

Research Article

## Water Quality Index Analysis for Water Drinking and Irrigation in the Sumowono Groundwater Basin

Thomas Triadi Putranto<sup>1\*</sup>, Novie Susanto<sup>2</sup>, Dina Rahayuning Pangestuti<sup>3</sup>, Aji Bagas Putro<sup>1</sup>

<sup>1</sup> Geological Engineering Department, Faculty of Engineering, Universitas Diponegoro, Jl. Prof. Soedarto, SH, Kampus Undip Tembalang, Semarang, Indonesia 50275

<sup>2</sup> Industrial Engineering Department, Fakultas Teknik, Universitas Diponegoro, Jl. Prof. Soedarto, SH, Kampus Undip Tembalang, Semarang, Indonesia 50275

<sup>3</sup> Public Health Nutrition and MCH Division, Faculty of Public Health, Universitas Diponegoro, Jl. Prof. Soedarto, SH, Kampus Undip Tembalang, Semarang, Indonesia 50275

\*Correspondence author, e-mail: [putranto@ft.undip.ac.id](mailto:putranto@ft.undip.ac.id)



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### Abstract

The Sumowono Groundwater Basin is a cross-district basin located in Central Java Province, between Temanggung Regency, Kendal Regency, and Semarang Regency. The people in this area obtain fresh water from either dug wells or springs. The purpose of this research is to determine the feasibility of groundwater for drinking water and irrigation purposes. The method used was hydrogeological mapping and physical and chemical analysis of 10 groundwater samples. The samples were subjected to empirical testing of the Groundwater Quality Index to determine the feasibility of drinking water and irrigation using Sodium Adsorption Ratio (SAR) analysis and Wilcox diagram. The results showed that all samples physically have tasteless and odorous properties. For the chemical properties produced in the ten samples, the pH value ranges from about 6.85 - 7.27. The electrical conductivity is between 71.6 - 511  $\mu\text{S}/\text{cm}$ . Total Dissolved Solids values are between 45.82 and 327.04 mg/L, with total hardness values ranging from 10 to 170 mg/L. From the results of the SAR analysis, it is found that the groundwater classes were included in S<sub>1</sub>C<sub>1</sub> and S<sub>1</sub>C<sub>2</sub>, so that groundwater has low alkaline in both sodium and salinity, respectively. Thus, groundwater is considered suitable for consumption and irrigation purposes,

**Keywords:** groundwater; sodium adsorption; Sumowono; water quality index; Wilcox diagram

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### 1. Introduction

A groundwater basin is defined as an area bounded by hydrogeological boundaries. All hydrogeological events such as filling, draining, and releasing groundwater occur, referring to the Regulation of the Minister of Energy and Mineral Resources No. 2 of 2017 concerning groundwater basin. Each groundwater basin has its hydrogeological characteristics, which can hydraulically relate to other groundwater basins or not at all (UU No. 17/2019). One of the basins in Central Java is the Sumowono Groundwater Basin. Groundwater produced and contained in the earth is based on several processes, including deposition due to atmospheric salt, interactions between groundwater and rocks, and

evapotranspiration (Putranto et al., 2018). Analysis of groundwater quality is a critical activity to determine the composition of groundwater that can be used to support the health of human life.

The groundwater quality assessment in this study was based on the Indonesian Minister of Health (Permenkes, 2010). According to Al-hadithi (2012), determining the quality of groundwater suitable for consumption requires an analysis of the Water Quality Index (WQI) by calculating some of the chemical content in groundwater using a weighting approach. This weighting assessment is based on several chemical parameters or the presence of ion content possessed by the entire groundwater sample and its effect on human health (Taloor et al., 2020). WQI analysis is used to classify groundwater resources for various purposes such as agriculture, drinking water, and many other activities (Udeshani et al., 2020). Proper sustainable groundwater management can support future development and ensure water supply availability that occurs in several climates. That effort may provide a sense of security related to food security and energy development. The stability of the availability of drinking water that is beneficial for industrialization development and sustainable urban development can also be provided (Bappenas, 2019).

The Sumowono groundwater basin is a cross-district basin located in Central Java Province, between Temanggung Regency, Kendal Regency, and Semarang Regency. Communities in this area get clean water from using groundwater, either using dug wells or springs. Agriculture, plantations, and settlements dominate land use in this area. Research related to natural resources, especially groundwater, is rarely carried out in this area. Therefore, along with regional developments in the Sumowono area, conducting studies related to groundwater quality is necessary.

The purpose of this study was to determine the groundwater quality index (WQI) in the Sumowono Groundwater Basin for drinking water and irrigation. Some researchers widely use WQI as an elective tool to assess the state of ecosystems, and this method is based on a group of physicochemical and biological characteristics of water samples (Namibia 2007; Simoes et al., 2008; Alobaidy et al., 2010; Kumar et al., 2013). It also assesses the feasibility level for irrigation using Sodium Adsorption Ratio (SAR) analysis and the Wilcox diagram (Wilcox, 1959). SAR is a measurement to express the ratio of Sodium ( $\text{Na}^+$ ) ions to  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in meq/L (Kumar et al., 2013). The SAR value will indicate the level of irrigation water undergoing cation exchange in the soil (Salifu et al., 2017). Meanwhile, the Wilcox diagram is used to represent the danger of sodium alkalinity in irrigation water quality based on the comparison of the percentage value of sodium ( $\text{Na}^+$ ) and the electrical conductivity/EC in  $\mu\text{S}/\text{cm}$ . Groundwater for irrigation with a SAR value of less than 10 meq/L is classified as an excellent/low hazard with a EC value  $<250 \mu\text{S}/\text{cm}$ . Meanwhile, a SAR value between 10 and 18 meq/L is called "Good/medium hazard" with a EC<sub>250-750</sub>  $\mu\text{S}/\text{cm}$  value and "Doubtful/high hazard" if the SAR value is between 18 and 26 meq/L with a EC<sub>750</sub> value.  $>2.250 \mu\text{S}/\text{cm}$ . SAR values greater than 26 meq/L and EC values  $> 2,250 \mu\text{S}/\text{cm}$  are considered unsuitable for agriculture (Salifu et al. 2017).

