SPATIAL DISTRIBUTION OF GROUNDWATER SALINITY IN THE COASTAL AREA OF ACEH BESAR DISTRICT

Muhammad Kalbadri[*], Ichwana Ramli[**], Muhammad Faisal[***]
[*]*Department of Environmental Master's Program, Universitas Syiah Kuala Banda Aceh, Indonesia, muhammadkalbadri@gmail.com*
[**]*Department of Agricultural Engineering, Universitas Syiah Kuala Banda Aceh, Indonesia*
Department of Environmental Master's Program, Universitas Syiah Kuala Banda Aceh, Indonesia
Research Center for Environmental and Natural Resources, Universitas Syiah Kuala Banda Aceh, Indonesia, ichwana.ramli@unsyiah.ac.id
[***]*Department of Chemical Engineering, Universitas Syiah Kuala Banda Aceh, Indonesia, mfaisal@unsyiah.ac.id*

Email Correspondence : ichwana.ramli@unsyiah.ac.id

Received : December 16, 2021 Accepted : November 17, 2022 Published : December 31, 2022

Abstract: Utilization of groundwater sources is still an alternative for people living in the coastal areas of Aceh Besar District. If the use of groundwater is carried out continuously, it will have a negative impact on the quality and quantity of groundwater. So the purpose of this study was to determine the distribution of groundwater salinity in the coastal areas of Aceh Besar District. The sample points were determined based on the random sampling method in grids. Sample testing for groundwater salinity was carried out directly in the field according to the planned location. The data obtained was inputted into Microsoft excel and mapping of groundwater salinity distribution using the Inverse Distance Weight (IDW) method with Argis software. A correlation test was performed with Pearson Product Moment. Based on the measurement results, 20 sample points of high salinity were measured. The distribution of salinity values also has a relationship with coastal distance, where the distribution of salinity in general, the farther the groundwater is from the coast, the lower the salinity value, and the closer the groundwater to the coast, the higher the salinity.
Keywords: spatial distribution; salinity; groundwater; coast

Abstrak: Pemanfaatan sumber air tanah masih menjadi alternatif bagi masyarakat yang tinggal di wilayah pesisir Kabupaten Aceh Besar. Jika pemanfaatan air tanah dilakukan secara terus-menerus akan berdampak negatif secara kualitas dan kuantitas air tanah. Sehingga tujuan penelitian ini adalah untuk mengetahui sebaran salinitas air tanah di wilayah pesisir Kabupaten Aceh Besar. Titik sampel ditentukan berdasarkan metode random sampling in grids. Pengujian sampel untuk salinitas air tanah dilakukan langsung di lapangan sesuai dengan lokasi yang telah direncanakan. Data yang diperoleh diinput ke dalam Microsoft excel dan pemetaan distribusi salinitas air tanah menggunakan metode Inverse Distance Weight (IDW) dengan perangkat lunak Argis. Uji korelasi dilakukan dengan Pearson Product Moment. Berdasarkan hasil pengukuran, nilai salinitas yang tinggi terukur sebanyak 20 titik sampel. Nilai salinitas tinggi pada umumnya dipengaruhi oleh intrusi air asin terhadap air tawar. Faktor sebaran salinitas air tanah terjadi akibat intrusi, penggunaan lahan yang dekat dengan tambak dan muara sungai, faktor sebaran salinitas juga dipengaruhi oleh kepadatan penduduk. Sebaran nilai salinitas juga memiliki hubungan dengan jarak pantai, dimana sebaran salinitas secara umum, semakin jauh air tanah dengan jarak pantai maka nilai

salinitasnya semakin rendah, dan semakin dekat air tanah dengan jarak pantai maka salinitasnya semakin tinggi.
Kata kunci: sebaran spasial; salinitas; air tanah; pesisir

Recommended APA Citation :
Kalbadri, M., Ramli, I., & Faisal, M. (2021). Spatial Distribution of Groundwater Salinity In The Coastal Area of Aceh Besar District. *Elkawnie*, *8*(2), 287-297. https://doi.org/10.22373/ekw.v8i2.11719

Introduction

Utilization of groundwater sources is still an alternative for people living in the coastal areas of Aceh Besar District. If the use of groundwater is carried out continuously, it will have a negative impact on the quality and quantity of groundwater. Report to the Office of Energy, Resources and Minerals of Aceh Province in 2019, the quality of groundwater originating from drilled wells in Peukan Bada Sub-District has a hardness and salinity value that exceeds the quality standard limit.

