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Analysis on unconfined groundwater availability during dry and rainy season using dynamic approach in Ngemplak, Sleman, Yogyakarta, Indonesia

Sadewa Purba Sejati[1], Riski Edi Prayoga

Universitas Amikom, Padjajaran Street, North Ring Road, Condongcatur, Depok, Sleman, Special Region of Yogyakarta, 55283, Indonesia
[1]Corresponding author, Email: sadewa@amikom.ac.id

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Abstract

Groundwater is a natural resource with disparity across the different regions throughout time. In comparison to surface water, the groundwater in unconfined aquifers is easily accessible and generally of good quality. Groundwater macro zoning is classified into three, namely water catchment areas, transition areas, and groundwater discharge areas. Based on the macro zoning, previous research has mostly been carried out in catchment areas and discharge areas with a focus on groundwater potential and temporary groundwater conditions. The dynamics of groundwater availability, especially in the water transition zone, has not been studied much, even though the dynamics of groundwater availability in the transition zone plays a vital role for areas in the discharge zone. This study identified the availability of groundwater during rainy and dry seasons in groundwater transition zone. Groundwater availability was assessed through a dynamic discharge approach. The study variables included the hydraulic conductivity of the aquifer, the hydraulic gradient, and the cross-sectional area of the aquifer. Dynamic discharges were analysed during the rainy and dry seasons. The results showed that the availability of groundwater during the rainy season was 4,333,906.1 liters/day and 3,898,850.4 liters/day during the dry season. Based on the calculation of the dynamic discharge (Q), the decrease in the quantity of groundwater is affected by the variable hydraulic gradient (I) and cross-sectional area of the aquifer (A). The numbers of these two variables are smaller during the dry season than the rainy season. The decrease in the quantity of groundwater during the dry season is of course closely related to reduced rainfall which is a source of infiltration and percolation. Reduced rainfall causes the groundwater level to decrease, then technically reduces the groundwater hydraulic gradient (I) and aquifer cross-sectional area variable (A). There was no indication of groundwater scarcity in the study area. This study can serve as a reference related to the application of dynamic discharge theory to assess groundwater availability. Periodic monitoring of groundwater quantity, rainwater harvesting, and intensification of water infiltration wells can be carried out as a recommendation to anticipate problems related to groundwater availability in the study area. This study can serve as a reference related to the application of dynamic discharge theory to assess groundwater availability.

Keywords: unconfined groundwater; dynamic approach

1. Introduction

Groundwater is a natural resource with disparity across the different regions throughout time. Groundwater quantity is significantly impacted by geological features, changes in land use, and climate change (Santosa & Adji, 2014; Sejati & Saputra, 2022). People's dependency on groundwater to fulfilling their needs also affects the groundwater dynamic (Sejati, 2021). This study was carried out in Ngemplak sub-district due to it is located in the groundwater transition zone in the southern area of Merapi Volcano (Hendrayana & Vicente, 2013). Most of the population in Ngemplak sub-district use dug wells to meet their clean water needs, as shown in Figure 1. The transition zone carries a strategic function to link the recharge and discharge zones. The groundwater disruption in the transition zone also results in issues in the water discharge zone. Additionally, the problems in the discharge zone potentially carry negative effects on a number of sectors since the discharge zone is commonly utilized in the field of economy and service. Thus, as a prevention, the study on groundwater availability in the Ngemplak sub-district is essential.

Figure 1. Dug Well in Ngemplak Sub-District, Location: a) Dongkelsari, Umbulmartani Village; b) Jimat, Widodomartani Village; c) Sorasan, Bimomartani Village; d) Morangan, Sindumartani Village; e) Sawan Lor, Wedomartani Village

Studies on groundwater have been carried out using different methodologies. Among those methods, the geographic information system is the most sophisticated device to predict and inventory groundwater availability in different locations. The inventory of groundwater condition is generally carried out through remote sensing and field survey data integration, producing the geospatial thematic information on groundwater potential (Adji & Sejati, 2014; Arulbalaji et al., 2019; Lee et al., 2019; Lee et al., 2020; Manny et al., 2016; Meerkhan et al., 2016; Viossanges et al., 2018; Yeh et al., 2016). However, previous studies primarily only focus only on the environmental variables affecting groundwater existence. Previous research has also focused more on temporary groundwater conditions. The dynamics of groundwater availability which is affected by the change of seasons has not been studied much . In contrast, this study focuses on the estimation of groundwater availability during the rainy and dry seasons.

This study aims to identify groundwater availability of groundwater during the rainy and dry seasons. The quantity of groundwater in unconfined aquifers was calculated using the Darcy Law. Darcy Law states that the groundwater quantity or availability can be estimated using the variables of hydraulic conductivity, hydraulic slope, and aquifer cross-sectional area (Riasasi & Sejati, 2019; Sejati & Adji, 2013; Todd, 2005). The research results were expected to enrich the literature on geohydrology, especially in the implementation of geohydrology in identifying the water availability during the rainy and dry seasons.

