Spatial distribution change of groundwater quality in deep aquifer of Semarang alluvial plains area in past five years

Susanto¹*, Syafrudin¹ and T T Putranto²

¹Departement of Environmental Engineering, Diponegoro University, Semarang, Indonesia
²Department of Geological Engineering, Diponegoro University, Semarang, Indonesia

susantocabdinss2021@gmail.com

Abstract. Over time, excessive groundwater usage in urban areas can affect groundwater conditions both in quantity & quality. In some regions, groundwater in the unconfined aquifer has been heavily involved, but for confined aquifers that are deep & tend to be protected, they are not involved too much. The extensive effect, especially groundwater quality, is very significant, especially in coastal areas where seawater intrusion is common & changes in water salinity occur within a specific time range. Regarding these conditions, research was carried out related to changes in spatial & temporal distribution patterns of groundwater quality, exceedingly physical & chemical parameters related to salinity in confined aquifer conditions in coastal areas. By taking a case study in the alluvial plains of Semarang City, this study aims to determine whether there are significant changes in the five years, starting from 2016 to 2020. By using data sourced from groundwater quality tests taken in the reference year, the results gained from the data processing explained that the groundwater quality parameters such as electrical conductivity, total dissolved solids (TDS), acidity (pH), & chloride ions (Cl⁻) are changing respectively, both spatially & temporally.

1. Introduction

Water has long been a necessity for fulfilling human life & all forms of life on Earth [1]. Unfortunately, not all types of water can be directly consumed, although the composition of the Earth is known to be mostly water. Only groundwater accounts for 0.625% of the total water on Earth & is the most desirable for meeting needs because most of it is freshwater, up to 96% [2-3]. It is due to the easy accessibility to obtain it & the broad scope of use to affect the social & economic conditions of an area [4-7]. The amount of groundwater extracted on a world scale, based on 2010 data, is estimated at 982 km³/year, with the countries with the most significant utilization being India, China, & the United States [8].

Groundwater can be found in rocks below the surface that can store & drain the water, namely aquifers [9]. The aquifer is divided into aquifers: namely, free aquifers, which are located just below the ground surface which are in direct contact with the air, & confined aquifers, which are bounded by two impermeable layers [10-11]. Communities themselves, mainly those close to water sources, generally use shallow groundwater by making dug wells & springs, but in some cases, people prefer to build private or group wells to take groundwater from a deep confined aquifer [12]. The construction of these wells has significantly increased both in quantity & quantity, especially in developing
countries, & requires high availability of clean & freshwater [13-15]. This condition has not considered the number of wells that do not provide information to policymakers or relevant agencies in their area to facilitate monitoring of the quantity & quality of wells & water.

Over time, both in quantity & quality, groundwater has undergone significant changes with time. In this case, it has decreased. Several cases such as the decrease in mean groundwater level, saltwater or seawater intrusion, draining of river flows, & subsidence or land subsidence are triggered mainly by excessive & uncontrolled pumping [15-16]. In a short time, these impacts will not be felt too much but will be felt more & more over time & trigger negative impacts, especially in coastal areas where groundwater changes are very dynamic [6, 17-18].

The Semarang City area itself is one of the many big cities in Indonesia experiencing several groundwater problems, especially those whose areas are near the coast. Massive water use was triggered by significant population growth over the past 20 years, with an increase from 0.37% to 1.17% for its growth rate & 987 people per km² to 1,113 people per km² for population density [19-21]. The largest concentration of the population is in the area near the coast, especially in the area included in the alluvial lowlands that stretch from west to east. Semarang City population growth is also accompanied by an increased number of groundwater supplies, which is proven by the increased number of wells reported to the relevant agencies during the period 1990 to 2010, & continues to increase over time [15, 22].

Several studies have shown the effect of increasing the number of wells & the high number of water withdrawals with physical & chemical conditions from groundwater, especially related to groundwater salinity in Semarang City [23-28]. In general, the typical groundwater being studied is sourced from shallow aquifers that have suffered significant damage, both in terms of quality & quantity. Studies on the quality & quantity conditions and the significant effect of quality & salinity have not been discussed for the groundwater domain in confined aquifers. In this study, analysis of quality data was carried out by considering groundwater's physical & chemical parameters in the deep aquifer & collaborated with changes in its distribution in several years. This mechanism has been widely developed to find out changes & distributions with map representations, & in some cases, related to the distribution of land-use changes [29-32].

