

Groundwater Recharge Estimation Using Water Budget and Water Table Fluctuation Method in the Jakarta Groundwater Basin

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ABSTRACT

The Jakarta Groundwater Basin is one of the groundwater basins with the highest development, economic, and business activities in Indonesia. Groundwater damage has become a major growing issue in the Jakarta groundwater basin. Intensive development has led to the overuse of groundwater in this basin. Efforts are needed to manage, protect, and conserve groundwater in this basin to support the development and economic activities sustainably. Jakarta, as the capital city of Indonesia, is located in the groundwater basin. Groundwater sustainability is determined by the amount of groundwater recharge in those basins, so knowledge of groundwater recharge is important. Groundwater is an important part of a hydrological cycle, and groundwater recharge ensures groundwater sustainability in some areas. This study aims to estimate groundwater recharge in the Jakarta groundwater basin using the water budget and water table fluctuation method. The water budget method used is Thornthwaite, Dingman, and Edijatno-Michel. The Water Table Fluctuation methods used are Dellin and Delottier. Analysis of the amount of groundwater recharge estimation is carried out using the ESPERE Version 2 software. Output data is then further analyzed using descriptive and inferential statistical approaches to determine whether there is a difference in groundwater recharge amount based on the water budget and water table fluctuation. The results show that groundwater recharge based on water budget methods is 209–885 mm/year. The estimation of the largest amount of recharge was obtained using the Edijatno-Michel approach. The smallest amount of recharge was estimated using the Dingman-Hamon method. The average recharge of groundwater in Tanjung Priok is 305 mm/year, Kemayoran is 209 mm/year, and Bogor is 885 mm/year. Only 8–15 % of the annual rainfall that converted into groundwater recharge at the study area. Based on the analysis using the water table fluctuation method, groundwater recharge in this basin has a value of 240 mm/year. The variation of the amount of groundwater recharge is caused by the pros and cons of each method. Apart from that, geological factors, land use/land cover factors, and climatic variations in this basin can affect the research results. By considering the amount of groundwater recharge, groundwater management in the Jakarta groundwater basin needs to be carried out for harmonious development and groundwater conservation.

Keywords: Groundwater recharge, Jakarta Groundwater Basin, ESPERE, Water Budget, Water Table Fluctuation

INTRODUCTION

Water is a basic need for living things on earth, including humans [1]. Humans need water to meet their daily necessities, such as drinking, cooking, sanitation needs, etc. The need for water resources is completed from a river, lake, or groundwater, increasing demand for water and decreasing surface water quality. Therefore, excessing from

groundwater extraction cannot be avoided. Groundwater extraction is carried out intensively in big cities worldwide, including Jakarta [2]. Jakarta is the capital city of Indonesia, one of Indonesia's economic and business centers. Jakarta is a megapolitan in Indonesia, with more than 10 million [3]. The people of Jakarta continue to grow rapidly. Jakarta in 1950 was inhabited by around 1.5

million people, which increased more than seven times in 2010 to 11.5 million, with a population density of 14,469 people per km² [4]. Population growth in the 2000–2010 period was around 1.4% per year, which is expected to increase in the following years [5]. Jakarta plays a role in the development of the Indonesian economy. However, this city is experiencing problems related to groundwater and its issues, one of which is land subsidence [6–9]. Groundwater related issues need to be resolved to make the city of Jakarta sustainable to support Indonesia's economy and development.

In the hydrogeological system, Jakarta is located inside Jakarta's groundwater basin [10]. The groundwater potential of Jakarta's groundwater basin is estimated at around 52 million m³/year [11]. Groundwater extraction in Jakarta's groundwater basin is estimated at approximately 21 million m³/year [12]. The groundwater sustainability is determined by the amount of groundwater recharge in that basin, so knowledge of groundwater recharge is important. With the high value of groundwater extraction, it is necessary to understand groundwater recharge in this groundwater basin; this ensures groundwater sustainability in this basin. Groundwater is an important part of a hydrological cycle, and groundwater recharge ensures groundwater sustainability in some areas.

The groundwater basin recharge area is located around the Jakarta groundwater basin in the upland area [10]. The groundwater discharge area is in the central and northern parts of the Jakarta groundwater basin. The Jakarta groundwater basin's groundwater recharge area is located in the southern part of the Jakarta groundwater basin [13]. According to [14], Jakarta's groundwater is mostly supplied by the groundwater basin

itself, especially from recharge areas that extend from Depok, in the east, to South Tangerang, in the west.

The city of Jakarta is a lowland area with an average height of ± 7 meters above sea level (masl). In terms of climatic conditions, the average rainfall in the Jakarta area ranges from 2000–2700 mm/year [5]. The temperatures ranging from 23.4–35.2 °C and humidity ranging from 59–93% (BPS, 2017). Most of the rainfall in the DKI Jakarta area overflows the surface [15]. Only a small part of it burrows into the ground.

