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Evaluating Groundwater Quality in Makassar Using Cl/EC Diagrams: Insights into Saline Intrusion and Contamination

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Abstract

Groundwater in the Makassar coastal region is at risk due to natural and anthropogenic factors such as seawater intrusion and pollution. By employing Chloride (Cl) concentration and Electrical Conductivity (EC) measurements, this study aims to classify groundwater types and assess the extent of saline intrusion. The analysis, based on Cl/EC diagrams, identifies key areas affected by seawater intrusion and offers insights into sustainable groundwater management practices. Samples collected from various locations show different degrees of contamination, ranging from normal freshwater conditions to severe seawater intrusion. The study provides recommendations for managing groundwater resources to prevent further degradation.

Keyword: Groundwater Quality, Saline Intrusion, Cl/EC Diagram, Makassar, Seawater Contamination

INTRODUCTION

Groundwater is a vital resource, especially in coastal regions where it is often the primary source of freshwater for domestic, agricultural, and industrial uses (Gleeson *et al*., 2012; Famiglietti, 2014; Taylor *et al*., 2013). In many coastal areas, however, groundwater faces significant risks due to salinization caused by seawater intrusion and contamination from anthropogenic activities (Barlow & Reichard, 2010; Werner *et al*., 2013; Post *et al*., 2018; Michael *et al*., 2017). Makassar, a coastal city in South Sulawesi, Indonesia, is experiencing such challenges, with deteriorating groundwater quality becoming a critical concern (Sappa *et al*., 2015; Haryono *et al*., 2018; Prasetyo *et al*., 2020).

Saline intrusion, where seawater encroaches into freshwater aquifers, is primarily driven by over-extraction of groundwater and rising sea levels (Barlow & Reichard, 2010). This intrusion poses serious threats to water usability and quality (Ding *et al*., 2020). Additionally, pollution from urban and agricultural runoff exacerbates the situation (Rissman & Carpenter, 2015). In this study, we evaluate the groundwater quality in Makassar by utilizing Chloride (Cl) concentration and Electrical Conductivity (EC) as key indicators of salinity and contamination levels (Krishna *et al*., 2019). The Cl/EC diagram is used to classify groundwater into different zones, allowing for a better understanding of the extent and causes of water quality degradation in the area (Zaman *et al*., 2018).

The study focuses on the coastal region of Makassar, which covers approximately 72.46 km^2 (Figure 1). The area's boundaries include Makassar Straits in the West; Tallo River in the

North; Jeneberang River in the South; and The lithological boundary between alluvial deposits and the Camba Formation and Baturape Cindako volcanic rocks in the East.

The geology of the area is characterized by two main formations: the alluvium and coastal deposits (Qac) and the Camba Formation (Tmc) as shown in Figure 2 (Sukamto & Supriatna, 1982). The alluvial deposits consist primarily of sand, gravel, clay, and limestone, while the Camba Formation includes marine sedimentary rocks interbedded with volcanic rocks such as tuff and sandstone. These formations house two distinct aquifers: an unconfined aquifer and a semi-unconfined aquifer.