The research location is located in the Sumowono Groundwater Basin, between Temanggung Regency, Kendal Regency, and Semarang Regency (Figure 1) with an area of 207 km<sup>2</sup>. Sumowono groundwater basin has a topographical height of 206–1,010 meters above sea level (masl). The land use of the Sumowono groundwater basin area is dominated by land use in the form of plantations covering an area of 69.4 km<sup>2</sup>, bushes 45.2 km<sup>2</sup>, dry fields covering an area of 35.4 km<sup>2</sup>, and residential areas 11.2 km<sup>2</sup> (DESDM, 2016). Thus, the need for raw water sources for agricultural and drinking water is significant for evaluation related to the Groundwater Quality Index/WQI.

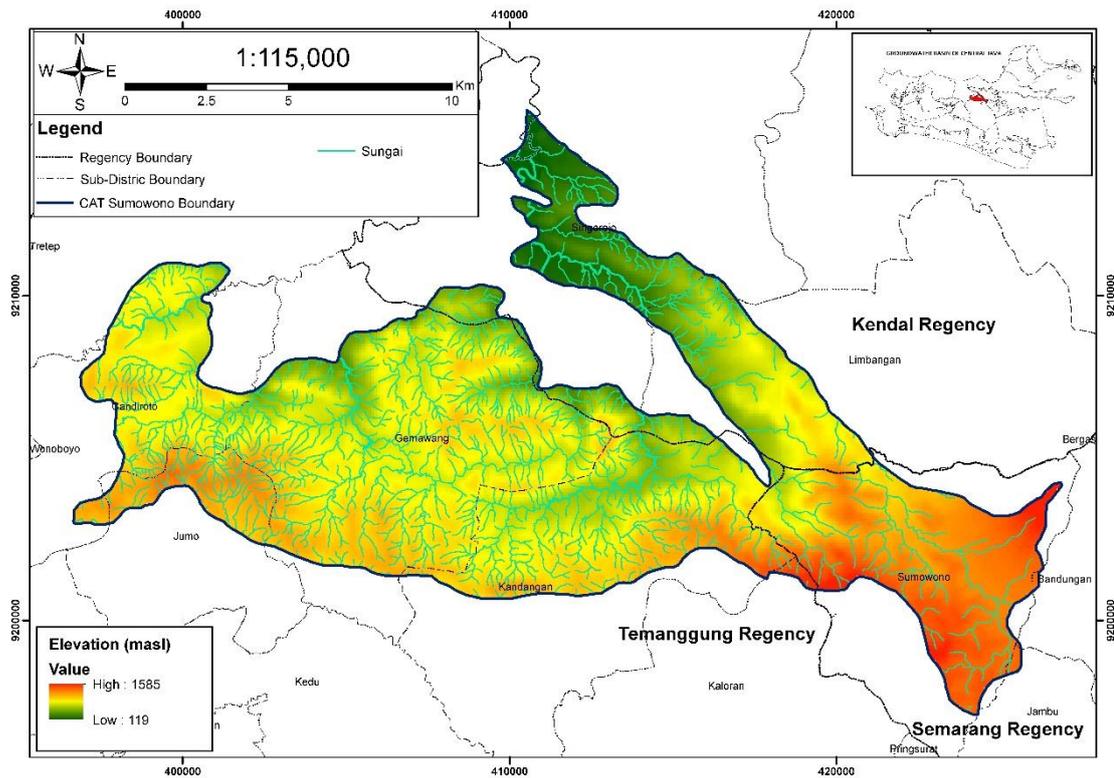


Figure 1. Sumowono groundwater basin location and its elevation

## 2. Methods

The methodology used in this study is an inventory of points of interest obtained from the results of hydrogeological mapping in the field. From the mapping activity, as many as 115 points of interest are obtained. To obtain the pH value and the value of Electrical Conductivity/ EC) in the field using WtW pH 3210 and Cond 3310 tools. From the entire hydrogeological mapping point (Figure 4), 10 samples of groundwater were selected based on variations in geological conditions (Figure 4). Figure 2) and land use, so that 9 samples from shallow wells and 1 spring water sample were obtained for detailed groundwater quality testing. Further testing of water samples to determine the chemical composition in each sample is carried out in the Envilab laboratory. The chemical data tested were total dissolved solids (TDS),  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and hardness/Total Hardness as in Varol (2020); Munagala et al. (2020); Acharya et al. (2018); Suvarna et al. (2020). The chemical parameter values obtained were used to calculate the WQI value. Horton first introduced this WQI method (1965) and Brown et al. (1970). Furthermore, this application has been developed by many other researchers as one of the considerations for groundwater management for drinking water (Debels et al., 2005; Saeedi et al., 2009; Tsegaye et al., 2006, HortonKannel et al., 2007; Sener et al., 2007). al., 2017; Aguilar et al., 2019). The higher the influence in groundwater, the greater the weight it has. The Sumowono groundwater basin area predominantly consists of agricultural areas with natural and chemical fertilization, so the presence of nitrate ( $\text{NO}_3^-$ ) concentrations is assumed to have a substantial impact. On the other hand, total hardness has an insignificant impact so that it is given the slightest weight.

The standard of drinking water quality in the Republic of Indonesia is based on the Regulation of the Minister of Health (Permenkes) No. 492/2010. It is necessary to calculate the Water Quality Index analysis by calculating the weighting of the chemical parameters of the groundwater, as shown in Table 1 above, to determine whether or not drinking water can be consumed. The results of this weighting consider the effect on human health. The determination and weighting will be relative because the content of each analyzed water will produce different hydrochemical concentrations. The WQI analysis

uses the regulations from the Government of Indonesia issued by the Minister of Health in 2010. The  $W_i$  value is obtained by dividing the weight of each parameter by the number of muscles (Equation 1), then calculating the  $q_i$  value, which is obtained from comparing the parameter value ( $C_i$ ) with the standard value. Equivalent ( $S_i$ ) is then multiplied by 100 (Equation 2). In addition, they are adding the values of  $W_i$  and  $q_i$  to perform the Sub Index ( $SI$ ) value of each parameter, as shown in Equation 3. After all  $SI$  values are obtained, the  $WQI$  value can be obtained from the total sum of all  $SI$  values of each parameter. (Equation 4). The results of these values will later be included in the  $WQI$  classification using the Permenkes No. standard. 492/2010, so that the quality of groundwater for drinking water will be known.

