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RESEARCH PAPER

Groundwater quality assessment for drinking and clean water in Bagelen and its surrounding area

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Abstract. Bagelen and its surrounding area are parts of the Kulon Progo Hills which have less water potential. However, groundwater can still be obtained from dug wells or several springs in the hills. This study aims to determine the quality of groundwater in the study area as clean water and drinking water. Hydrogeological surveys have been conducted to see the quality of this groundwater. Groundwater samples were taken from six dug wells and two springs. Groundwater can be found in sandstone, limestone and andesite breccias aquifers, through intergrains and cracks porosities. Groundwater usually has Ca-bicarbonate facies. The need for good quality groundwater for drinking and clean water has been investigated based on the WQI value. The WQI value is determined based on several physical parameters, including turbidity and TDS and chemical parameters such as pH, Fe, hardness, Mn, nitrate, Zn, sulfate, chloride and sodium. Based on the Minister of Health Regulation standard No. 492/2010 for drinking water and No. 32/2017 for clean water, the groundwater showed good - excellent value for drinking water and excellent value for clean water.

Keywords: Groundwater; quality; WQI; drinking water; clean water.

1. Introduction

Hydrogeological research has been developed in various regions throughout Indonesia to assist communities in the provision of clean water. Water is a basic need for human survival (Republik Indonesia, 2019). As a basic human right, water cannot be substituted by other commodities (PAAI & GWWG, 2016). Water is a critical and important natural resource for human life and development, and its existence cannot be replaced by other materials (Nugroho, 2007). Therefore, water must be maintained in sufficient quantities and of good quality. As a natural resource, water in an area can be obtained from surface water or ground water. The potential of the two types of water needs to be known to support the daily water needs of the community.

Surface water and groundwater may be used to provide clean water to the community. Rivers, lakes, swamps and the sea may all provide surface water. However, nowadays, surface water is occasionally polluted thus groundwater is a preferable alternative for meeting life's water demands. Groundwater pollution can be defined as the degradation of natural groundwater quality (Todd, 1980). It occurs when harmful substances (pollutants) enter groundwater (Geological Survey Ireland, 2022). Groundwater pollution can be sourced from domestic, industrial wastewater or landfills (Rahmawati et al., 2018). Therefore, the potential for

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groundwater in a given location must be studied in order to provide adequate and high-quality water.

In many regions, groundwater is the main source of water supply, and it is also a primary source for domestic use (Altchenko et al., 2011; Lapworth et al., 2017). In addition to surface water, groundwater may be used for irrigation at a rate of 43% (Siebert et al., 2010). Thus, degradation of water quality may be an issue in recent years (Oki & Akana, 2016), as a result of human activities such as industrial impact, urbanization, and agricultural cultivation (Li, 2016; Li et al., 2017; Foster et al., 2002; Nair et al., 2015; Singh et al., 2020). Li, (2016) and Li et al. (2017) explored groundwater quality and its impacts of human activities in China. Foster et al. (2002) discovered how to safeguard groundwater quality for municipal and environmental water utilities. Nair et al. (2015) investigated hydrochemical assessment and found that springs in the area may be developed as an alternative source for drinking water, by providing pH correction and proper disinfection. Meanwhile, Singh et al. (2020) investigated the anthropogenic effects on arsenic susceptibility.

Many hydrochemical studies have been conducted (Listyani, 2019; Peni & Listyani, 2018; Setiawan et al., 2020), including to determine the quality of groundwater and its potential for pollution. The quality of groundwater must be known to support the daily needs of human life. In many regions, people rely on groundwater, thus protecting natural resources is critical (Geological Survey Ireland, 2022). Groundwater is the most important source of drinking water, especially in areas with limited or polluted surface water supplies. Therefore, protecting groundwater quality is critical in order to maintain public health (Schmoll et al., 2006).

