JJEES

JJEES (2025) 16 (3): 220-226
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Infiltration Capacity and its Relation with Groundwater Potential in West Progo, Indonesia

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Received on January 7, 2025, Accepted o February 12, 2025

Abstract

West Progo area is in Kulon Progo Regency, Yogyakarta Province, Indonesia. This regency has recently developed quite rapidly and requires a lot of research to support regional development. This study aims to conduct a hydrogeological survey to investigate the relationship between infiltration capacity and groundwater potential in the area. The hydrogeological survey collected morphological data, including rock types and geological structures, as well as groundwater levels and measured infiltration rates using a double ring infiltrometer. The study results showed that the infiltration capacity values varied according to the soil cover in the latosol, grumusol, alluvial, and regosol zones, respectively, by 1.2, 12, 68.4, and 84 cm/hour. The average groundwater level in the zone showed a position of 7.94, 5.24, 2.18, and 3.52 m below the surface. There is a powerful correlation between infiltration rate and groundwater level. Infiltration capacity is in line with groundwater potential, where the greater the infiltration capacity, the shallower the groundwater level.

Keywords: *Infiltration, Groundwater, Groundwater Table, Soil Type, Hydrogeology*

1. Introduction

Kulon Progo Regency is a rapidly developing area in the Special Region of Yogyakarta Province, which aligns with constructing a new international airport in the Temon area, Kulon Progo. The development of regional areas requires the availability of natural resources, especially groundwater. Groundwater is a basic substance in life, especially fresh water. In fact, freshwater scarcity is one of the biggest threats facing people in recent years (Mohammed et al, 2024). Therefore, research on groundwater potential needs to be encouraged.

In general, groundwater potential is supported by the large amount of rainfall that enters the subsurface through infiltration. The issue of infiltration becomes critical when we encounter various types of soil cover or rock composition in an area. Water resources in a region are also significantly influenced by water infiltration into the subsurface (Freeze & Cherry, 1979; Listyani, 2022). This process is driven by the amount of rain in the area. Meanwhile, Yang et al. (2016) pointed out that the presence of water in soft rocks is significant when facing geological problems.

Infiltration is the process by which water enters the soil. This process plays a vital role in the hydrogeological cycle as it is the fundamental step for the existence of groundwater in the aquifer. Water that infiltrates and travels through the aeration zone contributes to the groundwater in the aquifer and is referred to as a groundwater recharge component. Besides originating from local groundwater recharge due to rainwater percolation, groundwater is also recharged by regional groundwater flow within the aquifer (Sophocleus, 2004). If the infiltration capacity is low during heavy rainfall, it can lead to surface water runoff, which may result in soil erosion, flooding, or even landslides.

Various hydrological/hydrogeological parameters, such as soil type, temperature, vegetation, and rainfall, are factors that influence the occurrence of infiltration. Of these various parameters, soil hydraulic conductivity is one of the most important factors that controls the infiltration process and then, determines groundwater potential (Sakellariou-Makrantonaki 2016; Sharief et al., 2023).

One of the main factors that affect infiltration is the type of land cover. This factor then determines the physical properties of the soil, such as soil texture, which strongly influences the behavior of water absorption into the soil. The rainfall factor influences where the infiltration capacity will be reached; if the rain exceeds this capacity, while in cases of rain that is less than the infiltration capacity, the average infiltration equals the rainfall (Seyhan, 1990). These changes then affect the behavior of groundwater absorption through infiltration, which also plays a role in local groundwater recharge in the area.

This study was conducted using the Horton model, which aims to determine the value of infiltration capacity in Kulon Progo and its relationship with groundwater potential. Therefore, a study of infiltration capacity needs to be conducted to understand the potential of water resources and support the development of this area.