2. Methodology

2.1. Research location

The research area focuses on the alluvial plain in Semarang City, which is located in the northern part of the city & spreads from west to east, & in the east, it extends to the south partly (Figure 1). Geographically, the position of this location is at 60° 55' 53.334" – 70° 4' 53.169" & 110° 17' 0.304" – 110° 30' 24.628 or in UTM it is in 420864 – 445521 E & 9217185 – 9233797 S. The area of the research area is 143.23 square kilometres, extending from the west bordering Kendal Regency to the east bordering Kendal Regency. The research area is directly adjacent to saltwater waters in the north, namely the Java Sea.

2.2. Data usage

Data for research related to changes in salinity in groundwater in confined aquifers at the study site used physical & chemical quality test data from the Department of Energy & Mineral Resources (ESDM) of Central Java Province. The data was obtained through individuals & industries who conducted groundwater tests at the laboratory agency, with a range of data utilization from 2016 to 2020. The details of the data included in this study cover the central area of Semarang City, which is then narrowed down into regional boundaries, detailed information as follows (Figure 2 & Table 1).

In this study, several components of physical & chemical quality tests were used to study groundwater quality. The details of the parameters used for this study are as follows in Table 2. Further, after spatial processing, the parameter data will be grouped based on specific classifications that characterize whether salinity is influenced in the tested groundwater content or the classification of the
tendency of the type of water to its quality. The details of the intended classification are as follows (Table 3).

Figure 1. Map of the research area in the Alluvial Plain of Semarang City.

Figure 2. Map of the distribution of drilled/deep well location data at research locations from 2016 to 2020.
Table 1. Details of information on the amount/availability of data for research.

| Data year | Total data (Research Area) | Number of data addition |
|-----------|----------------------------|-------------------------|
| 2016      | 30                         | 0                       |
| 2017      | 67                         | 37                      |
| 2018      | 113                        | 46                      |
| 2019      | 175                        | 63                      |
| 2020      | 199                        | 23                      |

Table 2. Details of parameters used for groundwater quality assessment.

| Parameters                              | Unit       | Test Tool         |
|-----------------------------------------|------------|-------------------|
| Electrical conductivity (EC)            | µS/cm      | WTW Cond 3310     |
| Total dissolved solid (TDS)             | Mg/L       | WTW Cond 3310     |
| pH                                      | -          | HACH sensIO       |
| Chloride                                | Mg/L       | Micro Burette (Titration) |

Table 3. Classification of physical & chemical quality parameters of groundwater [33-39].

| Parameters                              | Freshwater | Brackish water | Saltwater |
|-----------------------------------------|------------|----------------|-----------|
| Electrical conductivity (EC)            | 0-1.000 µS/cm | 1.000-15.000 µS/cm | 15.000-50.000 µS/cm |
| Total dissolved solid (TDS)             | 0-1.000 mg/L | 1.000-5.000 mg/L | >5.000 mg/L |
| pH                                      | 6.5-8      | 8-9             | More than 9 |
| Chloride                                | 0-500 mg/L | 500-5.000 mg/L | 5.000-19.000 mg/L |

2.3. Data processing methods

In processing the data owned, used methods based on geographic spatial or geographic information system (GIS). This method uses a database integrated with a computer to collect, check, integrate, & analyze the information held, as long as the information has been registered geographically. This method has a high degree of flexibility to analyze databases that include mathematics, statistics, & decision-making [40-42].

The data prepared through the GIS will then be interpolated using specific spatial analysis methods adapted to the data. Interpolation itself is defined in the form of a mathematical function or method to determine a magnitude of value from a point or position that has no previous value [43]. There are various types of interpolation methods, but the Inverse Distance Weighted or IDW type was used for this study. This interpolation method assumes that at each point, the input has a local effect & decreases with the distance between the points so that it is relatively affected by the value of the sample point, which is processed through mathematical equations. In data processing, the use of weight values plays a role in providing an overview of the derived value of the distance function between the data sample points & those whose values will be determined further [44-46].