In other locations of the Kulon Progo Hills and its surroundings, groundwater quality has also been tested to determine the pollution (Listyani & Peni, 2020b, 2020a). Putranto & Aryanto (2018) mapped the groundwater level in Purworejo, whereas Soewaeli et al. (2012) studied the groundwater quality in the southern part of Purworejo Regency. Meanwhile, an assessment of groundwater quality based on the WQI was conducted by Gemilang & Bakti (2019) in Aceh and showed good to excellent quality.

One use of the hydrochemical method is to assess the quality of groundwater in relation to its suitability for a particular purpose. The objective of the research is to evaluate groundwater suitability for drinking and clean water purposes. The results of the assessment of the quality of groundwater in the study area are expected to provide important discourse and information for the local community. Given the importance of good quality groundwater, this study was conducted to assess the quality of groundwater in Bagelen and its surroundings. The research area is in the Kulon Progo Hills area where water is scarce. However, groundwater may be obtained through dug wells and spring. The availability of high quality groundwater is critical for the community to fulfill its needs, both as clean water/sanitation and drinking water.

2. Methodology

2.1. Study area

The study area is depicted on Bakosurtanal's (2001) Bagelen topographic map. The research area is mainly located in a non-groundwater basin area, which means it is a water scarce area. Because there is only a small amount of groundwater potential, further studies on groundwater are needed, both in terms of quality and quantity. This area is divided into four sub-districts, namely Kokap, Kaligesing, Girimulyo and Bagelen. The map of the research area is shown in Figure 1.

In this groundwater quality study in and around Bagelen, ten groundwater samples were collected from six dug wells and four springs. The pH, TDS and EC parameters were determined in the field using the Hanna brand pH-meter, TDS-meter and EC-meter. At each location, two liters of water samples were taken, using two polyethylene plastic bottles, one each for cation and anion tests. The sample to be analyzed for cations is given drops of 0.1 N HNO_3 to prevent precipitation.

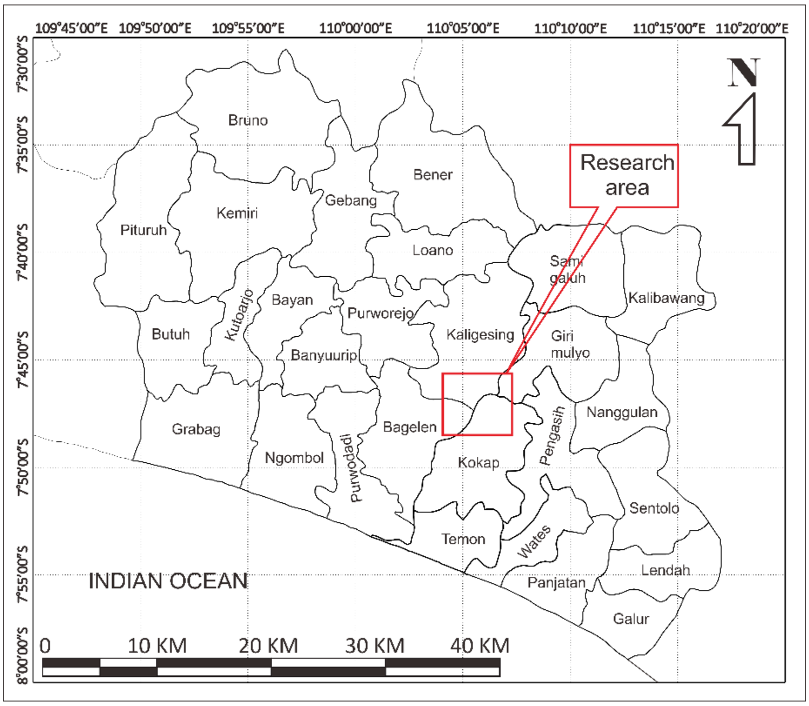

Figure 1. Location of research area.

