Groundwater study in Subang Industrial park and its recharge area as a suggestion for establishing recharge and discharge zones of Subang Groundwater Basin

Y Ashari*, L Pulungan, I K Wijaksana, N F Isniarno and D Mildan

Mining Engineering Dept., Universitas Islam Bandung, Bandung, Indonesia

*Yunus_ashari@yahoo.com

Abstract This research was conducted in Subang Groundwater Basin, West-Java, related to the prohibition of groundwater extraction in the Subang Industrial Park (SIP) area. This is because the area is considered as the Recharge Zone of the groundwater basin. The purpose of this study is to determine whether SIP stands above the Recharge Zone or not, moreover, find out which part of the Basin that supplies groundwater aquifers of SIP. The method used in this study is applied of DRASTIC method using ArcGIS and conducting field research measuring the infiltration rate of soil formations at selected points in the Basin, geologic and hydrogeological mapping of Lakes. The results of this study indicate that the SIP is indeed built on a recharge area, the soil where the SIP is established, has ability to infiltrate rainwater. However, the results of more detailed observations of wellbore logs in this area, it is known that between the groundwater aquifer used in SIP and the infiltration zone of the ground surface is separated by impermeable clay layers. This ensures that there is no relationship between surface water infiltration and groundwater being extracted by factories in the areas. Therefore, it is certain that the recharge area originates from other areas in the Basin. Key words: aquifer, recharge area, Subang Groundwater Basin.

1. Introduction

Water is essential for life, health and human dignity [1]. Water can be obtained from various sources, including surface water and groundwater. Surface water which was originally used as a main domestic and industrial uses water source is generally polluted and the quality is getting worse. This condition makes the use of groundwater a significant amount of potable water. The intensity of groundwater extraction increases every year in line with population growth and economic development. To support the development of urban areas, settlements and industries, an enormous supply of groundwater is needed. On the other hand, there are areas where groundwater extraction is prohibited, (in accordance to The Presidential Decree No. 26 of 2011 concerning Groundwater Basin) where groundwater withdrawal is prohibited in certain areas, that is recharge areas [2]. The aim of regulation is that the function of infiltration on the land not to change to other purpose. However, over time the development of the absorption zone has been disrupted by industrial activities that use large amounts of groundwater. The recharge area zone is becoming narrow due to poor land use management and changes in land use, causing disruption of groundwater recharge and discharge balance into and from aquifers. Subang Industrial Park is classified into intended areas as a part of Subang Groundwater Basin (figure 1). The area establishes prohibited of groundwater withdrawal, therefore, fulfillment of clean water is a big
problem for industries operation, which covers the districts of Pabuaran, Cipendeuy, Kalijati, Puwadadi, Pagaden and Subang.

However, based on the derivative of the law in the form of Government Regulation concerning Groundwater Basin (PP No. 43 of 2008) of Article No. 12, there is a clause stated that the stipulated Groundwater Basin can be reviewed if there are physical changes to the relevant groundwater basin and / or new data is found based on the criteria as referred to Article No. 8. The Article No. 8 itself states that the Groundwater Basin is determined based on the following criteria; (a) Has hydrogeological limits that are controlled by geological conditions and / or hydraulic conditions of groundwater, (b) Has a recharge area and groundwater release area in one groundwater formation system; and (c) Have a unified aquifer system. Based on the description above, then there is an opportunity to cancellation of prohibiting on groundwater extraction at the area of investigation, if new evidence is obtained in accordance to clause Article No. 12 PP No. 43 of year 2008 [3].

![Figure 1. Map of study area Subang Groundwater Basin.](image)

1.1. State of the problem

- Does the Subang Industrial Park build on Recharge Area of Subang Groundwater Basin?
- Whether groundwater taken from wells by industry is connected to rainwater or surface water infiltration in the region?
- Which part of the Subang Groundwater Basin may act as a Recharge Zone for deep groundwater aquifers?
1.2. Aim of the study

- Determine the type of hydrogeology area of the Subang Industrial Park;
- To determine kind of groundwater aquifer of Subang Industrial Park;
- To determine recharging source of the groundwater of Subang Industrial Park.

1.3. Outcome of study

Outcome of this study is criticized policies in determining the boundaries of the groundwater recharge area in the Subang Groundwater Basin in the Subang Regency. Rationale for this study is to discover new evidence about the condition of aquifer in Subang Industrial Park and surrounding areas.