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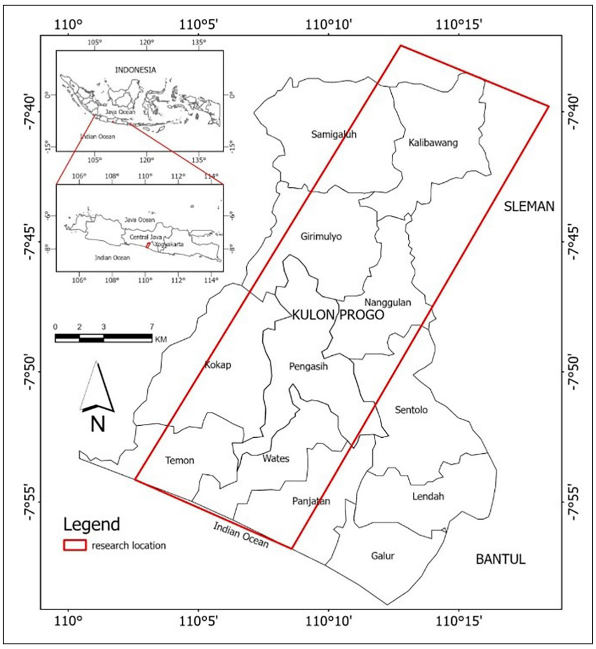

Figure 1. The research area is located in Kulon Progo Regency, Java.

2. Research Materials and Methods

This research was conducted in an area with the physiography of the Kulon Progo dome, the central depression zone to the South Coastal Plain of Java (Van Bemmelen, 1949). In the northern part, the research area has hilly morphology composed of Tertiary sedimentary rocks, including Nanggulan, Old Andesite, and Sentolo Formations (Rahardjo et al., 1995). Meanwhile, the central part of the research area is composed of fluvial-volcanic alluvial deposits resulting from the activities of Mt. Merapi and the Progo River. The southern part of the research area borders the Indian Ocean, consisting of coastal sandy plains and dunes.

The research area is in Kulon Progo, the northern part of the non-Groundwater Basin area or non-potential Groundwater Basin (Geological Agency, 2011). According to the DPWHEMR & CV. CPK (2016), this area is included in the Menoreh Basin. In addition, the Wates Groundwater Basin includes the southern part of the research area (Geological Agency, 2011).

The research area is located in Kulon Progo Regency, part of the Pekalongan regional hydrogeological map area on the southeast side. According to the regional hydrogeological map (Effendi, 1985), the research area comprises varying hydrogeological units, from highly productive to low. Some places even show the local area to rare groundwater potential. Under this condition, the groundwater level and aquifer potential also vary.

Field hydrogeological surveys have been conducted, starting with determining location points in several places, each representing a different soil cover, namely latosol, grumusol, alluvial, and regosol soils. Furthermore, geological descriptions and groundwater level mapping were conducted at several points in each soil zone.

Infiltration speed is measured, using two interrelated parameters: infiltration rate and infiltration capacity. The infiltration rate is the amount of water that enters the soil through the soil surface at a specific time (Maghfiroh, 2020). It is usually expressed in m/s or cm/hour. Meanwhile, infiltration capacity is the maximum infiltration rate in a specific soil type (Harimi, 2018).

Infiltration rate measurements were carried out using a double ring infiltrometer measuring 20 cm high, 15 cm inner ring diameter, and 30 cm outer ring (Figure 2). David et al. (2016) stated that both rings have different functions; the outer ring functions to reduce the possibility of water not moving horizontally and the inner ring functions to measure the diameter. Infiltration measurements were carried out at one selected location representing each soil zone (Figure 3).

Infiltration capacity analysis was carried out using the Horton model. In the Horton method analysis (1940), the infiltration rate can be expressed mathematically using the following equation:

$$f = fc + (f0 - f_c) .e^{-kt} \quad (1)$$

Where:

f: infiltration rate (cm/hr)

f_c: infiltration rate after constant

f_0: initial infiltration capacity

k: rate constant of infiltration capacity reduction

e: exponential number (2.718)

t: time (minutes)

The groundwater level measurements were conducted throughout the research area in each soil zone. For example, the groundwater level measurements in shallow wells are given in Figure 4. Furthermore, a statistical analysis of correlation regression was conducted to determine the relationship between infiltration capacity and the local groundwater level. This groundwater level position assessed the groundwater potential in the research area.