Groundwater recharge in 1991–2014 shows that generally, the Jakarta groundwater basin's recharge value is less than 250 mm/year [15]. However, there are a small number of areas that still have potential recharge values. The percentage value of recharge ranges from 4–20%, and the average recharge rate of groundwater in the Jakarta groundwater basin is 15% from rainfall annually. In their study, [15] used the water balance modification method in the Jabotabek Water Resources Management Study project to estimate the amount of groundwater recharge after urban development begins.

Based on groundwater recharge estimation for 1990 conditions in the JWRMS study, areas with recharge values <250 mm/year extend to North Jakarta, Bekasi District, parts of Central Jakarta, East Jakarta, and southern Tangerang District. Additive values between 750–1500 mm / year are only found in Bekasi City and Depok [15].

There are many approaches to determine and estimate the recharge amount of groundwater [10,16–18]. Several researchers use different techniques to estimate groundwater recharge. Some researchers use the water budget method, water table fluctuation. This study aims to estimate

groundwater recharge in the Jakarta groundwater basin using a water budget, water table fluctuation method.

GEOLOGY AND HYDROGEOLOGY

The Jakarta Basin, structurally, is part of the so-called Northern Zone comprising the low hilly areas of folded Tertiary strata and coastal lowlands bordering the Java Sea [19]. Regionally, Jakarta Area is occupied by a lowland area that has five main landforms [8] that consist of:

1. volcanic and alluvial landforms that are found in the southern part of the basin;
2. marine origin landforms, which are occupied the northern area adjacent to the coastline;
3. beach ridge landforms, which are discovered along the coast with east-west direction;
4. swamp and mangrove area landforms, which are encountered in the coastal fringe;
5. paleo-channels, which run perpendicular to the coastline.

Geologically, the study area is dominated by quaternary sediment and, unconformably, the base of the basin is formed by impermeable Miocene limestone sediments cropping out in the southern region, which were known as Bojongmanik and Klapanunggal Formation [8] (Figure 1). The basin fill, which consists of marine Pliocene and quaternary sand and delta sediments, is

up to 300 m thick [8]. Individual sand horizons are typically 1–5 m thick and comprise only 20% of the total fill deposits. Silts and clays separate these horizons. Fine sand and silt are very frequent components of these aquifers, and the sand layers were connected.

The aquifer system in the Jakarta groundwater basin is a multi-layer aquifer that is grouped into four aquifer systems based on its hydraulic properties, including an unconfined aquifer system with an average depth of fewer than 40 m, an upper confined aquifer system with an average depth of 40–140 m, the middle-confined aquifer system with an average depth of 140–250 m, and the bottom confined aquifer system with an average depth of more than 250 m below the ground surface. The aquifer system is generally composed of Quaternary deposits and covered by Tertiary deposits, which are impermeable. Based on the cap layer's characteristic, the Jakarta groundwater basin aquifer is divided into an unconfined aquifer system at a depth of less than 20 m and a confined aquifer depth of 20–300 m, which is divided into seven groups. Jakarta groundwater basin hydrostratigraphic zone divided into four zones, namely Zone 1, an aquifer consisting of sandstones and conglomerates, and claystone. Zone 2 is an aquitard composed of claystone with sand intercalation. Zone 3 is an aquifer composed of sandstones with breccias and claystone intercalation. Zone 4 is an aquitard composed of sandstone and claystone intercalation.