2.2. Geological condition of research area

The area under study is part of the Bagelen sheet topographic map area, but is included in the Kulon Progo dome. According to the Geological Agency (2011), this research area is included in the "non-groundwater basin or non-potential groundwater basin." Listyani & Budiadi (2018) have also examined some of these basins and their relation to shallow groundwater hydrogeology. Geomorphologically, the research area is included in the dome and hills zone in the central depression, especially the Kulon Progo Dome. These hills are part of the South Serayu Mountains (Van Bemmelen, 1949).

The regional stratigraphy of the Kulon Progo Hills from the oldest to the young is composed of the Nanggulan, Old Andesite, Jonggrangan, Sentolo Formations and Alluvial Deposits (Rahardjo et al., 1977). The Old Andesite Formation that makes up the study area is generally a member of Kaligesing, located in the western part of the spread of the Old Andesite Formation (Van Bemmelen, 1949). The lithology that makes up the research area includes limestone, sandstone, andesite, claystone and andesite breccia. Limestone and sandstone are potential aquifers because of their intergranular porosity, whereas massive andesite can function as aquifers if there are many connected cracks in them. This may be because the andesite in Kulon Progo Hills often has a highly connected network (Kusumayudha, 2010).

Rocks that function as groundwater aquifers in the study area include limestone, sandstones and andesite breccias (Figure 2). Sandstones and limestones can function as good aquifers, although in some areas, these rocks are found in compact and hard conditions, thereby reducing their permeability value, due to less intensive cracks. The porosity of limestone and sandstone is generally moderate to good because it is supported by the intergranular or solution porosity. Andesite breccias generally have poor porosity, poor - good permeability (when the rocks have dense joints or weathered). Andesite breccias can sometimes be potential aquifers, especially if there are many cracks.

Figure 2. Some rock samples that can function as groundwater aquifers in the study area. From left to right: limestone outcrops at Tlogoguwo (Kaligesing), sandstones in Kemanukan (Bagelen) and andesite breccias that produce springs in Durensari (Bagelen)

Spring can be found in locations with varying discharge, from small to medium. This spring appears in aquifer rocks with a predominance of porosity between grains. Crack porosity can be found in limestone and andesite breccias. Some of the dissolving holes in the limestone also add to the potential of these rocks as aquifers.

In addition to appearing on relatively compact and hard rocks, spring can also appear in weathered rocks. In general, spring in weathered rocks has a small discharge. The emergence of springs here is generally controlled by the difference in permeability between compact and weathered rocks.

2.3. Groundwater analysis

Ten groundwater samples were taken in the study area, from 6 dug wells (W) and 4 springs (S). The physical/chemical test was carried out in the laboratory of the Yogyakarta Center for Environmental Health and Environmental Health Engineering (BBTKLPP) which had been accredited by the National Accreditation Committee (KAN). The physical properties of groundwater tested in the laboratory include odor, temperature, taste, turbidity and TDS. Meanwhile, the chemical properties of groundwater being tested were pH and ionic content. Ca^{2+}, Na^{+}, Mg^{2+}, and K^{+} were analyzed using the Ion Chromatography System, while SO_4^{2-} and NO_3^{-} were tested with Spectrophotometer. Meanwhile, Cl^{-} and HCO_3^{-} were determined with argentometry and alkalinity, respectively. The content of major ions Na^{+}, HCO_3^{-}, NO_3^{-} and K^{+} was determined according to standard methods from the American Public Health Association (APHA, 2012). The pH value and ion content such as Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^{-}, Fe^{2+}, Mn^{2+}, Zn^{2+} were determined by the method according to National Standardization Agency of Indonesia (2004/2009).

Analysis of groundwater quality is assisted by statistical analysis of correlation matrix between ions. In addition, the type of groundwater was determined based on Piper's diagram analysis (Piper, 1944).