Figure 2. Double ring infiltrometer and geological hammer.

Figure 3. Example of infiltration rate measurement activity in the regosol soil zone.

Figure 4. Example of a shallow well where groundwater level measurements were taken.

3. Results

3.1 Hydrogeological Conditions

DPWHEMR & CV. CPK (2016) stated that the research area in the northern part has an aquifer that can be classified into a group of colluvium aquifers, which are Quaternary deposits. This aquifer group is formed from weathered material or Tertiary formation debris, so its thickness depends on the local weathering level (reaching 30 m in some places). The transmissivity value of this aquifer group ranges from 1 - 100 m^2 / day. This colluvium aquifer group is an unconfined aquifer.

In the southern part, the Wates and Yogyakarta Formations are young rocks that form alluvial. The Wates Formation in the research area is loose material, resulting from the current activity of the Progo River. At the same time, the Yogyakarta Formation is formed by loose material, resulting from the activity of Old and Young Merapi. In the eastern part, the Young Merapi deposits are scattered along the Progo River, which are fluvial-volcanic deposits. These deposits develop as moderate to good aquifers, with a transmissive value of 550 m^2/day (DPWHEMR & CV. CPK, 2016).

The southernmost part of the research area contains a coastal aquifer system, with a coastal alluvial aquifer subsystem formed by the Wates, Merapi, and Sentolo Formations and a dune subsystem.

From the hydrogeological survey and secondary data (KPRRDPA, 2024), it is known that the research area is composed of four soil zones on the surface, namely latosol, grumusol, alluvial, and regosol soils. Latosol soils are formed by the weathering of OAF andesite breccia or Nanggulan sandstone; grumusol soils come from limestone or tuff of the Sentolo Formation; while alluvial soils come from young fluvial-volcanic activities (Figure 5).

3.2 Infiltration Test

In each of these soil zones, one location was taken for infiltration rate testing. Recording water decline was carried out every 5 minutes. The recording was stopped when the water decline was considered stable, which was a minimum of four measurements with the same decline rate.

Table 1 presents the infiltration rate test data. Furthermore, the measurement results in the field are processed using the Horton model, one of the well-known infiltration models in hydrology. The calculation of the infiltration rate (f), f_c (constant infiltration rate), and f_0 (initial infiltration rate) at selected locations is given as an example in (Table 2).

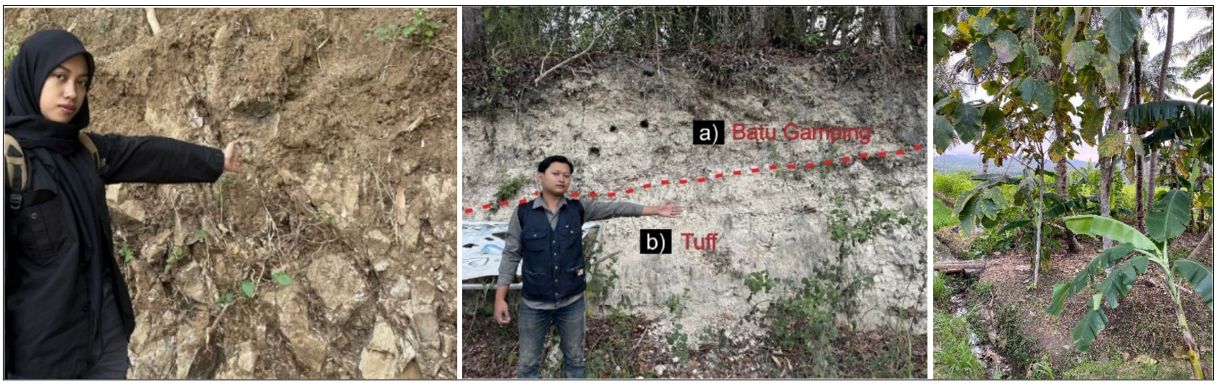

Figure 5. Sandstone outcrops (left), limestone, and tuff (center) in the northern part of the study area, and alluvial deposits scattered in the central part of the study area (right).