3. Result and discussion

3.1. Spatiotemporal changes in Electrical Conductivity (EC)

The first result of processing groundwater quality data obtained is electrical conductivity. The information presented in Figure 3 & Table 4 provides an overview of the pattern & magnitude of spatial & temporal changes in the value of electrical conductivity in the study area. Based on the data presented, the pattern of change from 2016 to 2020 varies, where the area of EC value is indicated as brackish water, which increased from 2016 to 2018 & then decreased significantly from 2019 to 2020, especially in the northern & central regions. However, in the process at that range, there was the appearance of areas with different electrical conductivity values indicating the emergence of new distributions in the western part of the study area in 2019 & 2020. The results of grouping groundwater salinity types based on the range of EC values obtained included two types referring to
classification: freshwater with a value range of 0 – 1,000 µS/cm & brackish water with a value range of 1,000 – 15,000 µS/cm.

![Spatiotemporal change in groundwater quality based on electric conductivity data](image)

**Figure 3.** Spatial & temporal changes in the distribution of electric conductivity values in the 2016 to 2020 range.

**Table 4.** Information on the area (km²) of EC value & groundwater quality referring to salinity parameters in the 2016 to 2020 range

| Groundwater Quality Type according to EC | Distribution of Area (km²) in Year |
|-----------------------------------------|-----------------------------------|
|                                         | 2016     | 2017     | 2018     | 2019     | 2020     |
| Fresh Water                             | 127.17   | 127.18   | 105.81   | 108.58   | 113.52   |
| Brackish Water (Low – Medium Salinity)  | 16.06    | 16.05    | 37.42    | 34.65    | 29.71    |
| Saltwater (High Salinity – Very High)   | -        | -        | -        | -        | -        |

3.2. Spatiotemporal change in Total Dissolved Solids (TDS)
The second result of processing groundwater quality data obtained is total dissolved solids (TDS). The information presented in Figure 4 & Table 5 provides an overview of the pattern & magnitude of spatial & temporal changes in the TDS value in the study area. Based on the data presented, the pattern of change from 2016 to 2020 experienced variations, where the area of the TDS value indicated as brackish water, which increased in 2016 to 2017, experienced a significant increase until areas with saltwater type appeared in 2018, then decreased in the area in 2018—2019 to 2020, especially in areas in the north. In the process of change, the central area experiencing expansion in the northern part, while in the central & northeastern parts, it appears locally related to changes in the type of groundwater salinity. The results of grouping the groundwater salinity based on the range of TDS values obtained include three types referring to the classification: freshwater with a value of 0 – 1,000 mg/L, brackish water with a value of 1,000 – 5,000 mg/L, & saltwater with a value > 5,000 mg/L.
Figure 4. Spatial & temporal changes in the distribution of TDS values in the 2016 to 2020 range.

Table 5. Information on the area (km²) of TDS value & groundwater quality referring to salinity parameters in the range 2016 to 2020.

| Groundwater Quality Type according to TDS | Distribution of Area (km²) in Year |
|------------------------------------------|-----------------------------------|
|                                          | 2016    | 2017    | 2018    | 2019    | 2020    |
| Fresh Water                              | 142.76  | 142.25  | 134.58  | 135.06  | 135.53  |
| Brackish Water (Low – Medium Salinity)   | 0.48    | 0.98    | 7.88    | 8.00    | 7.53    |
| Saltwater (High Salinity – Very High)    | -       | -       | 0.77    | 0.17    | 0.17    |

3.3. Spatiotemporal changes degree of acidity (pH)
The third result of processing groundwater quality data obtained is the degree of acidity (pH). The information presented in Figure 5 & Table 6 provides an overview of the pattern & magnitude of spatial & temporal changes in pH values in the study area. Based on the data presented, the pattern of change from 2016 to 2020 experienced variations, where the area of the pH value indicated as brackish water increased drastically from 2016 to 2017, then significantly expanded until 2019, & areas with typical saltwater appeared in 2020. In the process of change, the main areas that experience expansion is the north, east, northeast, southeast, & middle, while in the west & south, they appear locally related to changes in groundwater salinity types. The results of the grouping of groundwater salinity types based on the range of TDS values obtained include three types according to the classification: freshwater with a value range of about 7 to 8, brackish water with a value range of 8 to 9, & saltwater with a value range of more than 9.
Figure 5. Spatial & temporal changes in the distribution of pH values in the 2016 to 2020 range.