Furthermore, the analysis of groundwater quality is determined based on the value of the water quality index (WQI). This value is analyzed to see the suitability of the groundwater for drinking water and clean water which is used as sanitation. The standard referred to for the designation of drinking water is the Minister of Health Regulation Number 492/2010 (Minister of Health of the Republic of Indonesia, 2010). Meanwhile, clean water standards refer to the Minister of Health Regulation Number 32/2017 (Minister of Health of the Republic of Indonesia, 2017). According to these standards, several parameters used to determine the WQI of drinking water and clean water are turbidity, TDS, pH, Fe^{2+}, hardness, Mn^{2+}, NO_3^{-}, Zn^{2+}. In addition, for drinking water, WQI also added parameters Cl^{-} and Na^{+}.

The WQI calculation refers to the WQI value formula that has been used by previous researchers (Bowen, 1986; Kawo & Karuppannan, 2018; RamyaPriya & Elango, 2018). The WQI value is determined based on weight (wi) for each groundwater, relative weight (Wi) and quality rating scale (qi). The wi value is determined by referring to (Kawo & Karuppannan, 2018). The value of Wi is determined by the following formula.

$$Wi = wi / (\sum wi) \quad (1)$$

The value of qi is calculated based on the concentration of groundwater (ci) and standard value of groundwater (si) which refers to the standard of the Minister of Health Regulation (Permenkes) 492/2010 (Minister of Health of the Republic of Indonesia, 2010) for drinking water and Permenkes 32/2017 for clean water.

$$qi = ci / si \times 100 \quad (2)$$

The WQI value is the sum of SI, where SI is calculated based on the WI and qi values as presented in the following formula.

$$SI = Wi \times qi \quad (3)$$

$$WQI = \sum SI \quad (4)$$

Furthermore, the water class is determined based on the classification of Sahu & Sikdar (2008)

3. Result and discussion

3.1. Hydrochemistry of groundwater

Ten groundwater samples taken directly from spring and shallow wells were then tested for their physical and chemical properties in the laboratory. The parameters tested included turbidity, TDS, pH and ion content (Table 1). The table shows that the groundwater looks clear to cloudy, relatively acidic, with a low TDS (fresh) to quite high (brackish). The high standard deviation is indicated by the values of TDS, Mg^{2+}, and SO_4^{2-} due to anomalies in the shallow well groundwater sample in Piji (W4). The other samples generally showed acceptable groundwater quality. The results of the field survey showed that in general the groundwater from dug wells and springs is odorless, tasteless, colorless/clear, while there are some areas with low groundwater quality.

Table 1. Descriptive statistics and standard quality for drinking water and clean water according to the Minister of Health Regulation (Permenkes)

Parameter	Minimum	Maximum	Average	Standard Deviation	Permenkes 492/2010	Permenkes 32/2017
Turbidity (NTU)	1	22	6.1	7.80	5	25
TDS (mg/L)	90	1,659	286.1	484.44	500	1000
pH	5.6	6.5	6.22	0.27	6.5-8.5	6.5-8.5
Fe^{2+} (mg/L)	0.02	0.42	0.08	0.12	0.3	1
Hr	56.20	827.16	232.83	221.54	500	500
Mn^{2+} (mg/L)	10	38	23.4	11.24	0.4	0.5
NO_3^- (mg/L)	0.45	5.59	1.984	1.70	50	10
Zn^{2+} (mg/L)	0.0083	1.98	0.90	2.21	3	15
SO_4^{2-} (mg/L)	1	1,297	138	407.32	250	400
Cl^- (mg/L)	2.5	24.7	10.35	7.06	250	-
Na^+ (mg/L)	10	38	23.4	11.24	200	-
Ca^{2+} (mg/L)	15.28	223.51	68.54	59.34	-	-
Mg^{2+} (mg/L)	1.95	65.46	14/996	18.70	-	-
HCO_3^- (mg/L)	72.1	306.5	191.7	72.64	-	-

Physically, most of the groundwater is of good quality (according to quality standards). Hydrochemically, groundwater is generally of the bicarbonate type, which means it is suitable for use as clean water or drinking water (Nair et al., 2015).