Table 1. Summary of water reduction in infiltration tests.

No	Time (t) (minutes)	*Water level drawdown*(cm)			
		Latosol	Grumusol	Alluvial	Regosol
		Loc. 77	Loc. 78	Loc. 79	Loc. 80
1	5	10	10	8	8.4
2	10	10	8	7.5	7.3
3	15	10	5.2	7	7.1
4	20	7.7	2.5	6.8	7
5	25	7.2	2.5	6.5	7
6	30	6	2.5	6	7
7	35	2.7	2.3	6.1	7
8	40	2.8	2.2	6	7
9	45	1.9	1.4	5.7	
10	50	1.3	1	5.7	
11	55	1	1	5.7	
12	60	1	1	5.7	
13	65	0.7	1		
14	70	0.3			
15	75	0.1			
16	80	0.1			
17	85	0.1			
18	90	0.1			

Juliastuti and Suhendra (2011) stated that the f_c value is a constant infiltration capacity that depends on the soil type. The f_0 and f_c values are functions of soil type and cover. Meanwhile, Juwita and Santoso (2019) asserted that fc is the maximum infiltration rate in a situation where the soil's ability to absorb water has reached its maximum. The f value is the maximum infiltration rate, obtained from a particular soil type.

The value of k in the Horton equation is an empirical constant. Applying the Horton equation requires determining the parameters f0, fc, and k. The value of f0 is set as the initial infiltration rate data. Meanwhile, fc and k are established by trial and error or through any optimization procedure to ensure that the Horton curve best fits the data using the fitting method. The Horton equation is an exponential function that shows the soil infiltration rate decreases over time (Duhita et al., 2021). Each soil has an asymptotic value that represents the final infiltration rate, defined as the infiltration capacity.

Horton (1933,1940) observed that infiltration starts from a standard value of f_0 and exponentially decreases to a constant condition of f_c (Andayono, 2018). The f value is the maximum infiltration rate, obtained from a particular soil type. Furthermore, the reference, used to determine the infiltration rate, is the Kohnke classification (1968) based on the f value (Table 3)

Table 2. Example of infiltration calculation in the regosol soil zone.

No	Time (t) (minutes)	Decrease (cm)	Infiltration Rate (f) (cm/min)	fc (cm/min)	$f-f_c$ (cm/min)	Log $(f-f_c)$
	0		1.8	1.4	0.4	-0.40
1	5	8.4	1.68	1.4	0.28	-0.55
2	10	7.3	1.46	1.4	0.06	-1.22
3	15	7.1	1.42	1.4	0.02	-1.70
4	20	7	1.4	1.4	0	
5	25	7	1.4	1.4	0	
6	30	7	1.4	1.4	0	
7	35	7	1.4	1.4	0	
8	40	7	1.4	1.4	0	

Table 3. Classification of infiltration rate (Kohnke, 1968).

Class	Infiltration Rate (f) (mm/hr)
Very fast	> 254
Fast	> 127 - 254
Rather fast	> 63 - 127
Medium	> 20 - 63
Rather slow	> 5 - 20
Slow	1 - 5

Figure 6 shows the graph of the relationship between time (t) and log $(f-f_c)$. Each graph shows the gradient of the regression line. The relationship between the gradient of the regression line and the value of k is shown in the following formula:

$$m = \frac{-1}{k \log e} \quad (2)$$

The formula above can be used to determine the value of k, which is the constant decrease in infiltration rate. For example, in Figure 6, the relationship between water decline time (t) and log (FC) is shown by the equation log $(f-f_c)$ = -0.0247 t + 0.06269, where the gradient of the regression line from the relationship between the two is -0.0247.

