Groundwater Characteristics and Their Associations with Paleogeomorphological Dynamics in Gantiwarno, Klaten Regency, Central Java Province, Indonesia; A Preliminary

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Abstract. Ensuring the safety of groundwater is essential in ensuring people's health in Gantiwarno, as most rely on groundwater. However, based on the data on disabilities in Gantiwarno, it is very probable that something hidden within its groundwater has caused a high rate of many disability forms. This study analyzes the data on the disability rate in Gantiwarno and its surrounding areas to find the anomaly. Once the rate pattern was figured out, intensive and extensive reference research was performed to find the paleo and current geomorphological characteristics of Gantiwarno. Besides, this study tries to analyze the hydrogeochemistry of the area. The groundwater in Gantiwarno originates from a mixed process called sulfate groundwater. The groundwater in the study location is dominated by Na2SO4 type and unsuitable for health. Contaminants that have caused a high rate of disability in Gantiwarno possibly exist in its groundwater. All of this is possibly caused by the geohydrology, and paleogeomorphological dynamics of Gantiwarno, especially during and after the formation of the Gantiwarno Swamp. This preliminary study has tried to see some possible factors that have caused the situation and invites other researchers to conduct their study in Gantiwarno to investigate further this condition.
Keywords: disabilities, paleogeomorphology, swamp, Gantiwarno, contaminants

1 Introduction

Groundwater is the water contained beneath the surface in rocks and soil and is the water that accumulates underground in aquifers [1]. Groundwater travels through soil, sediment, and rocks contacting natural substances such as minerals from the Earth's surface. Water is a suitable solvent for dissolving these natural substances [2]. Groundwater constitutes 97 percent of global freshwater and is an essential source of drinking water in many regions of the world. Groundwater purity and natural taste make it the best water for human

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consumption. Most systems are naturally well protected against contamination partly due to the filtration effect of the aquifer strata's lower underlying layers and purification potential [1], [3]. Groundwaters often require little or no treatment to be suitable for drinking [1].

Over the last few decades, groundwater quality has become a global concern. People's reliance on groundwater has grown prominently during the past half-decade due to urbanization, intensified agriculture, and industrialization [4]. Groundwater is the most extracted raw material globally, with withdrawal rates currently around 982 km3/year [3]. In many nations, the majority of the extracted groundwater is for domestic water supplies, and globally it provides 25% to 40% of the world's drinking water [3]–[5]. As a result, people rely more on groundwater to fulfill their needs [4].

In Klaten Regency, Central Java, 92.1 percent of its population relies on groundwater for daily water needs, as indicated in figure 1.

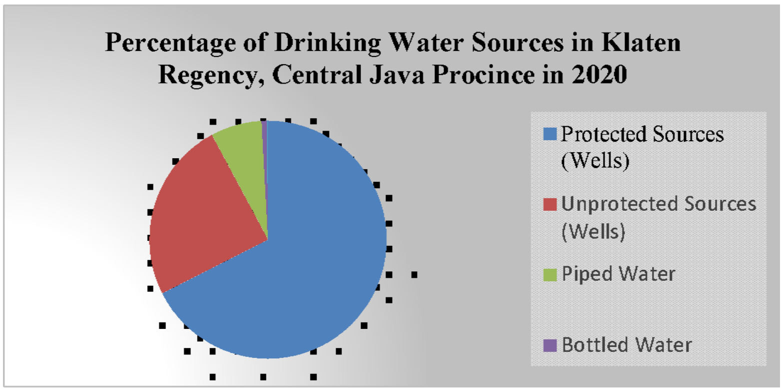

Fig. 1. Drinking water sources in Klaten Regency, Central Java Province in 2020.
Source: https://sidesa.jatengprov.go.id/

A critical aspect of groundwater for human consumption is water safety. Safe drinking water is necessary for humans and other organisms [6]. Safe water should be free from harmful microbials that potentially cause infectious diseases; be suitable for drinking in terms of color, taste, and smell; and have only allowed or safe levels of natural or anthropogenic contaminants to avoid risking people's health [2].

Water sources, especially groundwater, are often unsafe for consumption due to water contamination. Water contamination indicates the addition of compounds, elements, chemical substances, organisms, or pathogens into the surface water or groundwater that change water resources' physical, chemical, and biological characteristics [2], [7]. Groundwater is also often contaminated by many substances [7] including geogenic contaminants such as As, Hg, CN, and other substances [8]. Groundwater contamination can cause severe deterioration of soil and groundwater quality [7]. Whether the contaminants affect the aesthetic quality of groundwater or cause potentially negatively affect people's health depends on the amounts of substances present in groundwater [2].

