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Regional Case Study

Groundwater Potential of the Jakarta Groundwater Basin using the Darcy Equation Method

Imsak Aditya Respati Priyono[1], Thomas Triadi Putranto[1], Taat Setiawan[2]*

[1] Geological Engineering Department, Faculty of Engineering, Universitas Diponegoro, Jalan Prof. Soedarto, SH, Kampus Undip Tembalang, Semarang, Indonesia 50275

[2] Groundwater Conservation Center, Center for Groundwater and Environmental Management Geology, Geological Agency, Ministry of Energy and Mineral Resources, Jalan Tongkol No.4, Ancol, Pademangan, North Jakarta, Special Capital Region of Jakarta, Indonesia 14430

* Corresponding Author, email: taat.setiawan@esdm.go.id

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Abstract

The annual increase in population leads to a growing demand for water. To control groundwater utilization in a directed manner is to extract groundwater according to groundwater potential. The research aims to analyze the groundwater potential in the Jakarta Groundwater Basin in terms of quantity and quality. The method used is primary data analysis by determining quantity potential using the Darcy equation method with additional calculations of groundwater volume and quality potential based on drinking water quality standards from the Republic of Indonesia Minister of Health Regulation no. 2 of 2023 and WHO of 2022. The dynamic potential for unconfined aquifers ranges from 2,663–1,372,901 m^3/year, while for confined aquifers range from 184,991–1,895,288 m^3/year. The static potential for unconfined aquifers ranges from 266,852–3,252,654 m^3, while for confined aquifers ranges from 1,317,862–30,620,266 m^3. Based on groundwater quality standards for drinking water from the Minister of Health and WHO for the parameters pH, TDS, Na^+, Cl^-, SO_4^{2-} and NO_3^-, there are 15 samples from 53 samples of unconfined aquifer and 36 samples from 75 samples of confined aquifer that meet standards.

Keywords: Groundwater; Jakarta groundwater basin; potential; quantity; quality

1. Introduction

Groundwater is a source of freshwater used to meet human life needs. One place where groundwater collects is in groundwater basins. One of the areas in the Jakarta Groundwater Basin is the Special Capital Region of Jakarta. The population in the Special Capital Region of Jakarta was 9,607,787 people in 2010, increasing to 10,562,088 people in 2020 (DKI Jakarta Provincial Central Statistics Agency, 2021). According to Karunia and Ikhwali (2020), Jakarta has experienced a water shortage since 2010 due to the increasing population from year to year, increasing in raw water demand, where Jakarta's raw water balance deficit in 2018 was approximately 8,654.73 L/sec, and it is projected to reach 10,007.6 L/sec in 2030. Excessive groundwater extraction in Jakarta is related to the limited coverage of piped water supplies which will only cover 65.0% of Jakarta (PAM Jaya, n.d.). Piped water in Jakarta is supplied by PAM Jaya.

Changes in land use due to urban development can result in a lack of groundwater recharge areas. Based on Seizarwati et al. (2017), the results of recharge calculations for 23 years in the Jakarta Groundwater Basin show no indication of a decrease in rainfall values, but groundwater recharge tends to decrease. Most of the groundwater recharge in the Jakarta Groundwater Basin was less than 250 mm/year in 2014. Excessive and undirected use of groundwater can lead to a decline in the water table and a reduction in groundwater reserves. Without replenishment by new infiltration water, the aquifers and the soil layer above it may shrink (Anna, 1993). Excessive pumping in coastal areas can change the discharge and flow of groundwater to the sea, resulting in seawater intrusion (Anna, 1993).

In research related to groundwater quantity, Ambarwati (2022) conducted an examination of water availability in the Jakarta groundwater basin through water balance analysis utilizing F.J. Mock data spanning from 2016 to 2020, Seizarwati et al. (2018) performed simulations of Jakarta's groundwater flow under various scenarios employing IMOD (Interactive MODeling), and Samsuhadi (2009) investigated groundwater utilization in Jakarta based on simulation results of the groundwater potential within the Jakarta aquifer basin. In research related to groundwater quality, Matahelumual (2010) conducted research on Jakarta's groundwater conditions in 2010.

The directed use of groundwater involves extracting it according to the groundwater potential, which is a description of the condition of groundwater that has the potential to be utilized for daily needs (Adji et al., 2014). Groundwater potential can be determined by collecting data directly in the field or via remote sensing. Arifiyanto and Adji (2015) researched the potential of the unconfined aquifers in the Wates Groundwater Basin, Kulon Progo Regency by calculating the potential for groundwater availability statically, dynamically and the safe results of groundwater impoundment. Pangestu and Waspodo (2019) also researched predicting potential groundwater reserves using the Darcy equation in Dramaga District, Bogor Regency. Apart from that, Shirazi et al. (2015) also conducted research related to groundwater quality and productivity of the Malacca aquifers in Peninsular Malaysia using pumping test data and groundwater samples for water quality analysis.

The aim of the research is to analyze the potential of groundwater in the research area in terms of quantity and quality. This is because determining groundwater potential is very necessary to find out whether an area can be utilized optimally and in formulating the creation of groundwater conservation zones for planning and developing groundwater in an area.

2. Methods

This research uses data from 2022 as new research data and uses data measured directly in the field as the research base. This research aims to analyze the groundwater potential in the Jakarta groundwater basin in terms of quantity and quality. The study area (Figure 1) covers the Jakarta Province and its surroundings.