Figure 7 is made to show the graph of the relationship between test time (t) and the infiltration rate value (f). The initial infiltration value (f_0) can be determined from this graph. Duhita et al. (2021) illustrate this relationship (Figure 8).

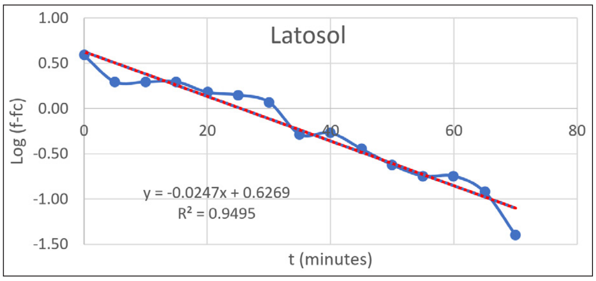

Figure 6. Graph the relationship between time (t) and log (f-fc) in the latosol soil zone.

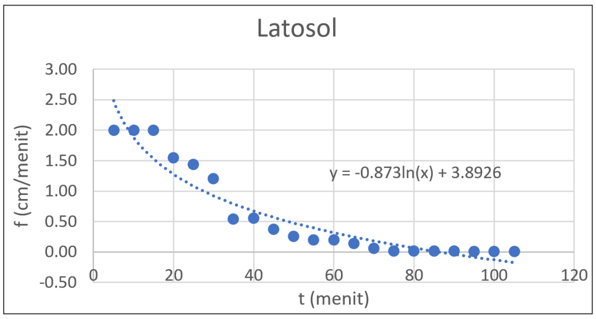

Figure 7. The example of a graph of the relationship between time (t) and f in the latosol soil zone.

The calculation results, based on the Horton formula (1933), obtained the infiltration capacity value in the research area, as listed in Table 4. According to the Kohnke classification (1968; Table 3), the infiltration capacity is in the slow until rather slow category (Table 5). Figure 9 compares f_0, f_c and f values at the four observation locations.

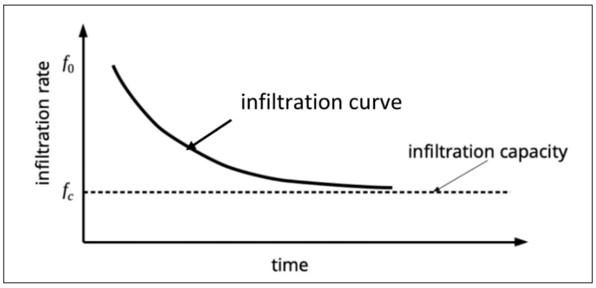

Figure 8. The graph shows the relationship between time (t) and infiltration rate (f) (Duhita et al., 2021).

Table 4. The initial infiltration rate (f_0), constant infiltration rate (f_c), and infiltration capacity (f) are based on the Horton model at the research location.

No	Loc.	f_0 (cm/min)	f_c (cm/min)	Gradient (m)	k	f (cm/min)
1	77	3.89	0.02	-0.0247	93.23174	0.020
2	78	3.03	0.20	-0.0304	75,75078	0.200
3	79	1.95	1.14	-0.041	56,16644	1.140
4	80	1.80	1.40	-0.0914	25,19501	1.400

Table 5. The infiltration capacity of the research area is based on Kohnke's classification (1968).

