Int. J. Econ. Environ. Geol. Vol. 13 (4) 10-15, 2022
Journal home page: www.econ-environ-geol.org

Open Access
ISSN: 2223-957X

Recharge Zone of Shallow Groundwater at Southeastern Part of Kulon Progo District Area based on Groundwater Facies

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Abstract: The Galur and Lendah areas are in the southeastern part of Kulon Progo Regency, Yogyakarta, Indonesia. This area has become a developing area because of the new airport in this district. Along with its development, the need for groundwater in this area is increasing, so groundwater research is also increasingly needed. A study on groundwater is required to support the development of this region. This time, a groundwater study was conducted to determine the potential for the recharge-discharge zone, also groundwater flow patterns based on the chemical facies of the groundwater. The hydrogeological survey was carried out with groundwater sampling from 9 (nine) dug wells and 1 () spring for physical/chemical testing of groundwater in the laboratory. The results showed groundwater in the study area generally flows south or northwest, with a radial pattern anomaly in the north. The shallow groundwater studied was bicarbonate type with Ca, Na, and Mg cations variations. The groundwater facies characterizes groundwater that is typical in the catchment area. Based on this fact, recharge zones can occur throughout the study area, with local to medium flow systems.

Keywords: Groundwater, facies, hydrochemistry, recharge, flow.

Introduction

Water is a vital and strategic need. Therefore water must be maintained in adequate quantities and of good quality. Hydrogeological research has been developed in various regions throughout Indonesia to assist communities in providing clean water.

One of the potential groundwater studies in an area can be done by knowing the site's position in a groundwater basin. The lack of data on groundwater quality in this area has prompted researchers to investigate groundwater in terms of its quality and flow patterns. In addition, groundwater potential in a place needs to be supported by understanding the zoning of the recharge–discharge area. By knowing the recharge-discharge zone of a site, we can better protect groundwater and maintain its sustainability.

Hydrochemical Studies for Groundwater Zoning

The delineation of the recharge-discharge zone needs to be supported by groundwater quality data, especially in terms of facies. Groundwater facies can explain the genetics of groundwater in an area (Geological Agency, 2011). Groundwater in the recharge zone is generally of the bicarbonate type, in line with the hydrochemical evolution developed by Chebotarev (1955, in Freeze and Cherry, 1979). Therefore, to ensure the recharge-discharge zoning of an area, hydrochemical methods need to be used to verify other data. Researchers have also conducted hydrochemical research in the West Progo area (Listyani et al, 2021), but with a different objective, namely to understand the groundwater flow system in the Kulon Progo dome area. This time, the hydrochemical study aims to determine the recharge-discharge zone in the southeastern part of the Kulon Progo Regency.

This study was conducted in the Districts of Galur and Lendah, Kulon Progo Regency, Special Region of Yogyakarta (Fig. 1). This area is located at the end of the Kulon Progo Regency, close to the city of Yogyakarta, which is already quite developed. The research area is an area that is growing quite rapidly along with the opening of a new airport in the Kulon Progo Regency. Therefore, various necessities of life and infrastructure are increasingly needed along with the development of this region.

Materials and Methods

Geological and Hydrogeological Setting

Most of the research area is in the physiography of the Solo Zone (Van Bemmelen, 1949), which is composed of alluvial and coastal deposits, including sand, silt, and clay deposits (Rahardjo et al, 1995). A small part of the study area comprises compact rock from the Sentolo Formation and the Old Andesite Formation, where outcrops can be found in the northern and northeastern parts of the Lendah district.

The center of the study area is an alluvial plain. The plain name refers to the difference in height <5 m and slope <2% (Van Zuidam and Cancelado, 1979; Listyani, 2019). This morphology is spread lengthwise in the west-east direction. The dominant flow pattern is dendritic, indicating uniform rock resistance and a non-dominant structure (Srijono et al, 2011). The lithology that composes this morphology is alluvial deposits consisting of clay to gravel produced by fluvial-volcanic processes (Santosa, 2020).