**Table 1.** Chemical parameter for determining the  $WQI$

Parameter	Permenkes (2010)	Weight ( $w_i$ )	$W_i$
pH	6.5-8.5	4	0.18
TDS (mg/L)	500	4	0.18
$SO_4^{2-}$ (mg/L)	250	4	0.18
$Cl^-$ (mg/L)	250	3	0.14
$NO_3^-$ (mg/L)	50	5	0.23
Total Hardness (mg/L)	500	2	0.09
Total		22	1.00

The Wilcox diagram (Wilcox, 1955) is used to determine water quality for irrigation purposes. The results of this Wilcox diagram will get the suitability of water for irrigation purposes with the Sodium Hazard condition of the SAR with the EC value contained. If the EC value and sodium value condition are high, then the water is not suitable for irrigation (Brindha and Elango, 2011).

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \dots\dots\dots (1)$$

$$q_i = \frac{C_i}{S_i} \times 100 \dots\dots\dots (2)$$

$$SI = W_i \times q_i \dots\dots\dots (3)$$

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

The method of determining the Wilcox diagram uses the percentage of sodium hazard from the value of Sodium Absorption Ratio/SAR (Richards, 1954) with the value of EC. Calculation of the concentration of each chemical parameter for SAR analysis is presented in meq/L. The EC value obtained can be related to the TDS. The higher the salinity value contained in the water, the higher the number of ions or minerals dissolved in the water. This high ion content indicates that the dissolved salt content is high. If a water source has high salt content, this is physically harmful to plant growth. This condition can occur due to toxins formed due to osmosis at the absorption of water in the soil (Todd, 1980). The magnitude of the SAR value (Richards, 1954) is calculated from equation 5 below:

$$SAR = Na^{(+)} / (\sqrt{(Ca^{2+} + Mg^{2+} / 2)}) \dots\dots\dots (5)$$

### 3. Result and Discussion

#### 3.1 Geological Condition

The lithology that dominates the Sumowono groundwater basin is volcanic rock. If sorted from old to young formation according to the Geological Map Sheet, Magelang-Semarang (Thaden et al., 1996) (Figure 2) consists of andesite intrusion (Tma) and basalt intrusion (Tmb). The Kerek Formation (Tmk) consists of alternating claystone, marl, tuff sandstone, conglomerate, sandstone, volcanic breccia, and limestone. Above the Kerek Formation, the Penyetan Formation (QTp) comprises tuffaceous sandstone, volcanic breccia, tuff, claystone, and lava flows that dominate the Sumowono groundwater basin area. Then, the Kaligetas Formation (Qpkg) with volcanic breccia lithology, tuff, lava flows, tuffaceous sandstone, and claystone. Above it are rocks of Mount Kemalon and Mount Sangku (Qks) in the form of

plagioclase sortie, solid to smooth hollow lava. Jembangan volcanic rock (Qj) in the form of lava flows. Gajahmungkur Volcanic Rock (Qhg) is composed of andesite lava flows. Sindoro Volcanic Rock (Qsu) consists of andesite augite olivine lava. Cleft Volcanic Rock (Qls) is composed of hyperstein augite lava. Alluvium (Qa) deposits are composed of gravel, gravel, sand, and silt.