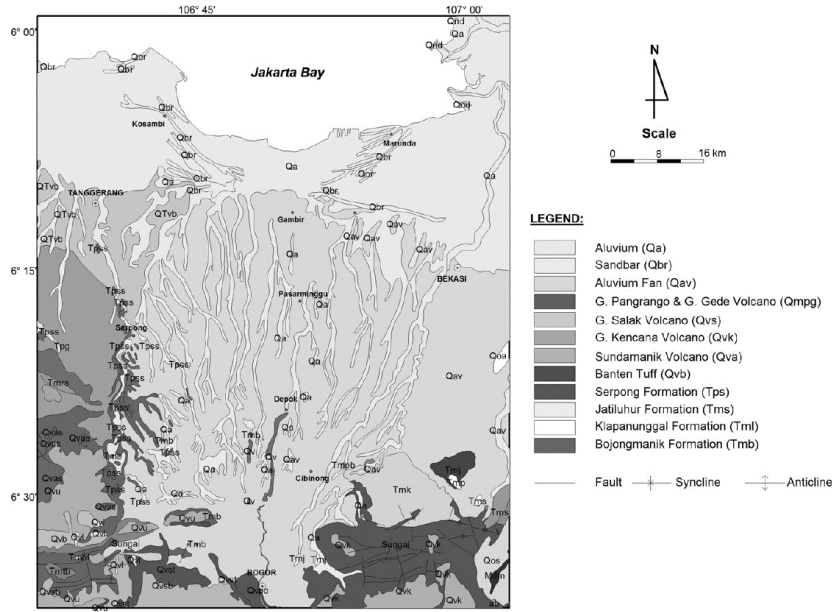


Figure 1. Geology Regional of Jakarta Groundwater Basin

MATERIAL AND METHOD

This study uses ESPERE version 2 2020 [20]. ESPERE is a Microsoft Excel application that allows the application of several methods commonly used to quickly and simultaneously estimate groundwater recharge [20]. According to available data, users can apply and compare the results of three empirical methods, three water budget methods, groundwater level fluctuation method and three hydrograph separation algorithms. This research will use the water budget method [21–23] in ESPERE ver. 2.

Thornthwaite

Thornthwaite and Mather created the water balance equation in 1957 (Figure 2, equation 1). The water balance can be calculated over a certain area and time period depending on its needs [21,24]

$$P = ET_0 + \Delta S_t \quad (1)$$

where:

P = Precipitation (mm/month)

ET_0 = Evapotranspiration (mm/month)

ΔS_t = Changes in water storage (mm/month)

The groundwater recharge value can be estimated using the equation (2) and (3):

$$\text{recharge} = (\text{precip} + \text{snowmelt} + \text{inflow}) - (\text{interception} + \text{outflow} + \text{ET}) - \Delta \text{Soil moisture} \quad (2)$$

$$\text{recharge} = \text{Sources} \pm \text{Sinks} \quad (3)$$

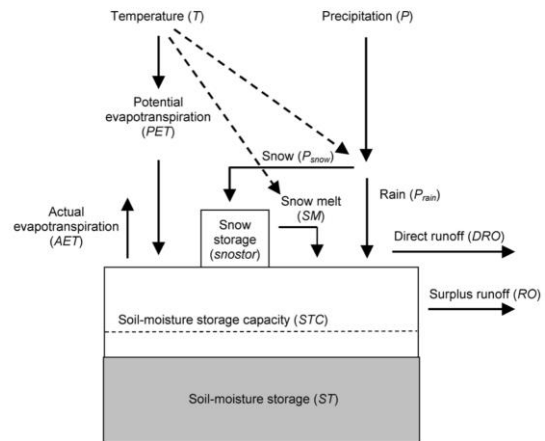


Figure 1. Thornwaite Water Budget Model

Dingman-Hamon

The equation (4) and (5) for Dingman-Hamon water budget (Figure 3) method is [22]:

$$P + G_{in} - (Q + ET + G_{out}) = \Delta S \quad (4)$$

Where:

P = Precipitation (Lt^{-1})
 G_{in} = groundwater inflow (Lt^{-1})
 Q = surface runoff (Lt^{-1})
 ET = evapotranspiration (Lt^{-1})
 G_{out} = groundwater outflow (Lt^{-1})
 ΔS = change in storage (Lt^{-1})

and

$$Q = P - ET - \Delta S \quad (5)$$

where:

P = Precipitation (Lt^{-1})
 Q = surface runoff (Lt^{-1})
 ET = evapotranspiration (Lt^{-1})
 ΔS = change in storage (Lt^{-1})

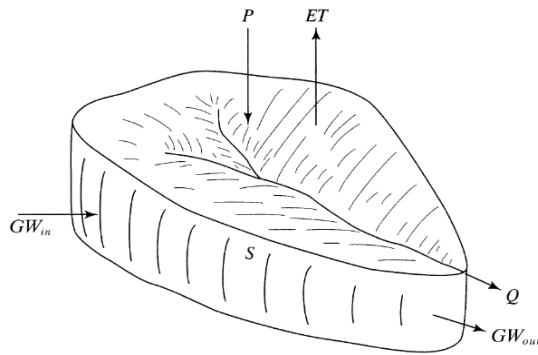


Figure 2. Dingman-Hamon Water Budget Model

Hamon's formula for the estimation of potential evapotranspiration are [25] showing at equation (6), (7), (8) and (9):

$$PET_{Hamon} = 13.97 \times d \times D^2 \times W_t \quad (6)$$

Where

PET_{Hamon} = Potential Evapotranspiration (mm),
 d = total day in a month
 D = average of sunshine duration in 12 hours
 W_t = Saturated vapor in gr/m^3 that calculated using:

$$W_t = \frac{4.95 \times e^{0.062 \times T}}{100} \quad (7)$$

where T average of monthly temperature

the formula can be simplified:

$$P = Q + E + T + R \quad (8)$$

where

P = Precipitation (mm)
 E = Evaporation (mm)
 T = Transpiration (mm)
 R = Recharge (mm)

Groundwater recharge can be obtained using :

$$R = P - Q \quad (9)$$

Where:

R = Recharge/Infiltration (Lt^{-1})
 P = Precipitation (Lt^{-1})
 Q = Surface runoff (Lt^{-1})

Edijatno-Michel

Water budget Edijatno-Michel (Figure 4) can be explained in equation (10) to (19):

Condition 1

If $P > Kc.ETP$,

$$\text{so } P_n = P - Kc.ETP \text{ and } E_n = 0. \quad (10)$$

$$dRU = [1 - (RU/RU_{max})^2] \cdot dP_n \quad (11)$$

$$ETR = ETP \quad (12)$$

$$dPeff = (RU/RU_{max})^2 \cdot dP_n \quad (13)$$

integration:

$$RU_{i+1} = [RU_i + RU_{max} \cdot \tanh(P_n/RU_{max})] / [1 + (RU_i/RU_{max}) \cdot \tanh(P_n/RU_{max})] \quad (14)$$

Condition 2

if $P < Kc.ETP$,

$$\text{so } P_n = 0 \text{ and } E_n = Kc.ETP - P. \quad (15)$$

$$dRU = [(RU/RU_{max})^2 - 2 \cdot RU/RU_{max}] \cdot dE_n \quad (16)$$

$$dETR = -dRU \quad (17)$$

$$Peff = 0 \quad (18)$$

integration:

$$RU_{i+1} = RU_i \cdot [1 - \tanh(E_n/RU_{max})] / [1 + (1 - RU_i/RU_{max}) \cdot \tanh(E_n/RU_{max})] \quad (19)$$

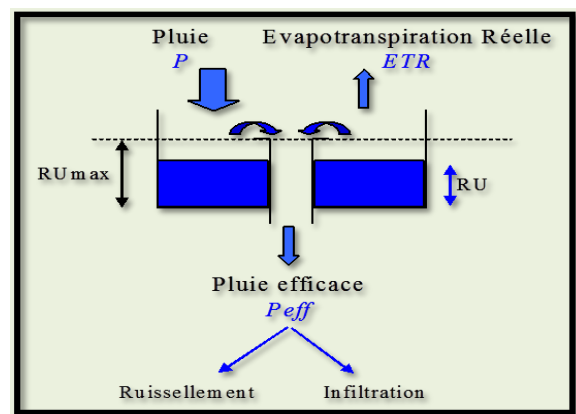


Figure 3. Edijatno-Michel Water Budget Method

Water table Fluctuation

The method is based on relating changes in measured water-table elevation with changes in the amount of water following equation (20) where [26,27] (Figure 5):

$$R = Sy \cdot DH / Dt \quad (20)$$

where

R groundwater recharge between times t_0 and t_1 ,

y the specific yield,

DH the piezometric rise attributed to recharge between $Dt = t_1 - t_0$.

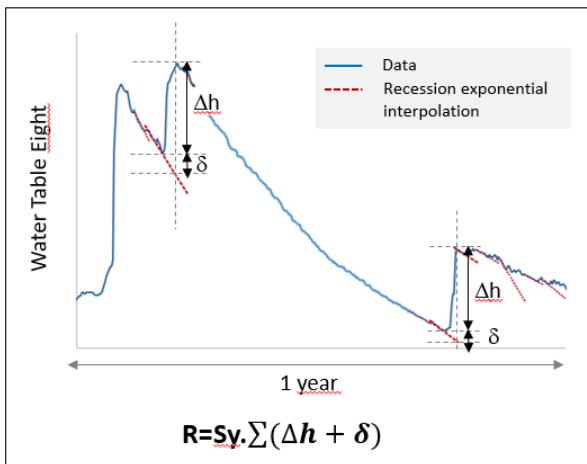


Figure 4. Water Table Fluctuation method

It is assumed that piezometric variations are only linked to recharge and recession and that Sy is constant and uniform. The procedure implemented in ESPERE_v2 sums water-table rise over each year, accounting for an unrealized recession (event-based method).

Data Availability

Table 1 shows the climatology/meteorology stations that were analyzed for the data. The data on the stations listed in Table can be obtained at <http://dataonline.bmkg.go.id/home> with detailed daily data in the level of minimum Temperature, maximum Temperature, average Temperature, and average humidity, rainfall, sunshine, maximum wind speed, wind direction, average wind speed, and

average wind direction on 1 January 2015–31 December 2019. The data needed for groundwater infiltration analysis using ESPERE are daily rainfall data, potential evapotranspiration, and Temperature. ESPERE requires several parameter settings [28–31], as shown in Table 2:

Table 1. Climatology and meteorological station

No	Station	Long.	Lat.	Elev.
1	Bogor Climatological Station	106.75	-6.50	207
2	Kemayoran Meteorological Station	106.84	-6.16	4
3	Tanjung Priok Maritime Meteorological Station	106.88	-6.11	3