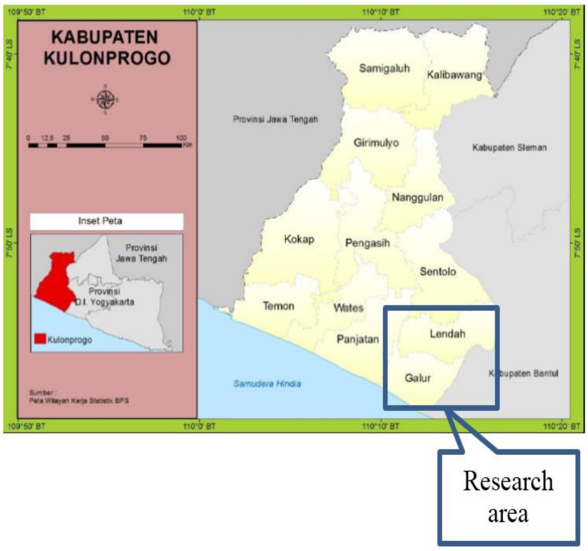

Fig. 1. Research locations on the Kulon Progo map (Central Bureau of Statistics of Kulon Progo Regency, 2021).

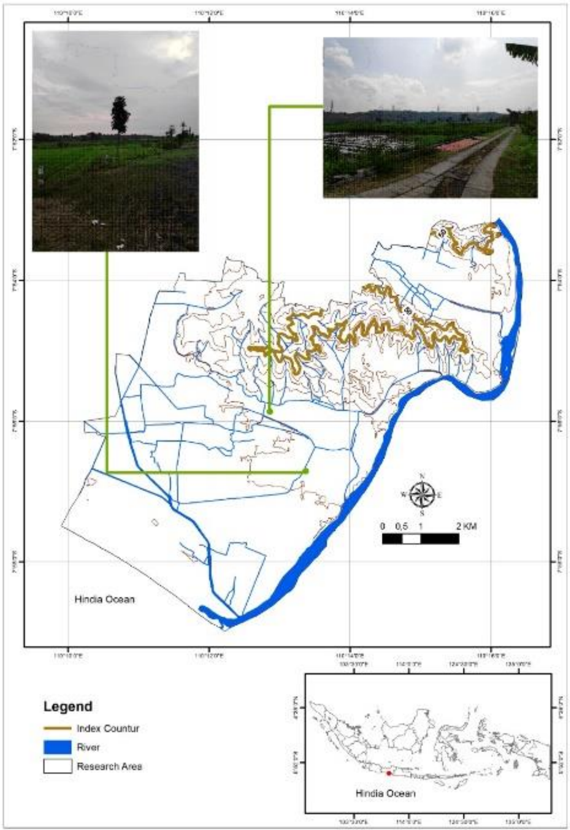

Fig. 2. Structural rolling morphology spread over the northern part of the study area (left); fluvial plain is the dominant landscape, scattered over the northeast, middle to the south of the study area (right).

This alluvial/fluvial plain is a landscape that dominates the study area (Fig. 2). This plain is formed by fluvial-volcanic material in fine sand to conglomerate sand. In addition, this plain also receives a reshuffle from the Sentolo Formation and the Old Andesite, originating from the West Progo hills to the north. The materials are clay, silt, sand, tuffaceous sand, and limestone debris or andesite breccia. The West Progo hills have undergone many tectonic processes, even neotectonic ones (Budiadi, 2008). The existence of tectonic and exogenic processes causes many intensive geomorphic processes to produce rock debris that can be transported to lower areas, including in the central to the southern part of the study area.