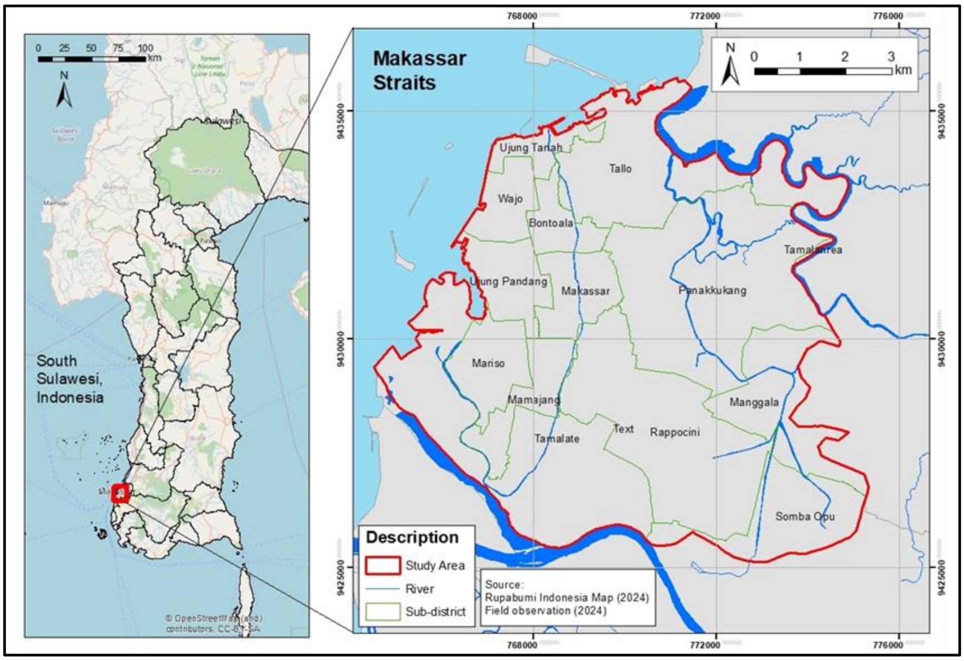

Figure 1. Study Area

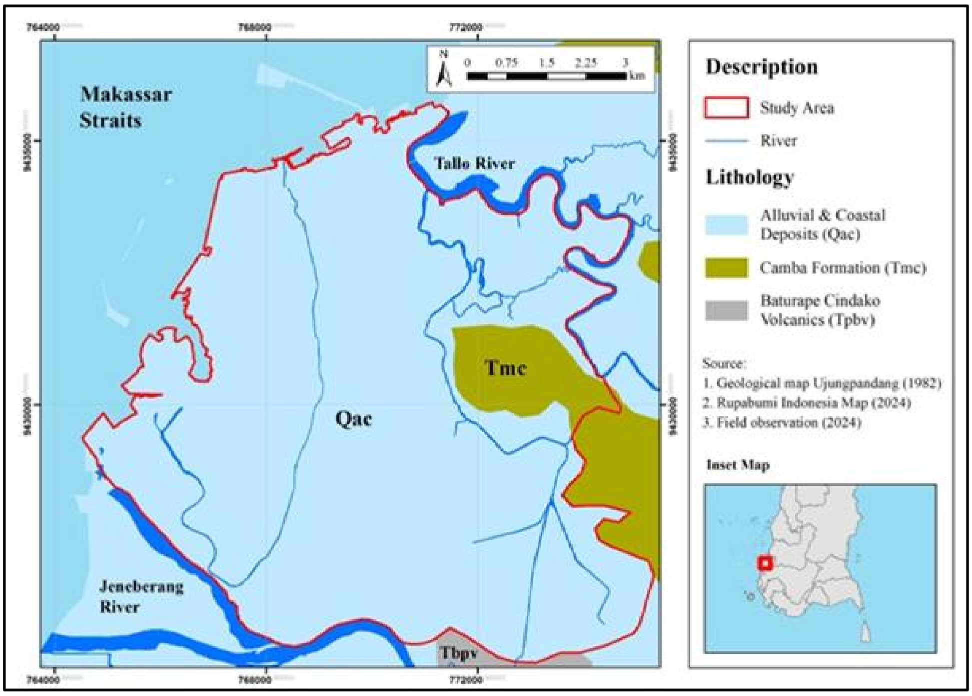

Figure 2. Regional Geological Map of the Study Area

METHOD

Eighteen groundwater samples were collected from different locations within the study area, using secondary data from Nugroho *et al*. (2024), as shown in Figure 3. While the original study focused on other geochemical analyses, this research reanalyzes the Cl- concentrations and EC values using a Cl/EC diagram to provide new insights into contamination patterns. The sample locations were chosen based on their proximity to the coastline and potential contamination sources, such as over-extraction wells and urban areas.