Laboratory test results in the form of major ion content were used to determine groundwater facies (Table 2). Ca cation is the dominant cation in groundwater, with variations of Na and Mg in several places. Based on the dominant anion, almost all samples showed bicarbonate facies. An anomaly occurred in W4 sample which showed sulfate facies.

Table 2. Main ionic content in groundwater

No.	Parameters (mg / L)	W1	W2	W3	W4	S5	W6	S7	W8	S9	S10
1	Ca^{2+}	74.77	15.28	36.98	223.51	67.94	28.14	62.71	24.12	70.75	81.2
2	Na^-	35	38	30	37	11	26	20	16	10	11
3	K^+	1	3	1	2	1	1	1	1	1	1
4	Mg^{2+}	18.08	4.39	16.12	65.46	2.93	6.35	13.19	1.95	5.86	15.63
5	Cl^-	16.5	6	24.7	12.6	14	12.6	7.6	2.5	3.5	3.5
6	HCO_3^-	258.4	108.2	138.2	186.3	210.3	168.3	210.3	72.1	258.4	306.5
7	SO_4^{2-}	10	3	23	1,297	1	6	21	17	1	1
Hydrochemical Facies		Ca-HCO_3	Ca, Na-HCO_3	Ca, Mg-HCO_3	Ca, Mg-SO_4	a- HCO_3	Ca, Na-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3

3.2. Correlation between Ions in Groundwater

The correlation between ions is useful for analyzing genetic groundwater. The relationship between the groundwater ions studied is presented in Table 3. The table shows that there is a strong correlation (0.60 - 0.799; Sugiyono, 1997) on the Na^+ - K^+, K^+ - Mn^{2+}, Fe^{2+} - NO_3^- and HCO_3^--pH relationships. The very strong correlation (≥ 0.80) is shown by the relationship between Ca^{2+} - Mg^{2+}, Ca^{2+} - SO_4^{2-}, Ca^{2+} - TDS, Mg^{2+} - SO_4^{2-}, Mg^{2+} - TDS, Fe^{2+} - Zn^{2+}, Zn^{2+} - NO_3^- and SO_4^- - TDS. This relationship shows that TDS is strongly influenced by the concentration of Ca^{2+}, Mg^{2+} and SO_4^-. This occurs because in general Ca^{2+} is the main ion in all samples, while Mg^{2+} and sulfate are the dominant ions in the W4 well which showed an anomaly in terms of chemical facies and salinity due to its high TDS (Carroll, 1982 in Todd, 1980).

Table 3. Matrix of groundwater parameters correlation in research area.

Parameter	Ca^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Fe^{2+} (mg/L)	Mn^{2+} (mg/L)	Zn^{2+} (mg/L)	NO_3^- (mg/L)	HCO_3^- (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	pH	TDS (mg/L)
Ca^{2+} (mg/L)	1												
Na^+ (mg/L)	0,21	1											
K^+ (mg/L)	0,13	**0,63**	1										
Mg^{2+} (mg/L)	**0,93**	0,49	0,26	1									
Fe^{2+} (mg/L)	-0,16	-0,03	-0,06	-0,13	1								
Mn^{2+} (mg/L)	-0,31	0,39	**0,75**	-0,20	0,49	1							
Zn^{2+} (mg/L)	-0,04	-0,21	-0,20	-0,10	**0,93**	0,32	1						
NO_3^- (mg/L)	0,14	0,11	-0,04	0,39	**0,66**	0,17	**0,82**	1					
HCO_3^- (mg/L)	0,35	-0,36	-0,39	0,14	-0,04	-0,33	0,11	0,17	1				
SO_4^{2-} (mg/L)	**0,92**	0,43	0,36	**0,95**	-0,17	-0,16	-0,13	0,34	-0,03	1			
Cl^- (mg/L)	0,09	0,47	-0,15	0,25	-0,18	-0,26	-0,08	0,23	-0,07	0,12	1		
pH	0,55	-0,39	-0,21	0,35	-0,06	-0,71	0,17	0,38	**0,66**	0,24	0,08	1	
TDS (mg/L)	**0,93**	0,46	0,34	**0,97**	-0,16	-0,17	-0,13	0,36	-0,01	**0,996**	0,16	0,28	1