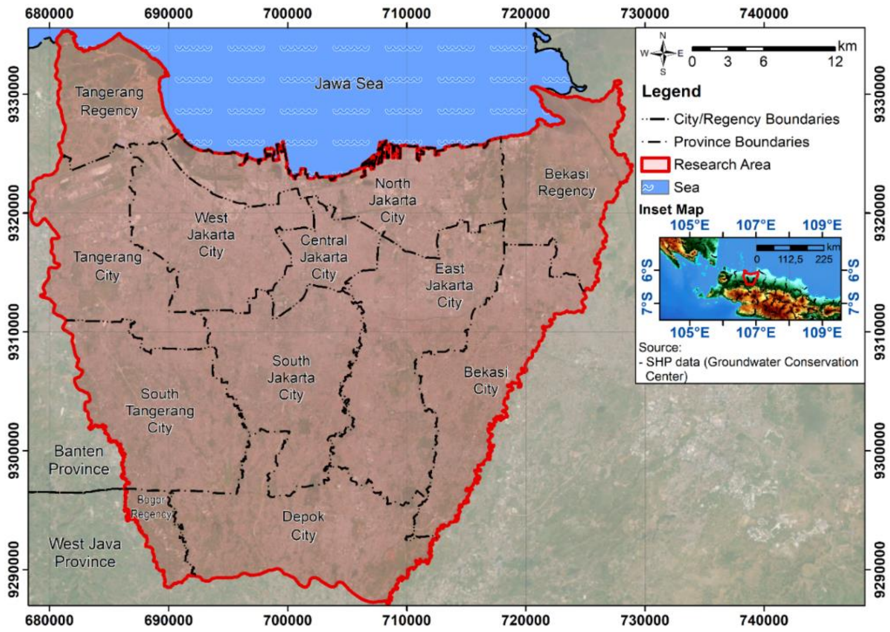

Figure 1. Map of the research plot area

The research materials needed include drilling log data, groundwater table and groundwater piezometric elevation data from dug wells, drilled wells, and monitoring wells, laboratory analysis data on groundwater geochemistry from samples obtained from dug wells, drilled wells, and monitoring wells, and pumping test data. Drilling log data, groundwater elevation data, groundwater chemistry data, and pumping test data, are sourced from the Groundwater Conservation Center.

The research method consists of two analyses: the potential quantity of groundwater and the potential quality of groundwater. In analyzing the potential quantity of groundwater, is divided into dynamic potential and static potential. The dynamic potential is calculated using the Darcy equation method outlined in Todd and Mays (2005). The Darcy equation explains the ability of a fluid to flow through porous media such as stone (Pangestu & Waspodo, 2018). This method is explained as follows to obtain Equation (1) to (4):

$$Q = K \cdot A \cdot I \quad (1)$$

$$Q = K \cdot (b \cdot W) \cdot \left(\frac{dh}{dl}\right) \quad (2)$$

$$Q = (K \cdot b) \cdot W \cdot \left(\frac{dh}{dl}\right) \quad (3)$$

$$Q = T \cdot W \cdot i \quad (4)$$

where Q is groundwater discharge (m^3/day), K is hydraulic conductivity (m/day), A is the cross-sectional area of the aquifer (m^2), i is the hydraulic gradient, b is the aquifer thickness (m), W is the aquifer width (m), dh is the height difference of the groundwater segment (m), dl is the length of the groundwater segment (m), and T is transmissivity (m^2/day). The static potential of groundwater is based on the volume of groundwater available in the part of the aquifer that is eternally saturated in the phreatic zone (Kumar, 2013). The groundwater volume from the unconfined aquifer group is estimated based on the sand volume multiplied by the effective porosity (or specific yield, S_y) (Zhang, 2022). Equation (5) and (6) is the equation used to calculate the groundwater volume of unconfined aquifers.

$$V_w = V_{uc} \cdot S_y \quad (5)$$

$$V_w = (A \cdot b) \cdot S_y \quad (6)$$

where V_w is the volume of ground water (m^3), V_{uc} is the volume of the free aquifer (m^3), S_y is the specific yield, A is the area of the aquifer (m^2), and b is the thickness of the aquifer (m). For the volume of groundwater in confined aquifers, it is estimated based on Equation (5) with S_y replaced by S (storativity) (Zhang, 2022). Storativity (Storage coefficient, S) is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface (Todd & Mays, 2004). Storativity is formulated in Equation (7):

$$S = S_s \cdot b \quad (7)$$

where S is storativity, S_s is specific storage (m^{-1}), and b is aquifer thickness (m). Specific storage is related to aquifer compressibility α and water compressibility (β). Specific storage is formulated in Equation (8):

$$S_s = \rho \cdot g \cdot (\alpha + n \cdot \beta) \quad (8)$$

where S_s is specific storage (m^{-1}), ρ is the density of water (1,000 kg/m^3), g is the acceleration of gravity (9.8 m/sec^2), α is the compressibility of the aquifer (m sec^2/kg or m^2/N), n is total porosity, and β is water compressibility ($4.4 \cdot 10^{-10}$ m^2/N or Pa^{-1}). Equation (9) to (11) is the equation used to calculate the groundwater volume of confined aquifers.

$$V_w = V_c \cdot S \quad (9)$$

$$V_w = (A \cdot b) \cdot (S_s \cdot b) \quad (10)$$

$$V_w = A \cdot b^2 \cdot S_s \quad (11)$$

where V_w is the volume of ground water (m^3), V_c is the volume of the confined aquifer (m^3), S is storativity, A is the area of the aquifer (m^2), b is the thickness of the aquifer (m), S_s is specific storage (m^{-1}). In quality analysis, groundwater chemical samples are subjected to Charge Balance Error (CBE) analysis using Equation (12). After passing the CBE analysis, it is then plotted on the Piper diagram and the groundwater quality is determined based on Republic of Indonesia Minister of Health Regulation no. 2 of 2023 and Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda from

WHO published in 2022 for the parameters pH, TDS, Na^+, Cl^-, SO_4^{2-}, and NO_3^-. The use of drinking water quality standards from WHO (2022) and Ministry of Health Regulations (2023) is to determine whether groundwater can be used as drinking water following equation (12)

$$CBE = \frac{\sum z{\cdot}m_c - \sum z{\cdot}m_a}{\sum z{\cdot}m_c + \sum z{\cdot}m_a} \cdot 100\% \qquad (12)$$

Where CBE is the charge balance error expressed in percent, z is the ionic valence, m_c is the molality of the cation species, and m_a is the molality of the anion species.

3. Result and Discussion

3.1. Subsurface Conditions

3.1.1. Cross-section of Subsurface Hydrosratigraphy

The cross-section was made with 3 incisions in a north-south direction (A–A', B–B', and C–C') and 3 incisions in a west-east direction (D–D', E–E', and F–F'). Based on the drilling log data processing results, the subsurface consists of layers including sand, clay–sandy clay, gravel, and limestone. Section A–A' (Figure 2a) is dominated by interbeds between sand and clay–sandy clay, with limestone found at one point in the drilling log. Section B–B' (Figure 2b) is dominated by interbedded sand with clay–sandy clay, with gravel found at several points in the drilling log. Section C–C' (Figure 2c) is dominated by interbedded sand with clay–sandy clay, but at one point in the drilling log, limestone and gravel interbedded with clay–sandy clay was found. Section D–D' (Figure 2d) is dominated by clay–sandy clay with a slight interbedded of sand with clay–sandy clay, but at several points in the drilling log the presence of limestone was found. Section E–E' (Figure 2e) is dominated by interbedded sand with clay–sandy clay, but at one point in the drilling log, gravel was found and limestone was found at another point in the drilling log. Section F–F' (Figure 2f) is dominated by slightly interbedded sand with clay–sandy clay. Judging from the dominance of the subsurface layers, the aquifers in the Jakarta Groundwater Basin are classified into unconfined and confined aquifers. The large number of interbedded sands with clay–sandy clay indicates the presence of unconfined aquifers, composed of widespread layers of sand and gravel at several points. Confined aquifers are identified by widespread layers of sand, local gravel, and local limestone.