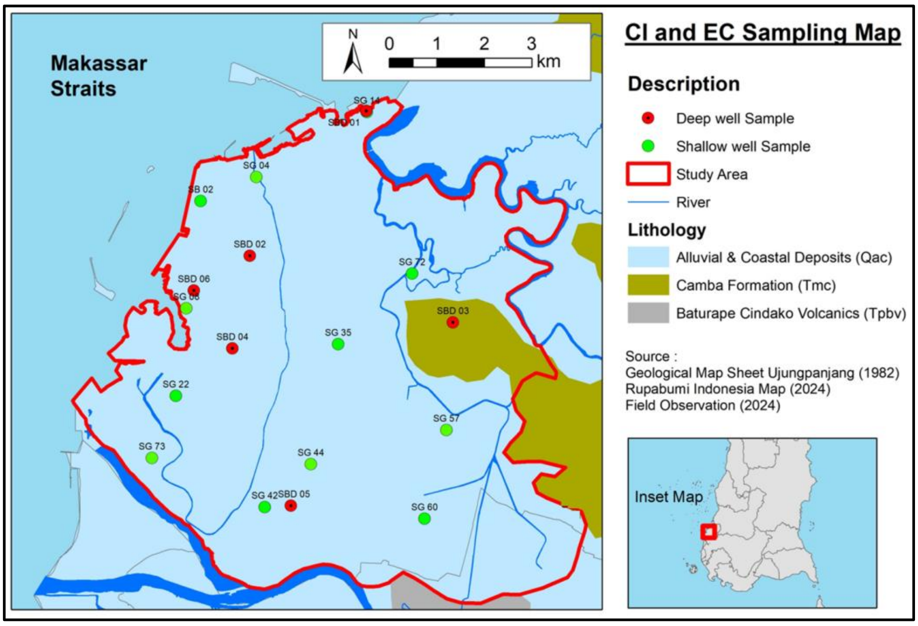

Figure 3. Sampling Location Map

The results were plotted on a Cl/EC diagram, following the method developed by the Washington State Department of Ecology (2005). The Cl/EC diagram classifies groundwater into three main zones:

1. Normal Zone: Low Cl^- and EC values, indicating little to no contamination.
2. Mixing Zone: Intermediate Cl^- and EC values, suggesting a mix of freshwater and seawater or contamination from other sources.
3. Seawater Intrusion Zone: High Cl^- and EC values, indicating significant seawater intrusion into the groundwater.

Analysis was also conducted on the Cl^- and EC values themselves to determine the groundwater type using other references. The classification of groundwater types based on Cl^- values follows the classification from Saline Agricultural Worldwide (2020) as shown in the Table 1, while the classification of groundwater types based on EC values uses the classification from PAHIAA (1986) as shown in the Table 2.

Table 1. Groundwater classification based on EC values (PAHIAA, 1986)

No	Types	EC (µS/cm)
1	Freshwater	< 1,500
2	Slightly brackish	1,500 - 5,000
3	Brackish	5,000 - 15,000
4	Saline	15,000 - 50,000
5	Brine	> 50,000

Table 2. Groundwater classification based on Cl- value (Saline Agricultural Worldwide, 2020)

No	Types	Cl- (mg/L)
1	Freshwater	< 280
2	Slightly brackish	280 - 600
3	Medium brackish	600 - 2,800
4	Brackish	2,800 - 9,000
5	Strong brackish	9,000 - 18,000
6	Sea water	> 18,000

RESULTS AND DISCUSSION

The Cl- and EC concentrations from eighteen groundwater samples are presented in Table 3. Using these values, a graph was then constructed, as shown in Figure 4.

Table 3. Cl and EC concentration

No	Sample	Cl^- concentration (mg/L)	EC value (µS/cm)
1	SBD 01	128,76	892
2	SBD 02	19,78	715
3	SBD 03	19,32	363
4	SBD 04	7.712,12	17.630
5	SBD 05	115,75	1.338
6	SBD 06	1.742,51	8.616
7	SG 14	593,98	2.832
8	SG 22	1.489,02	11.527
9	SG 35	54,75	1.628
10	SG 42	88,89	1.268
11	SG 60	147,41	2.671
12	SG 72	274,64	3.575
13	SB 02	241,53	2.566
14	SG 04	34,97	1.811
15	SG 08	34,06	637
16	SG 44	13,82	824
17	SG 57	136,77	1.726
18	SG 73	83,18	1.129

