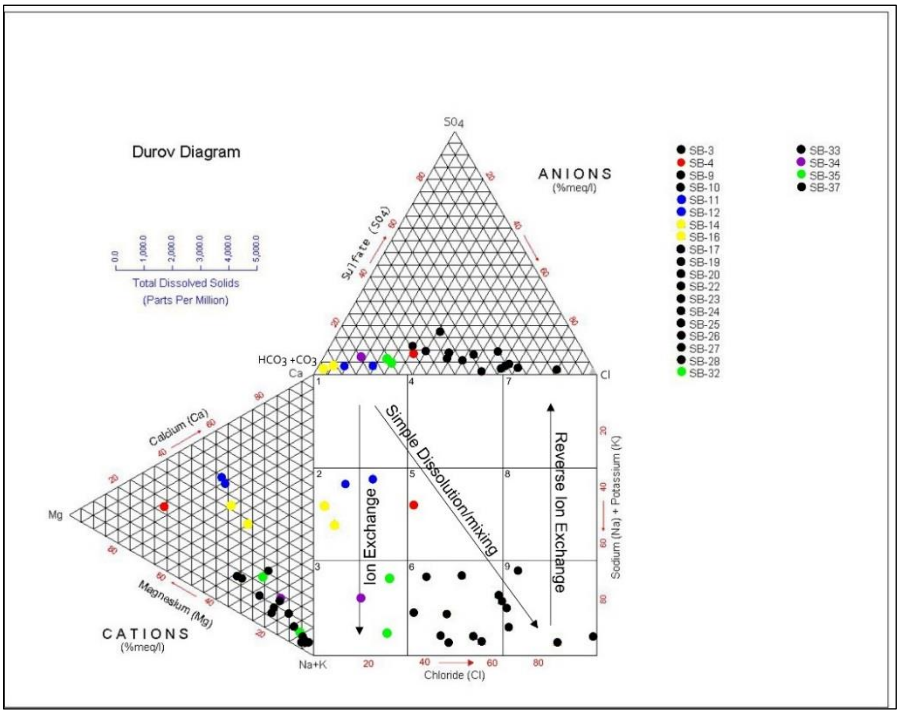

Fig 4. Durov diagram shows the interaction mechanism of ion

3.3.2 Durov Diagram

Based on the results plotted on the Durov diagram, the dominant samples are plotted in field 6. According to Lloyd and Heathcote (1985), this field is characterized by processes of simple dissolution or mixing. In areas where ion mixing or simple dissolution occurs, it may be due to a leaking aquifer causing groundwater to mix with different aquifers. The water in this field consists of Mg-Cl facies in sample SB-4 and Na-Cl facies, which is the most dominant in the study area. The plot results in field 6 suggest that the water has traveled a significant distance, allowing the mixing process to occur. In fields 2 and 3, indicated ion exchange processes occur in groundwater. Field 3 consist of samples SB-32, SB-34 and SB-35, while field 2 consist of samples SB-11, SB-12, SB-14 and SB-16. The ion exchange in field 2 indicates that water circulation is local to intermediate distance as evidenced by the dominant presence of Ca and HCO_3 in the samples. The Ca and Na ions in the rocks originate from the interaction of water with volcanic rocks containing plagioclase minerals. In contrast, field 3, which includes samples SB-32, SB-34, and SB-35 with Na-HCO_3 and Na-HCO_3-Cl facies, shows longer circulation of groundwater indicated by the dominance of Na and Cl.

Field 9 on the Durov diagram indicates reverse ion exchange process in groundwater. This group includes samples SB-23, SB-25, SB-27 and SB-33, all with Na-Cl facies. The plot in field 9 suggests that the reverse ion exchange process has recently begun or has not been occurring for long. Over a longer circulatioin, dominance ion in groundwater will shifts from chloride to bicarbonate anions and from sodium to calcium cations. The other source of Na and Cl in groundwater is from mixing process with seawater and can be used to identify the occurance of seawater intrusion in the study area.