In many regions of the world, high levels of toxicants, such as fluoride and nitrate, have been found in groundwater beyond the threshold limit, rendering them unfit for drinking. In many cases, the impact of the contaminants is devastating, as they cause many health-related issues (abnormal growth, high risk of breast cancer, diabetes, obesity, and others), including mental and central nerve activity issues [5].

Groundwater contamination possibly has happened in Gantiwarno, Klaten Regency, Central Java Province, Indonesia. Gantiwarno sees the highest rate on three out of four disability forms in Klaten Regency (according to the classification by The Government of Indonesia). It witnesses the highest rate of disabilities in "physical & mental disabilities –

tuna daksa & mental" (2.27 disabled people in 1000 populations), "physical disabilities – tuna daksa" (3.91 disabled people in 1000 populations), and "former mental disabilities – bekas penderita gangguan jiwa" (2.27 disable people in 1000 populations). However, under the classification of "retarded-mental disabilities – tuna mental retardasi," Gantiwarno sees 3.12 disabled people in 1000 populations; and this is outrated just by two sub-regencies (Karangnongko and Wedi) from the total of 26 sub-regencies in Klaten Regency (see figure 2).

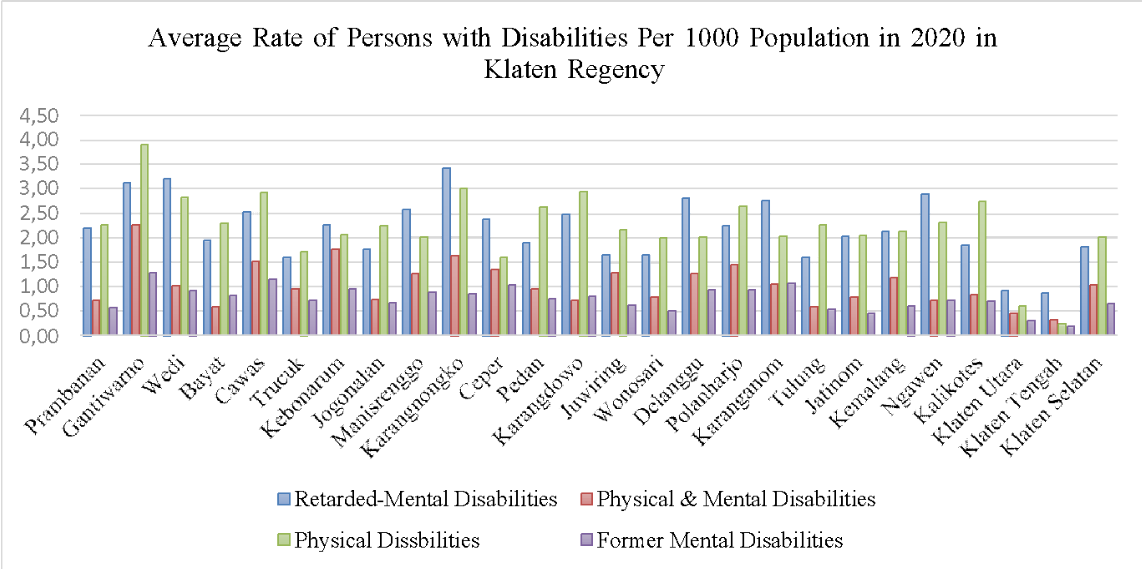

Fig. 2. Average Rate of Persons with Disabilities Per 1000 Population in 2020 in Klaten Regency. Source: https://sidesa.jatengprov.go.id/

This rate is remarkable compared to the average rate of physical & mental disabilities in Klaten Regency and Central Java Province. Under the classification of "retarded-mental disabilities," from 1000 populations, there are, on average, only 2.16 disabled people in Klaten Regency and 1.42 disabled people in Central Java Province. Under the classification of "physical & mental disabilities," from 1000 populations, there are, on average, only 1.60 disabled people in Klaten Regency and 1.02 disabled people in Central Java Province. Under the classification of "physical disabilities," from 1000 populations, there are, on average, only 1.01 disabled people in Klaten Regency and 0.64 disabled people in Central Java Province. Meanwhile, under the classification of "former mental disabilities," from 1000 populations, there are, on average, only 1.60 disabled people in Klaten Regency and 1.16 disabled people in Central Java Province.