2. Theoretical consideration

Groundwater basin defined as (1) A general term used to define a groundwater flow system that has defined boundaries and may include permeable materials that are capable of storing or furnishing a significant water supply. The basin includes both the surface area and the permeable materials beneath it. (2) The underground area from which groundwater drains. The basins could be separated by geologic or hydrologic boundaries [4,5].

According to Freeze and Cherry groundwater recharge can be defined as the entry into the saturated zone of water made available at the water-table surface, together with the associated flow away from the water table within the saturated zone [4]. Similarly, to groundwater recharge is deep drainage or deep percolation is a hydrologic process where water moves downward from surface water to groundwater. Recharge is the primary method through which water enters an aquifer [6]. Recharge also defined as water added to an aquifer. For instance, rainfall that seeps into the ground [7].

Groundwater discharge can be defined as the removal of water from the saturated zone across the water-table surface, together with the associated flow toward the water table within the saturated zone. It should be clear from the previous section that these two saturated processes are intimately interrelated to a pair of parallel processes in the unsaturated zone. Let us define the process of infiltration as the entry into the soil of water made available at the ground surface, together with the associated flow away from the ground surface within the unsaturated zone [4]. In a similar term is exfiltration defined as the removal of water from the soil across the ground surface, together with the associated flow toward the ground surface within the unsaturated zone. Natural discharge from ground-water systems including and not only the flow of springs and seepage of water into stream channels or wetlands, but also evaporation from the upper part of the capillary fringe, where it occurs within a meter or so of the land surface. Large amounts of water are also withdrawn from the capillary fringe and the zone of saturation by plants during the growing season. Thus, discharge areas include not only the channels of perennial streams but also the adjoining flood plains and other low-lying areas. One of the most significant differences between recharge and discharge areas are that the areal extent of discharge areas is invariably much smaller than recharge areas [8].
Aquifers are replenished with water from the surface through a process called recharge. This occurs as a part of the hydrologic cycle when water from rainfall percolates into underlying aquifers. The rate of recharge can be influenced by different factors, such as soil, plant cover, water content of surface materials, and rainfall intensity. Groundwater recharge may also occur from surface water bodies in arid areas. According to European Environment Agency (EEA, 2019) over the withdrawal of groundwater occurs when the discharge of groundwater in an aquifer exceeds the recharge rate over a period of time. Groundwater also discharges through springs, whereby groundwater moves laterally through permeable such as sandstone and emerges at an outcrop [9].

3. Regional Subang Groundwater Basin

The Subang Groundwater Basin is composed of two groups of geological units, namely (1) The floodplain deposited in the Northern part of the basin, obscuring the rock units of volcanic products that are not in harmony. This group is dominated by clay and tuff, with a thickness of up to 5 m and is generally not an aquifer, and (2) Rock volcanic product, located in the Southern part of the basin, covers the Subang Formation and Kaliwangu Formation in an out of harmony. This clastic volcanic group is dominated by sandstones, tuffs and conglomerates, with a thickness of around 125 m. Generally, these are rocks that escape water so that they can be included as aquifers (layers of permeable unit). Based on its hydraulic characteristics, the Subang Groundwater Basin consists of an unconfined aquifer system in the South and a confined aquifer system in the North. The two systems are interconnected in one aquifer system, with thickness ranging from 0 - 130 m and range in depth from 0 - 130 m. Lithological data resulting from drilling log of several boreholes in the Recharge Zone area that the surface part is covered by weathered soils and thinning clay to the South, while from west to east the surface part is covered by sandy clay.

4. Materials and method

The method employed in this research including analysis and correlation of well logging data, field geological mapping around of lakes in the area and field test of infiltration.

4.1. Delineation of recharge zone area

Recharge Zone delineated using method of Groundwater Management Technical Guide [10]. Basically this guide applied of DRASTIC method in which generally used seven hydrogeological parameters to assess groundwater vulnerability. The parameter i.e. depth to the water table (D), recharge (R), aquifer
material (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C), of DRASTIC formula approach as follow:

\[
\text{Recharge Value} = K_b \cdot K_p + P_b \cdot P_p + S_b + S_p + L_b \cdot L_p + M_b \cdot M_p
\]

Where:
- \( K \) = permeability or conductivity of rocks
- \( P \) = annual average rainfall
- \( S \) = Ground cover
- \( L \) = Slope
- \( M \) = water table
- \( b \) = Weight value
- \( p \) = Rating value

A multiplier defined as weight was multiplied with each parameter rating for each interval and then the products were summed up to calculate the final DRASTIC index.