Salinity is the level of saltiness or the level of salt dissolved in water (Folorunso, 2021). The salinity level describes the total salt content in a solution, meaning that the higher the salinity value, the higher the salt content (Abulibdeh et al., 2021). The high value of groundwater salinity in an area is influenced by several factors, namely the occurrence of sea water intrusion, soil and rock permeability, its location close to the coast, land use and also influenced by population density. Overexploitation of groundwater in coastal areas has resulted in saltwater intrusion into fresh water, leading to high salinity in coastal aquifers (Reznik et al., 2020).

The distribution of groundwater salinity the farther the groundwater is from the sea then the lower the salinity value, and the closer the groundwater is to the sea then the higher the salinity (Baroroh et al., 2019). Based on research conducted by Basri in 2012, said that the groundwater in Lhoknga Sub-District is not good because the salinity level is still high even though the pH of the water is relatively neutral. Geographical conditions that are close to the coast cause the water in the area to be intrusive from salt water so it has a high salinity value and is not suitable for consumption.

If excessive groundwater extraction occurs on land, it will cause the groundwater level to decrease. Groundwater salinity is a problem that often occurs in coastal areas, this problem is always related to the need for clean water, where clean water is water that is fit for consumption (Bloomfield et al., 2020). The more seawater that pollutes the fresh water, the more dissolved salts in the fresh water will cause, so the salinity value will be even greater. From several research results, it is stated that the majority of wells along the coast are more susceptible to salinity due to seawater intrusion, this is due to high water consumption for community needs (Idowu & Lasisi, 2020).

Increased salinity of groundwater will have a negative impact on the health, ecology, economic progress of local communities, and productivity of coastal plants through the accumulation of salt in plants and soil (Matsuura et al., 2021). The increase in salinity also has a negative impact on the quality of drinking water which is harmful to human health (Kreyns et al., 2020). Assessment of the spatial variation of groundwater salinity is important for water resource management practices (Sahour et al., 2020). Therefore, this research needs to be done to find out how the spatial distribution of groundwater salinity in the coastal area of Aceh Besar District can be used as a basis for consideration for water resource management and also coastal resource development in the future.

Methods

Materials

This research was conducted in six Sub-Districts located in the coastal area of Aceh Besar District which consists of Lhoong, Leupung, Lhoknga, Peukan Bada, Baitussalam and Mesjid Raya Sub-District, with a certain distance from the shoreline Figure 1.

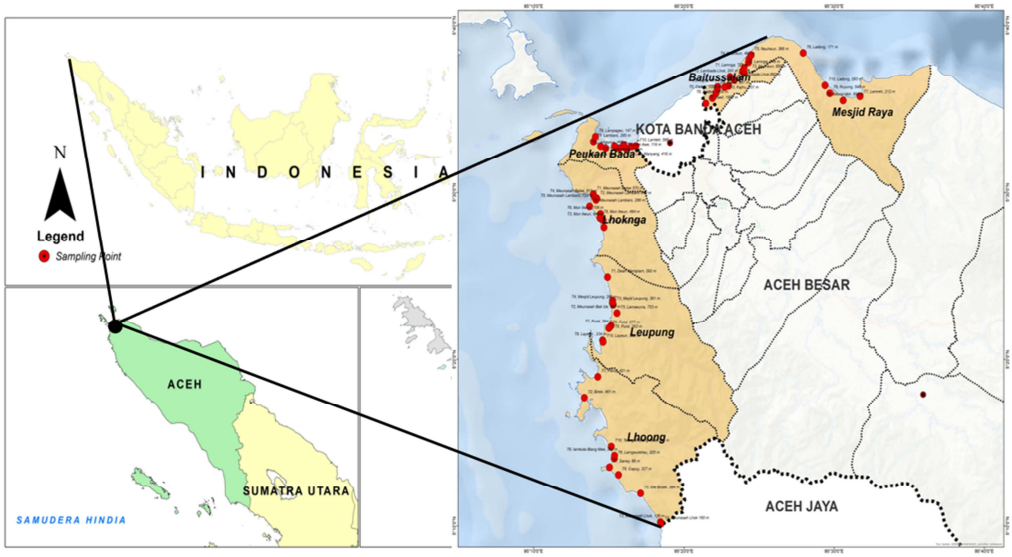

Figure 1. Map of sampling points

Equipments

The tools for measuring data in the field are the Global Positioning System (Garmin Montana 650), meter (Morizt measuring tape), portable refractometer (RHS-10ATC), vertical water sample (WSH-GOPAS 22), and questioner.