So far, this phenomenon has yet to be studied, as no publication has been published. Therefore, a study regarding the high rate of disability in Gantiwarno is essential, as a high disability rate will impair the area's economic and human resource development. This study is conducted to shed light on what is happening in Gantiwarno in terms of its high disability rate and its possible driving factors, especially its geohydrology and paleogeomorphological dynamics and their derivative effects until this very present. This preliminary study will become a strong foundation for other researchers to examine the groundwater contaminants and high disability rates in Gantiwarno. By doing this, solutions to the people in Gantiwarno that are suffering from the disabilities could be formulated. Besides, this branch of scientific knowledge for could be developed for better human future.

1.1 Literature review

The type and concentration of substances in groundwater may be affected by naturally occurring processes and actions directly associated with human activities [5], [6], [9], [10]. Without human influences, natural processes would influence water quality only [6]. Natural factors influence water quality through soil-matrix [5], [9], [11], geological setting and processes [5], [6], [8], [11]–[14], topography [6], type of rock, the local climate [6], [8], natural disasters, climate change [5], [11], hyporheic exchange [5], extent of host-rock and water interaction [12], degree of weathering of bedrock minerals [6], [12], [14], natural leaching of minerals, organic matter and nutrients from soil and aquifer rock [6], [12]; sorting processes [14], atmospheric processes involving evapotranspiration, deposition of dust and salt by wind, hydrological factors leading to runoff, and biological dynamics in the aquatic environment that may change the physical and chemical composition of water [6].

The changes in natural groundwater quality start in the soil, where infiltrating rainfall dissolves carbon dioxide from biological activity in the soil to produce weak carbonic acid that may assist the removal of soluble minerals from the underlying rocks, e.g., calcite cement [9].

Geological factors influence groundwater composition, mainly through the effect of chemical water-rock interactions in aquifers [6]. The natural quality of groundwater varies from one rock type to another and within aquifers along groundwater flow paths [2], [9], [11]. An area's geology fundamentally controls the environmental chemical distribution, as particular chemical substances are generally associated with particular rock types [6], [11]. Because groundwater movement is typically slow and residence times are long, there is potential for interaction between the rock material and the water [9].

Naturally occurring processes, such as the decomposition of organic material in soils or the leaching of mineral deposits, can increase concentrations of several substances. Aquifers in migmatites and metamorphic rocks generally show lower dissolved contents than in carbonate or sedimentary rocks [9]. Sedimentary rocks and soils usually indicate the presence of various compounds such as magnesium, calcium, chlorides, or even chromium in groundwater [13]. Very high concentrations of substances can occur in rocks associated with specifically mineralized areas [11].

2 Methods

This study was conducted in Gantiwarno Sub-Regency (further, it will be called only with its name "Gantiwarno"), Klaten Regency, Central Java Province, Indonesia (see figure 3). The area of Gantiwarno is 256.40 km2, consisting of 161.81 km2 of paddy field and 94.63 km2 for various purposes. Gantiwarno is bordered by Wedi and Jogonalan Sub-regencies in the north, Gunung Kidul Regency, Yogyakarta in the south; Wedi Sub-regency in the east, and bordered by Prambanan Sub-regency in the west. Administratively, Gantiwarno is divided into 16 villages (BPS Kabupaten Klaten, 2022), as shown in figure 3.

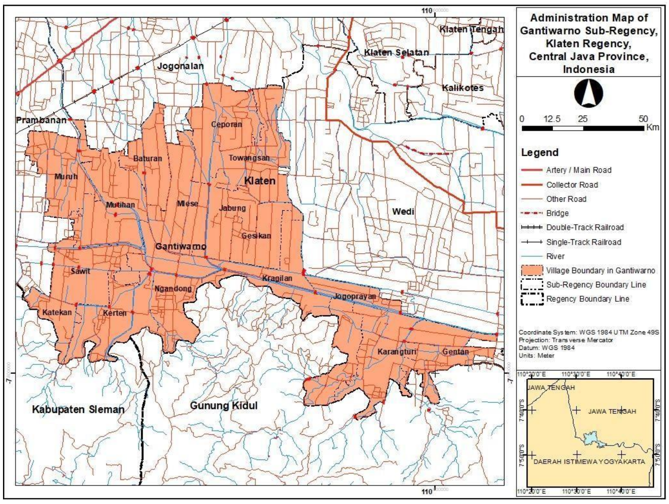

Fig. 3. Administration map of the study location

In 2021, the population in Gantiwarno was 38,620 people, with 19,259 males and 19,361 females. The village with the largest population was Kalangan Village, with a total of 5,592 people, and the village with the minuscule population was Lemahireng Village, with 1,605 people [15].