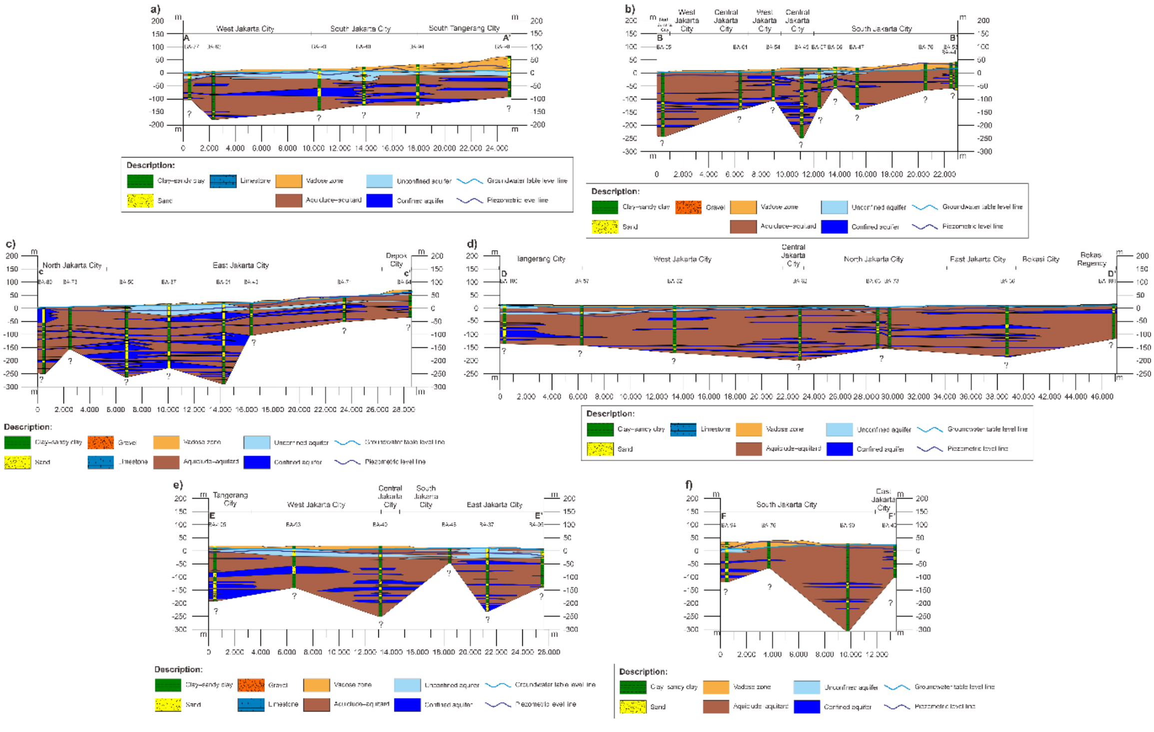

Figure 2. Cross-section of hydrostratigraphic of the study area

3.1.2. Aquifer Thickness

To determine the thickness of both unconfined and confined aquifers in the research area, the calculation involved measuring the thickness of the layers of sand, gravel, and limestone. Unconfined aquifers were determined by calculating from the sand layer to the first clay-sandy clay layer, while confined aquifers were calculated from the overall thickness of the sand, gravel, and/or limestone layers.

Unconfined aquifers have a thickness ranging from 0–40 m, while confined aquifers have a thickness ranging from 2–129 m. The unconfined aquifers are interpreted to have that thickness because the layer of sand that is above the layer of sandy clay and that borders the groundwater table is not thick, while the confined aquifers are interpreted to have that thickness because there are many layers of sand with clay–sandy clay.

Based on Soekardi (1986) in Suherman and Sudaryanto (2009), the Jakarta Groundwater Basin aquifers system is divided into 3 groups, namely aquifer group I unconfined aquifer with a depth of 0-40 m, aquifer group II upper confined aquifers with a depth of 40-140 m and group aquifer III lower confined aquifers with a depth of 140–250 m. From the processing results obtained, it is interpreted that the unconfined aquifers are following what was stated previously, while the confined aquifers analyzed are included in aquifer group II, upper confined aquifers and part of aquifer group III, lower confined aquifers.

3.2. Potential Quantity of Groundwater

3.2.1. Groundwater Elevation

The groundwater level of the unconfined aquifers in the study area (Figure 3a) ranges from -4–106 meters above sea level (masl). Groundwater in unconfined aquifers predominantly moves from southeast to north, west and northwest. The piezometric groundwater of the confined aquifers in the study area (Figure 3b) has a range from -38–80 masl. Generally, groundwater in confined aquifers moves from south to north but changes direction near the point of groundwater withdrawal. The southern area of the study is a groundwater recharge area. Several cones formed around the data collection points, possibly caused by excessive groundwater extraction leading to cone-shaped depressions.

3.2.2. Hydraulic Conductivity

Hydraulic conductivity is processed based on pumping test data. Hydraulic conductivity in the research area ranges from 1–3 m/day, equivalent to 1.1574×10^{-5}–3.4722×10^{-5} m/sec. According to the classification of Freeze and Cherry (1979), the conductivity comes from muddy sand to clean sand. The conductivity is to have that value because the aquifers in the research area consist of quite a bit of sand and silty sand compared to other aquifer systems such as aquifers. According to Samsuhadi (2009), low hydraulic conductivity values cause groundwater flow velocities to be low and local (not continuous).

3.2.3. Groundwater Transmissivity

Groundwater transmissivity in unconfined aquifers ranges from 0.002–82.36 m^2/day, while in confined aquifers, it ranges from 1.97–188.31 m^2/day. Based on the classification of Krasny (1993), transmissivity is divided into several classes, namely: imperceptible (<0.1 m^2/day), very low (0.1–1 m^2/day), low (1–10 m^2/day), medium (10–100 m^2/day), high (100–1,000 m^2/day), and very high (>1,000 m^2/day). In the study area, transmissivity falls into the categories of invisible, very low, low, and medium for unconfined aquifers, and low, medium, and high for confined aquifers. For unconfined aquifers and confined aquifers, the medium class dominates. The medium class is interpreted to mean that potential groundwater can be withdrawn for local water supplies (small communities, factories, etc.).