Research Procedure

The research procedure consisted of a preliminary survey stage, field measurement stage (water sampling and interviews with the community) and data processing stage using ArcGIS tools for mapping. The sampling point was determined based on the Random Sampling in Grids sampling method (Gok and Gurbuz, 2020). Sampling was carried out for 1 month, by taking 10 groundwater samples from community wells in each Sub-District. The sample in this study was groundwater from drilled wells used by the community for clean water sources.

Sampling and analysis of groundwater refer to SNI 6989.58:2008, while salinity is based on the standard reference method of a refractometer. Measurement of groundwater salinity was carried out directly in the field. The results of the measurement of salinity values were inputted into Microsoft Excel, then the data was processed with ArcGIS tools for mapping. Mapping the spatial distribution of groundwater salinity using the Inverse Distance Weight (IDW) method. Inverse Distance Weight (IDW) was an interpolation method to find out and take into account the surrounding points (Hu et al., 2021).

$$u(x)= \sum_{i=0}^{n} \cdot \frac{Wi\,(X)ui}{\sum_{j}^{N}=0\ wj\,(x)} \quad wi\,(x)= \frac{1}{d(\,X,\,Xi)p} \quad \text{……..(1)}$$

Where:

u_i = u (x_i), for I=0,1,…N
X = interpolation point
X_i = known point
d = distance x – xi
N = number of samples
p = power value

To find out the relationship between the distribution of salinity and the distance to the coast, the Pearson Product Moment correlation test was carried out from the two parameters.

$$r\ xy= \frac{n\ \sum XY-\sum X\ \sum Y}{\sqrt{n\sum X^2-(\sum X)}\sqrt{n\sum Y^2-(\sum Y)}} \text{……(2)}$$

Where:

r_{xy} = correlation between x and y
x_i = value of x towards-i
y_i = value of *y* towards-*i*
n = number of values

Results and Discussion

Salinity Measurement Results

The results of measurements of groundwater salinity show different values seen from the sample points taken in each District. Sampling was at 116 – 661 m from the beach (Table 1). The topography of the research area is relatively diverse, namely lowland flat (0-8%), sloping (8-15%), and slightly steep (15-25%). Steep (25-45%).

Table 1. Characteristics of sample in terms of distance from coastal and salinity value

Sub-District	Sample point	Distance from coastal (m)	Salty sample point	Altitude from Sea Level (masl)	Salinity value (‰)	Slope (%)
Lhoong	10	325	0	14	0.0-0.02	25-45
Leupung	10	122	1	4	0.0-1.0	15-25
Lhoknga	10	70-194	2	11	1.5-2.0	8-15
Peukan Bada	10	116-558	6	5	0.8-2.5	0-8
Baitussalam	10	400-661	6	1	1.0-2.5	0-8
Mesjid Raya	10	171-656	5	3	1.0-3.0	0-8

The distribution of sampling points is generally found in the East North Coastal and West Coast areas. Based on the measurement results (Figure 2), 20 sample points of high salinity were measured. High salinity values were measured in as many as 6 sampling points in Peukan Bada Sub-District, 6 sampling points in Baitussalam Sub-District, 5 sampling points in Mesjid Raya Sub-District, 2 sampling points in Lhoknga Sub-District and 1 sampling point in Leupung Sub-District, while for Lhoong Sub-District there was no measured high salinity value.