The climate in Gantiwarno is typically tropical, with alternating rainy and dry seasons throughout the year, with an average air temperature of 28-30 degrees Celsius with wind speeds of 10-20 km/hour. The average rainfall in 2021 was 170 mm per month, with the highest rainfall in February (433 mm) and the lowest in July (0 mm). The average rainy day in 2021 was eight days per month [15].

This study analyzes the data on the disability rate in Gantiwarno and its surrounding areas to find the anomaly. Once the rate pattern was figured out, intensive and extensive reference research was performed to find the geomorphological characteristics of Gantiwarno, including its paleogeodynamics. Besides, this study tries to analyze the hydrogeochemistry of the area, to determine the groundwater characteristics and its evolution processes. The method of this study can be seen in figure 4.

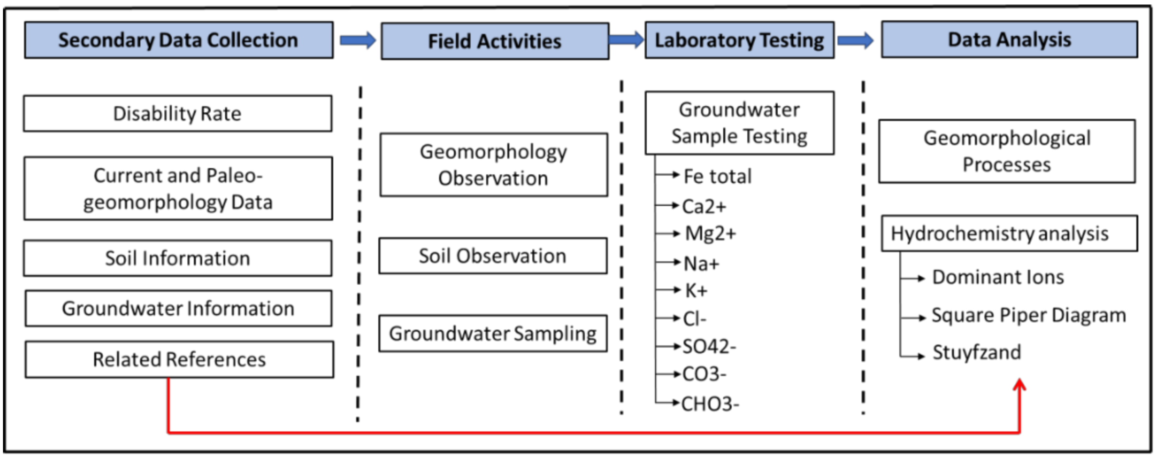

Fig. 4. Methodological scheme of the study

3 Results and discussions

3.1 Paleogeomorphological dynamics of gantiwarno

Gantiwarno sits in an area referred to as Gantiwarno Plain [16]. Gantiwarno is next to (below) the Baturagung Structural Hill Escarpment to the south, part of the Southern Mountain Zone, which was created through lifting (becoming horst) during ancient geomorphological processes. The escarpment is the evidence of a past tectonic event in the form of an lifting process which resulted in a fault (see figure 5). Gantiwarno Plain is part of Solo Zone which is part of the descending rock formation (graben) [17] (see figure 6).

Fig. 5. Geomorphological condition of the study location

Most of Gantiwarno area is part of the current alluvial plain. Currently, the landform of Gantiwarno is influenced by two main agents – fluvial processes of the Dengkeng River and its tributaries and the depositional process of eroded materials of the Baturagung Hills in the south. Erosion processes produce clay and other materials that are deposited in Gantiwarno area. Meanwhile, the depositional process influenced by the fluvial process makes the deposited materials well sorted. The fluvial process also flattens Gantiwarno area. According to (Santosa, 2006), four landforms can be found in Gantiwarno: Alluvial Wavy Plains, Flood Plains, Foot Plains of Baturagung Hills, and Alluvial Fan of Baturagung Hills.

The physiographical formation of the Southern Mountains (possibly started during the Middle Pleistocene) was mainly from the lifting process. This process resulted in Oligo-Miocene-mountain ranges with volcanic rocks as the primary materials which form the northern and western boundaries of the Southern Mountains to the Solo Depression Zone and the Yogyakarta Basin. One proof of this lifting process is the flow of the Ancient Bengawan Solo, which previously headed south toward the Indian Ocean, which had changed its direction to the north [18]. The evidence of this process is still present in the area around Sadeng Beach, Gunungkidul Regency, Yogyakarta Province, as a dry valley. The dry valley was formerly the Bengawan Solo River, emptying into the South Java Sea. Due to the lifting process, the direction of the ancient Bengawan Solo flow turned to the north because it could not erode the rock layers that were gradually lifted [19].