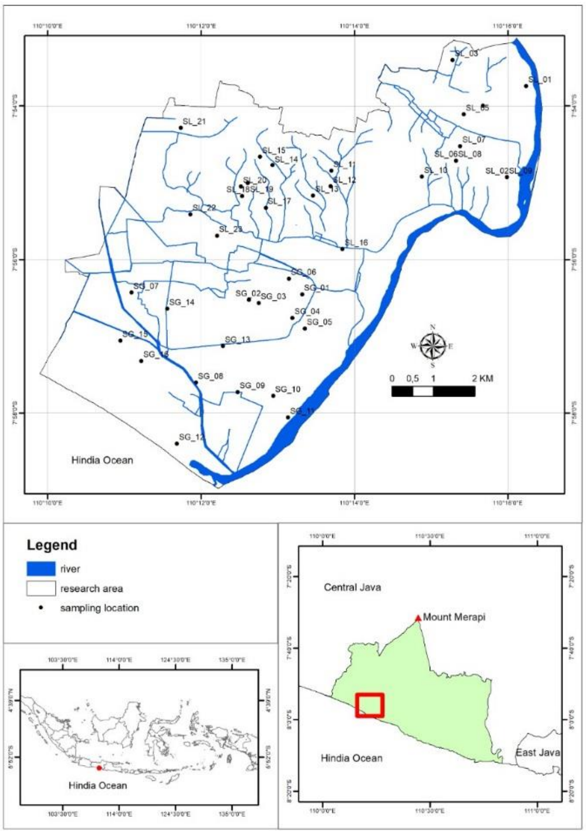

Fig. 3. Location map of groundwater sampling.

The southern part of the research area forms a coastal plain morphology spread along the south coast. The rocks that make up this area are coastal alluvial deposits (fluvio-marine). As in the morphology of the alluvial plain, the drainage pattern in this area also develops dendritic. Meanwhile, the northern part of the study area develops as a high morphology part of the Kulon Progo Hills (Fig. 2).

The research area is included in the Pekalongan regional hydrogeological map sheet (Efendi, 1985) and is part of the eastern part of the Groundwater Wates Basin (Geological Agency, 2011). Furthermore, alluvium deposits in the West Progo may be divided into the Wates Formation and the Yogyakarta Formation (McDonald and Partners, 1984). The Yogyakarta Formation is composed of loose material resulting from volcanic activity, especially the activity of Mount Merapi Muda. The lithologies produced by the activity of young Mount Merapi include tuff, ash, breccia, agglomerates, and lava flows (Rahardjo *et al*, 1995). The Yogyakarta Formation in the study area is composed of loose (undifferentiated) material resulting from the fluvial activity, especially the Progo River. This formation is spread out in the central part of the research area to the south coast (Hendrayana, 2011; Yogyakarta Special Region Local Government Public Works and Housing Department Service – CV. Cita Prima Consultant, 2016).

Fig. 4. Groundwater sampling locations include dug wells (SG 01) in Galur and spring (MA 01) in Lendah.

Hydrogeological Survey

A hydrogeological survey was conducted to determine the position of the shallow groundwater table at 20 dug wells. The groundwater level in the study area is presented in Table 1. The lowest groundwater level is found at SG12 well in Sidorejo Hamlet, Banaran, Galur, with a position of 2.1 m asl, while the highest part is at an elevation of 73.65 m asl in SL06 well in Dusun Tubin, Sidorejo, Lendah.

Sampling and Groundwater Hydrochemistry

Field surveys indicated dug wells in several locations. Still, only one spring was found (Fig. 3). One example of dug wells and springs is shown in Fig. 4. Groundwater conditions generally show clear, tasteless, odorless properties, low turbidity, and normal temperature.

Laboratory Analysis

Groundwater samples were then tested for physical/chemical properties in the laboratory, which can be seen in Table 2. The data show that the groundwater quality is quite good, with low turbidity (0.5 – 3.2 NTU).

Results and Discussion

Groundwater Flow Pattern

The groundwater-surface mapping results help us know the groundwater flow pattern in the research area. The groundwater level map is presented in Figure 4. The figure shows that the high groundwater level is in the highlands to the north of the study area, namely in the district of Lendah. The groundwater level gradually gets lower towards the south towards the coastal plain. In general, the position of the groundwater table in the study area is in line with the relief of the ground surface. It is common in an area

Table 1. The shallow groundwater table of the study area.