4.2. Field infiltrometer test

To determine the potential for surface infiltration, an infiltrometer field test was conducted. The recharge area is characterized by a high infiltration rate. Although this is influenced by the natural water content of a land, at one point the soil will have a saturation level, at which point the infiltration rate is constant. In determining the magnitude of the infiltration rate, a device commonly used called ring infiltrometer, even double or single ring. The process of water seeps into the soil (infiltration), the amount of infiltration power is different depending on the condition of the soil. Each land surface has a certain infiltration capacity that is the maximum ability of the soil to absorb rainwater that falls on it (\( f_p \)). The requirements for the infiltration process are stated as follows:

- If \( I < f_p \), then all the rain will seep into the ground \((f_o = I)\); there will be no surface runoff;
- If \( I > f_p \), then some rain will seep into the ground \((f_o = f_p)\); surface runoff will occur.

To find out the amount of infiltration rate, can use infiltration test. This test is carried out to find out how fast the water is seeping into a land. In its implementation, this test refers to SNI 7752 year 2012 concerning the procedures for measuring the infiltration rate of soil in the field using a double ring infiltrometer (Figure 3) [11]. The use of a double ring infiltrometer can be carried out at the soil surface, at certain depths in excavation, in vacant land or in vegetation. A double ring infiltrometer is an infiltrometer consisting of two tubes of different diameters and placed centrally. The ring can be made of iron, steel or mixed metal with a thickness of 3 mm. The outer ring uses a diameter ranging from 45 cm to 60 cm, while the inner ring uses a diameter of 30 cm. At the center of the ring is a scale bar to measure the drop in surface water. This test also requires a number of other equipment, including a hammer with a weight of 5 kg which is used to plug the ring into the ground to a certain depth and also a retaining beam.
Normally measurements can only be made if meet 4 conditions i.e. (a) The location must be accessible to transport equipment and supplies, (b) The area required is at least 2 m by 2 m, (c) Land has a permeability coefficient (K) between $10^{-6}$ m/s to $10^{-2}$ m/s, (d) The measurement point must be flat, and (e) Must not be carried out on cracks in the ground when inserting the infiltrometer ring. In practice, the infiltration test begins with checking and calibration of all equipment to be used. This activity includes checking the shape of the infiltrometer ring so that it is always in the shape of a perfect circle. Also, make sure the tip of the water level marker needle is kept sharp and the scale on the measuring cup and ruler can be read clearly. The next step is determining the place of measurement. Determination can be determined from the topographic map. Select a location on the ground that represents the unit of land created on a flat surface with an area of at least 2 m x 2 m. Annotation point of test location details is numbers point, coordinates, elevation, and descriptions of geological unit of surrounding point test. To install the infiltrometer ring can be done by placing one ring with the tip of the runкук at the bottom. Plug in the ring by using a hammer which is slammed into the brace that has been mounted above the ring to a depth of about 15 cm. Place the other ring in the same way. Pour water into the inner and outer rings to have the same water level, generally until the water reaches 25 cm from the ground surface. To make it easier, it can use a watermark needle that has been embedded in both rings. Then measure the change in water level in the ring in each time interval. Calculate the infiltration rate value from the data obtained by the following equation:

$$F = \left(\frac{\Delta h_c}{\Delta t}\right) \times 60$$

Where:
- $f$ = estimated infiltration rate (cm / hour)
- $\Delta h_c$ = change in water level every time interval (cm)
- $\Delta t$ = measurement time interval (minutes)

To determination of infiltration rate, can be used several methods. This method is empirical and is still often used, including Horton Model, The Kostiakov model and Green and Ampt Model [12]. In this study, The Kostiakov model was employed.

5. Result

5.1. Recharge zone
Using DRASTIC method Aller et al., applied to recharge delineation of Southern part of Subang Groundwater Basin, covers 4 districts i.e Sagalatherang, Jalancagak, Cisalak, Kalijati and Subang District. The area was gridding into 0.5 km x 0.5 km, then for each parameter was described, valued,
weighted and calculated. Value of DRASTIC index of each grid is around 54 – 66 (figure 4). This means that all of the area potential act as Recharge Zone (figure 5) [13].