3.2.4. Dynamic Potential of Groundwater

Dynamic potential describes the groundwater discharge that can enter the aquifer based on the characteristic parameters of the aquifer, including the transmissivity value, hydraulic gradient and width of the aquifer. The values of transmissivity, hydraulic gradient, and aquifer width for each area in the research area in calculating the dynamic potential using Equation (4) can be seen in Tables 1 and 2, then the segments used in the calculation can be seen in Figure 4. The dynamic potential for unconfined aquifers in the study area ranges from 2,663–1,372,901 m^3/year, while the dynamic potential for confined aquifers ranges from 184,991–1,895,288 m^3/year.

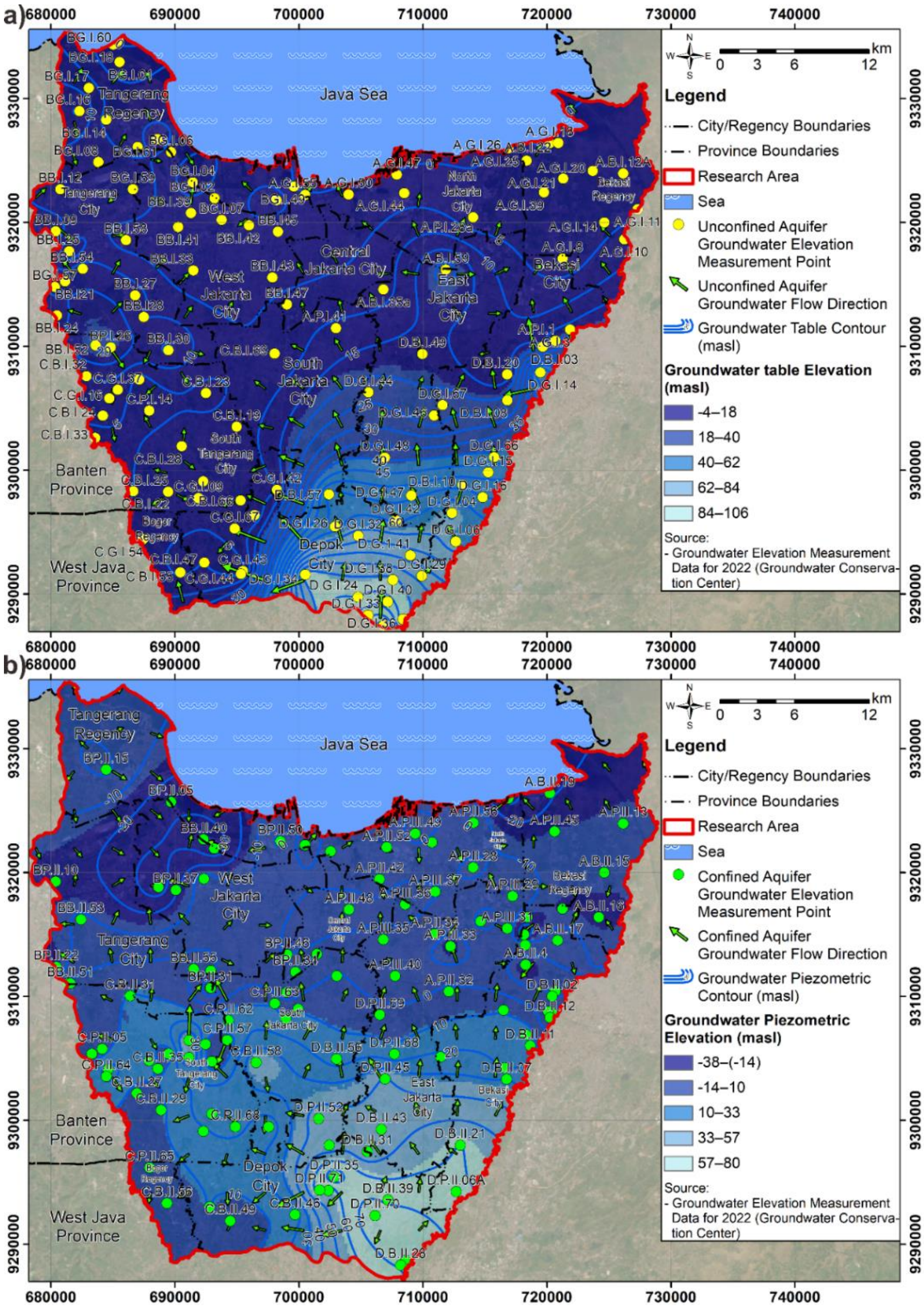

Figure 3. Unconfined aquifers groundwater table elevation map (a) and Confined aquifers groundwater piezometric elevation map (b)