3.3.3 Cl Ion Molar Ratio

Seawater intrusion effect on groundwater in the study area identified using Cl versus Na/Cl ratio, Na/Cl ratios ≤ 0,86 indicates seawater intrusion while Na/Cl ratios ≥1 indicates the anthropogenic sources (Sudaryanto and Naily, 2018; Sunkari et al., 2021). The result shows that 10 groundwater samples with Na-Cl facies are affected by seawater intrusion while 13 samples with differ facies may be affected by anthropogenic activities or rock-water interaction.

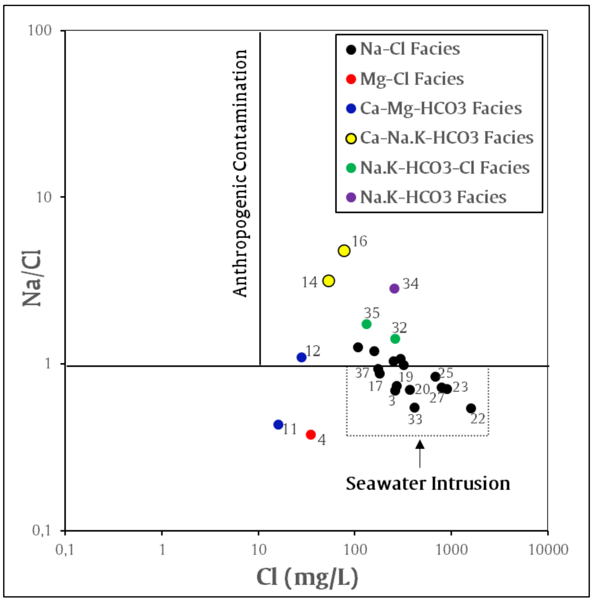

Fig 5. The Cl vs Na/Cl ratio for identify the source of Na and Cl ions of groundwater

4. Discussion

Based on analysis using Piper diagram, Durov diagram and Cl versus Cl/Na diagram, the groundwater in the study area can be categorized into three groups as shown in Table 2:

4.1 Group 1

This group consists of 7 locations: SB-11, SB-12, SB-14, SB-16, SB-32, SB-34, and SB-35. Hydrochemical facies in this group are diverse and Durov diagram shows that ion exchange is the main process of major ion enrichment in groundwater. There is no indication of seawater intrusion into aquifer in this group. The origin of chemical content is from the rock-groundwater interaction during circulation within the aquifer, it is also supported by the EC value that remains normal or <1000 µS/cm. For the samples with EC value >1000 µS/cm (SB-32 and SB-34), anthropogenic or human activities might also contribute to the chemical content and indicates the surface contamination to groundwater .

4.2 Group 2

The group 2 consists of 6 locations: SB-4, SB-9, SB-10, SB-24, SB-26, and SB-28. Hydrochemical facies in this group are Mg-Cl at SB-4 and Na.K-Cl at the other locations. Durov diagram shows the mixing process occur in this group. The mixing process of groundwater with different characteristics can occur in leaky aquifer or caused by well contruction. The Na.K-Cl hydrochemical facies with EC value >1000 µS/cm, indicates the occurence of seawater intrusion with moderate level and the aquifers at these locations needs special attention to prevent seawater intrusion to become more severe (Abdalla, 2016; Jiao and Post, 2019).

4.3 Group 3

This group consists of 10 locations: SB-3, SB-17, SB-19, SB-20, SB-22, SB-23, SB-25, SB-27, SB-33 and SB-37, all with Na.K-Cl hydrochemical facies. Durov and Cl versus Na/Cl ratio diagram indicates the occurrence of seawater instrusion in this locations. The presence of dominant Na and Cl ions are originating from seawater with reverse ion exchange as shown by Durov diagram. The seawater intrusion in this group is also supported by EC value >1000 µS/cm, or between 1034 – 5980 µS/cm (Abdalla, 2016; Jiao and Post, 2019).