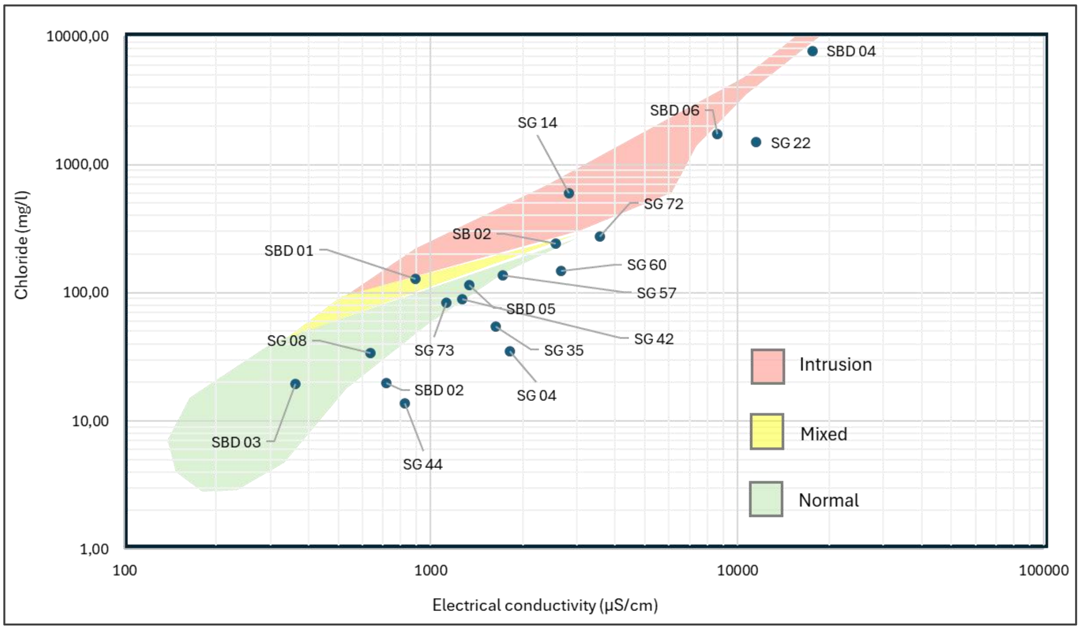

Figure 4. Cl/EC Diagram

From Figure 4, some samples that are outside the group boundaries are classified in the nearest group. Cl/EC Diagram classified 4 samples in the Seawater Intrusion Zone (SG64, SG14, SBD06, SG22), 3 samples in mixed zone (SBD01, SB02 and SG72), and the other samples in normal zone (11 samples). Based on the Cl/EC diagram, a table of analysis results is created (Table 4), along with the groundwater type based on Saline Agricultural Worldwide (2020) for Cl values and PAHIAA (1986) for EC values.

Table 4. Groundwater Quality Analysis based on Cl and EC Analysis Results

No	**Sample**	**Cl/EC Diagram**	**Cl^- concentration (mg/L)**	**Cl Classification**	**EC value (µS/cm)**	**EC Classification**	**Conclusion**
1	SBD 01	**Mixing Zone**	128,76	Freshwater	892	Freshwater	-
2	SBD 02	Normal Zone	19,78	Freshwater	715	Freshwater	-
3	SBD 03	Normal Zone	19,32	Freshwater	363	Freshwater	-
4	SBD 04	**Seawater Intrusion Zone**	7.712,12	**Brackish**	17.630	**Saline**	**Seawater Intrusion**
5	SBD 05	Normal Zone	115,75	Freshwater	1.338	Freshwater	-
6	SBD 06	**Seawater Intrusion Zone**	1.742,51	**Medium brackish**	8.616	**Brackish**	**Seawater Intrusion**
7	SG 14	**Seawater Intrusion Zone**	593,98	**Slightly brackish**	2.832	**Slightly brackish**	**Seawater Intrusion**
8	SG 22	**Seawater Intrusion Zone**	1.489,02	**Medium brackish**	11.527	**Brackish**	**Seawater Intrusion**
9	SG 35	Normal Zone	54,75	Freshwater	1.628	**Slightly brackish**	-
10	SG 42	Normal	88,89	Freshwater	1.268	Freshwater	-