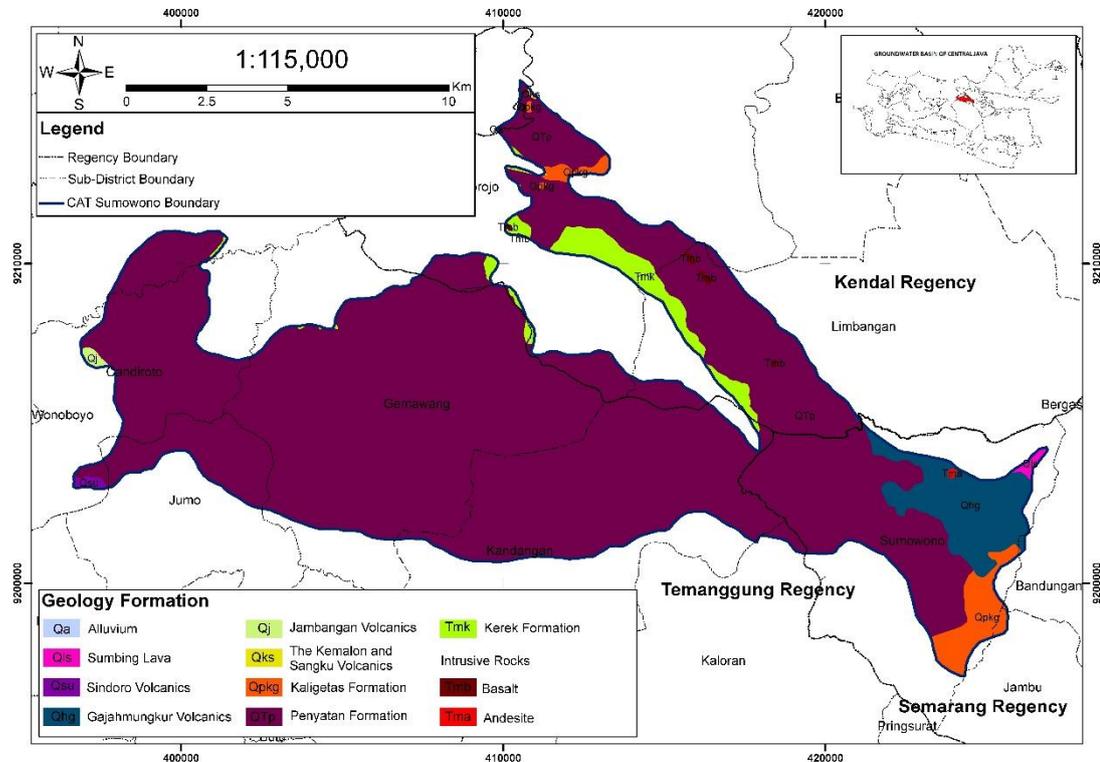
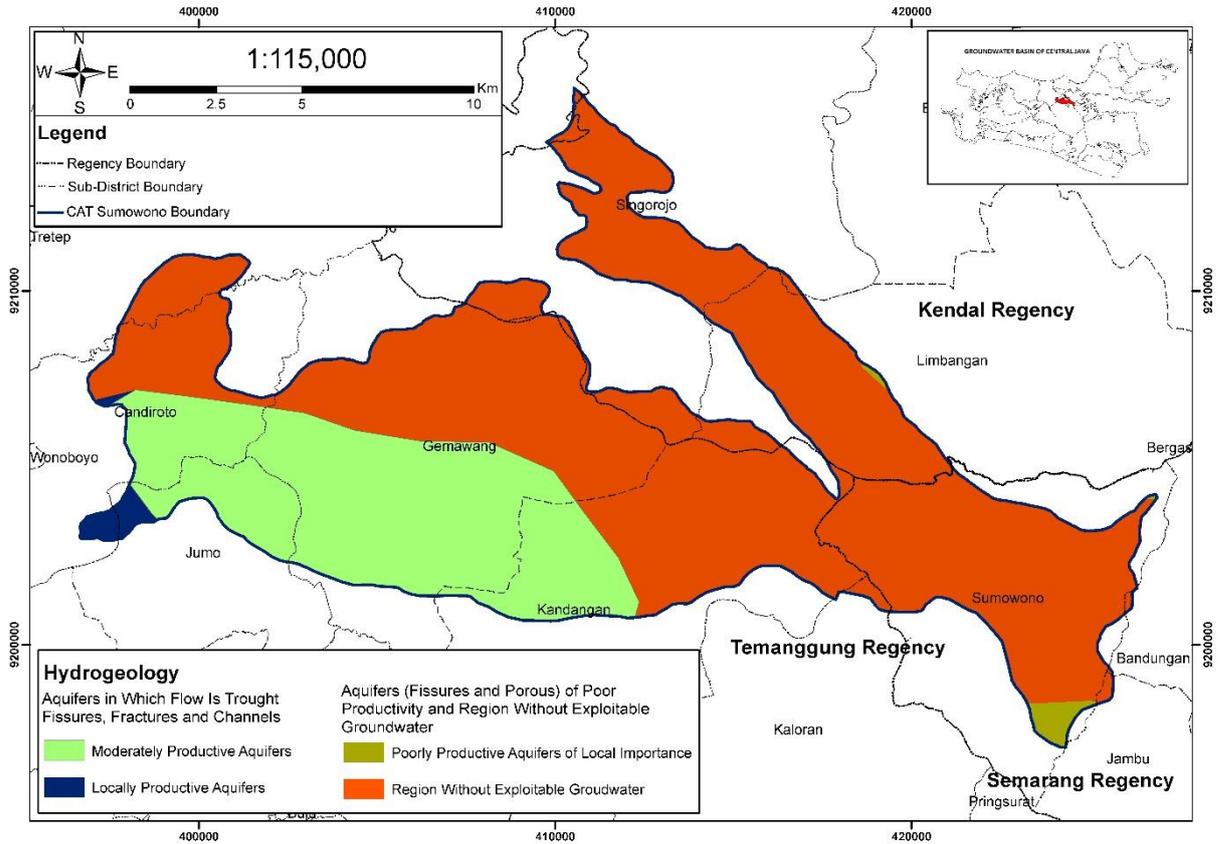


Figure 2. Regional geological map of Sumowono groundwater basin (Thanden, et al., 1996).

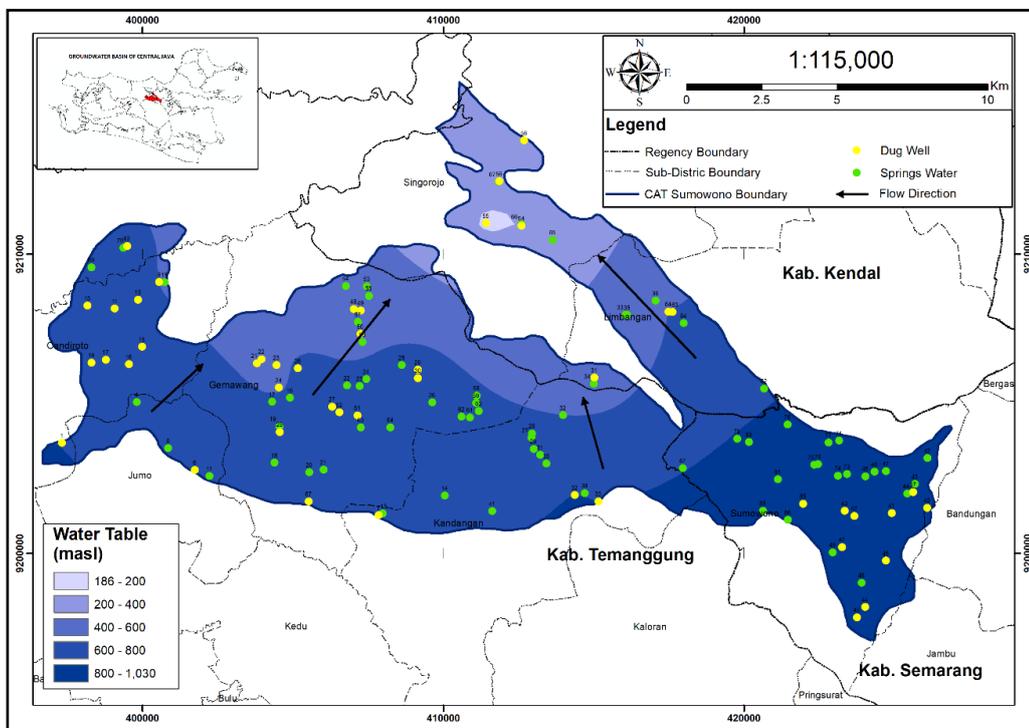
### 3.2 Hidrogeological Condition

Based on the Regional Hydrogeological Map, the Sumowo CAT consists of the Pekalongan Sheet (Effendi et al., 1985) and the Semarang Sheet (Said and Sukrisno, 1988). Sumowono groundwater basin consists of 2 types of groundwater and aquifer productivity, namely aquifers with flow through fissures, fractures, and channels (aquifers with moderate to high productivity), and aquifers or nests with low productivity and rare groundwater, which is composed of two parts, namely aquifers with low productivity. Small local productivity means and areas of groundwater are scarce (Figure 3). Existing aquifers are free aquifers

From the results of the hydrogeological mapping, 46 dug wells and 69 springs were found (Figure 4). The groundwater availability is mainly located in the Penyetan Formation, which has a lithology dominated by tuff sandstones and volcanic breccias. Based on regional hydrogeological maps, the aquifer system develops through fissures, fractures, and channels. Aquifers have moderate to high productivity levels. Most of it is used for domestic household needs, irrigation, and fisheries. The direction of groundwater flow is from the south and southeast to the north of the study area. For the characteristics of this free aquifer, it follows a topographical pattern. Namely, the elevation is in the south and valleys or hillsides in the north as described by Fetter (2001) and Barkah et al. (2015).