Table 2. The result of hydrochemical analysis in the study area

Group	Location Code	Piper Diagram	Durov Diagram	Cl Ion Ratio
1	SB-11, SB-12	Ca-Mg-HCO$_3$	Ion Exchange	-
	SB-14, SB-16	Ca-Na.K-HCO$_3$	Ion Exchange	Water-Rock Interaction / Anthropogenic Activities
	SB-34	Na.K-HCO$_3$	Ion Exchange	Water-Rock Interaction / Anthropogenic Activities
	SB-32, SB-35	Na.K-HCO$_3$-Cl	Ion Exchange	Water-Rock Interaction / Anthropogenic Activities
2	SB-4	Mg-Cl	Mixing	-
	SB-9, SB-10, SB-24, SB-26, SB-28	Na.K-Cl	Mixing	Water-Rock Interaction / Anthropogenic Activities
3	SB-3, SB-17, SB-19, SB-20, SB-22, SB-23, SB-25, SB-27, SB-33, SB-37	Na.K-Cl	Mixing; Reverse Ion Exchange	Seawater Intrusion

5. Conclusion

The groundwater in the study area is divided into 3 groups. The groundwater in group 1 is freshwater groundwater, the chemical content of groundwater in this group related to the rock-groundwater interaction within the aquifer with some location indicating the surface contamination might also contribute to chemical content of groundwater. The group 2 indicates the mixing of groundwater from different aquifer layer. Based on EC value and hydrochemical facies, some locations of groundwater in group 2 indicates the seawater intrusion in moderate level. The group 3 is brackish groundwater, hydrochemical analysis indicates the occurence of seawater intrusion into the aquifer of groundwater in this group. Seawater intrusion in the study area mainly occur in the northern part of Semarang city which relatively near with coastal line. The seawater intrusion also occur in the eastern part of study area. In this area, the seawater intrusion is more severe, reaching area with further distance from coastline compared to Semarang city.

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References

Abdalla, F. Ionic ratios as tracers to assess seawater intrusion and to identify salinity sources in Jazan coastal aquifer, Saudi Arabia. Arab J Geosci 9, 40 (2016). https://doi.org/10.1007/s12517-015-2065-3.

Alviyanda, Anjar Dwi Asterina, Redhatul Irma, 2023. Identification of Saltwater Intrusion Distribution in North Padang Cermin Area, Lampung, Indonesia. J. Geosci. Eng. Environ. Technol. 8, 281–287. https://doi.org/10.25299/jgeet.2023.8.4.12236

Appelo, C.A.J., & Postma, D. 2005. Geochemistry, Groundwater and Pollution (2nd ed.). CRC Press. https://doi.org/10.1201/9781439833544

Ardaneswari, T.A., Yulianto, T., Putranto, T.T., 2016. Analisis Intrusi Air Laut Meggunakan Data Resistivitas Dan Geokimia Airtanah Di Dataran Aluvial Kota Semarang. Youngster Phys. J. 5, 335–350.

Asrifah, D. 2012. Evaluasi Potensi airtanah Bebas untuk Penyediaan Air di Kalasan dan Prambanan. Majalah Geografi Indonesia, 27 (1), 56-78.

Chebotarev, I.I., 1955. Metamorphism of natural waters in the crust of weathering-1. Geochimica et Cosmochimica Acta, 8 (1-2), p.22-48. https://doi.org/10.1016/0016-7037(55)90015-6

Domenico, P.A., Schwartz, F.W., 1990. Physical and chemical hydrogeology. John wiley & sons.

Freeze, R.A.&, Cherry, J.A., 1979. Groundwater, Prentice-Hall, Inc., Englewood Cliffs, N.J. 07632.

Haryadi, Burhanul Arifin & Achmad Mulyana. 1991. Groundwater Quantification for Four Urban Development Areas: Semarang. Directorate of Environmental Geology Bandung – Federal Institute for Geoscience and Natural Resources Hannover.