2. Method

The groundwater quantity was estimated using the Darcy Law. We used the concept that water flows horizontally through the aquiver cross-section (Todd, 2005). The concept was later developed into a mathematical formula to find the groundwater quantity flowing through the aquiver cross-section per unit of time (Hendrayana & Vicente, 2013; Riasasi & Sejati, 2019; Santosa & Adji, 2014; Sejati & Adji, 2013) . The dynamic debit variable consisted of the hydraulic conductivity, hydraulic gradient, and cross-sectional area of the aquifer. Meanwhile, the groundwater dynamic (Q, unit m^3/day) is the result of multiplication from the free aquiver attributes, consisting of hydraulic conductivity (K), hydraulic gradient (I), and cross-sectional area (A) (Riasasi & Sejati, 2019; Sejati & Adji, 2013; Todd, 2005). The mathematical formula for the dynamic debit is presented in Formula 1.

$$Q = A \times I \times K \qquad (1)$$

In which:
Q = dynamic
I = hydraulic gradient
K = hydraulic conductivity
A = aquifer cross-sectional area

Hydraulic conductivity (K) was identified using the lithology profile data. Meanwhile, the hydraulic gradient (I) and cross-sectional area (A) were determined from the flow nets. Flow nets are the thematic spatial information that visualizes the prediction of groundwater flow. It consists of two primary components, namely the groundwater level contour line and flow direction. The flow nets were determined using the data of groundwater level gathered through the field survey. The groundwater level was measured in the dug well. Meanwhile, the well location was determined using a random sampling method. The measurement was carried out during the rainy and dry seasons to find various groundwater levels. During the rainy season, the measurement was carried out in March 2019, while in the dry season, it was carried out in August 2020. In March 2019, we collected data from 76 dug well, while in August 2020, we garnered data from 70 dug well.

The obtained data on groundwater level were analyzed using the spatial interpolation method to attain the groundwater counter line. The spatial interpolation was completed using the ordinary Kriging method through the Arc GIS Pro software. Further, the obtained groundwater counter line was used as the basis for examining the groundwater flow direction. Besides, we used the principle of groundwater flow lines that intersect perpendicularly with the groundwater contour line (Todd, 2005). The formed flow nets were identified, and the flow net segment with a close to rectangular shape was used to determine the groundwater hydraulic slope or gradient (I) and aquifer cross-sectional area (A). The research procedure is illustrated in Figure 2.

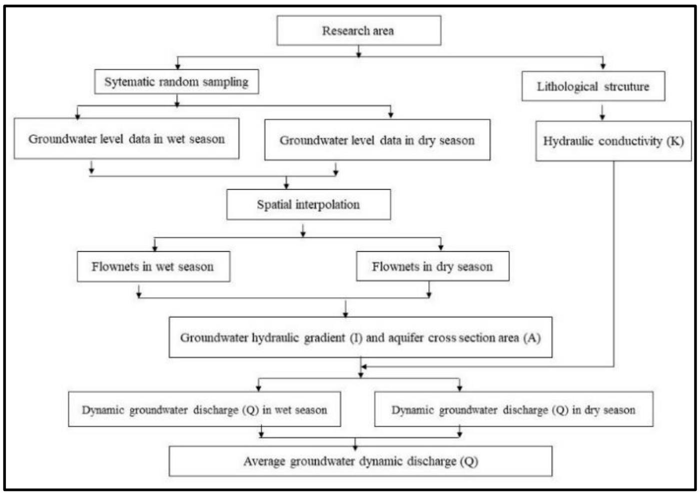

Figure 2. Research Procedures

3. Results and Discussion

This study was carried out in the Ngemplak sub-district, Yogyakarta, Indonesia. Ngemplak sub-district was chosen as the research area because the area is categorized in the groundwater transition zone. Estimating the availability of groundwater in different seasons needs to be done to identify symptoms of groundwater problems in the area. Ngemplak sub-district is located in the 49 S zone, with UTM coordinates of 434000-443000 East and 914200-9152000 North, as shown in Figure 3. The geographic coordinate of our research location was at 7.41'54" south latitude and 110.26'42" east longitude.