**Figure 3.** Regional hydrogeological map of Sumowono groundwater basin (Effendi, 1985; Said and Sukrisno, 1988)



**Figure 4.** Water table map and its direction of Sumowono groundwater basin

### 3.3 Groundwater Geochemical Properties

The results of the analysis of the geochemical parameters of the groundwater studied are presented in total (Table 2). The values of pH, EC, TDS, total hardness in CaCO<sub>3</sub>, Mg, Ca, Na, Cl, NO<sub>3</sub>-N, and SO<sub>4</sub> were analyzed for chemical concentrations for WQI and SAR calculations.

The degree of acidity (pH) value ranged from 6.85 to 7.27 (Figure 5). These results indicate that the degree of acidity contained in the groundwater tends to be neutral. From these results, according to Permenkes No. 492/2010 is suitable for drinking water standards. The lowest pH value was found in SG 10 (6.85), while the highest was in SG-9 (7.27) located in Limbangan District, Kendal Regency (Table 1).

**Table 2.** Geochemical analysis of groundwater samples in Sumowono groundwater basin

No.	Coordinate		Sample Code	EC µS/cm	pH	TDS mg/L	Mg <sup>2+</sup> mg/L	Ca <sup>2+</sup> mg/L	Na <sup>+</sup> mg/L	Cl <sup>-</sup> mg/L	CaCO <sub>3</sub> <sup>-</sup> mg/L	NO <sub>3</sub> -N mg/L	SO <sub>4</sub> <sup>2-</sup> mg/L
	X	Y											
Maximum allowed (492/MENKES/PER/IV/2010)				6.5-8.5	500				200	250	500	50	250
1	398993	9208185	SG-01	111	7.22	71.04	21.6	36.6	6.83	16	14	1.15	11
2	398929	9206408	SG-02	158	7.25	101.12	21.6	61.6	8.64	22	41	4.62	12
3	407292	9201919	SG-03	256	7	163.84	16.6	59.3	9.21	24	72	1.91	27
4	406543	9204732	SG-04	123	7.1	78.72	10.9	63.9	7.01	16	35	1.20	7.3
5	407018	9208160	SG-05	377	6.97	241.28	30.9	82.9	9.89	27	85	1.83	63
6	411626	9201402	MA-06	71.6	6.4	45.824	9.55	35.9	6.82	3	10	1.40	22
7	423854	9198023	SG-07	271	7.04	173.44	17.6	51.5	14.1	9	49	1.58	34
8	424901	9201236	SG-08	340	7.16	217.6	29.7	85.6	10.8	13	103	1.27	22
9	417533	9208116	SG-09	171	7.27	109.44	12.7	53.9	8.24	4	66	0.671	13
10	411339	9210931	SG-010	511	6.85	327.04	18.3	94.5	12.3	8	170	0.595	72

Chemical parameters widely found in drinking water are Calcium (Ca<sup>2+</sup>) and Magnesium(Mg<sup>2+</sup>). Calcium and magnesium in drinking water have many beneficial effects on human health. However, at very high concentrations, they can also have some adverse effects. Calcium, for example, can block the absorption of heavy metals in the body and is thought to cause an increase in bone mass and prevent certain types of cancer (Jaworek, 2014). On the other hand, very high concentrations can affect the absorption of other essential minerals in the body. Magnesium is an essential element in the functioning of the heart and blood vessels. However, high drinking water levels may have a laxative effect, especially in the case of water with a high concentration of magnesium sulfate. The concentration of Mg<sup>2+</sup> in Sumowono groundwater basin ranged from 9.6-30.9 mg/L while Ca<sup>2+</sup> was 35.9-94.5 mg/L. Based on Jaworek (2014), calcium levels in mineral water in Europe range from 47-222 mg/L, while Mg<sup>2+</sup> is lower between 9-70 mg/L. From the results of the chemical analysis of groundwater samples, the concentrations of Ca<sup>2+</sup> and Mg<sup>2+</sup> are included in the range of chemical concentrations of mineral water.

Meanwhile, Sodium (Na<sup>+</sup>) content in groundwater in Wonosobo groundwater basin is 6.8-14.1 mg/L. The value of Na<sup>+</sup> concentration is still allowed as drinking water-based on Permenkes No. 492/2010. In addition, the value of hardness (Total Hardness/CaCO<sub>3</sub>) in Sumowono groundwater basin ranges from 10-170 mg/L. This value is still below the limit according to Permenkes No. 492/2010. Based on the classification of hardness values (Sen, 2015), the Sumowono groundwater basin area is composed of low-high hardness. Judging from the spatial map in Figure 8, the higher the hardness value towards the north, composed of volcanic rocks rich in Ca<sup>2+</sup> minerals (Thanden et al., 1996).

The concentration of Cl<sup>-</sup> values in groundwater samples at Sumowono groundwater basin ranged from 3-27 mg/L. This value is still below the limit for drinking water based on Permenkes No. 492/2010. Groundwater in Sumowono groundwater basin is natural groundwater that comes from rainwater. Some groundwater samples have a chloride concentration of less than 10 mg/L. By leaching chlorides from chemical fertilizers in agricultural soils or wastewater discharged to the soil surface, chloride concentrations in groundwater can increase to 20 or 30 mg/L or more (Environmental Southland, 2020).