Hutabarat, J., Muhammad, A. S., Iskandarsyah, T. Y. W. M., Listiawan, Y., Trisnadiansyah, M. R., Andhira, P. A., & Hendarmawan, H. 2023. Geological Trap Controlling the Residence Time of Groundwater in Assessment of Exploitation Zone for Its Sustainable Resources Case Study: The Slope of Karang Mount, Banten Province, Indonesia. Indonesian Journal on Geoscience, 10(3), 419-432. https://doi.org/10.17014/ijog.10.3.419-432

Irawan, D.E., Putranto, T.T., 2016. Hydrochemical assessment of Semarang area using multivariate statistics: A sample based dataset. Earth Syst. Sci. Data Discuss. 1–11. https://doi.org/10.5194/essd-2016-29

Jiao, J., & Post, V. 2019. Coastal hydrogeology. Cambridge University Press.

Listiawan, Y., Hadian, M.S.D., Iskandarsyah, T.Y.W.M., Muhammad, A.S. and Barkah, M.N., 2020. Karakteristik Air Tanah Pada Akifer Vulkanik di Lereng Tenggara Gunung Pulosari, Pandegalang, Provinsi Banten. Bulletin of Scientific Contribution: Geology, 18(1), pp.57-62.

Listiawan, Y., Suganda, N.B., Cipta, E., 2015. Kajian Potensi Intrusi Air Laut Berdasarkan Karakteristik Hidrokimia Airtanah Di Daerah Karangwuni Kecamatan Wates Kabupaten Kulon Progo Provinsi DI Yogyakarta, in: Seminar Nasional Ke-II FTG Universitas Padjadjaran.

Lloyd, W., & Heathcote, A. 1985. Natural Inorganic Hydrochemistry in Relation to Groundwater, an Introduction. Oxford: Clarendon Press.

Mulyana, A., Wahid, Hendra, M.T. 1994. Survei Konservasi Airtanah Daerah Semarang, Demak, Kendal. Directorate Environmental Geology: Bandung.

Pasaribu, Manaris. 2003. Pemantauan Kuantitas Dan Kualitas Airtanah Cekungan Airtanah Semarang – Demak. Direktorat Geologi Tata Lingkungan dan Kawasan Pertambangan (DEG): Bandung.

Lubis, R.F., Delinom, R., Bakti, H., 2013. HAGI-IAGI Joint Convention Medan 2013 Urban Hydrogeology ; Assessment of Groundwater Stress at Semarang City.

Piper, A.M. 1944. A graphic procedure in the geochemical interpretation of water analyses, transition. Journal of American Geophysical Union 25:914-923.

Pradesh, A., 2014. Assessment of Seawater Intrusion Into the Coastal Aquifers in Nellore 2, 387–397.

Putra, D.B.E., Yuskar, Y., Kausarian, H., Wan Yaacob, W.Z., Hadian, M.S.D., 2019. Saltwater Intrusion Zone Mapping on Shallow Groundwater Aquifer in Selat Baru, Bengkalis Island, Indonesia. J. Geosci. Eng. Environ. Technol. 4, 16. https://doi.org/10.25299/jgeet.2019.4.1.2672

Putranto, T.T., Rüde, T.R., 2016. Hydrogeological model of an urban city in a coastal area, case study: Semarang, Indonesia. Indones. J. Geosci. 3, 17–27. https://doi.org/10.17014/ijog.3.1.17-27

Putranto, T.T., Widiarso, D.A., Susanto, N., 2017. Assessment of Groundwater Quality to Achieve Sustainable Development in Semarang Coastal Areas. IOP Conf. Ser. Earth Environ. Sci. 79, 1–10. https://doi.org/10.1088/1755-1315/79/1/012001

Rahmawati, N., Vuillaume, J.F., Purnama, I.L.S., 2013. Salt intrusion in coastal and lowland areas of semarang city. J. Hydrol. 494, 146–159. https://doi.org/10.1016/j.jhydrol.2013.04.031

Revelle, R. 1941. “Criteria for Recognition of Sea Water in Ground Water”. America Geophysical Union, V.22.