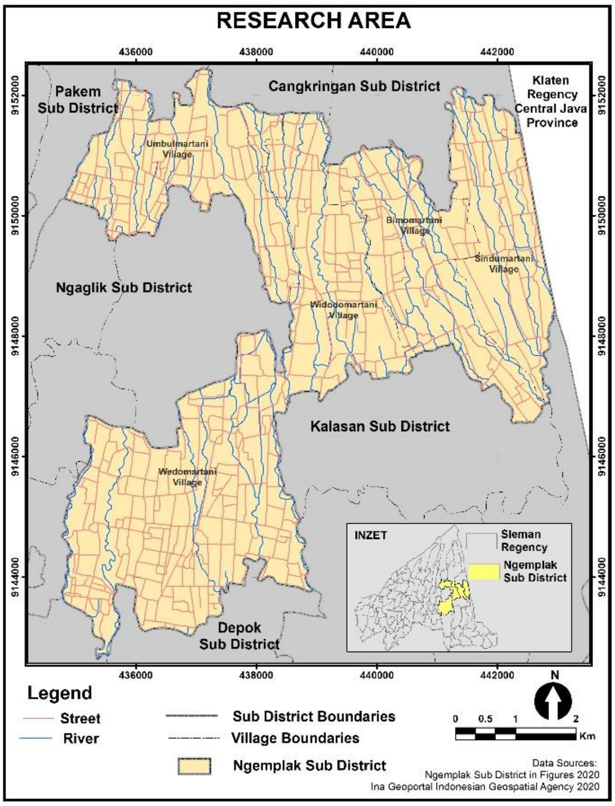

Figure 3. Map of Research Location

The area of our research site was 35,71 km^2. Meanwhile, the administrative border for our research location was the Ngaglik, Depok, Kalasan, Cangkringan, and Pakem sub-districts, along with the Klaten districts, as illustrated in Figure 3. Our research site was also part of the foot of Merapi Volcano. According to the results of Schmidt Fergusson climate classification, our research location had the average C climate index with the highest rainfall of 144 mm (Central Bureau of Statistics of Sleman Regency, 2018; Sejati & Adji, 2013). The data on groundwater level are illustrated in Figures 4 and 5. Meanwhile, the detailed data obtained from the dug well are presented in Table 1 and 2.

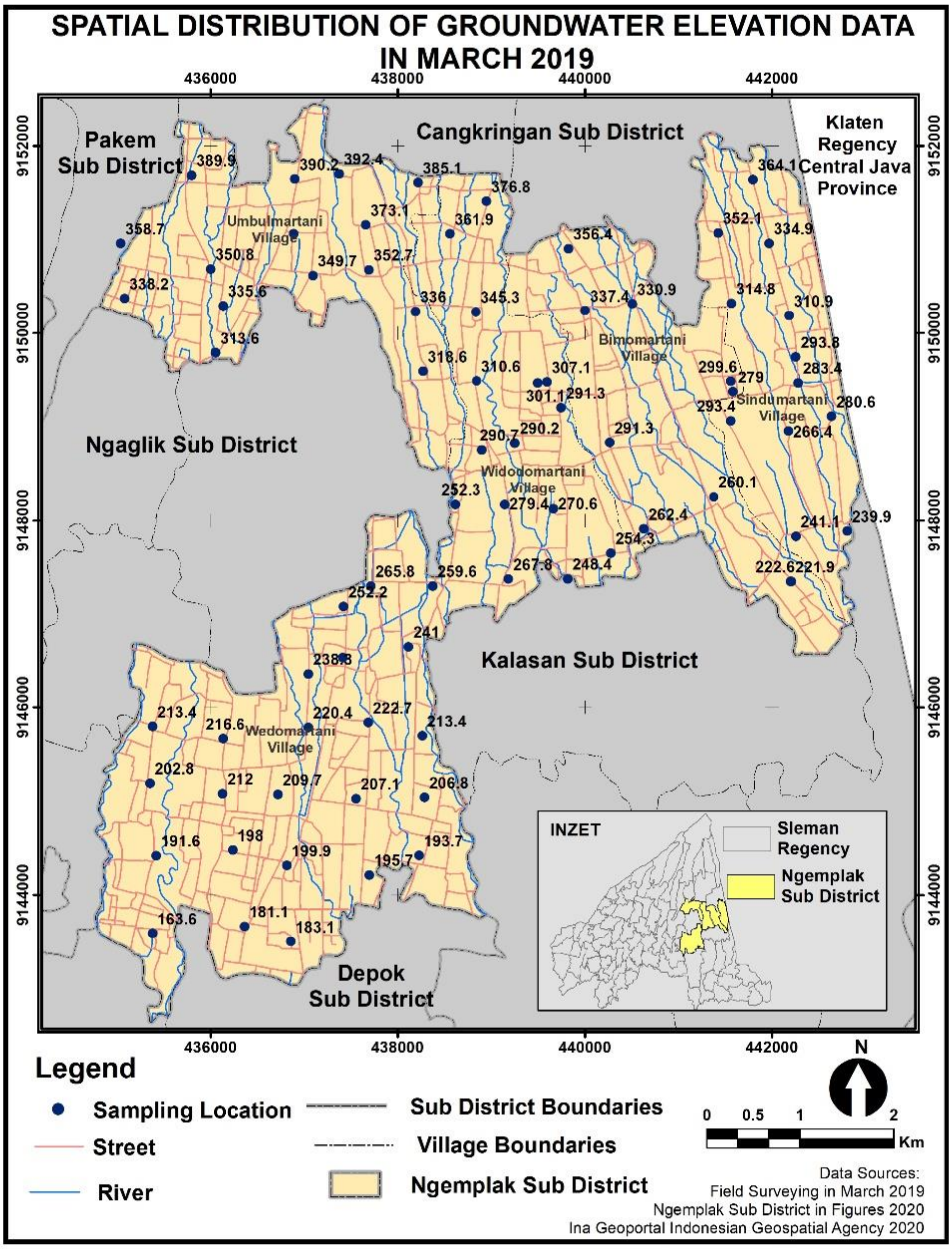

Figure 4. Map of Groundwater Level During the Rainy Season Collected in March 2019

The availability of groundwater in our research location is influenced by the lithology of unconfined aquifer components. Our analysis of the lithology data showed that the unconfined aquifers in the Ngemplak sub-districts consist of unconsolidated materials, such as fine, medium, and coarse sand. These materials are correlated with the activities of Merapi Volcano in the past. The aquifer system in our research location is classified as Merapi Aquifer System, which is dominated by loose material (Hendrayana & Vicente, 2013). Groundwater flows appropriately through the empty spaces or pores formed in those aquifer layers. The results of lithostratigraphic data analysis showed that the average unconfined aquifer hydraulic conductivity in our research site was 17.7 meters/day, with the average aquifer thickness reaching 45.7 meters. The configuration of the unconfined aquifers materials is listed in Table 3.