A very strong relationship between Ca^{2+} - Mg^{2+} and Fe^{2+} - Zn^{2+} is related to the sedimentary rocks that make up many of the groundwater aquifers, including limestone, sandstones and andesite breccias. These elements can be obtained from dissolving feldspar, pyroxene, clay minerals and carbonate minerals. Meanwhile, a very strong correlation between Mg and sulfate can be caused by the presence of clay minerals or rock fragments (Bowen, 1986; Davis & De Wiest, 1966). The process of dissolving this mineral can be accelerated by weathering of silicate minerals (Appelo & Postma, 1996).

3.3. Types of groundwater

To see the type of water, the Piper diagram (Figure 3) s used to depict each major ion content of groundwater as shown in Table 2in. From Piper's interpretation, it is known that the groundwater studied is generally included in classes 1, 3 and 5. Anomalies occur in W4 samples that are included in classes 1, 4 and 6.

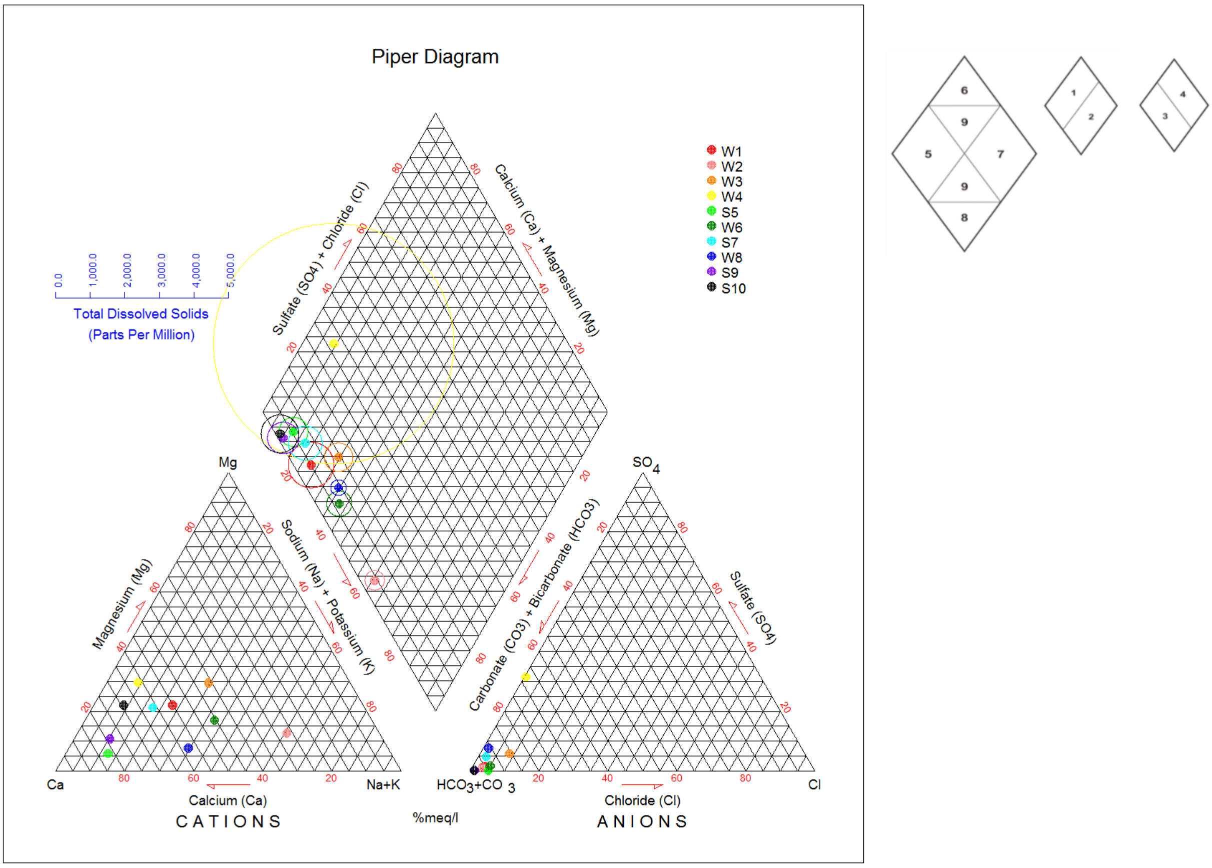

Figure 3. The groundwater sample plot in the Piper's diagram (Piper, 1944)

The predominance of the chemical type of groundwater under study shows classes 1, 3 and 5, which have the following meanings:

1. Class 1: The alkaline content of the soil exceeds the alkaline content
2. Class 3: Weak acid content exceeds strong acid
3. Class 5: Carbonate hardness (secondary alkalinity) of more than 50%, chemical properties Groundwater is dominated by alkaline soils and weak acids.

One sample (W4), in addition to being in class 1, is also included in classes 4 and 6, which contain the following meanings:

1. Class 4: Strong acid content exceeds weak acid
2. Class 6: Non-carbonate hardness (secondary salinity) more than 50%

All of the groundwater samples studied showed a predominance of calcium cations (Ca^{2+}), with some variations in the dominance of Na^+ and Mg^{2+}. The dominant anion in the groundwater which was shown in all samples was bicarbonate except for sample W4 which showed the dominance of sulfate ions. The chemical types of groundwater generally developed as Ca - HCO_3, Ca,Mg - HCO_3 and Ca,Na - HCO_3. W4 sample was assigned an anomaly with the chemical type groundwater Ca, Mg-sulfate.