Satrio, Prasetio, R., Hadian, M.S.D., Syafri, I., 2017. Stable isotopes and hydrochemistry approach for determining the salinization pattern of shallow groundwater in alluvium deposit Semarang, Central Java. Indones. J. Geosci. 4, 1–10. https://doi.org/10.17014/ijog.4.1.1-10

Sudaryanto, Naily, W., 2018. Ratio of Major Ions in Groundwater to Determine Saltwater Intrusion in Coastal Areas. IOP Conf. Ser. Earth Environ. Sci. 118. https://doi.org/10.1088/1755-1315/118/1/012021

Sunkari, E.D., Abu, M., Zango, M.S., 2021. Geochemical evolution and tracing of groundwater salinization using different ionic ratios, multivariate statistical and geochemical modeling approaches in a typical semi-arid basin. J. Contam. Hydrol. 236, 103742. https://doi.org/10.1016/j.jconhyd.2020.103742

Susana, Mamlucky & Harnadi, Dadi. 2007. Penelitian Hidrogeologi Daerah Imbuhan Dengan Metode Isotop Dan Hidrokimia Di Cekungan Air Tanah Semarang-Demak, Provinsi Jawa Tengah. Pusat Lingkungan Geologi (DEG). Bandung.

Talabi, A.O., Tijani, M.N. 2013. Hydrochemical and stable isotopic characterization of shallow groundwater system in the crystalline basement terrain of Ekiti area, southwestern Nigeria. Appl Water Sci 3, 229–245. https://doi.org/10.1007/s13201-013-0076-3

Taufiq, A., Hosono, T., Ide, K., Kagabu, M., Iskandar, I., Effendi, A.J., Hutasoit, L.M., Shimada, J., 2018. Correction to: Impact of excessive groundwater pumping on rejuvenation processes in the Bandung basin (Indonesia) as determined by hydrogeochemistry and modeling (Hydrogeology

Journal, (2018), 26, 4, (1263-1279), 10.1007/s10040-017-1696-8). Hydrogeol. J. 26, 1281–1284. https://doi.org/10.1007/s10040-018-1728-z

Thanden, R.E., Sumadirdja, H., Richards, P.W., Sutisna, K. & Amin, T.C. 1996. Geological Map of The Magelang and Semarang Sheet, Java, Scale 1:100.000. Geological Research and Development Centre. Bandung.

Toth, J. 1999. Groundwater as a geologic agent : An overview of the causes , processes , and manifestations. Hydrogeol. J. 7, 1–14.

Trisnadiansyah, M.R., Listiawan, Y., Barkah, M.N., Sukiyah, E. and Hadian, M.S.D., 2024. Karakteristik fisika air tanah dan air permukaan serta hubungannya dengan kondisi geologi di lereng selatan Gunung Manglayang, Sumedang, Jawa Barat. Jurnal Pendidikan Geografi: Kajian, Teori, dan Praktek dalam Bidang Pendidikan dan Ilmu Geografi, 27(1), p.8.

Virgianty, A.S., Listiawan, Yudhi., Pramudyo, T., Iskandasyah, T.Y.W.M., 2021. Karakteristik dan Sistem Aliran Airtanah Daerah Semarang Utara Berdasarkan Analisis Fisika-Kimia Airtanah. Padjajaran Geosci. J. 5, 484–491.

Wahid & Hendra, M.T. 1998. Konservasi Airtanah Daerah Semarang-Demak Dan Sekitarnya. Directorate of Environmental Geology. Bandung.

Wijatna, A.B., Kayis, M., Satrio, S. and Pujiindiyati, E.R., 2019. Study of Seawater Intrusion in Deep Aquifers of Semarang Coast Using Natural Isotopes and Hydrochemicals. Indonesian Journal on Geoscience, 6(1), pp.17-28.