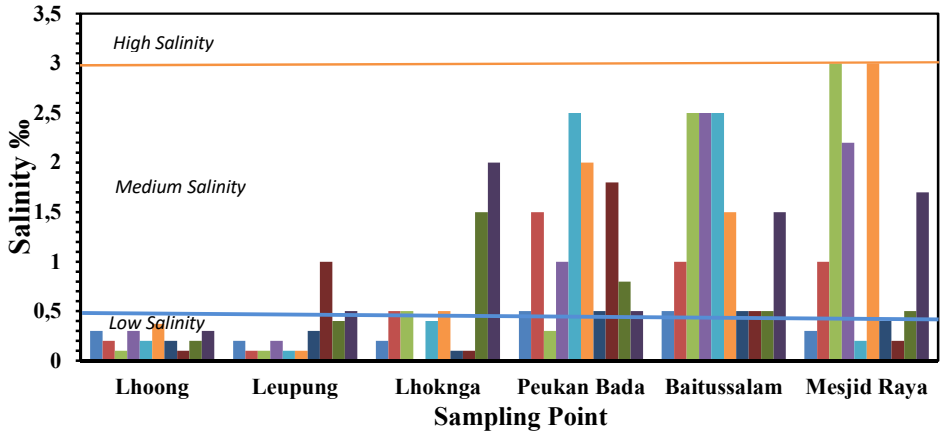

Figure 2. Salinity value from measurement results

Based on the criteria for assessing groundwater salinity, if the groundwater has a salinity value of less than 0,5 ‰ then the water is categorized as fresh water (Low Salinity), if the salinity value is 0,5-3,0 ‰ then the water is categorized as brackish water (Medium Salinity), and if the salinity value is more than 3,0-5,0 ‰ then the water is categorized as High Salty (Tran *et al.,* 2021).

The results of measurements of groundwater samples that have been carried out, in general, the type of fresh groundwater that dominated is as many as 40 wells, while for brackish water as many as 20 wells and no salt groundwater is found. The results of the salinity measurement were carried out by mapping aimed to see the spatial distribution of salinity based on the Regulation of the Minister of Energy and Mineral Resources Number 31 of 2018 concerning Guidelines for Groundwater Conservation Zones. In the regulation, the characteristics of groundwater conservation zones are divided into save zone, vulnerable zone, critical zone dan broken zone. The results of mapping the distribution of groundwater salinity in the coastal area of Aceh Besar District can be seen in Figure 3.

The mapping of the spatial distribution of groundwater salinity using the Inverse Distance Weight (IDW) method. results show that based on the status of the groundwater conservation zone, Peukan Bada and Baitussalam Sub-District are included in the damaged zone status, marked with a red area on the map. Lhoknga and Mesjid Raya Sub-District are included in the critical zone marked with a yellow area, while Lhoong and Leupung Sub-District is included in the safe zone marked with a green area on the groundwater salinity distribution map.

The highest salinity (Table 1) values were found in the Peukan Bada Sub-District, the number of samples measured high was 6 sample points, and the salinity range value was 0,8-2,5 ‰. The type of land use in Peukan Bada Sub-District is dominated by fish ponds and land affected by the Tsunami disaster in 2004. In addition, the pattern of population settlements in the Peukan Bada Sub-District is only 116-558 meters from the beach. The distribution of salinity values in the Baitussalam Sub-District ranges from 1,0-2,5 ‰. The type of land use at the sampling location is in a residential area close to ponds and river mouths. This area is an area directly affected by the tides between the river estuary and the sea.