![Figure 4. Score of DRASTIC index an approach for recharge zone in Subang Groundwater Basin.](image1)

![Figure 5. Map of potential area act as recharge zone.](image2)

5.2. Subsurface data correlation
Correlation of drilling data is carried out based on the production well sample data in the study area and supported by geophysical well logging. Logging was carried out on 9 wells scattered in several locations in CAT Subang. The type of logging used is log resistivity and spontaneous potential. The logging results are then presented in the form of a lithology log that displays lithological variations vertically. To find out the distribution of aquifers below the surface, correlation is made to permeable layers that
have the potential to be aquifers. The A-A cross section is trending east-west, while the B-B cross is relatively North-South (figure 6 and 7). C-C' cross section correlates some well logs with the location of the alleged rock outcrop on the surface (Figure 7). Based on the results of correlations on cross sections A-A’, B-B’, and C-C’ it is known that the area currently expressed as a catchment area in the CAT Subang has a distressed aquifer system at varying depths. The water supply in these distressed aquifers certainly comes from different catchment areas. It is suspected that the recharge area that supplies water to the distressed aquifer system in the study area is in the Southern area whose elevation is higher than the Subang CAT. This area is highly possibility located in the districts of Sagalaherang, Jalancagak, Cisalak, Tanjungsiang, Cijambe, Subang and Kalijati.

Figure 6. Line section A-A’ (West to East, left) and B-B’ (North to South, right) of Subang Groundwater Basin.

There was a lack of data to correlation for continuing lithological spread to the Southern border of the Basin. Therefore, the cross-section of CC’ is interpreted as a continuous aquifer layer that appears on the surface in the Southern part of the basin location as seen in figure 7.

Figure 7. Estimated continuity of the aquifer layer (Line section C-C’- North to South direction).

5.3. Infiltration rate
A total of 22 test points (figure 8) were conducted in the Districts of Jalancagak, Sagalaherang and Cisalak. The area is interpreted as a continuing to surface of the aquifer that was deposited in the Subang Industrial Park. As previously discussed, to find the ability of soil infiltration a ring infiltrometer is used, referring to SN1 No. 7752 year 2012 concerning procedures for measuring the infiltration rate of soil in the field using a double ring infiltrometer. Based on existing provisions, there are 2 diameter rings used. The inner ring has a diameter of 30 cm, while the outer ring uses a diameter of 60 cm. Both rings are
made of iron plates with a thickness of 3 mm. Before taking measurements, make sure the ring is in a perfect circle [11].

Figure 8. Soil infiltration rate field test using double ring infiltrometer.

Observations on the geology around the infiltration test site showed that the area generally composed of volcanic rock material, weathered strong, thick to reach 3 meters. The rate of infiltration in this area ranges from 0.22 - 1.42 cm/minute, mostly > 0.5 cm/minute which shows that this area has the potential to act as infiltrate surface water and rainwater (figure 10).

Figure 9. Some of geological conditions around the infiltration test area.
Figure 10. Some typical infiltration rate graph model at the investigation site.

Based on infiltration tests in these areas it can be concluded that the non groundwater basin area has a good ability to absorb rainwater and has the potential to act as an infiltration zone.

Figure 11. Map of infiltration rate distribution.
5.4. Lakes observation
Field observation of lakes in Subang Groundwater Basin conducted in early October, according to BMKD data (BMKG, 2019, Figure 12) there has been no rain on almost 7 months later. Some lakes dried up (Situ Cibugang, Situ Nagrog) and some others naturally still store of water, although some of them come from the river that flows into it [14]. However, Situ Citapen (Purwadadi) and Situ Blendungan (Cibogo) reserves water that is expected to come from groundwater (springs) both from the bottom and sides of the lake wall, no evidence of gather from surface water (figure 13).

![Figure 12. Map of successive dry season without rain > 60 days [14].](image)

Based on the description above, it can be said that the area of lakes and is always filled with water that supplied from groundwater (Figure 13 and 14), which in this case is springs, is characteristics of the Discharge Area [5].

![Figure 13. Some geological observation around the lake (Citapen-left, Blendungan-right).](image)
Figure 14. Lake Dangdeur (Cibogo), a lake that never dries (left) and tuff breccia lithology on the lake's edge.