Location	Water Table (m asl)	Saturation Zone (m)	Location	Water Table (m asl)	Saturation Zone (m)
SG_01	13.6	1.40	SL_04	31.7	2.31
SG_02	10.7	2.10	SL_05	30.9	1.20
SG_03	17.6	2.80	SL_06	73.6	5.00
SG_04	18.0	3.80	SL_07	28.3	7.08
SG_05	14.5	1.10	SL_08	59.0	4.65
SG_06	10.5	1.10	SL_09	28.7	7.88
SG_07	13.1	8.30	SL_10	39.0	5.46
SG_08	10.4	2.10	SL_11	34.8	7.80
SG_09	9.60	2.40	SL_12	31.7	2.60
SG_10	10.6	0.80	SL_13	36.0	9.20
SG_11A	9.60	1.20	SL_14	44.0	7.00
SG_11B	8.10	0.60	SL_15	31.8	7.00
SG_12	2.10	1.30	SL_16	17.7	7.60
SG_13	14.0	1.50	SL_17	31.8	7.50
SG_14	9.80	1.50	SL_18	31.8	7.80
SG_15	14.0	1.30	SL_19	40.1	12.0
SG_16	5.90	0.60	SL_20	16.0	9.40
SL_01	31.6	8.00	SL_21	17.3	3.50
SL_02	31.7	4.10	SL_22	15.0	1.50
SL_03	42.2	4.80	SL_23	16.8	2.50

Table 2. Results of groundwater physical/chemical tests from the laboratory.

No	Parameter	SL-02	SL-09	SL-20	SL-16	SL-23	MA-01	SG-01	SG-07	SG-10	SG-12
1	Ca^{2+}	155.2	79.2	115.2	54.4	48	136	46.4	65.6	44.4	24
2	Na^{+}	19	42	14	36	33	17	44	47	89	44
3	K^{+}	1	18	1	10	6	2	14	12	33	16
4	Mg^{2+}	22.36	22.36	23.33	23.33	25.27	15.55	32.08	40.34	31.1	27.22
5	Cl^{-}	23.8	43.4	17.9	21.3	18.9	13.4	5.5	22.8	54.1	32.3
6	HCO_3^{-}	549.3	319.4	408.8	306.6	319.4	479	357.7	427.9	447.1	191.6
7	SO_4^{2-}	14	29	7	25	39	13	17	27	43	38
8	Fe^{2+}	<0.0168	0.0248	<0.0168	0.0379	0.0639	0.035	0.1199	0.0282	0.0622	0.035
9	Mn^{2+}	<0.0066	0.011	<0.0078	<0.0066	0.5894	0.0078	0.0635	0.0651	1.2971	0.011
10	Zn^{2+}	<0.0381	<0.0381	<0.0381	<0.0381	<0.0381	<0.0381	<0.0381	<0.0381	<0.0381	<0.0381
11	PO_4^{2+}	0.122	0.371	0.046	0.989	0.521	0.12	0.991	3.244	1.219	6.034
12	NO_3^{-}	3.87	37.43	35.55	2.55	2.58	6.8	0.4	3.45	2.58	61.53
13	Turbidity	0.5	0.7	0.5	2.9	3.2	0.9	1	1.6	0.8	0.7

Note: All parameter units in mg/L except turbidity (in NTU)

Table 3. Determination of groundwater facies in the study area.

No	Para-meter	SL-02	SL-09	SL-20	SL-16	SL-23	MA-01	SG-01	SG-07	SG-10	SG-12
Cation (epm)		10.1	7.65	8.07	5.99	5.58	8.59	6.69	8.32	8.49	5.26
1	Ca (%)	76.6	51.7	71.2	45.3	42.9	79.0	34.6	39.4	26.1	22.8
2	Na (%)	4.80	14.0	4.44	15.4	15.1	5.06	16.8	14.4	26.8	21.4
3	K (%)	0.43	10.2	0.54	7.26	4.68	1.01	9.10	6.28	16.9	13.2
4	Mg (%)	18.2	24.0	23.8	32.0	37.3	14.9	39.5	39.9	30.1	42.6
Anion (epm)		9.97	7.06	7.3	6.15	6.58	8.50	6.37	8.22	9.75	4.84
5	Cl (%)	6.74	17.3	6.87	9.78	8.10	4.45	2.44	7.83	15.6	18.8
6	HCO_3 (%)	90.3	74.1	91.1	81.9	79.6	92.4	92.0	85.3	75.2	64.8
7	SO_4 (%)	2.92	8.55	1.98	8.47	12.3	3.18	5.55	6.84	9.18	16.3