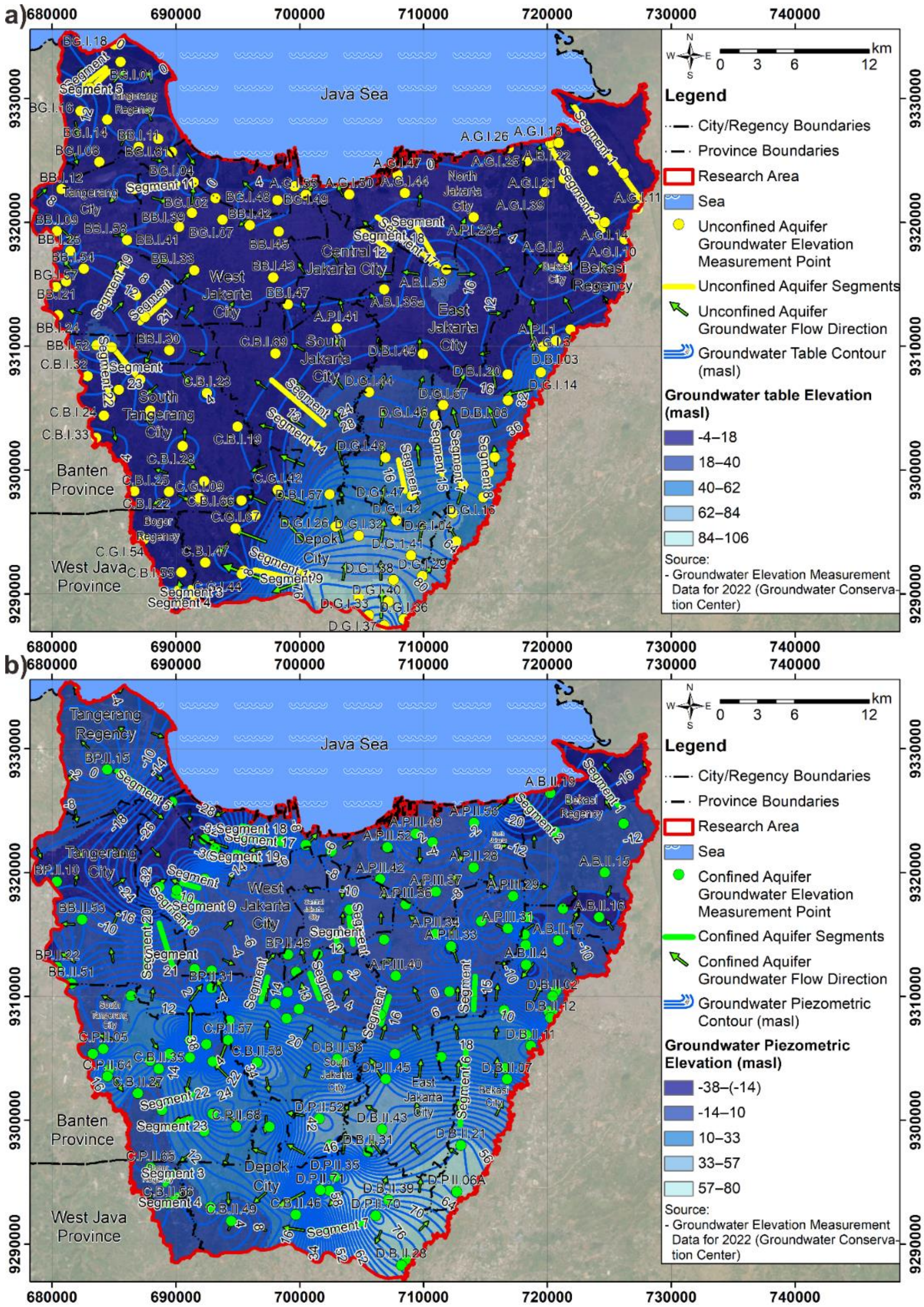

Figure 4. Groundwater potential calculation map for unconfined aquifers (a) and for confined aquifers (b)

Table 1. Dynamic potential of unconfined aquifers

No.	Region	Average i	Average T (m²/day) [a]	W (m)	Q (m³/ day)	Q (m³/year)
1	Bekasi Regency	$4.60 \cdot 10^{-4}$	1.39	12,346	7.30	2,663
2	Bogor Regency	$3.55 \cdot 10^{-3}$	17.67	3,069	204.66	74,702
3	Tangerang Regency	$3.66 \cdot 10^{-3}$	4.55	10,319	173.31	63,258
4	Bekasi City	$5.09 \cdot 10^{-3}$	16.56	6,110	577.10	210,641
5	Depok City	$1.63 \cdot 10^{-2}$	18.58	12,714	3,761.37	1,372,901
6	West Jakarta City	$2.84 \cdot 10^{-3}$	12.63	8,392	300.80	109,790

No.	Region	Average i	Average T (m^2/day) [a]	W (m)	Q (m^3/ day)	Q (m^3/year)
7	Central Jakarta City	$1.50{\cdot}10^{-3}$	9.78	10,225	149.60	54,605
8	South Jakarta City	$3.38{\cdot}10^{-3}$	7.82	14,331	325.22	118,704
9	East Jakarta City	$5.23{\cdot}10^{-3}$	9.96	9,109	524.44	191,419
10	North Jakarta City	$2.77{\cdot}10^{-3}$	2.72	15,170	104.45	38,124
11	Tangerang City	$1.90{\cdot}10^{-3}$	17.47	14,555	578.21	211,047
12	South Tangerang City	$4.40{\cdot}10^{-3}$	19.77	10,179	734.11	267,950

Source: [a] Processing of drilling log data, groundwater elevation data, and pumping test data (Groundwater Conservation Center)

Table 2. Dynamic potential of confined aquifers

No.	Region	Average i	Average T (m^2/day) [a]	W (m)	Q (m^3/ day)	Q (m^3/year)
1	Bekasi Regency	$2.72{\cdot}10^{-3}$	33.08	11,861	506.82	184,991
2	Bogor Regency	$1.90{\cdot}10^{-3}$	55.36	7,788	709.26	258,879
3	Tangerang Regency	$5.20{\cdot}10^{-}3$	101.46	7,557	3,988.41	1,455,769
4	Bekasi City	$5.28{\cdot}10^{-3}$	49.67	7,398	1,939.81	708,029
5	Depok City	$9.54{\cdot}10^{-3}$	51.61	8,449	4,157.76	1,517,583
6	West Jakarta City	$6.91{\cdot}10^{-3}$	50.74	7,228	2,407.37	878,691
7	Central Jakarta City	$2.00{\cdot}10^{-3}$	39.11	7,497	546.88	199,611
8	South Jakarta City	$4.80{\cdot}10^{-3}$	32.65	12,780	1,536.04	560,656
9	East Jakarta City	$3.99{\cdot}10^{-3}$	48.80	9,126	1,993.98	727,803
10	North Jakarta City	$6.80{\cdot}10^{-3}$	51.07	3,943	1,474.81	538,305
11	Tangerang City	$4.46{\cdot}10^{-3}$	102.62	10.992	5,192.57	1,895,288
12	South Tangerang City	$4.06{\cdot}10^{-3}$	72.58	12.272	3,707.91	1,353,389

Source: [a] Processing of drilling log data, groundwater elevation data, and pumping test data (Groundwater Conservation Center)

3.2.5. Static Potential of Groundwater

The static potential of groundwater is obtained from the calculation of Equation (6) and Equation (11), which in Equation (6) requires area (A), thickness of unconfined aquifer (b), and specific yield (S_y), while in Equation (11) requires area (A), thickness of confined aquifer (b), and specific storage (S_s). For specific storage, it is based on the calculation of Equation (8). The specific yield (Sy) value used comes from the representative specific yield value for sand material from Heath (1983) is 0.22. The values of area, unconfined aquifer thickness, and specific yield for each area in the research area in calculating the static potential using Equation (6) can be seen in Tables 3. The static potential for unconfined aquifers in the study area ranges from 266,852–3,252,654 m^3. To determine specific storage using Equation (8), the representative value of aquifer compatibility (α) for sand material from Freeze & Cherry (1979) is 10^{-8} m^2/N and porosity (n) for sand material from Heath (1983) is 0.25. The values of area, confined aquifer thickness, and specific storage for each area in the research area in calculating the static potential using Equation (11) can be seen in Tables 4. The static potential for confined aquifers ranges from 1,317,862–30,620,266 m^3.