Table 6. Information on the size of the area (km$^2$) pH value & groundwater quality referring to salinity parameters in the range 2016 to 2020.

| Groundwater Quality Type according to pH | Distribution of Area (km$^2$) in Year |
|----------------------------------------|-------------------------------------|
|                                        | 2016 | 2017 | 2018 | 2019 | 2020 |
| Fresh Water                            | 109.43 | 86.12 | 80.03 | 73.99 | 71.39 |
| Brackish Water (Low – Medium Salinity) | 33.8 | 57.12 | 63.2 | 69.24 | 71.83 |
| Saltwater (High Salinity – Very High)  | - | - | - | - | 0.01 |

3.4. Spatiotemporal changes in Chloride (Cl) content

The fourth result of processing groundwater quality data obtained is the chloride (Cl) component. The information presented in Figure 6 & Table 7 provides an overview of the pattern & magnitude of spatial & temporal changes in the Cl value in the study area. Based on the data presented, the pattern of change from 2016 to 2020 experienced variations & patterns similar to the TDS value, where the area of Cl value indicated as brackish water, which increased from 2016 to 2017, experienced a significant increase in 2018 & 2019, until experiencing shrinkage in 2020, particularly in the northern regions. In the process of change, the central area experiencing expansion in the northern part, while in the central & northeastern parts, it appears locally related to changes in the type of groundwater salinity. The results of the grouping of groundwater salinity types based on the range of Cl values are different from TDS, which is obtained includes two types referring to the classification: freshwater with a value range of 0-5500 mg/L & brackish water with a value range of 500 – 5,000 mg/L.
Figure 6. Spatial & temporal changes in the distribution of Cl values in the 2016 to 2020 range.

Table 7. Information on the area (km$^2$) of Cl value & groundwater quality referring to salinity parameters in the range 2016 to 2020.

| Groundwater Quality Type according to Cl | Distribution of Area (km$^2$) in Year |
|-------------------------------------------|--------------------------------------|
|                                           | 2016  | 2017  | 2018  | 2019  | 2020  |
| Fresh Water                               | 142.76| 142.25| 134.58| 135.06| 135.53|
| Brackish Water (Low – Medium Salinity)    | 0.48  | 0.98  | 7.88  | 8.00  | 7.53  |
| Saltwater (High Salinity – Very High)     | -     | -     | 0.77  | 0.17  | 0.17  |

4. Conclusion
Changes in the spatial & temporal distribution of groundwater quality types based on salinity parameters in confined aquifers in the Alluvial Plain of Semarang City from the 2016 to 2020 range experienced significant fluctuations. Several parameters experienced a gradual increase and a drastic decrease (pH) & expansion (EC, TDS, & Cl). Considering the reference grouping based on the type of salinity, some parameters gave rise to two types of salinity: freshwater & brackish water (EC & Cl), while the remaining parameters gave rise to three types added with saltwater (TDS & pH).

References
[1] Todd D K and Mays L W 2005 *Groundwater Hydrology 3rd edition* (New Jersey: John Wiley & Sons Inc)
[2] Bouwer H 1978 *Groundwater Hydrology* (New York: McGraw Hill Book)
[3] Purnama Ig L S 2005 *Saltwater Distribution in Coastal Plains: A Case Study in Semarang City* (Yogyakarta: Faculty of Geography Gadjah Mada University)
[4] Gorelick S M & Zheng C 2015 *Water Resour Res* 51 3031–3051
[5] Braga A C R, Serrao-Neumann S and de Oliveira Galvão C 2020 *Environ Manag* 65 321–333
[6] Sahour H, Gholami V and Vazifedan M 2020 *J Hydrol* 591 1-12
[7] Gasparovic M and Singh S K 2020 *Int Arch Photogram Rem Sens Spatial Inf Sci* 43 401–405
[8] Margat J and van der Gun J 2013 *Groundwater around the World: A Geographic Synopsis* (Florida: CRC Press, Taylor & Francis Group: Boca Raton)

[9] Salako A and Adepelumi A 2018 *Aquifer Classification & Characterization. In Aquifers - Matrix & Fluids* (London: Intechopen)

[10] Heath R C 1987 *Basic Ground-Water Hydrology* (US: Library of Congress Cataloging in Publication Data)

[11] Reichard J J 2011 *Environmental Geology 1st ed* (New York: The McGraw Hill Companies)

[12] Alihar F 2018 *Jurnal Kependudukan Indonesia 13(1)* 67-75

[13] Mining & Energy Agency Central Java Province (DESDM Central Java Province) 2012 *Recapitulation of Water Count & Water Acquisition Value 2001–2010: Internal Report (Unpublished)* (Mining & Energy Agency of Central Java Province: Semarang, Indonesia)