Note: The yellow shadow represents the major ion that gave the name of the groundwater facies Epm = equivalent per millio

where the shallow groundwater table usually resembles local topographic conditions (Freeze and Cherry, 1979; Listyani et al, 2019).

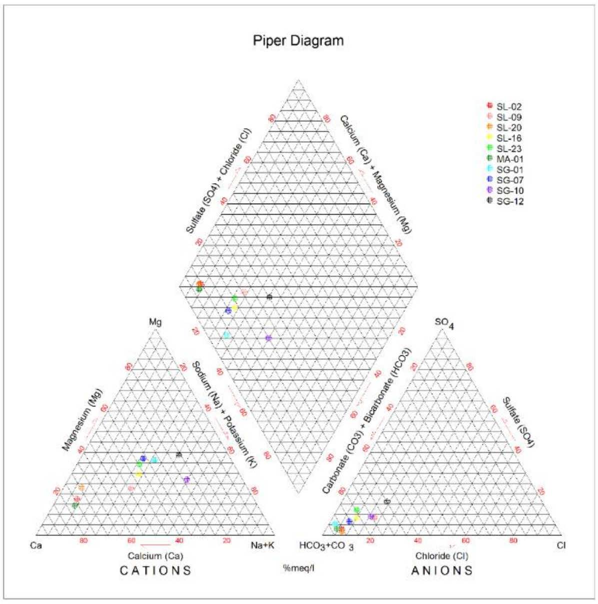

Fig 5. The plot of studied groundwater samples on the Piper diagram.

Groundwater Facies

The results of groundwater chemistry testing in the laboratory are then analyzed to determine the shallow groundwater facies in the study area. The analysis results (Table 3) show that all the groundwater samples studied were of the bicarbonate type, with a variation of the Ca-HCO_3; Ca,Mg-HCO_3; Ca,Na,Mg-HCO_3; and Mg-HCO_3 facies. The Piper diagram shows the groundwater type (Fig. 5). Groundwater is a type of freshwater that has not undergone a mixing process, so this groundwater does not yet have significant salinity.

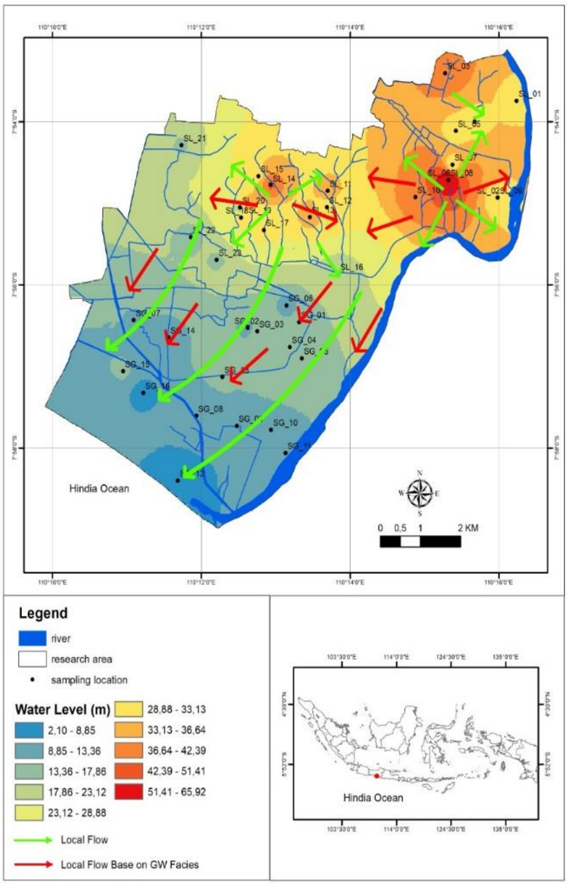

Fig. 6. Groundwater table map of the research area.