Table 3. Static potential of unconfined aquifers

No.	Region	A [a] (m^2)	Average b [b] (m)	S_y [c]	V_w (m^3)
1	Bekasi Regency	118,918,069	1.02	0.22	266,852
2	Bogor Regency	24,776,532	7.40	0.22	403,362
3	Tangerang Regency	80,441,705	2.75	0.22	486,672
4	Bekasi City	138,838,802	9.91	0.22	3,026,964
5	Depok City	170,331,689	8.68	0.22	3,252,654

No.	Region	A [a] (m^2)	Average b [b] (m)	S_y [c]	V_w (m^3)
6	West Jakarta City	125,218,355	8.41	0.22	2,316,790
7	Central Jakarta City	47,417,602	9.47	0.22	987,898
8	South Jakarta City	145,100,381	5.78	0.22	1,845,096
9	East Jakarta City	184,479,836	7.47	0.22	3,031,742
10	North Jakarta City	138,652,268	2.33	0.22	710,732
11	Tangerang City	134,137,205	8.23	0.22	2,428,688
12	South Tangerang City	149,360,680	8.40	0.22	2,760,185

Source: [a] Processing of SHP data (Groundwater Conservation Center); [b] Processing of drilling log data and groundwater elevation data (Groundwater Conservation Center); and [c] Representative value of specific yield of sand material (Heath, 1983).

Table 4. Static potential of confined aquifers

No.	Region	A [a] (m^2)	Average b [b] (m)	S_s [c] (m^{-1})	V_w (m^3)
1	Bekasi Regency	118,918,069	24.39	$9.91 \cdot 10^{-5}$	7,008,881
2	Bogor Regency	24,776,532	23.17	$9.91 \cdot 10^{-5}$	1,317,862
3	Tangerang Regency	80,441,705	61.40	$9.91 \cdot 10^{-5}$	30,046,593
4	Bekasi City	138,838,802	35.94	$9.91 \cdot 10^{-5}$	17,768,233
5	Depok City	170,331,689	23.26	$9.91 \cdot 10^{-5}$	9,130,448
6	West Jakarta City	125,218,355	34.98	$9.91 \cdot 10^{-5}$	15,180,457
7	Central Jakarta City	47,417,602	36.91	$9.91 \cdot 10^{-5}$	6,400,367
8	South Jakarta City	145,100,381	23.32	$9.91 \cdot 10^{-5}$	7,818,130
9	East Jakarta City	184,479,836	36.92	$9.91 \cdot 10^{-5}$	24,914,348
10	North Jakarta City	138,652,268	45.76	$9.91 \cdot 10^{-5}$	28,765,786
11	Tangerang City	134,137,205	48.00	$9.91 \cdot 10^{-5}$	30,620,266
12	South Tangerang City	149,360,680	30.51	$9.91 \cdot 10^{-5}$	13,775,201

Source: [a] Processing of SHP data (Groundwater Conservation Center); [b] Processing of drilling log data and groundwater elevation data (Groundwater Conservation Center); and [c] Specific storage calculation results, with ρ water = 1,000 kg/m³, g = 9.8 m/sec², α sand = $1 \cdot 10^{-8}$ m²/N (Freeze & Cherry, 1979), n sand = 0.25 (Heath, 1983), β water = $4.4 \cdot 10^{-10}$ m²/N.

3.3. Potential of Groundwater Quality

3.3.1. Groundwater Facies

For unconfined aquifers, there are three groundwater facies based on Piper diagram plotting, namely: alkaline earth water facies with predominantly hydrogen carbonate, alkaline water facies predominantly hydrogen carbonate, and alkaline water facies predominantly chloride. For confined aquifers, there are four groundwater facies based on Piper diagram plotting, namely: alkaline earth water facies predominantly hydrogen carbonate, alkaline earth water facies with higher alkaline content predominantly hydrogen carbonate, alkaline water facies predominantly hydrogen carbonate, and alkaline water facies predominantly chloride. Figure 5 shows the Piper diagram plotting for unconfined aquifers and confined aquifers in the study area.

3.3.2. Acidity Level (pH) of Ground Water

Groundwater in unconfined aquifers has an acidity level (pH) ranging from 5.86–9.09, while groundwater in confined aquifers has a pH ranging from 6.09–11.45. Groundwater that settles for a long time due to the sloping contours of the clay tends to become alkaline. Based on groundwater quality standards for drinking water according to quality standards from WHO (2022) and Minister of Health Regulation (2023) for pH parameters ranging from 6.5–8.5. Out of the 53 samples for unconfined aquifers, 8 samples do not meet the standards, and out of the 75 samples for confined aquifers, 21 samples do not meet the standards. Figure 6 shows the distribution of pH for unconfined aquifers and confined aquifers in the study area.