Table 2. Setting Parameter pada ESPERE Ver. 2

Property	Unit	Value
Groundwater recharge area surface	km ²	1439
Infiltration/Effective rainfall ratio (ERI)	/	0.20*
Soil-water storage capacity	mm	208**
Latitude	°	-6.5
Specific Yield (Sy)	/	8.0000***
Hydrogeological catchment surface	km ²	226

Notes:

*Jaworska-Szulc (2009)

**Agriculture (2015)

***Johnson (1967)

The potential evapotranspiration value (21) was calculated using the CROPWAT 8 software [29]. CROPWAT 8 software calculates the potential evapotranspiration value using the equation (Monteith, 1965):

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)} \quad (21)$$

Where :

ET_0 = Potential Evapotranspiration ($mm \ day^{-1}$)

Δ = vapor gradient curve ($kPa \ ^\circ C^{-1}$)

R_n = radiation ($MJ \ m^{-2} \ day^{-1}$)

G = ground heat flux ($MJ \ m^{-2} \ day^{-1}$)

T = air temperature (1°C)
 U_2 = wind speed (ms^{-1})
 e_s = saturated vapor (kPa)
 e_a = actual vapor pressure (kPa)
 γ = psychrometric constant ($\text{kPa } 1^{\circ}\text{C}^{-1}$)

There are also inputs needed by the CROPWAT 8 software to calculate the value of potential evapotranspiration, i.e., the minimum & maximum temperature, air humidity, wind speed, and sunshine.

Groundwater Level data acquired from <http://bkat.geologi.esdm.go.id/monas>, Groundwater Research Division (Balai Konservasi Airtanah/ BKAT in Indonesia Language), well code: 31720800015001, sensor code: 6285192045586, Latitude: -6,20, Longitude: 106,92. Groundwater level data from 1 September 2019–31 Agustus 2020 (**Kesalahan! Sumber referensi tidak ditemukan.**).

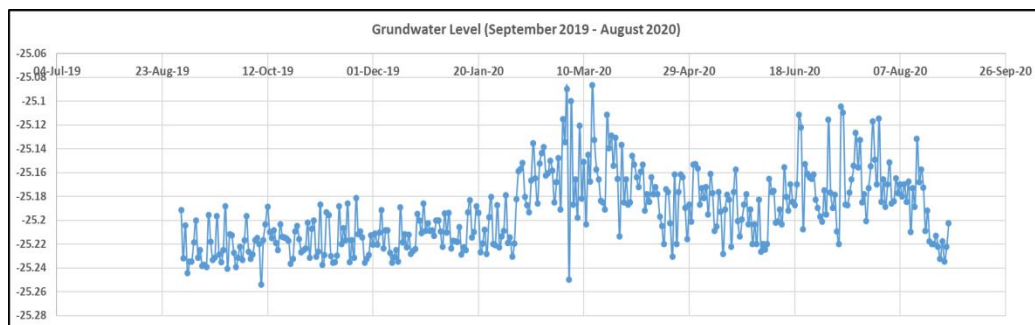


Figure 6. Groundwater level in Jatinegara

RESULTS AND DISCUSSION

Table 3 shows the estimated annual groundwater recharge around Tanjung Priok Station. Each method provides different estimation results compared to other methods. The estimated annual recharge in Tanjung Priok is in the range of 294–323 mm/year. The Dingman-Hamon method provides the lowest estimated annual recharge value (290 mm/year) compared to other methods.

Table 1. Annual recharge in Tanjung Priok

Annual RECHARGE (mm/year)	
	Interannual means
Thornthwaite	294
Dingman with Hamon PET	290
Dingman	314
Edijatno & Michel	323

Meanwhile, the Edijatno-Michel method offers the highest estimated annual recharge value (323 mm/year) compared to other methods. Thornthwaite (294 mm/year) and Dingman (314 mm/year) methods have moderate values.

Figure 7 shows the estimated annual recharge value of each method in 2015–2019. The estimated groundwater recharge in 2019 is the lowest compared to previous years. Meanwhile, the highest groundwater recharge estimate was in 2015. February is the month with the highest estimated groundwater recharge. July and October are the months with the lowest groundwater recharge compared to other months in 2015–2019.