The groundwater chemical data plot in the Piper trilinier diagram shows that the groundwater studied was fresh water, except for sample number W4 which was brackish with TDS of 1,659 mg/L. The hydrochemical process that occurs generally is leaching of rocks/minerals. The anomaly in sample number W4 indicates the mixing process, possibly due to the presence of pollutants in the groundwater (Todd, 1980).

3.4. Groundwater and its suitability for drinking water and clean water

The results of the WQI calculation of groundwater samples generally show that the groundwater in the Bagelen area and its surroundings is good water in its designation as drinking water and excellent water as clean water (Table 4). The WQI value for drinking water was 58.53, whereas for clean water the WQI was 38.12. This value is calculated from the average concentration of all the samples studied.

Table 4. Calculation of WQI groundwater studied as drinking and clean water

Parameter	Average	Weight		Relative Weight		Drinking Water[4]			Clean Water[5]		
		(wi)[1.4.5] Drinking water	(wi)[1.4.5] Clean water	(Wi) Drinking water	(Wi) Clean water	si	qi	SI	si	qi	SI
Turbidity (NTU)	6.10	5	5	0.17	0.19	5	122.00	20.33	25	24.40	4.69
TDS (mg/L)	286.10	5	5	0.17	0.19	500	57.22	9.54	1,000	28.61	5.50
pH	6.22	4	4	0.13	0.15	6.5 - 8.5	95.69	12.76	6.5 - 8.5	95.69	14.72
Fe (mg/L)	0.08	2	2	0.07	0.08	0.3	26.08	1.74	1	7.82	0.60
Hr (mg/L)	232.83	2	2	0.07	0.08	500	46.57	3.10	500	46.57	3.58
Mn (mg/L)	0.03	2	2	0.07	0.08	0.4	8.62	0.57	0.5	6.90	0.53
NO_3 (mg/l)	1.98	5	5	0.17	0.19	50	3.97	0.66	10	19.84	3.82
Zn (mg/l)	0.90	3	3	0.10	0.12	3	29.97	3.00	15	5.99	0.69
Sulfat (mg/L)	138.00	3	3	0.10	0.12	250	55.20	5.52	400	34.50	3.98
Cl (mg/L)	10.35	1	-	0.03		250	4.14	0.14			
Na (mg/L)	23.40	3	-	0.10		200	11.70	1.17			
	Σ	30	26	1	1			58.53			38.12
WQI[2]							58.53			38.12	
Type of water[3]							Good water			Excellent water	