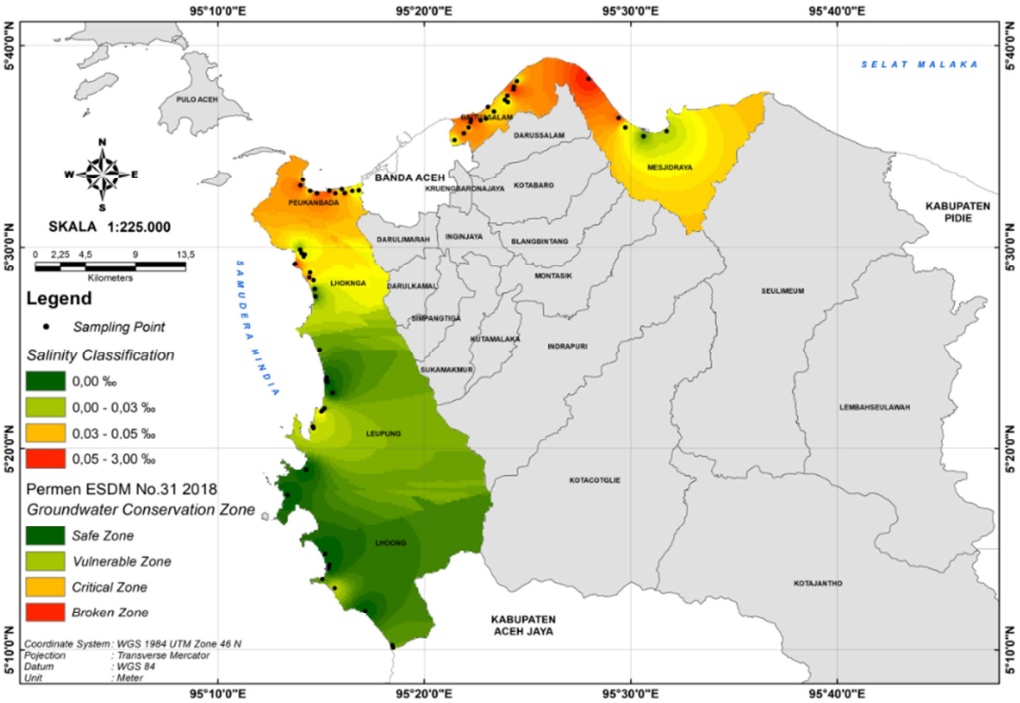

Figure 3. Salinity Value distribution map

In the measurement of salinity values carried out in the Lhoknga Sub-District, there are only 2 sampling points with high salinity values with a salinity value range of 1,5-2,0 ‰. Types of land use at the sampling point are rice fields and fields. The distribution of salinity values in Mesjid Raya Sub-District ranges from 1,0-3,0 ‰, high measured salinity sampling points are located in residential areas adjacent to fish ponds and river mouths, which are 171-656 meters from the coast.

The distribution of high salinity in the Leupung District has only one sampling point with a salinity value of 1,0 ‰ (Figure 2). The sampling point in the area is 122 meters from the beach and the type of land use is a rice field area close to a river that empties into the sea. Salinity measurements carried out in Lhoong Sub-District did not have a high salinity sampling point. The pond area is 874 ha which is only found in the Districts of Mesjid Raya, Baitussalam, and Peukan Bada. The results of observations of the salinity distribution map of the research area, sampling points with high measured salinity values are generally influenced by saltwater intrusion into fresh water, this is due to the location of the sampling points adjacent to the sea, fish ponds and river estuaries. High salinity values were also measured at the sampling locations in densely populated residential areas.

Salinity Distribution Factor

Salinity is the level of saltiness or the level of salt dissolved in water. The problem of groundwater salinity in coastal areas is usually caused by saltwater intrusion into fresh water. The salinity level describes the total salt content in a solution, meaning that the higher the salinity value, the higher the salt content. Excessive pumping of freshwater in coastal areas results in saltwater intrusion into deep freshwater aquifers, leading to the salinization of coastal aquifers. Variable Geological structure is an important factor in determining the distribution of salinity in coastal aquifers (Kreyns *et al*., 2020) which has not been included in this study.

The high salinity values are generally located close to the coastline and also land use close to ponds and river mouths. Saltwater intrusion occurs when seawater seeps into underground water, this depends on the value of the permeability and porosity of the sediment and rock conditions in the area (Kshetrimayum & Laishram, 2020). Lhoong and Leupung, although near the coastal, are directly connected to the highlands with a slight and steep slope and have low salinity. The process of high and low tides also causes salt water to seep into fresh water. This happens because of the hydraulic relationship between salt water and fresh water (Prusty & Farooq, 2020). When the hydrostatic pressure in the land aquifer system decreases, the sea water will press towards the upper fresh water flow first so that the interface layer will tilt towards the mainland, after the hydrostatic balance is reached then the lower interface layer pushes forward towards the mainland. The depth of the aquifer in production wells in this research district ranges from 61 to 108 meters.

Groundwater quality is very important to know because it supports human health, the economy, development and ecological diversity (Ramli I *et al.,* 2019). Various community activities, especially the use of groundwater in coastal aquifers, can increase seawater intrusion because groundwater pressure is reduced and will be relatively smaller than seawater pressure. Extraction of groundwater will lower the groundwater level, causing many wells near the coast to be contaminated. Wells located near the coast generally experience saltwater intrusion, but sometimes mixing occurs even though the well is quite far from the coast. The influence of environmental conditions around the well and the depth of the well will affect the quality of the well water (Shagega et al., 2020).

The factor of salinity distribution is also influenced by population density, this occurs due to the intensity of water intake in residential areas which tends to be higher to meet the sanitation needs of the population (Murtadha et al., 2017). It's proven by the high value of salinity in the two Sub-Districts in the research area, namely Baitussalam and Peukan Bada Sub-District, which are densely populated areas. Reduction of groundwater potential if it occurs in coastal aquifers can cause a hydrostatic imbalance between freshwater and saltwater (Reznik *et*

al., 2020). The increase in salinity is also caused by changes in land use in residential areas, urban areas and road networks (Wen et al., 2019).