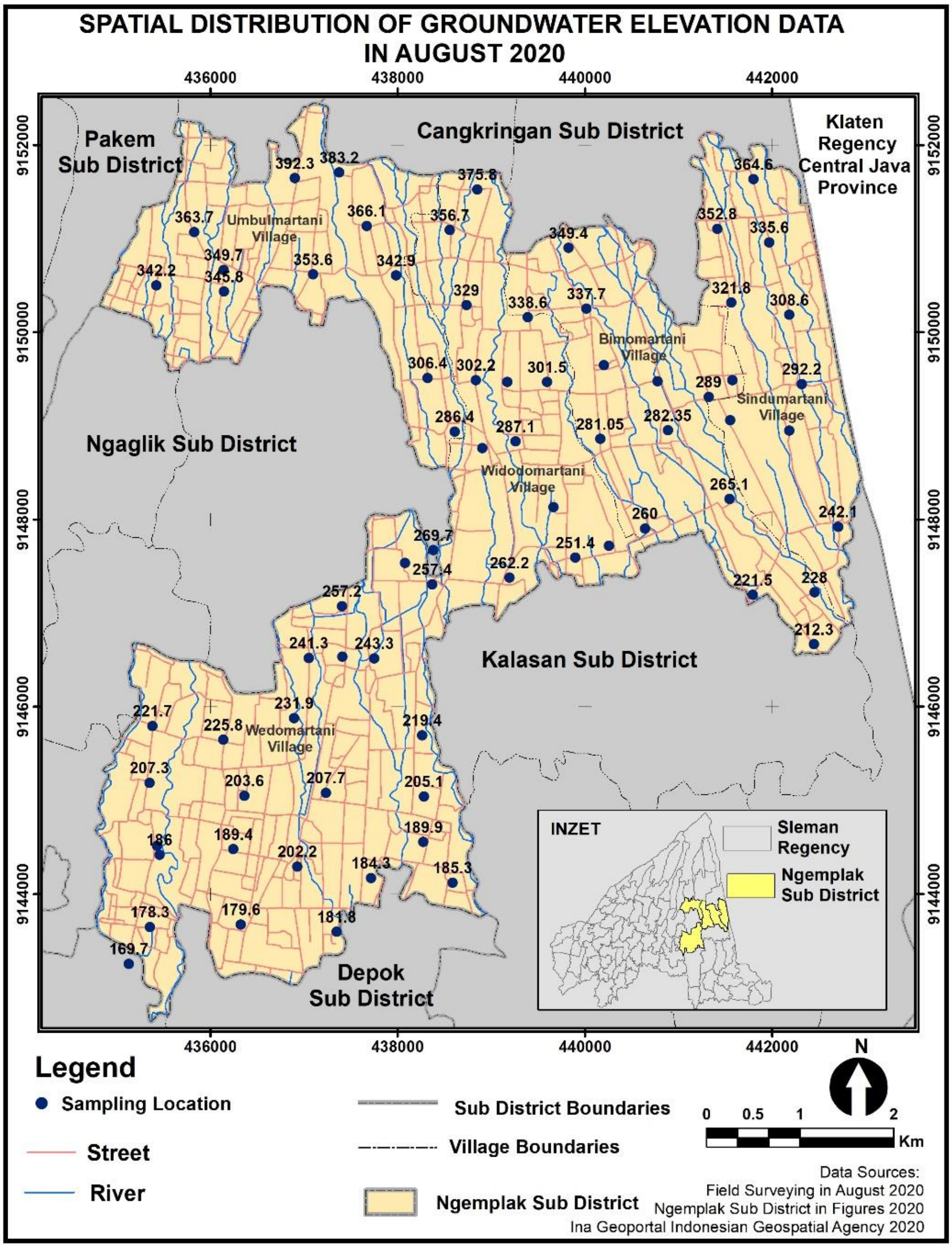

Figure 5. Groundwater Level During Dry Season Obtained in August 2020

Table 1. Data of Dug Well Measurement during the Rainy Season Obtained in March 2019