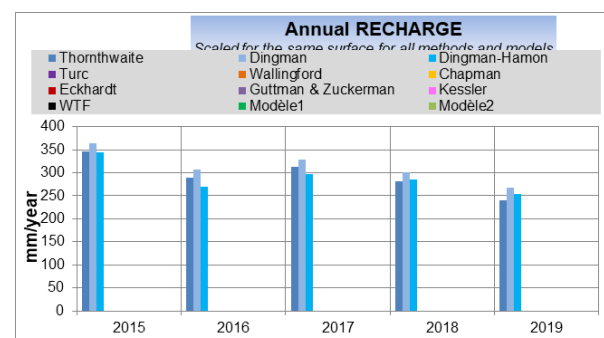


Figure 7. The annual recharge bar chart in Tanjung Priok

Table 4 shows the estimated amount of groundwater recharge based on the four methods. The Thornthwaite method has an estimated groundwater recharge value of 281–346.5 mm/year. The highest groundwater recharge based on the Thornthwaite method was 2015 (346.5 mm/year), and the lowest 2019 (239.7 mm/year). The Dingman method had the highest groundwater recharge value in 2015 (363.3 mm/year) and the lowest in 2019 (267.2 mm/year). The Dingman-Hamon method had the highest groundwater recharge value in 2015 (343.6 mm/year), and the lowest is in 2019 (254.1 mm/year). The Edijatno-Michel method had the highest groundwater recharge value in 2015 (384.3 mm/year), and the lowest was in 2019 (271.1 mm/year). In general, the four methods confirm the same groundwater recharge pattern, namely the highest groundwater recharge in 2015 and the lowest in 2019.

Table 4. Groundwater recharge for each method period 2015-2019 in Tanjung Priok

Years	Thornthwaite	Dingman	Dingman-Hamon	Edijatno & Michel
2015	346.5	363.3	343.6	384.3
2016	289.4	306.6	269.3	309.8
2017	313.8	329.1	297.5	332.6
2018	281.0	301.5	285.2	317.9
2019	239.7	267.2	254.1	271.1

Table 5 shows the Yearly sum of precipitation, ETP, and Temperature. Like the groundwater recharge estimation pattern based on the four methods, the annual rainfall value has a very similar pattern to the groundwater recharge pattern. Year 2015 (3130.4 mm/year) has the highest rainfall compared to the years after. Meanwhile, 2019 (2840.8 mm/year) has the lowest rainfall compared to previous years. The evapotranspiration value in 2019 (1701.3 mm/year) is the highest compared to last year.

Table 5. The yearly sum of precipitation, ETP, and Temperature in Tanjung Priok

Calendar Year						
Yearly sum (precipitations et ETP) or yearly mean (Temperature and flowrates)						
Year	Rainfall (mm)	Snow (mm)	Precipitations (mm)	ETP (mm)	T (°C)	Q (m3/s)
2015	3130.4	0.0	3130.4	1640.8	29.0	0.0
2016	2973.1	0.0	2973.1	1535.2	29.2	0.0
2017	3128.9	0.0	3128.9	1553.4	29.1	0.0
2018	3000.4	0.0	3000.4	1618.6	29.2	0.0
2019	2840.8	0.0	2840.8	1701.3	29.3	0.0

Table 6 shows the estimated annual groundwater recharge around Kemayoran. Each method provides different estimation results compared to other methods. The estimated annual recharge in Kemayoran is in the range of 183–229 mm/year. The Dingman-Hamon method provides the lowest estimated annual recharge value (183 mm/year) compared to other methods. Meanwhile, the Edijatno-Michel method offers the highest estimated annual recharge

value (229 mm/year) compared to other methods. Thornthwaite (203 mm/year) and Dingman (222 mm/year) methods have moderate values.

Table 2. Annual Recharge in Kemayoran

Annual RECHARGE (mm/year)	
Interannual means	
Thornthwaite	203
Dingman with Hamon PET	183
Dingman	222
Edijatno & Michel	229

Figure 9 shows the estimated annual recharge value of each method in 2015–2019. The estimated amount of groundwater recharge in 2019 is the lowest compared to previous years. Meanwhile, the highest groundwater recharge estimate was in 2015. February is the month with the highest estimated groundwater recharge. October is the month with the lowest groundwater recharge when compared to other months in 2015–2019.

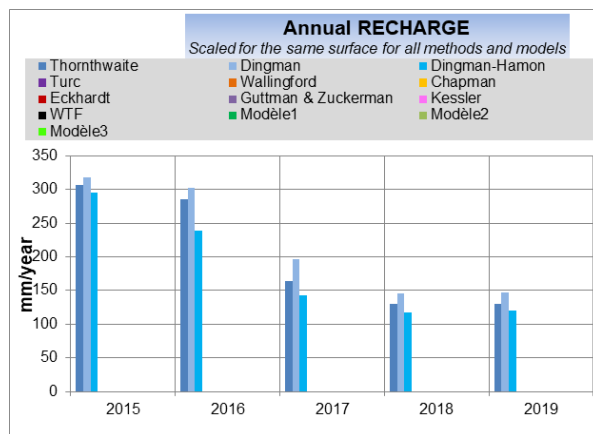


Figure 9. Annual recharge in bar chart in Kemayoran

Table 7 shows the estimated amount of groundwater recharge based on the four methods. The Thornthwaite method has an estimated groundwater recharge value of 130.1–307.3 mm/year. The highest groundwater recharge based on the Thornthwaite method was in 2015 (307.3 mm/year), and the lowest was in 2018 (130.1 mm/year). The Dingman method has the highest groundwater recharge value in 2015 (318.2 mm/year), and the lowest was in 2018 (145.9 mm/year). The Dingman-Hamon method has the highest groundwater recharge value in 2015 (295.9 mm/year), and the

lowest was in 2018 (117.6 mm/year). The Edijatno-Michel method had the highest groundwater recharge value in 2015 (332.2 mm/year), and the lowest was in 2019 (149.2 mm/year). In general, the four methods confirm the same groundwater recharge pattern, namely the highest groundwater recharge in 2015 and the lowest in 2018.