[14] Tirtomihardjo H 2011 *Groundwater Resource Potential in Indonesia & Their Management: Presentation Report (Unpublished)* (Geological Agency; Ministry of Energy & Mineral Resources: Bandung, Indonesia)

[15] Lo W, Purnomo S N, Sarah D, Aghnia S and Hardini P 2021 *Water 13* 1395

[16] Molle F, López-Gunn E, & van Steenbergen F 2018 *Water Altern 11* 445–457

[17] Abu-alnaeema F M, Yusoff I, Ngb FT, Alias Y, & Raksme M 2018 *Sci Total Environ 615* 972–989

[18] Gholami V, Khaleghi MR, & Sebghati M 2017 *Appl Water Sci 7(7)* 3633–3647

[19] Indonesian Central Statistics Agency 2021 *Indonesia Statistics 2021* (Jakarta: Indonesian Central Statistics Agency)

[20] Central Java Provincial Statistics Agency 2021 *Central Java Province in Figures 2021* (Semarang: Central Java Provincial Statistics Agency)

[21] Central Bureau of Statistics of Semarang City 2021 *Semarang City in Figures 2021* (Semarang: Central Bureau of Statistics of Semarang City)

[22] Marsudi 2001 *Prediction of Lk & Subsidence Rate in the Alluvial Plain of Semarang, Central Java Province Doctoral Dissertation* (Institut Teknologi Bandung (ITB): Bandung, Indonesia)

[23] Rahmawati N and Marfai M A 2013 *Indonesian Journal of Geology 8(2)* 107-118

[24] Satrio, Hendramawan, Hadian M S D and Pujindiyato E R 2015 *A Sci J Appl Isotopes Radiat 11(1)* 73-86

[25] Priyambodo D G, Prihantono J and Supriyadi 2016 *J Kelaut Nas 11(3)* 89-95

[26] Ardaneswari TA, Yulianto T and Putranto T T 2016 *Youngster Physic Journal 5(4)* 335-349

[27] Putranto T T and Rüde T R 2016 *Indones J Geosci 3(1)* 17-27

[28] Sarah D, Hutasoit L M, Delinom R M, Sadisun I A and Wirabuana T 2018 *Geosci 8(130)* 1-20

[29] Arslan H 2012 *Agric Water Manage 113* 57–63

[30] Maliqi E, Jusufi K and Singh S K, 2020 *Anal Chem Lett 10(2)* 152–180

[31] Neissi L, Golabi M and Gorman J M 2020 *Ecol Indic 117* 1-11

[32] Abulibdeh A, Al-Awadhi T, Al-Nasiri N, Al-Buloshi, and Andelghani M 2021 *Groundw Sustain Dev 12* 1-15

[33] Malmberg C G 1965 *J Res Natl Bur Std&A Phys Chem 69* 39–43

[34] Jakarta Saltwater Intrusion Ad Hoc Committee (PAHIAA-Jakarta) 1986 *Classification of Saltiness of Waters* (Jakarta)

[35] Hehanusa P E & Bhakti H (eds) 2005 *Water Resources on Small Island* (Bandung: Lipi Press)

[36] Rusydi A F 2018 *IOP Conf Ser Earth Environ Sci 118* 012019

[37] Jonsson J, Smedfors K, Nyholm L, & Thornell G 2013 *Int J Oceanogr*

[38] Eng M H, Ita M K, and Urata K M 2005 *Anal Sci 21* 95–99

[39] Nthunya L N, Maifadi S, Mamba B B, Verliefelde A R, & Mhlanga S D 2018 *Water 10* 990

[40] Prahasta E 2002 *Basic Concepts of Geographic Information Systems* (Bandung: Informatika)

[41] Thomas A 2015 *Int J Adv Remote Sens GIS 4(1)* 828–862

[42] Achu A L, Thomas J and Reghunath R 2020 *Groundw Sustain Dev 100*365
[43] Azpurua M and Ramos K D 2010 Prog Electromagn Res M 14 135-145
[44] Watson D F and Philip G M 1985 Geoprocessing 2 315-327
[45] Merwade V M, Maidment D R and Golf J A 2006 J Hydrol 331 731-741
[46] Pasaribu J M and Haryani N S 2012 Jurnal Penginderaan Jauh 9(2) 126-139