Location	X	Y	Elevation (msl)	Groundwater depth (m)	Groundwater level (msl)
1	437422	9147081	256	3.22	252.23
2	437414	9146531	248	3.2	244.1
3	437048	9146358	239	0.28	238.3
4	437047	9145787	224	3.1	220.4
5	436136	9145668	223	5.92	216.6
6	435383	9145797	221	6.9	213.4
7	435353	9145191	212	8.4	202.8
8	435421	9144419	203	10.54	191.64
9	435383	9143588	173	8.84	163.6
10	436369	9143663	189	7.22	181.1
11	436239	9144479	206	7.8	198
12	436128	9145080	221	8.39	212
13	436723	9145072	214	3.7	209.65
14	436820	9144315	205	4.49	199.9
15	436862	9143501	187	3.3	183.05
16	437698	9144213	203	6.75	195.65
17	438229	9144421	202	7.83	193.65
18	437714	9147302	269	2.3	265.8
19	438375	9147302	263	2.55	259.6
20	438116	9146648	244	2.4	241
21	438264	9145697	220	5.92	213.4
22	438287	9145041	214	6.25	206.75
23	437555	9145028	211	3.2	207.1
24	437687	9145840	227	3.95	222.7
25	439186	9147375	270	1.58	267.8
26	439146	9148173	281	0.6	279.4
27	438614	9148173	257	4.05	252.25
28	438900	9148754	297	5.56	290.7
29	439255	9148827	297	6.15	290.2
30	439497	9149469	313	10.97	301.1
31	439597	9149477	312	4.16	307.1
32	439748	9149202	297	5.12	291.3
33	439667	9148124	272	0.55	270.6
34	439817	9147378	251	1.83	248.4
35	440278	9147652	255	0.15	254.35
36	440630	9147911	263	0.16	262.4
37	441377	9148252	261	0.42	260.15
38	442206	9147351	224	0.53	222.63
39	442200	9147348	223	0.59	221.87
40	442257	9147832	243	1.86	241.1
41	442802	9147887	242	2.05	239.95
42	435042	9150960	362	2.6	358.7
43	435083	9150373	348	9.27	338.2
44	436134	9150293	341	4.58	335.65
45	436053	9149792	323	8.67	313.65
46	436001	9150688	354	2.5	350.8
47	435799	9151689	393	2.34	389.95
48	436901	9151649	391	0.3	390.2
49	436890	9151063	370	2.2	367.35
50	437097	9150618	353	2.55	349.7
51	437695	9150680	355	1.7	352.7
52	437660	9151160	375	1.25	373.05
53	437375	9151704	398	4.7	392.4

Location	X	Y	Elevation (msl)	Groundwater depth (m)	Groundwater level (msl)
54	438217	9151611	392	6.12	385.1
55	438843	9149490	315	2.35	310.6
56	438836	9150228	347	1.01	345.25
57	438189	9150233	337	0.3	336
58	438269	9149592	321	2.45	318.55
59	438558	9151064	365	2.21	361.95
60	438952	9151412	378	0.74	376.75
61	439827	9150905	358	1.2	356.4
62	440004	9150242	340	1.95	337.35
63	440508	9150314	332	0.97	330.9
64	441562	9149485	305	4.82	299.6
65	441585	9149375	280	0.22	279
66	441562	9149063	296	1.95	293.35
67	442279	9149468	287	2.82	283.35
68	442255	9149746	299	4.42	293.8
69	442183	9150188	311	0.1	310.9
70	441972	9150963	336	0.28	334.94
71	441798	9151642	365	0.02	364.13
72	441427	9151074	354	1.15	352.05
73	441568	9150320	318	2.57	314.75
74	442176	9148954	268	0.85	266.4
75	442635	9149111	284	2.8	280.6
76	440265	9148832	292	0.2	291.3

Table 2. Data of Dug Well Measurement during Dry Season Obtained in August 2020

Location	X	Y	Elevation (msl)	Groundwater Depth (m)	Groundwater Level (msl)
1	441548	9148221	268	2.87	265.1
2	440645	9147905	261	1.2	259.8
3	440018	9150253	343	5.3	337.7
4	439828	9150903	352	2.6	349.4
5	440778	9149479	300	8.3	291.7
6	440206	9149650	309	12.7	296.3
7	440168	9148863	285	3.95	281.1
8	440887	9148955	285	2.65	282.4
9	442455	9147222	232	3.98	228.0
10	442449	9146669	215	2.7	212.3
11	441796	9147197	225	3.55	221.5
12	441555	9149064	274	1.05	273.0
13	441565	9150319	327	5.25	321.8
14	441418	9151108	356	3.25	352.8
15	441803	9151638	366	1.4	364.6
16	441971	9150962	337	1.45	335.6
17	442183	9150188	311	2.4	308.6
18	442317	9149450	296	3.8	292.2
19	442184	9148951	270	1.1	268.9
20	442707	9147925	246	3.9	242.1
21	438320	9149514	317	10.63	306.4
22	438611	9148941	296	9.63	286.4
23	437377	9151709	391	7.8	383.2
24	437671	9151139	372	5.9	366.1
25	437099	9150621	363	9.45	353.6
26	436902	9151648	373	6.8	366.2