[1]Kawo & Karuppannan (2018)
[2]Brown et al. (1972) in Kawo & Karuppannan (2018)
[3]Sahu & Sikdar (2008)
[4]Permenkes 492/2010 (Minister of Health of the Republic of Indonesia, 2010)
[5]Permenkes 32/2017 (Minister of Health of the Republic of Indonesia, 2017)

Meanwhile, when the WQI value for each sample was calculated, anomalies appeared in the groundwater taken from shallow wells W4 in Piji, Bagelen. The determination of WQI as drinking water showed the excellent groundwater type at six locations (Table 5), and three locations with the good water type, with one location being the poor water type. Meanwhile, as clean water, all samples showed excellent water type, except well W4 which was poor water type. W4, a well with anomaly of groundwater quality, is suspected to have contaminated by human activities, possibly from household or agricultural waste (Geological Survey Ireland, 2022).

Table 5. Calculation of the WQI value at each groundwater sampling location

Sample	Location	Drinking water		Clean water	
		WQI	Water type	WQI	Water type
W1	Hargomulyo, Kokap	32.63	Excellent water	30.11	Excellent water
W2	Sokoagung, Bagelen	82.93	Good water	35.24	Excellent water
W3	Tlogokotes, Bagelen	26.56	Excellent water	24.29	Excellent water
W4	Piji, Bagelen	145.10	Poor water	106.67	Poor water
S5	Donorejo, Kaligesing	31.88	Excellent water	29.24	Excellent water
W6	Hargorejo, Kokap	94.81	Good water	37.17	Excellent water
S7	Durensari, Bagelen	72.09	Good water	45.55	Excellent water
W8	Durensari, Bagelen	49.79	Excellent water	26.35	Excellent water
S9	Jatimulyo, Girimulyo	23.86	Excellent water	22.39	Excellent water
S10	Tlogoguwo, Kaligesing	25.69	Excellent water	24.17	Excellent water

The analysis of the ten samples above shows that in general the groundwater in the study area is of good to excellent quality, both from dug wells and springs. A low WQI value indicates a type of good quality water (Sahu & Sikdar, 2008), which is indicated by groundwater from both types of water sources. This suggests that groundwater in the studied area is generally still far from being polluted. Anthropogenic effects that sometimes occur in tropical springs (Singh et al., 2020) have not been seen in Bagelen springs.

4. Conclusion

This hydrogeological survey was conducted in the Bagelen area and its surroundings, by taking ten groundwater samples from shallow wells and springs. The results of the field observations indicated that in general the groundwater studied was of good quality, although some were slightly cloudy or brackish. Groundwater pH values tended to be slightly acidic. The groundwater was dominated by Ca-bicarbonate facies, with a chemical type of groundwater that had a carbonate hardness (secondary alkalinity) of more than 50% and the chemical properties of the groundwater were dominated by alkaline soil and weak acids. The WQI value for groundwater in general was good - excellent water for drinking water, with an average WQI of 58.53 and excellent water for clean water, with an average WQI of 38.12. An anomaly was only found at one location, the W4 well in the Piji area of Bagelen.

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