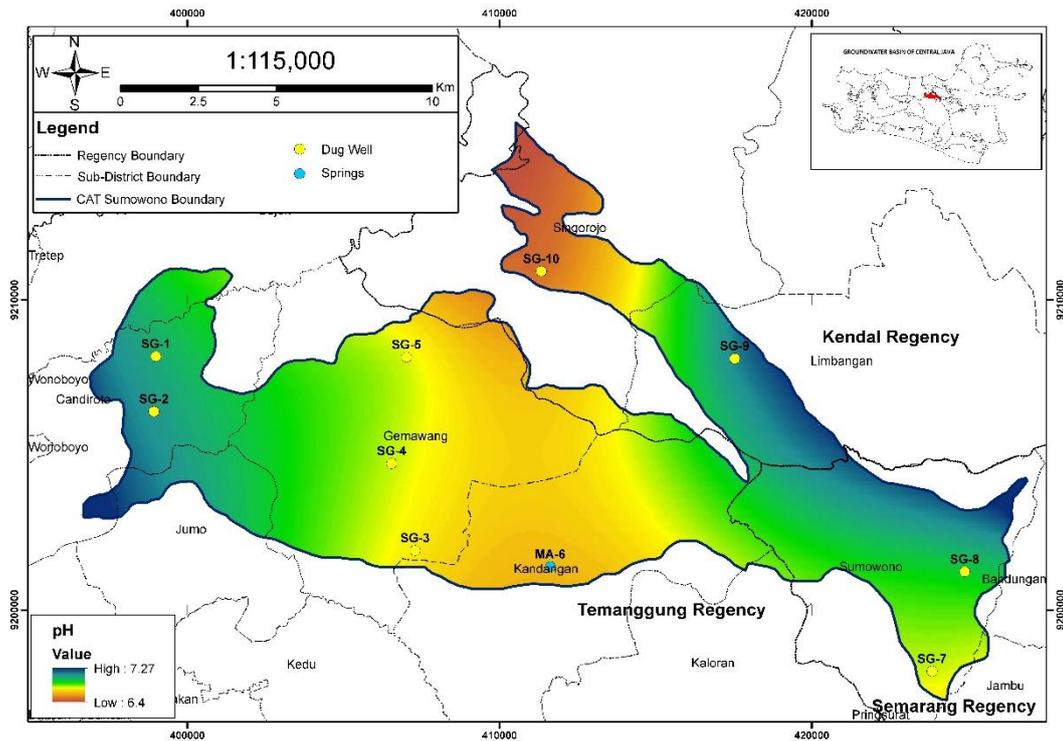


Figure 5. pH map of groundwater samples in Sumowono groundwater basin.

The EC value in the study area has a value ranging from 71.6 – 511  $\mu\text{S}/\text{cm}$ . From the EC value obtained, it can be said that the research area has good-very good groundwater quality (Sen, 2015). Based on the EC map shown in Figure 6, it can be seen that the dominant high EC number (above 500  $\mu\text{S}/\text{cm}$ ) is located on the north side of the study area, SG 10, with claystone lithology in the Kerek Formation (Thanden et al., 1996).

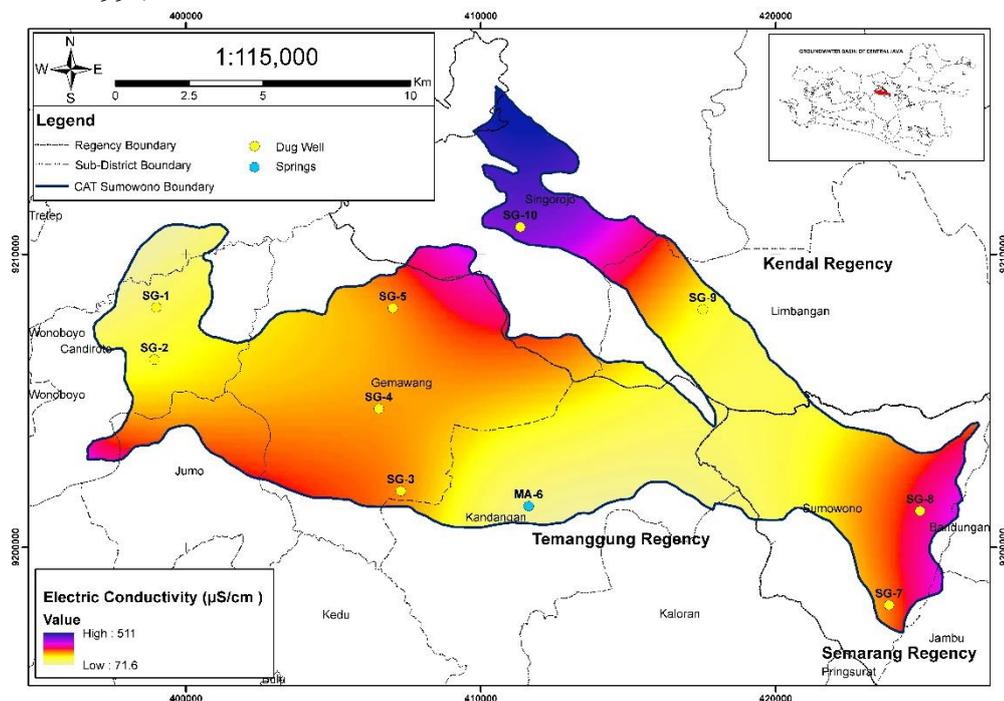


Figure 6. Electrical conductivity map of groundwater samples in Sumowono groundwater basin.

The value of dissolved solids (TDS) in the study area ranged from 45.82 – 327.04 mg/L. Based on the results of the TDS value, the Sumowono groundwater basin area does not exceed the allowable limit (<500 mg/L) for drinking water (Permenkes No. 492/2010). Judging from the TDS contour map (Figure 7), the TDS contour looks more prominent towards the north of the study area. The contact between rocks and groundwater influences the magnitude of the TDS value in groundwater. The rocks in the northern part are sedimentary rocks that are readily soluble in water (Sen, 2015; Appelo and Postma, 2005).