Salinity Relationship With Coastal Distance

The results of data processing using Pearson product moment correlation show that the correlation between salinity and coastal distance has a value of -0,575 and a significance value of 0,000 <0,05, the relationship between salinity values and coastal distances is categorized as moderate.

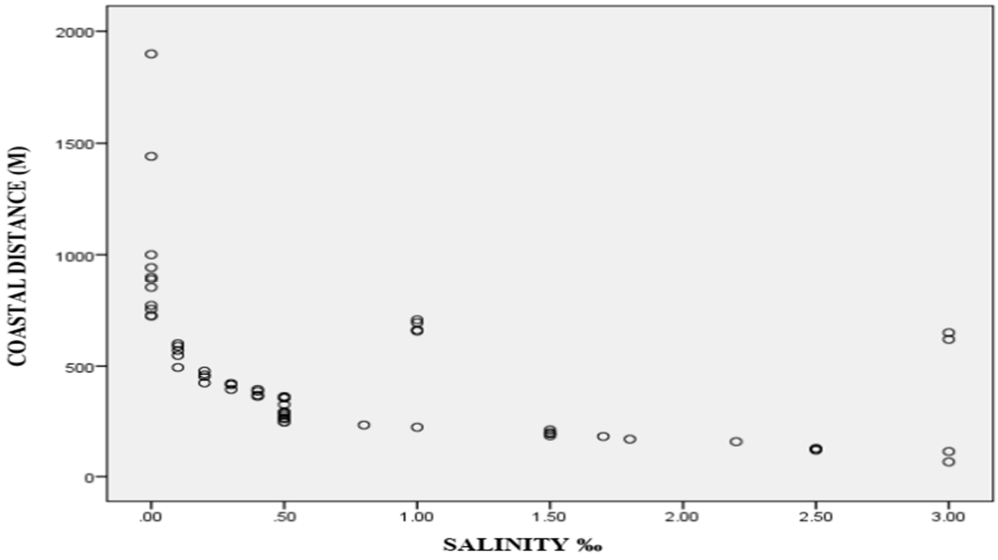

Figure 4. Relationship of salinity to coastal distance

In general, the high and low values of groundwater salinity are closely related to the distance to the coast (Folorunso, 2021). Figure 4 shows the relationship of salinity value to coastal distance, where the lower the salinity value, the plot point will be further away from the beach distance, and vice versa, the greater the salinity value, the plot point will be closer to the beach distance. However, two plot points experience anomalies, this is due to land use in the area which is close to ponds and river mouths (Lane et al., 2020).

Conclusion

Based on the results of the research that has been done, it can be concluded that the results of salinity measurements from 60 points of measurement of groundwater samples, 20 of which were detected as brackish. High salinity values were measured in as many as 6 sampling points in Peukan Bada Sub-District, 6 sampling points in Baitussalam Sub-District, 5 sampling points in Mesjid Raya Sub-District, 2 sampling points in Lhoknga Sub-District and 1 sampling point in Leupung Sub-District, while for Lhoong Sub-District there was no measured high salinity value.

High measured salinity values are generally influenced by saltwater intrusion into fresh water. Groundwater salinity distribution factor occurs due to intrusion, and land use close to ponds and river mouths, salinity distribution factor is also influenced by population density. The distribution of salinity values also has a relationship with coastal distance, where the distribution of salinity in general, the farther the groundwater is from the coast, the lower the salinity value, and the closer the groundwater to the coast, the higher the salinity.

Acknowledgement

The authors thanks the Universitas Syiah Kuala Banda Aceh for their support in this research.

Reference

Abulibdeh, A., Al-Awadhi, T., Al Nasiri, N., Al-Buloshi, A., & Abdelghani, M. (2021). Spatiotemporal mapping of groundwater salinity in Al-Batinah, Oman. *Groundwater for Sustainable Development*, *12*, 100551. https://doi.org/10.1016/j.gsd.2021.100551

Baroroh, Z. F., Harsono, T. N., Ali Sya'ban, M. B., & Dahlia, S. (2019). Sebaran Salinitas Air Tanah Bebas di Desa Pulogading Kecamatan Bulakamba Kabupaten Brebes Jawa Tengah. *Jurnal Geografi, Edukasi dan Lingkungan (JGEL)*, *3*(2), 69. https://doi.org/10.29405/jgel.v3i2.3579