LP	Soil Type	f (cm/min)	f (mm/hr)	Class
77	Latosol	0.020	1.2	Slow
78	Grumusol	0.200	12	Rather slow
79	Alluvial	1.140	68.4	Rather fast
80	Regosol	1.400	84	Rather fast

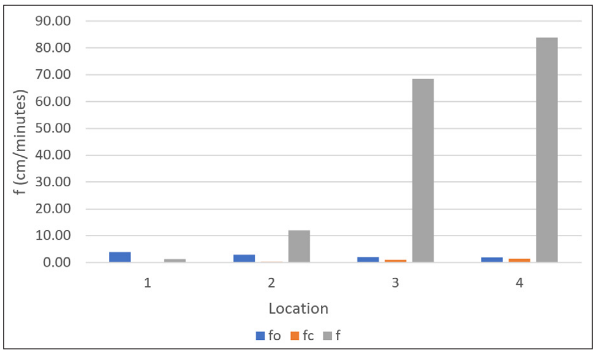

Figure 9. Graph showing the values of f0, fc, and f at locations 1 (latosol), 2 (grumusol), 3 (alluvial), and 4 (regosol).

3.3. Groundwater Level Measurement

Seventy-six dug wells, spread throughout the research area, have had their groundwater levels measured. Examples of dug wells are found in Figure 10. In all observation locations, residents' wells appear to have groundwater, and no dry wells were found. Groundwater levels were also measured at several points around the test location. In this area, the groundwater level is 1.4-12.3 m above sea level or 3.48-123.5 m above sea level, with a measured saturated zone thickness of 0.84-4.5 m. The average groundwater level in the latosol, grumusol, alluvial, and regosol zones is 7.94, 5.24, 2.18, and 3.52 m from the local ground surface, respectively.

Figure 10. Example of the appearance of dug wells, found in the research area.

In the research area, dug wells appear to have groundwater everywhere, as evidenced by data collection. For reference, the survey was conducted in July, which is usually the peak of the dry season. The CSA of Kulon Progo Regency (2022) noted that in that month, the Kulon Progo area generally had the lowest rainfall, with just 2.8 mm and had one rainy day. Although all dug pond wells had water when visited, some of these wells also have the potential to dry up if there is a long dry season.

Generally, the groundwater flow pattern tends towards the south, with variations to the east/southeast (Figure 11). The westward flow pattern is only found a little, on coastal plains or dunes, where it develops locally. The direction of the groundwater flow pattern is in line with the theory of shallow flow patterns, which states that the direction of shallow groundwater flow is generally determined by surface topography (Freeze & Cherry, 1979; Listyani & Budiadi, 2018; Listyani, 2019).

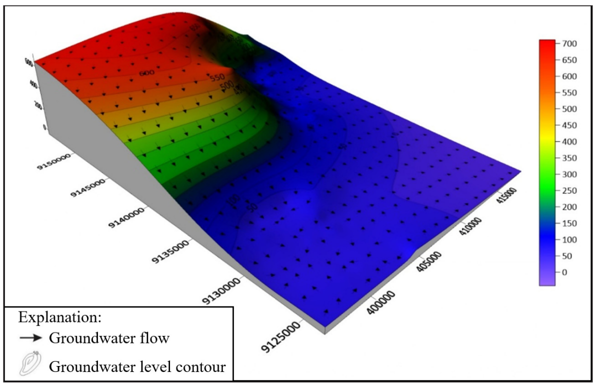

Figure 11. The 3D map of groundwater level in the Kulon Progo area.

4. Discussion

Soil cover (soil type) determines the infiltration capacity (Juwita & Santoso, 2019). The infiltration rate is generally used to evaluate soil quality and health (Saltiel et al., 2022). Therefore, this study conducted an analysis of infiltration capacity on different types of soil. CALRRD (2018) pointed out that several soil types in the study area were latosol, grumusol, alluvial, and regosol. The soil cover's physical properties are essential for studying water resources in certain regions (Listyani et al., 2022).

Infiltration analysis, at selected points representing varying soil cover, yields different values. This analysis means that the infiltration rate is determined by the type of soil cover (soil type). Furthermore, the infiltration rate will be linked to local recharge, by looking at the position of the groundwater table (Table 6; Figure 12).