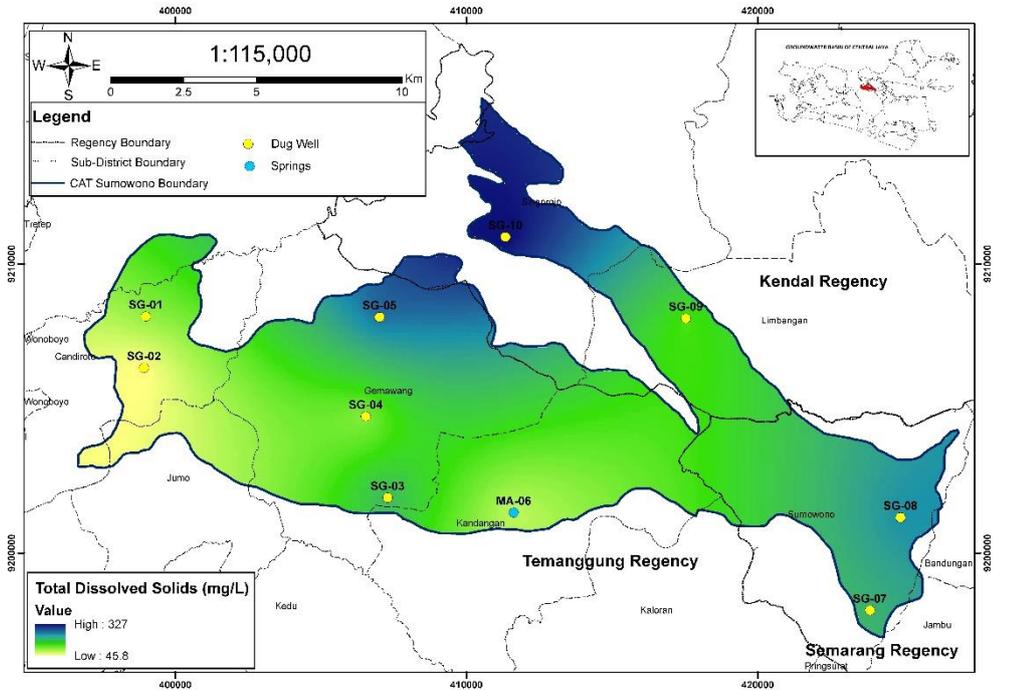


Figure 7. TDS map of groundwater samples in Sumowono groundwater basin.

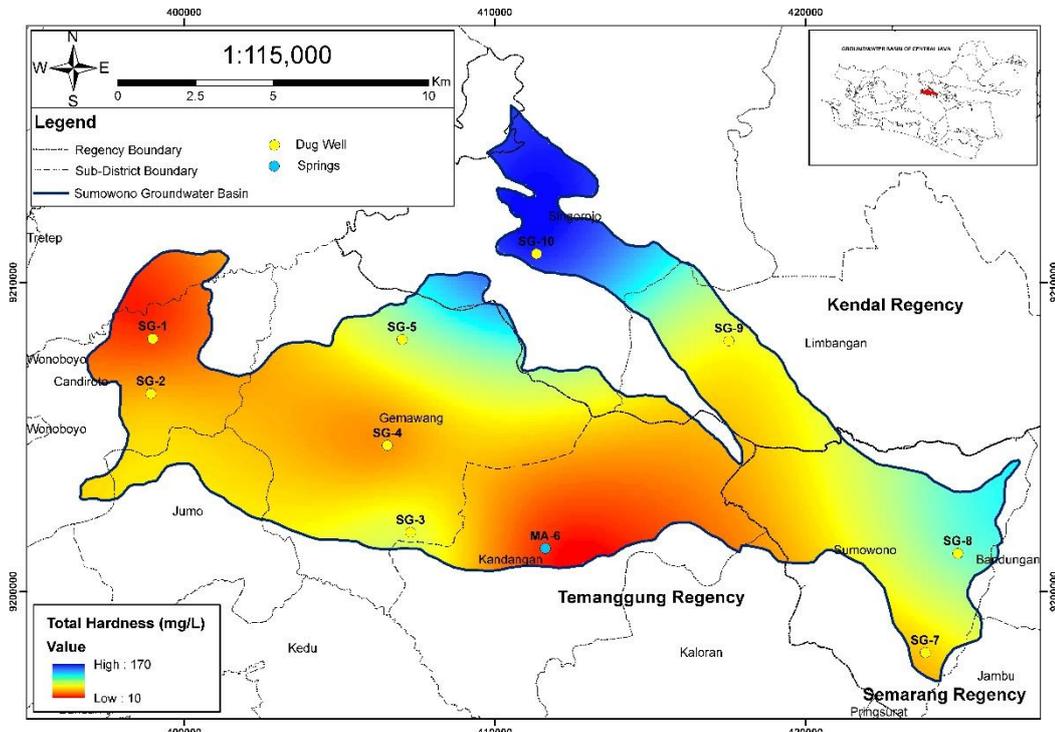


Figure 8. Total hardness map of groundwater samples in Sumowono groundwater basin.

### 3.4 Groundwater Quality Analysis for Drinking Water Using the WQI Method

WQI is defined as an assessment technique that provides the combined effect of individual water quality parameters on the overall quality of water for human consumption (Mitra, 1998). For this purpose, six water quality parameters have been selected (Table 1). Parameter considerations for developing a WQI depend on the intended use of the water. The parameters are selected according to the availability of data. They are relatively crucial in determining the quality of water for human consumption. The standards set for this purpose are by Permenkes No. 492/2010. The empirical formula for calculating WQI is presented in equations 1-4. From the results of the calculation of WQI according to the classification of the Minister of Health No. 492/2010 groundwater in Sumowono groundwater basin has potable and excellent conditions with values between 22.88-48.14 (Table 3). The spatial map of the WQI analysis is presented in Figure 9.

**Table 3.** WQI analysis based on Permenkes No. 492/2010

WQI scale	Level	Distribution (%)	Sample no.
< 50	Excellent	100	SG 01, 02, 03, 04, 05, 07, 08, 09, 10, and MA 06
50-100	Good	-	
100-200	Moderate	-	
200-300	Low	-	

### 3.5 Groundwater Quality Analysis for Irrigation Water Based on SAR Value

Sodium adsorption ratio (SAR) is a measurement of the ratio of Sodium ( $\text{Na}^+$ ) ions to Calcium ( $\text{Ca}^{2+}$ ) and Magnesium ( $\text{Mg}^{2+}$ ) ions, expressed in meq/L, according to equation 5. Irrigation water containing large amounts of Sodium is of particular concern because of the effect on the soil and poses a Sodium hazard. The continuous use of water with a high SAR value causes damage to the soil's physical structure. Sodium is absorbed and becomes bound to soil particles. The soil then becomes hard and dry compact, and increasingly resistant to water penetration. Fine-textured soils, especially those with high clay content, are most subject to this action. Certain amendments may be required to keep soils below a high SAR (Salifu et al., 2017). If present in large enough quantities in the soil, Calcium and Magnesium will counter the effects of Sodium and help maintain good soil properties (Fipps 2003).