Table 7. Groundwater recharge for each method period 2015-2019 in Kemayoran

Years	Thornthwaite	Dingman	Dingman-Hamon	Edijatno & Michel
2015	346.5	363.3	343.6	384.3
2016	289.4	306.6	269.3	309.8
2017	313.8	329.1	297.5	332.6
2018	281.0	301.5	285.2	317.9
2019	239.7	267.2	254.1	271.1

Table 8 shows the Yearly sum of precipitation, ETP, and Temperature. The year 2016 (2721.3 mm/year) has the highest rainfall compared to the years after. Meanwhile, 2019 (1630.2 mm/year) has the lowest rainfall compared to previous years. The evapotranspiration value in 2019 (1483 mm/year) is the highest compared to last year.

Table 9 shows the estimated annual groundwater recharge around Bogor station. Each method provides different estimation results compared to other methods. The estimated annual recharge in Bogor is in the range of 865–894 mm/year. The Dingman-Hamon method provides the lowest estimated annual recharge value (865 mm/year) compared to other methods. Meanwhile, the Edijatno-Michel method has the highest estimated annual recharge value (893 mm/year). Thornthwaite (890 mm/year) and Dingman (894 mm/year) methods have relatively high values among other methods.

Table 8. The yearly sum of precipitation, ETP, and Temperature in Kemayoran

Calendar Year						
Yearly sum (precipitations et ETP) or yearly mean (Temperature and flowrates)						
Year	Rainfall (mm)	Snow (mm)	Precipitations (mm)	ETP (mm)	T (°C)	Q (m3/s)
2015	2312.4	0.0	2312.4	1420.2	28.9	0.0
2016	2721.3	0.0	2721.3	1338.4	29.0	0.0
2017	2263.4	0.0	2263.4	1394.4	29.0	0.0
2018	1711.6	0.0	1711.6	1412.2	29.0	0.0
2019	1630.2	0.0	1630.2	1483.7	29.2	0.0

Table 3. Annual Recharge in Bogor

Annual RECHARGE (mm/year)	
Interannual means	
Thornthwaite	890
Dingman with Hamon PET	865
Dingman	894
Edijatno & Michel	893

Figure 11 shows the estimated annual recharge value of each method in 2015–2019. The estimated amount of groundwater recharge in 2019 is the highest compared to previous years. Meanwhile, the lowest groundwater recharge estimate was in 2015. August is the month with the highest estimated groundwater recharge. September is the month with the lowest groundwater recharge when compared to other months in 2015–2019.

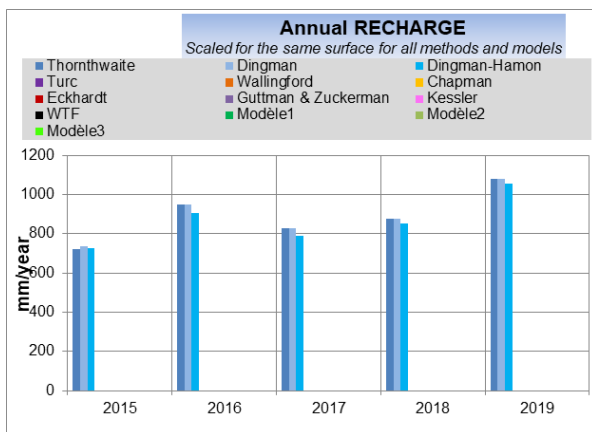


Figure 11. Annual recharge bar chart in Bogor

Table 10 shows the estimated amount of groundwater recharge based on the four methods. The Thornthwaite method has an estimated groundwater recharge value of 722.5–1078.2 mm / year. The highest

groundwater recharge based on the Thornthwaite method was in 2019 (1078.2 mm/year), and the lowest was in 2015 (722.5 mm/year). The Dingman method has the highest groundwater recharge value in 2019 (1079.5 mm/year), and the lowest is in 2015 (737.4 mm/year). The Dingman-Hamon method has the highest groundwater recharge value in 2019 (1074.1 mm/year), and the lowest was in 2015 (726.2 mm/year). The Edijatno-Michel method had the highest groundwater recharge value in 2019 (1074.1 mm/year), and the lowest was in 2015 (732.9 mm/year). In general, the four methods confirm the same groundwater recharge pattern, namely the highest groundwater recharge in 2015 and the lowest in 2018.