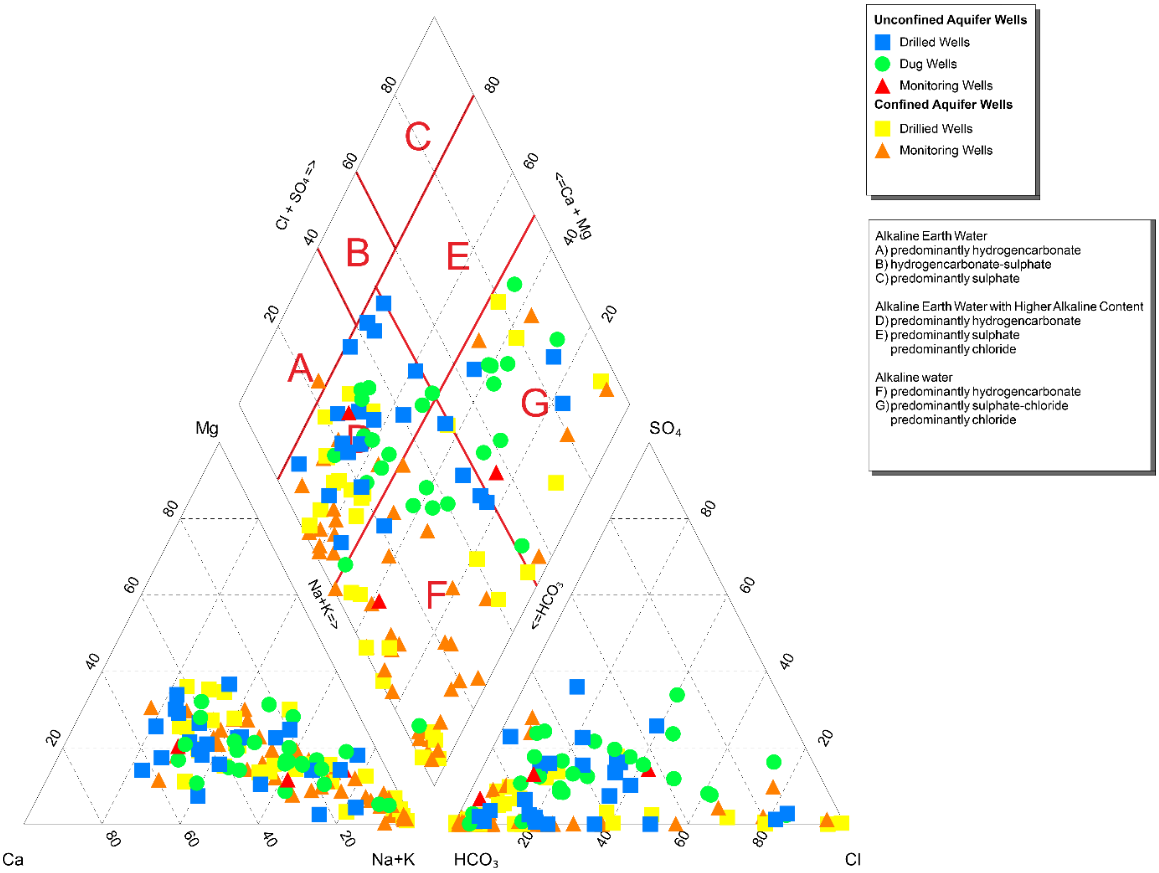

Figure 5. Groundwater facies in unconfined aquifers and confined aquifers

3.3.3. Total Dissolved Solids (TDS) of Groundwater

Groundwater in the unconfined aquifers has a TDS in the range of 121.87–3,363.4 mg/L and in the confined aquifers, it has a TDS range from 94.6–4,053.5 mg/L. Based on the USGS classification of water TDS (Heath, 1983), groundwater in unconfined aquifers and confined aquifers in the study area is divided into three classes, namely fresh (<1,000 mg/L), slightly saline (1,000–3,000 mg/L), and moderately saline (3,000–10,000 mg/L). It is interpreted that groundwater on the north side of the study area is influenced by sea water. In addition, there is formation water from sea water in the bedrock of the groundwater basin close to the surface on the southwest side of the research area. Based on groundwater quality standards for drinking water according to quality standards, the TDS parameter is <600 mg/L from WHO (2022) and <300 mg/L from the Minister of Health Regulation (2023). For unconfined aquifers, 32 samples met WHO standards, of which 19 samples met the Minister of Health Regulations, and 21 samples did not meet either standard. For confined aquifers, 59 samples met WHO standards, of which 43 samples met the Minister of Health Regulations, and 16 samples did not meet either standard. Figure 7 shows the distribution of TDS for unconfined aquifers and confined aquifers in the study area.

3.3.4. Hardness of Ground Water

Groundwater in unconfined aquifers has a hardness ranging from 35.05–1,137.26 mg/L $CaCO_3$, and in confined aquifers has a hardness ranging from 11.48–1,106.82 mg/L $CaCO_3$. Based on the classification of water hardness by Sawyer et al. (2003), groundwater in unconfined aquifers and confined aquifers in the research area is divided into 4 classes: soft water (0–75 mg/L $CaCO_3$), moderately hard (75–150 mg/L $CaCO_3$), hard (150–300 mg/L $CaCO_3$) and very hard (>300 mg/L $CaCO_3$). Water with a hardness of more than 75 mg/L $CaCO_3$ is interpreted to come from clay which contains lots of Ca^{2+} and Mg^{2+} ions and possibly from formation water in the form of sea water trapped in bedrock.

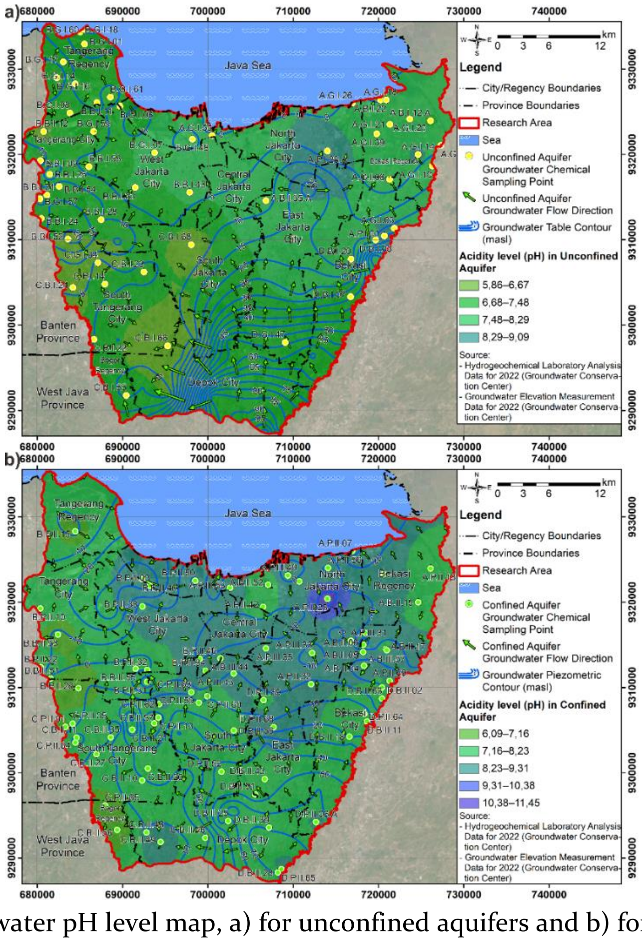

Figure 6. Groundwater pH level map, a) for unconfined aquifers and b) for confined aquifers