Location	X	Y	Elevation (msl)	Groundwater Depth (m)	Groundwater Level (msl)
27	436145	9150437	355	9.25	345.8
28	435424	9150504	351	8.85	342.2
29	435829	9151074	371	7.3	363.7
30	435131	9143254	184	14.25	169.8
31	435355	9143647	189	10.7	178.3
32	435457	9144420	198	12	186.0
33	435350	9145188	218	10.72	207.3
34	435382	9145796	230	8.33	221.7
35	436138	9145648	233	7.2	225.8
36	436894	9145879	235	3.1	231.9
37	437050	9146521	244	2.75	241.3
38	437411	9146535	244	4.3	239.7
39	437406	9147075	263	5.8	257.2
40	437985	9150609	351	8.1	342.9
41	436326	9143675	186	6.42	179.6
42	436244	9144479	197	7.6	189.4
43	436364	9145050	211	7.4	203.6
44	437237	9145080	213	5.3	207.7
45	436931	9144294	207	4.8	202.2
46	437349	9143595	185	3.25	181.8
47	437718	9144171	191	6.7	184.3
48	441578	9149491	299	7.15	291.9
49	438587	9144121	195	9.75	185.3
50	438273	9144555	200	10.15	189.9
51	438283	9145043	214	8.95	205.1
52	438262	9145696	227	7.6	219.4
53	437751	9146518	248	4.67	243.3
54	438078	9147536	270	1.3	268.7
55	438369	9147309	262	4.6	257.4
56	436902	9151648	396	3.75	392.3
57	438904	9148763	295	8.57	286.4
58	438837	9149491	312	9.8	302.2
59	438737	9150291	333	4	329.0
60	438557	9151094	360	3.3	356.7
61	438851	9151528	379	3.2	375.8
62	440260	9147722	259	1.7	257.3
63	439899	9147593	255	3.6	251.4
64	439665	9148133	280	1.5	278.5
65	439259	9148836	295	7.9	287.1
66	439173	9149470	317	17.2	299.8
67	439597	9149470	315	13.5	301.5
68	439391	9150162	345	6.4	338.6
69	438383	9147674	271	1.35	269.7
70	439196	9147380	265	2.8	262.2

Table 3. Configuration of Unconfined Aquifers Materials Based on the Dug Well Data

Dug well in Jelapan Village	Dug well in Kenthingan Village	Dug Well in Bokesan Village
Fine textured sand	Fine textured sand	Fine textured sand
Coarse textured sand	Coarse textured sand	Coarse textured sand
Medium textured sand	Medium textured sand	Volcanic breccia

Source: Central Bureau of Statistics of Sleman Regency (2018)

In addition, the constructed flow nets suggested that the groundwater flows from the north to the south of our research location. This groundwater flow is significantly correlated with the area altitude. Accordingly, the north area of our research location is higher than the south area. The groundwater flow pattern in our research site is similar to the pattern of groundwater flow in the Manglayang Mountain area, Sumedang, West Java, Indonesia. The groundwater flow pattern in this study is classified as the radial flow pattern which is commonly found in volcano or mountain slope areas (Trisdiyansyah et al., 2022). Besides, the comparison of flow nets in the dry and rainy seasons suggested that, generally, the seasons possess no effects on the groundwater flow pattern. The variable of the season only influences the groundwater level. In the rainy seasons, we observed higher groundwater levels than in the dry season. In the rainy season, the groundwater level is closer to the ground level or shallower, while the groundwater gets deeper during the dry season. The higher equipotential of groundwater was observed in the rainy season than in the dry season, as shown in Figures 6 and 7.