The studied groundwater flows in shallow aquifers in the eastern Wates groundwater sub-basin. The general pattern of shallow groundwater flow in this area can be started from a relatively high location in the north and then spread radially in adjacent regions and flows further south to the sea. Thus, shallow groundwater flow patterns in this area can be local to medium. By looking at the general direction of the groundwater flow pattern towards the south or southwest, there is a tendency for the northern area to be a catchment area.

This groundwater flow only reaches areas that are narrow enough. Local flow patterns occur in relatively close areas, likely in the northern and northeastern regions with a radial pattern. Meanwhile, intermediate flow patterns can emerge from north to south rather long distances from the recharge zone to the South Sea. The recharge zone is in the northern part of the study area by looking at the flow pattern.

However, potential of the catchment area can also be viewed from hydrochemical facies of the groundwater. All groundwater samples studied showed bicarbonate facies with the major cation Ca, except for groundwater from SG12, which was of Mg-bicarbonate type.

Bicarbonate facies type groundwater occurs in the early stages of the evolution process. Evolution is also one of the causes of salinity in groundwater (Listyani et al, 2019). Chebotarev (1955, in Freeze and Cherry, 1979) suggests the changes in groundwater facies along the drainage process as follows:

$HCO_3^- \rightarrow HCO_3^- + SO_4^{2-} \rightarrow SO_4^{2-} + HCO_3^- \rightarrow SO_4^{2-} + Cl^- \rightarrow Cl^- + SO_4^{2-} \rightarrow Cl^-$.

Groundwater in Galur/Lendah shows bicarbonate facies, as does groundwater in the central West Progo Hills, with local cation variations (Listyani *et al*, 2021; Listyani and Prabowo, 2022). This type of groundwater occurs due to influence of the season/rainwater (Listyani *et al*, 2021). Groundwater with bicarbonate facies is generally young, recently seeped below the surface. Changes in facies according to groundwater evolution are also influenced by the flow distance. The longer drainage process and or longer drainage distance, the groundwater facies will resemble seawater.

The Ca-bicarbonate groundwater facies indicate that the study area's shallow groundwater in the catchment area. resembles rainwater, meaning that the groundwater under study is groundwater that has not yet traveled far in its subsurface drainage system. Therefore, the entire research area has the potential as a catchment zone.

Based on the shallow groundwater table in the study area, it can be interpreted that the groundwater flow pattern has a local flow pattern in most places and a local radial flow in the northern part. The consequence of this can then be interpreted that in the lowlands (alluvial plains) to the coastal plains, it is also possible for groundwater to infiltrate, which means that local groundwater flows are also developing over short distances (Fig. 6). Thus, the entire research area can function as a recharge zone based on its hydrochemical facies.

Groundwater facies can also help understand the delineation of the recharge-discharge zone. However, understanding the recharge-discharge zone needs to be supported by other aspects, such as land use, land cover, and rock hydrogeological conditions, especially permeability.

Conclusion

The Galur and Lendah areas are dominated by plain morphology, with a slight elevation in the north. In general, groundwater flows from north to south/northwest (intermediate flow system), with some radial anomalies in the northern part of the study area (local flow system). Shallow groundwater in this area can be obtained through several dug wells and one spring.

Groundwater throughout this area develops with bicarbonate facies, with variations in Ca, Na, and Mg cations. Therefore, shallow groundwater in the study area can be categorized as young groundwater, typical for the catchment zone. Thus, the entire study area can function as a catchment zone with a local groundwater flow system based on the groundwater facies.

Acknowledgements

The author would like to thank our institution ITNY, through the 2021 internal research fund, so this paper was successfully written. The authors also would like to thank all those who have assisted in the research and preparation of this paper, especially the field assistants Bella, Vilma, Basith, and Tareq.

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