No	Sample	Cl/EC Diagram	Cl^- concentration (mg/L)	Cl Classification	EC value (µS/cm)	EC Classification	Conclusion
		Zone					
11	SG 60	Normal Zone	147,41	Freshwater	2.671	**Slightly brackish**	-
12	SG 72	**Mixing Zone**	274,64	Freshwater	3.575	**Slightly brackish**	Contamination
13	SB 02	**Mixing Zone**	241,53	Freshwater	2.566	**Slightly brackish**	Contamination
14	SG 04	Normal Zone	34,97	Freshwater	1.811	**Slightly brackish**	-
15	SG 08	Normal Zone	34,06	Freshwater	637	Freshwater	-
16	SG 44	Normal Zone	13,82	Freshwater	824	Freshwater	-
17	SG 57	Normal Zone	136,77	Freshwater	1.726	**Slightly brackish**	-
18	SG 73	Normal Zone	83,18	Freshwater	1.129	Freshwater	-

From Table 4, four samples (SG14, SG22, SBD04, and SBD06) are categorized in the seawater intrusion zone, indicating significant intrusion of seawater into the aquifers. Two samples (SBD01 and SG72) fall into the mixing zone, suggesting contamination but not direct seawater intrusion. The remaining samples are in the normal zone, indicating freshwater conditions. Figure 5 shows the highlighted areas affected by seawater intrusion, including shallow wells in the Tallo and Mariso districts and deep wells in the Ujung Tanah district. The study identifies zones most vulnerable to saline intrusion and recommends further research and monitoring.

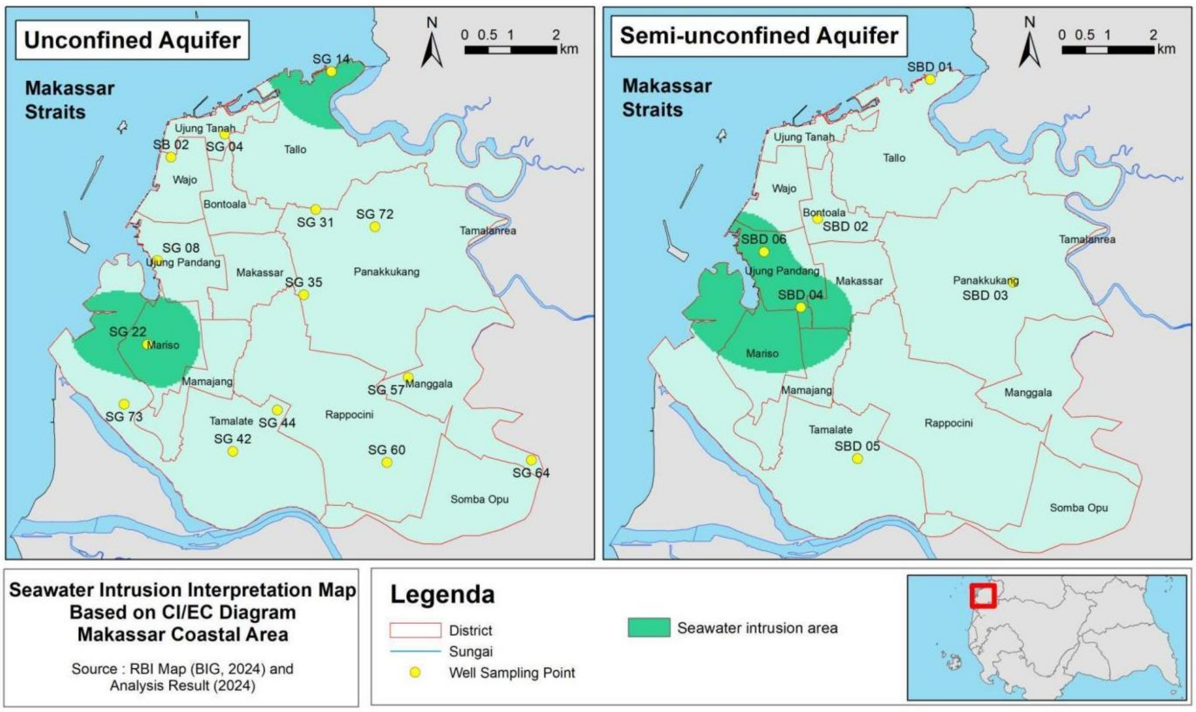

Figure 5. Seawater Intrusion Interpretation Map

CONCLUSION

Based on Cl/EC analysis, it is clear that several areas in Makassar are experiencing groundwater quality degradation due to seawater intrusion. Specifically, the Tallo and Mariso districts show signs of intrusion in shallow wells, while Ujung Tanah is affected in deep wells. Some areas also exhibit signs of contamination unrelated to seawater intrusion, highlighting the need for broader pollution control measures. Proper groundwater management practices are essential to prevent further contamination, including limiting groundwater extraction in vulnerable areas and promoting artificial recharge techniques. Future research should focus on long-term monitoring of groundwater quality in Makassar to ensure sustainable use of this vital resource.