Bloomfield, J. P., Lewis, M. A., Newell, A. J., Loveless, S. E., & Stuart, M. E. (2020). Characterising variations in the salinity of deep groundwater systems: A case study from Great Britain (GB). *Journal of Hydrology: Regional Studies*, *28*, 100684. https://doi.org/10.1016/j.ejrh.2020.100684

Folorunso, A. F. (2021). Mapping a spatial salinity flow from seawater to groundwater using electrical resistivity topography techniques. *Scientific African*, *13*, e00957. https://doi.org/10.1016/j.sciaf.2021.e00957

Hu, W., Xin, X., Zou, X., Li, L., Niu, S., Li, Q., Yu, G., & Wang, L. (2021). Application of production splitting method based on inverse distance weighted interpolation in X Oilfield. *Energy Reports*, *7*, 850–855. https://doi.org/10.1016/j.egyr.2021.09.189

Idowu, T. E., & Lasisi, K. H. (2020). Seawater intrusion in the coastal aquifers of East and Horn of Africa: A review from a regional perspective. *Scientific African*, *8*, e00402. https://doi.org/10.1016/j.sciaf.2020.e00402

Kreyns, P., Geng, X., & Michael, H. A. (2020). The influence of connected heterogeneity on groundwater flow and salinity distributions in coastal volcanic aquifers. *Journal of Hydrology*, *586*, 124863. https://doi.org/10.1016/j.jhydrol.2020.124863

Kshetrimayum, K. S., & Laishram, P. (2020). Assessment of surface water and groundwater interaction using hydrogeology, hydrochemical and isotopic constituents in the Imphal river basin, Northeast India. *Groundwater for*

Sustainable Development, *11*, 100391. https://doi.org/10.1016/j.gsd.2020.100391

Lane, J. W., Briggs, M. A., Maurya, P. K., White, E. A., Pedersen, J. B., Auken, E., Terry, N., Minsley, B., Kress, W., LeBlanc, D. R., Adams, R., & Johnson, C. D. (2020). Characterizing the diverse hydrogeology underlying rivers and estuaries using new floating transient electromagnetic methodology. *Science of The Total Environment*, *740*, 140074. https://doi.org/10.1016/j.scitotenv.2020.140074

Matsuura, T., Tebakari, T., Oda, A., & Ueda, A. (2021). Flow characteristics of artesian groundwater in coastal area of Kurobe River basin, Toyama Prefecture, by long-term and spatial observation of water temperature and electric conductivity. *Groundwater for Sustainable Development*, *13*, 100555. https://doi.org/10.1016/j.gsd.2021.100555

Murtadha, S., Yussof, I., Fauzi, R., & Ramli, I. (2017). Analysis of groundwater quality for irrigation purposes in shallow aquifers: A case study from West Aceh, Indonesia: Groundwater quality. *Singapore Journal of Tropical Geography*, *38*(2), 185–200. https://doi.org/10.1111/sjtg.12197

Prusty, P., & Farooq, S. H. (2020). Seawater intrusion in the coastal aquifers of India—A review. *HydroResearch*, *3*, 61–74. https://doi.org/10.1016/j.hydres.2020.06.001

Reznik, I. J., Purtschert, R., Sültenfuβ, J., Weinstein, Y., Shalev, E., & Yechieli, Y. (2020). Fresh and saline groundwater ages and flow dynamics in a perturbed coastal aquifer. *Journal of Hydrology*, 125721. https://doi.org/10.1016/j.jhydrol.2020.125721

Sahour, H., Gholami, V., & Vazifedan, M. (2020). A comparative analysis of statistical and machine learning techniques for mapping the spatial distribution of groundwater salinity in a coastal aquifer. *Journal of Hydrology*, *591*, 125321. https://doi.org/10.1016/j.jhydrol.2020.125321

Shagega, F. P., Munishi, S. E., & Kongo, V. M. (2020). Assessment of potential impacts of climate change on water resources in Ngerengere catchment, Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, *116*, 102804. https://doi.org/10.1016/j.pce.2019.11.001

Wen, X., Lu, J., Wu, J., Lin, Y., & Luo, Y. (2019). Influence of coastal groundwater salinization on the distribution and risks of heavy metals. *Science of The Total Environment*, *652*, 267–277. https://doi.org/10.1016/j.scitotenv.2018.10.250