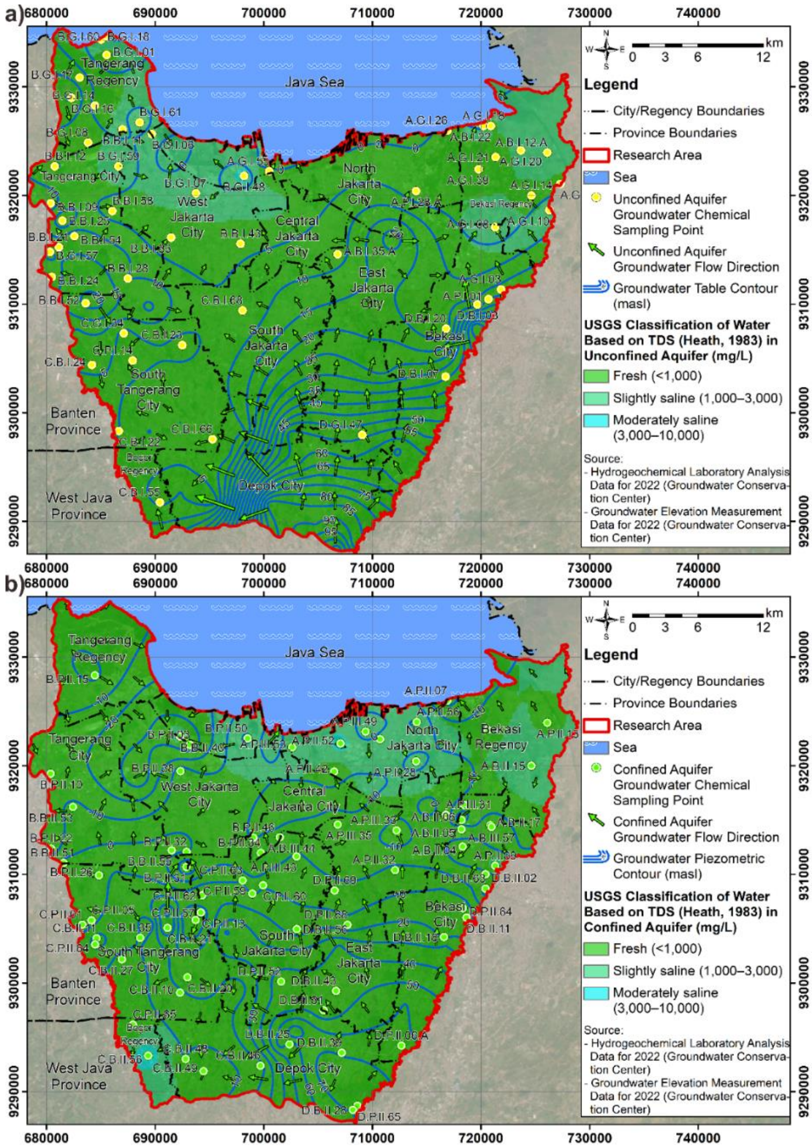

Figure 7. Groundwater salinity map based on TDS for unconfined aquifers (a) and for confined aquifers (b)

3.3.5. Sodium (Na^+) Content of Ground Water

Groundwater in unconfined aquifers has Na^+ levels ranging from 8.64–823.66 mg/L, and in confined aquifers, Na^+ levels range from 6.20–1,050.99 mg/L. Based on Todd and Mays (2004), Na^+ can be found in clay minerals, which are often located below the surface in the study area. Based on groundwater quality standards for drinking water, the Na^+ parameter should be <200 mg/L (WHO, 2022). Out of the 53 samples for unconfined aquifers, 13 samples do not meet the standards, and out of the 75 samples for confined aquifers, 15 samples do not meet the standards.

3.3.6. Chloride (Cl^-) Content of Ground Water

Groundwater in unconfined aquifers has Cl^- levels ranging from 3.64–1,520.79 mg/L, and in confined aquifers, Cl^- levels range from 0.67–1,787.5 mg/L. Cl^- is interpreted to originate from seawater trapped in clay sediments and reacting with groundwater. Based on groundwater quality standards for drinking water, the Cl^- parameter should be <250 mg/L from (WHO, 2022). Out of the 53 samples for unconfined aquifers, 9 samples do not meet the standards, and out of the 75 samples for confined aquifers, 10 samples do not meet the standards.

3.3.7. Sulfate (SO_4^{2-}) Content of Ground Water

Groundwater in unconfined aquifers has SO_4^{2-} levels ranging from 0.02–324.12 mg/L and in confined aquifers, SO_4^{2-} levels range from 0–143.6 mg/L. Based on Torres-Martínez et al. (2020), SO_4^{2-} can be found in both domestic and industrial wastewater, seawater intrusion, and atmospheric deposition that enters the groundwater. Based on groundwater quality standards for drinking water, the SO_4^{2-} parameter should be <250 mg/L from (WHO, 2022). Out of the 53 samples for unconfined aquifers, 2 samples do not meet the standards, while all 75 samples for confined aquifers met the standards.

3.3.8. Nitrate (NO_3^-) Content of Ground Water

Groundwater in unconfined aquifers has NO_3^- levels ranging from 0–151.7 mg/L and in confined aquifers, NO_3^- levels range from 0–10.4 mg/L. Based on Sudaryanto and Suherman, (2008), NO_3^- can be caused by artificial fertilizers and leachate from domestic waste entering groundwater. For the parameter NO_3^- content, which should be <50 mg/L (WHO, 2022) and <30 mg/L (Minister of Health Regulation, 2023), only 1 of the total 53 samples for unconfined aquifers did not meet the standards, while all 75 samples for confined aquifers met the standards.

4. Conclusions

Based on the results of research related to groundwater quantity, the unconfined aquifer cannot be used for groundwater because the groundwater discharge is 2,663–1,372,901 m³/year, and the groundwater volume is 266,852–3,252,654 m³ less than the confined aquifer where the groundwater discharge is 184,991–1,895,288 m³/year and the groundwater volume is 1,317,862–30,620,266 m³ so it is feared that it could cause negative impacts if utilized, while the confined aquifer can still be partially utilized to meet needs through monitoring.

Based on the results of research related to groundwater quality, in both unconfined aquifers and confined aquifers, only some areas can be used to meet water needs because only some of them meet drinking water quality standards. Where on groundwater quality standards for drinking water from the Minister of Health and WHO for the parameters pH, TDS, Na^+, Cl^-, SO_4^{2-} and NO_3^-, there are 15 samples from 53 samples of unconfined aquifer and 36 samples from 75 samples of confined aquifer that meet standards. If groundwater in unconfined aquifers and confined aquifers is consumed, it is feared that it will cause health problems.

From the conclusions of the research conducted, recommendations that can be made to increase the groundwater potential in the Jakarta groundwater basin are: the government or relevant policy stakeholders supervise and control the extraction of groundwater in release areas to prevent a decrease in water availability and monitoring the possibility of pollution and damage to the groundwater environment. The government or relevant policy stakeholders also can make regulations regarding groundwater extraction, manage water quality and control water pollution in an integrated manner, promote surface water use programs, as well as protecting groundwater recharge areas to prevent a decrease in groundwater recharge by increasing groundwater recharge by increasing green open space, infiltration wells, and carrying out artificial groundwater recharge projects. People can use groundwater as effectively and efficiently as possible by prioritizing meeting basic daily needs. Apart from that, people can also use surface water to fulfill their water needs, such as using water from water utility for clean water purposes and collecting rainwater using rainwater harvesting techniques using building roofs. Due to the limitations of this research, researchers or related agencies are expected to be able to create groundwater conservation zone maps, and groundwater extraction control maps and also be able to conduct research regarding groundwater balance calculations for unconfined and confined aquifers, environmental impacts due to groundwater use, changes in land use, as well as groundwater recharge methods to increase groundwater potential in the Jakarta groundwater basin.

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