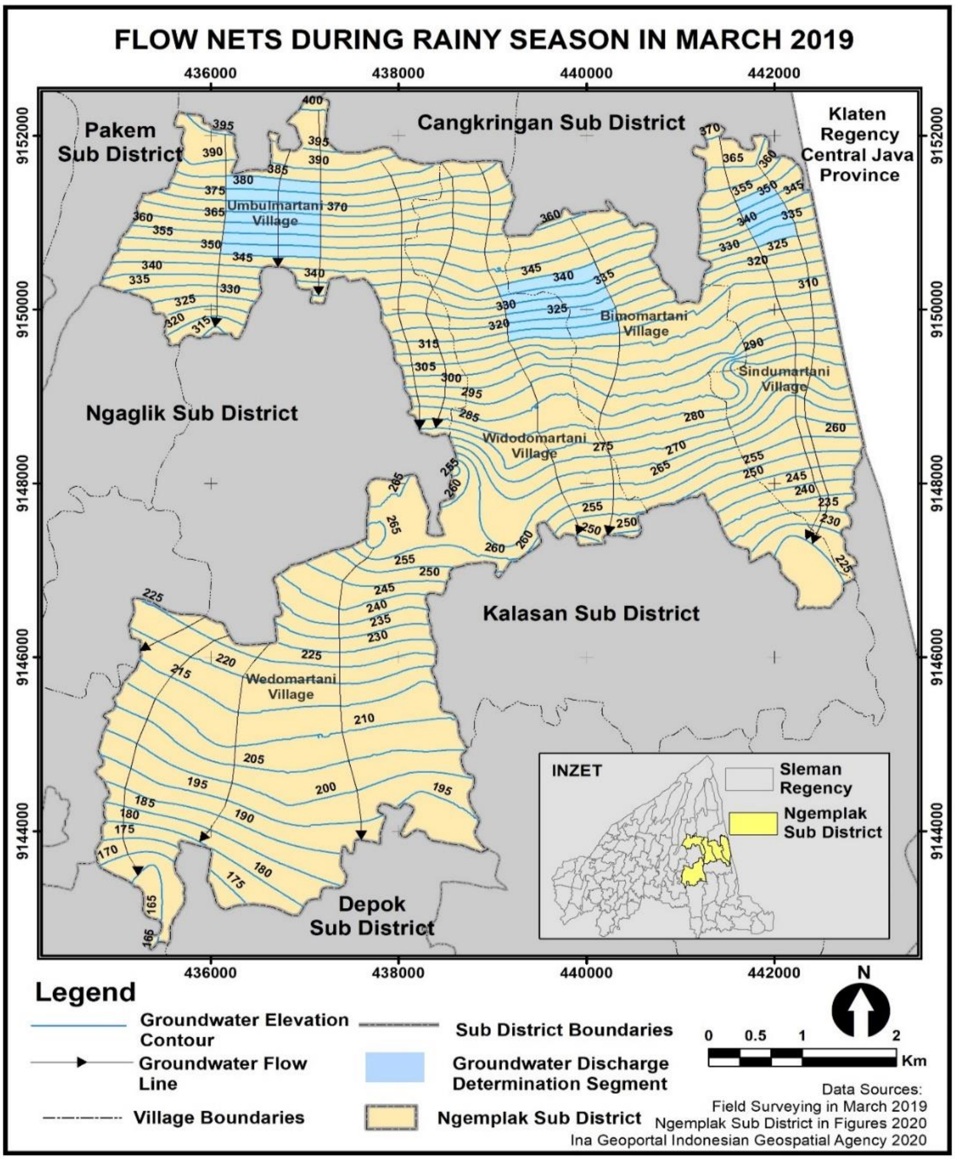

Figure 6. Flow Nets During the Rainy Season Obtained in March 2019

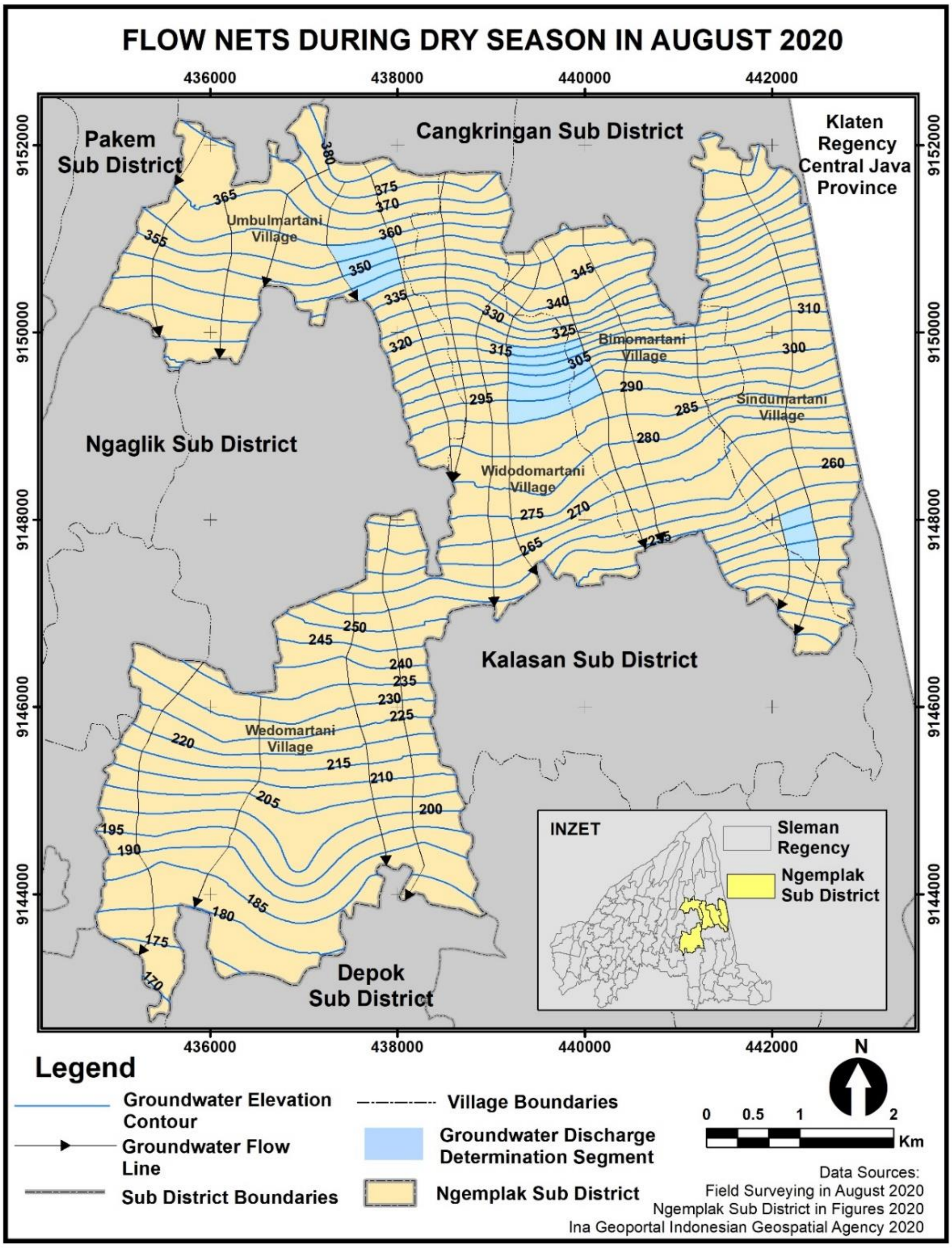

Figure 7. Flow Nets During the Dry Season Obtained in August 2020

The change of season bears no effect on the groundwater flow pattern in our research site, but it affects the hydraulic slope and the aquifer cross-sectional area used in determining the dynamic debit. The average groundwater slope during the rainy and dry seasons was 0.0066 and 0.0082, respectively. Meanwhile, the average aquifer cross-sectional area during the rainy season (wet cross-section) was 38,033.06 m^2, while in the dry season, it was 27,579.95 m^2. This decreasing wet cross-section area is induced by the lower groundwater level during the dry season, decreasing the groundwater contour compared to the contour in the rainy season. Consequently, it lowers the aquifer cross-section that is full of groundwater. Besides, it also results in different groundwater quantities. Our analysis results also showed that the groundwater dynamic is higher during the rainy season than in the dry season. In the rainy season, the groundwater dynamic was 4,333,906.1 Liter/day, while in the dry season, it was 3,898,850.4 Liter/day. The detailed results of dynamic groundwater calculation are shown in Tables 4.

Table 4. Groundwater Dynamic in Rainy and Dry Season

No	Season	Q segment 1 (L/ day)	Q segment 2 (L/ day)	Q segment 3 (L/ day)	Q average (L/day)
1	Rainy	4,548,612.6	5,839,916.2	2,613,189.6	4,333,906.1
2	Dry	4,938,168.1	4,345,886.7	2,412,496.3	3,898,850.4

In general, individuals have easy access to the groundwater at our research site. Meanwhile, the presence of sands with distinctive categories forms thick unconfined aquifers capable of properly flowing the groundwater through the inter-pore spaces. Additionally, the average groundwater depth during the rainy and dry seasons was 3.6 and 7.9 meters, as presented in Tables 1 and 2. Linearly the groundwater quantity during the rainy season was also more significant than in the dry season. The change of season, from the rainy to dry season, induced a decrease in groundwater quantity by 435,055.8 Liter/day. The dynamic of groundwater quantity causes no groundwater source scarcity. During the dry season, the groundwater quantity barely decreases by 2% from the rainy season. This decrease occurs due to the lower rainfall or precipitation during the dry season. Further, the reduced precipitation affects the infiltration and percolation process, decreasing the groundwater quantity (Sejati, 2021).