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REFERENCES

Barlow, P. M., & Reichard, E. G. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeology Journal*, *18*(1), 247-260.

Ding, G., Li, X., & Wang, Y. (2020). Impacts of seawater intrusion on groundwater quality and soil salinity in coastal areas. *Environmental Science and Pollution Research*, *27*(1), 1-12.

Famiglietti, J. S. (2014). The global groundwater crisis. *Nature Climate Change*, *4*(11), 945-948.

Gleeson, T., Wada, Y., Bierkens, M. F. P., & van Beek, L. P. H. (2012). Water balance of global aquifers revealed by groundwater footprint. *Nature*, *488*(7410), 197-200.

Haryono, E., Sappa, G., & Luciani, G. (2018). Groundwater quality assessment in the coastal area of Makassar, South Sulawesi, Indonesia. *Environmental Earth Sciences*, 77(24), 1-14.

Krishna, K. C. B., Bhattacharya, P., & Chandrasekharam, D. (2019). Groundwater quality assessment using Chloride and Electrical Conductivity as indicators. *Journal of Hydrology*, 573, 1-10.

Michael, H. A., Post, V. E. A., Wilson, A. M., Werner, A. D., & Person, M. (2017). Science, society, and the coastal groundwater squeeze. *Water Resources Research*, *53*(4), 2610-2617.

Nugroho, S.A., Wilopo, W. and Taufiq, A. 2024. Assessment of seawater intrusion based on geochemical and isotopic data in Makassar coastal area, South Sulawesi, Indonesia. *Journal of Degraded and Mining Lands Management, 12*(1):6563-6577, doi:10.15243/jdmlm.2024.121.6563.

PAHIAA. (1986). *The Classification of Groundwater Salinity*. Jakarta.

Post, V. E. A., Groen, J., Kooi, H., Person, M., Ge, S., & Edmunds, W. M. (2018). Offshore fresh groundwater reserves as a global phenomenon. *Nature, 504*(7478), 71-78.

Prasetyo, A. P., Sappa, G., & Luciani, G. (2020). Hydrogeochemical characterization of groundwater in Makassar City, Indonesia. *Journal of Hydrology: Regional Studies, 28*, 100676.

Rissman, A. R., & Carpenter, S. R. (2015). Pollution from urban and agricultural runoff: Impacts on groundwater quality. *Environmental Management, 56*(5), 1-12.

Saline Agricultural Worldwide. (2020). *Classification of Saline Water*. Saline Agricultural Worldwide. Retrieved May 5, 2024, from https://www.salineagricultureworldwide.com/classification-of-saline-water.

Sappa, G., Luciani, G., & Haryono, E. (2015). Groundwater quality degradation in the coastal area of Makassar, South Sulawesi, Indonesia. *Environmental Monitoring and Assessment, 187*(8), 1-14.

Sukamto, R., & Supriatna, S. (1982). Geological map of the Makassar sheet, South Sulawesi. Scale 1:250,000. Geological Research and Development Centre, Bandung, Indonesia.

Taylor, R. G., Scanlon, B., Döll, P., Rodell, M., van Beek, R., Wada, Y., … & Treidel, H. (2013). Groundwater and climate change. *Nature Climate Change, 3*(4), 322-329.

Washington State Department of Ecology. (2005). Guidelines for delineation of wellhead protection areas. Washington State Department of Ecology, Olympia, .WA.

Werner, A. D., Ward, J. D., Morgan, L. K., Simmons, C. T., Robinson, N. I., & Teubner, M. D. (2013). Vulnerability indicators of sea water intrusion. *Groundwater, 51*(3), 303-315).

Zaman, M., Shahid, S. A., & Heng, L. (2018). Classification of groundwater using Cl/EC diagram. *Journal of Environmental Management, 223*, 1-8.