Table 10. Groundwater recharge for each method period 2015-2019 in Bogor

Years	Thornth- waite	Dingman	Dingman- Hamon	Edijatno & Michel
2015	722.5	737.4	726.2	732.9
2016	947.5	948.9	904.1	954.3
2017	827.5	828.8	787.7	827.4
2018	875.3	876.8	851.7	874.8
2019	1078.2	1079.5	1057.1	1074.1

Table 11 shows the yearly sum of precipitation, ETP, and Temperature. The year 2019 (4988 mm/year) has the highest rainfall compared to the years after. Meanwhile, 2015 (4000 mm/year) had the lowest rainfall value compared to previous years. The evapotranspiration value in 2015 (1541.7 mm/year) is the highest compared to the years after.

Table 11. The yearly sum of precipitation, ETP, and Temperature in Bogor

Calendar Year						
Yearly sum (precipitations et ETP) or yearly mean (Temperature and flowrates)						
Year	Rainfall (mm)	Snow (mm)	Precipitations (mm)	ETP (mm)	T (°C)	Q (m3/s)
2015	4000.2	0.0	4000.2	1541.7	27.3	0.0
2016	4971.7	0.0	4971.7	1380.6	27.5	0.0
2017	4361.8	0.0	4361.8	1374.5	27.3	0.0
2018	4675.5	0.0	4675.5	1449.5	27.3	0.0
2019	4988.9	0.0	4988.9	1477.4	27.4	0.0

Water Table Fluctuation

Table 12 shows the estimation of groundwater recharge groundwater in the Jatinegara area using the water table fluctuation method. Annual recharge of groundwater around Jatinegara is estimated at around 212 mm/year.

Table 4. Annual groundwater recharge using Water Table Fluctuation method in Jatinegara

Annual RECHARGE (mm/year)	
Interannual means	
Water Table Fluctuation	212

Groundwater Recharge in Jakarta Groundwater Basin

Figure 13 shows the southern part of Jakarta's groundwater basin has a higher average annual recharge than the northern part of Jakarta's groundwater basin. The annual rainfall in the southern part of the groundwater basin is higher than in the northern part of Jakarta's groundwater basin.

Estimating groundwater recharge using the water budget technique is closely related to rainfall data, evapotranspiration, temperature, etc. The high potential evapotranspiration value in 2019 has caused a significant decrease in annual groundwater recharge in that year. Likewise, the amount of monthly recharge depends on the rainfall in a certain month. Of the annual rainfall, only 8–15% recharges groundwater in the research location. The groundwater recharge amount in the southern part of the Jakarta

groundwater basin tends to be higher than other areas in this basin. The average groundwater recharge in Tanjung Priok based on the water budget method is 305 mm/year. The average groundwater recharge in Kemayoran based on the water budget method is 209 mm/year. The average groundwater recharge in Bogor based on the water budget method is 885 mm/year.

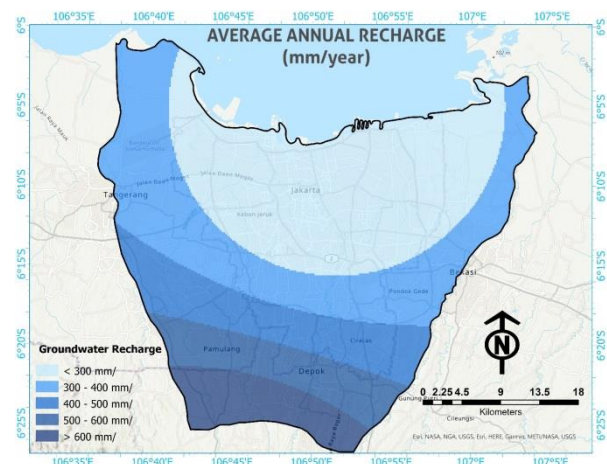


Figure 13. Average annual groundwater recharge in Jakarta Groundwater Basin

CONCLUSIONS

ESPERE version 2 2020 allows the application of several methods commonly used to quickly and simultaneously estimate groundwater recharge. It can apply and compare the results of three water budget methods. This software was quite powerful for estimating groundwater recharge. The southern part of Jakarta's groundwater basin has a higher average annual recharge than the

northern part of Jakarta's groundwater basin. The average groundwater recharge in Tanjung Priok based on the water budget method is 305 mm/year. The average groundwater recharge in Kemayoran based on the water budget method is 209 mm/year. The average groundwater recharge in Bogor based on the water budget method is 885 mm/year. Of the annual rainfall, only 8–15% converted to groundwater recharge in the study area. Based on the water table fluctuation method, the Annual recharge of groundwater around Jatinegara is estimated at around 212 mm/year.

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