A SAR value of more than 9 indicates moderate or high sodium or low calcium plus magnesium content in groundwater. Suppose this type of water is used in irrigation. In that case, it can cause dispersion of soil colloids, impairing soil texture and permeability. This result is in conditions similar to drought (Younger and Casey 2003). In the study area, the calculation of the SAR value using equation 5 obtained a value of 0.21-0.43. The Wilcox diagram (1955) as shown in Figure 10 shows that the sodium alkali hazard of groundwater samples shows a low level. Meanwhile, the EC value ranges from 71.6-511  $\mu\text{S}/\text{cm}$ , with a low to medium level of salt/salinity (low to medium). The Wilcox diagram shows 5 samples (50%) in the  $\text{C}_1\text{S}_1$  category (SG-01, SG-02, SG-04, MA-06, SG-10) in the west and south and one in the north, which is very good for irrigation. The other 50% of samples in the middle to the east are included in the  $\text{S}_1\text{C}_2$  category, suitable for irrigation. Thus, based on SAR analysis and Wilcox diagram, groundwater samples in Sumowono groundwater basin are suitable for use as a source of irrigation water.

## 4. Conclusion

It was found that 10 samples tested on Sumowono groundwater basin according to the Minister of Health's (2010) standard were classified as drinking water and the quality was excellent. For irrigation purposes, based on SAR analysis and Wilcox diagrams, 5 samples (SG-1, SG-02, MA-6, SG-03, and SG-10) showed that the 5 samples were perfect for irrigation purposes. The other 5 samples, namely numbers SG-04, SG-05, SG-07, SG-08, and SG-09 were included in the excellent category for irrigation purposes. The

study of monitoring well networks related to groundwater vulnerability due to pollution can be an effort in managing and monitoring groundwater in Sumowono groundwater basin in future research.

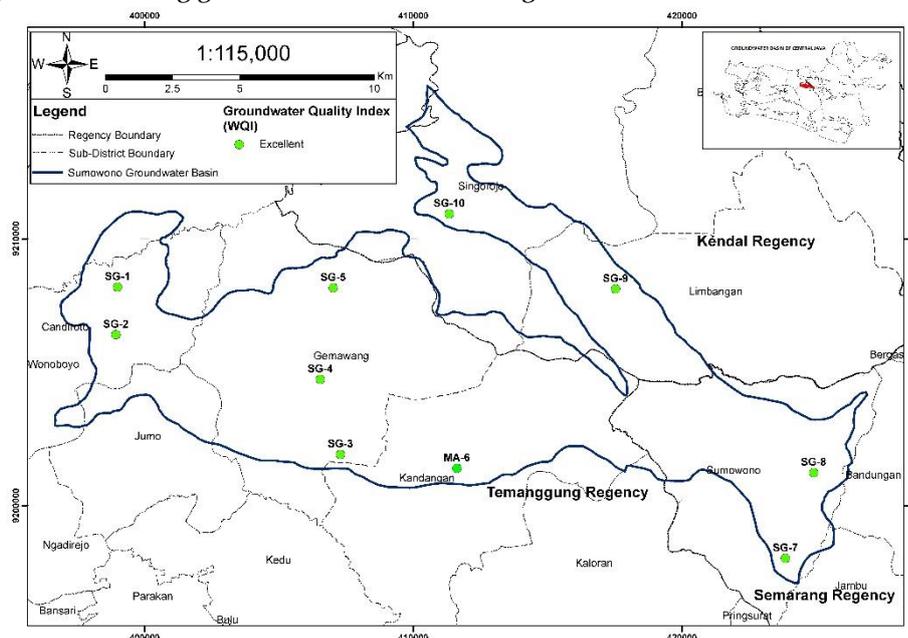


Figure 9. WQI analysis map based on Permenkes No. 492/2010 shows excellent quality.

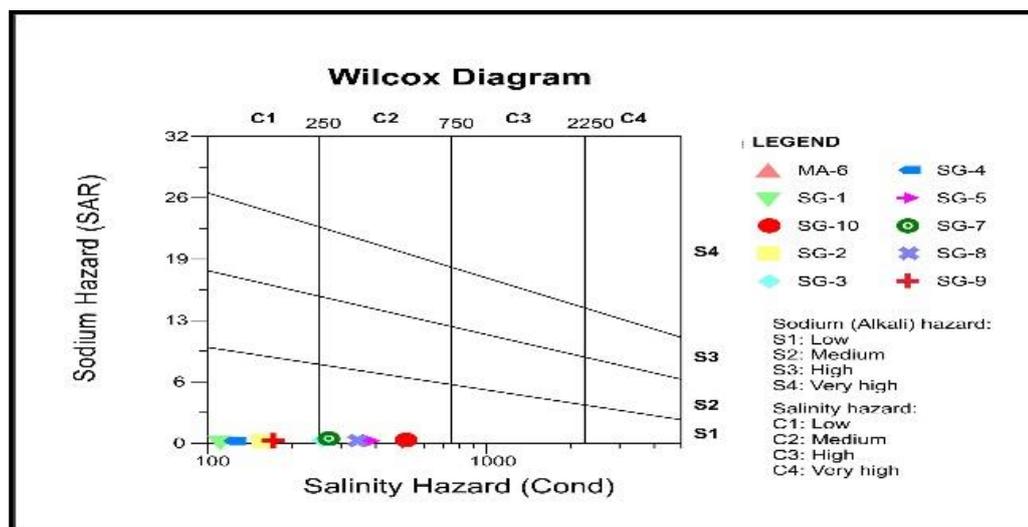


Figure 10. Wilcox diagram of Sumowono groundwater basin showing a group of SAR and Conductivity.

### 5. Acknowledgment

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