Although there has been a decrease in quantity, the availability of groundwater in the study area is still good. There were no symptoms of groundwater scarcity during the transition from the rainy season to the dry season (2019-2020). This decrease of groundwater quantity is normally affected by the natural physical situation, such as rainfall and lithology (Irawan et al., 2022; Riasasi & Sejati, 2019). Our research location is categorized as the C climate category or comparatively wet climate based on the Schmidt Fergusson climate classification (Sejati & Adji, 2013). Besides, according to the climate classification using the dry and wet months calculation, rain occurs throughout the year in our research site, with different intensities. Besides, the lithology in our research location was dominated by loose materials that were capable of absorbing the rainwater through the infiltration and percolation mechanism, resulting in reserved groundwater. The reserved groundwater is in the form of accessible groundwater in the unconfined aquifers.

Groundwater also has dynamics affected by natural and non-natural factors. Therefore, maintaining the groundwater quantity for future continuous usage becomes a new challenge. Our research site possesses high rainfall as it is located at the foot of Merapi Volcano, enabling precipitation during the rainy and dry seasons due to the orographic rainfall. Rainwater harvesting can be investigated as an alternative media to minimize the dependency on groundwater. This study can be a reference for the use of geohydrology science in the geography field, especially for studies related to groundwater availability. The popular groundwater dynamic theory, Darcy's Law (Todd, 2005), can also be used in examining spatial groundwater availability.

4. Conclusion

There was a decrease in the quantity of groundwater in Ngemplak sub district during the rainy season in 2019 to the dry season in 2020. The quantity of groundwater decreased by 435,055.8 liters/day. Based on the calculation of the dynamic discharge (Q), the decrease in the quantity of groundwater is affected by the hydraulic gradient of the groundwater (I) and the variable cross-sectional area of the aquifer (A). The numbers of these two variables are smaller during the dry season than the rainy season. The decrease in the quantity of groundwater during the dry season is of course closely related to reduced rainfall which is a source of groundwater filling. Reduced rainfall causes the groundwater level to decrease, then technically reduces the hydraulic gradient (I) and aquifer cross-sectional area variable (A). The difference in the quantity of groundwater during the rainy season and the dry season is normal. Even though its strength has decreased, the availability of groundwater in the study area is still good during the dry season. There was no indication of groundwater scarcity in the study area. Rainwater harvesting and intensification of water absorption can be carried out as a recommendation to anticipate problems related to the availability of groundwater in the study area.

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