The position of the shallow groundwater table can be a reference for assessing the potential of groundwater in an area. Areas with a lot of groundwater certainly tend to have relatively shallow groundwater tables. This groundwater table fluctuates. When the quantity of groundwater decreases, the groundwater table tends to become deeper. Therefore, in this study, the position of the groundwater table, measured from the local land surface, is used as one of the parameters to calculate the amount of groundwater recharge in the research area.

Table 6. Infiltration rate (f), saturated zone thickness, and groundwater level in the research area.

LP	Soil Type	f_o (cm/min)	f_c (cm/min)	f (cm/hr)	Groundwater Table (m below surface)
77	Latosol	3.89	0.02	1.2	7.94
78	Grumusol	3.03	0.2	12	5.24
79	Alluvial	2.45	0.2	68.4	2.18
80	Regosol	1.57	0.02	84	3.52

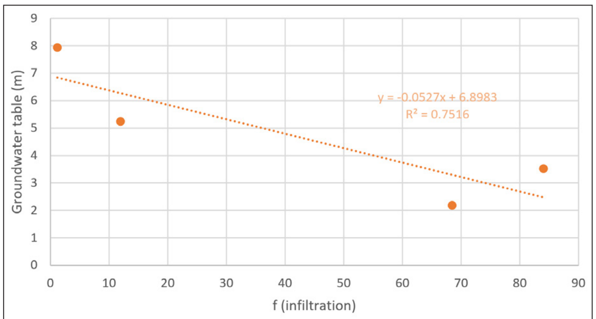

Figure 12. Relationship between infiltration capacity and groundwater table.

Figure 8 shows the relationship between the infiltration rate and local recharge represented by the groundwater level. The correlation between the two is 86.7%, which, according to Sugiyono (2022), shows a very strong correlation between the two variables.

Thus, the rate of rainwater infiltration into the soil in the study area shows powerful results about groundwater recharge, which is represented by the position of the groundwater table. A negative gradient indicates an inverse relationship between the two variables studied.

The higher the infiltration rate in an area is, the shallower the groundwater level will be. The shallowness of the groundwater level indicates that groundwater fluctuations are in good condition, which means that the groundwater potential is good.

Groundwater infiltration in shallow zones can carry materials that can pollute groundwater, such as bottom ashes. Many bottom ashes can percolate into groundwater by precipitation (Park et al., 2022). Therefore, it is necessary to manage materials that have the potential to pollute shallow groundwater. The potential of shallow groundwater in the research area, especially in the alluvial and regosol zones with large infiltration capacities, must be supported by various managements to avoid environmental pollution.

The infiltration process is important in water resource studies, especially in areas with less potential. Some areas that have few water resources can be categorized as an absolute water scarcity (Kharabshah and Alzboon, 2021). This scarcity is largely determined by low rainfall as the main parameter in the water budget (Al-Zboon, 2024). Apart from that, low rainfall can be exacerbated by low infiltration processes. Moreover, water resources also often face significant pressure due to climate change and increasing demand caused by increasing human activity (Abbas et al., 2024). Therefore, maintaining the quantity of water resources needs to be done by maintaining an optimal infiltration process. The potential of groundwater resources, of course, depends on rainfall which can infiltrate the land surface.

5. Conclusion

The infiltration rate values in several areas of Kulon Progo Regency vary according to their land cover in the latosol, grumusol, alluvial, and regosol zones, respectively, by 1.2, 12, 68.4, and 84 cm/hour. The average groundwater level in these zones is 7.94, 5.24, 2.18, and 3.52 m. below ground level. From the analysis results, it is known that there is a powerful correlation between the infiltration rate and the groundwater level. However, the two relationships are inversely proportional. Infiltration capacity is in line with groundwater potential, where the greater the infiltration rate is, the shallower the groundwater level will be.

Acknowledgments

The author would like to thank the Yogyakarta National Institute of Technology for funding internal research with contract number 41/ITNY/LPPMI/Pen.Int./PD/VI/ 2024 so that this paper can be written. The author would also like to thank the assistants who helped collect data in the field, especially Aditya, Triawan, Dhea, and Hezron.

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