Based on the description above, it can be said that the area of lakes and is always filled with water that supplied from groundwater, which in this case is springs, are characteristics of the Discharge Area [5].

6. Discussion

The use of the DRASTIC method for determining recharge areas is inappropriate, because the actual designation of this method is to assess groundwater vulnerability to pollution [13]. It is true, theoretically the assessment generated through the DRASTIC index shows that it is able to infiltrate surface water, but should not be interpreted as vertical percolation recharge for deep groundwater or confined aquifers. On the other hand, the application of this method by areas predicted to be the continuity of confined aquifers in the Subang Industrial Area through well bore lithology correlation, found evidence that in non-Groundwater Basin areas, it was able to infiltrate water at a very significant rate. Thus, the Jalancagak - Cisalak area and its surroundings are very likely to be designated as a Recharge Area Zone.

Observation of the lakes that are scattered in the Subang Groundwater Basin shows that the lakes are in an area that has been designated as a Recharge Zone (figure 15). On the contrary, the lake is able to provide water in the dry season and remain filled with water because it is supplied from groundwater (springs). This ensures that the area is a Discharge Zone.

Figure 15. Scattering lakes in the Subang Groundwater Basin (Area Discharge Zone) and location of the Infiltration test (Potential Recharge Zone Area).
7. Conclusion
This research produces the following conclusions:

- Subang Industrial Park is located in the Subang Groundwater Basin, in an area that has been considered and designated as a Recharge Zones, it is actually potential to be considered a Discharge Zone area;
- Groundwater taken from deep wells in the Subang Industrial Park is confined confined aquifer groundwater, which is confined by impermeable layers. Shallow groundwater aquifers consist of permeable layers that are exposed on the surface (unconfined aquifer), so that they have the ability to infiltrate rainwater. Therefore, recharge confined aquifers certainly do not take place in vertical percolation;
- The potential area as a source of recharge confined aquifers is the Southern Subang Basin i.e. Jalancagak, Cisalak, Subang and its surroundings which have been considered not a part of the groundwater basin.

References
[1] Reed B and Reed B 2011 Technical Notes on Drinking-Water, Sanitation and Hygiene In Emergencies. The World Health Organization (WHO) [Online] retrieved from: https://www.who.int/water_sanitation_health/publications/2011/tn9_how_much_water_en.pdf
[2] Keputusan Presiden Nomor 26 Tahun 2011 tentang Penetapan Cekungan Air Tanah
[3] Peraturan Pemerintah Republik Indonesia Nomor 43 Tahun 2008 Tentang Air Tanah.
[4] Freeze A and Cherry J 1979 Groundwater (New Jersey: Prentice Hall)
[5] Fetter C W 1994 Applied Hydrogeology, 3rd Ed (New York: Macmillan College Company) 681
[6] Wikipedia, accessed on October 06 2019
[7] USGS 2019 Dictionary of Water Terms [Online] retrieved from: https://www.usgs.gov/special-topic/water-science-school/science/dictionary-water-terms (accessed 06/10/2019).
[8] Heath R C 1998 Basic ground-water hydrology (Vol. 2220) US Department of the Interior, US Geological Survey
[9] European Environment Agency (EEA) 2019 Recharge area [Online] retrieved from: https://www.eea.europa.eu/about-us accessed on 08 Oct 2019.
[10] Indonesian Center for Geological Environment 2007 Groundwater Management Tech Guide.
[11] Badan Standardisasi Nasional 2012 Tata cara pengukuran laju infiltrasi tanah di lapangan menggunakan infiltrometer cincin ganda. SNI 7752:2012
[12] Rajasekhar M, Umabai D, Krupavathi K, Navyasai I and Gopi R 2018 Development and Comparison of Infiltration Models and Their Field Validation Int. Jour. Curr. Microbiol. App. Sci. 7(10) pp 2691-2701
[13] Aller L, Bennett T, Lehr J and Petty R 2004 DRASTIC: A Standardized System For Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings U.S Environmental Protection Agency, Washington, D.C., EPA/600/2-85/018.
[14] BMKG 2019 Monitoring of successive days without rain. Climate Early Warning System [Online] retrieved from: http://cews.bmkg.go.id/Peta/Hari_Tanpa_Hujan.bmkg