Before the topographic lifting due to geomorphological processes, the area around Gantiwarno was a Pliocene Sea. During the lifting processes, a fault occurred, dividing the continuously lifted southern mountains and the Solo Depression Zone - the Yogyakarta

Basin. The lifting of the Southern Mountains trapped the seawater (a large swamp called Gantiwarno Swamp) along the northern foot of the mountains, from Gantiwarno to Baturetno. The fault and lifting process of the Southern Mountains also blocked surface water flow along the northern foot of the mountains so that it accumulated in the lower basin just below the fault escarpment line [16], [20]. In addition, the swamp was formed due to the natural blocking of the high elevation of the Kendeng Hills in the north and Mount Merapi in the northwest (see figure 6).

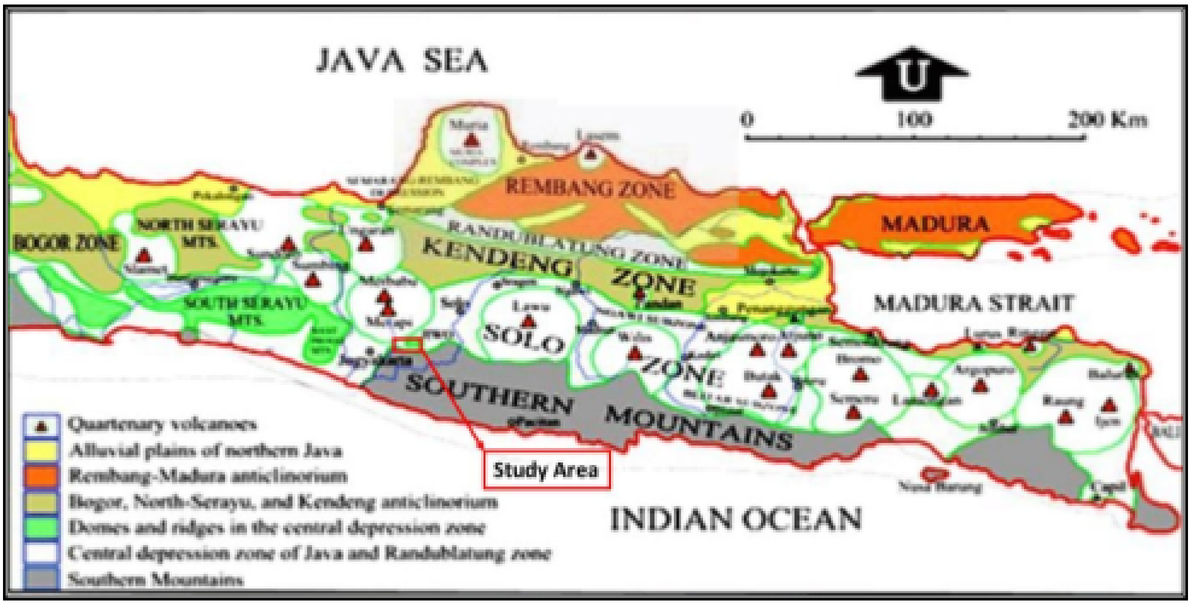

Fig. 6. Physiographic map of part of Java Island
Source: Dwijo et al. (2014); Van Bemmelen (1949)

Currently, the swamp has shrunk due to volcanic material deposition from the Merapi Volcano eruption [19], [20]. Geomorphological developments related to the activity of the Merapi Volcano from 20,000 to 310 years ago have deposited material in large volumes, shallowing the water-logged environment until it dries up. Meanwhile, on the plains – the foot of the volcano, local paleogeomorphological developments have occurred, which are laterally continuous. Flooding to siltation takes place gradually over a long time. During these 20,000 years, there was periodic flooding, then a sudden siltation every 50-150 years, but in general and slowly, the waterlogging decreased [20].

Around the 9th-11th centuries, the activity of Merapi was more active, producing a more extensive volume of volcanic deposits. As a result, Gantiwarno Swamp pool shrank and dried up more and more [20]. Swamp Gantiwarno is estimated to be still quite extensive around the 10th century. This large swamp stretches between the foot of the Southern Mountains in the south and west, to the north, until it reaches the area around the Yogyakarta-Surakarta highway [16]. The presence of an irrigation system for draining and plantations on Gantiwarno Plain, built in the 19th century, shows that the area was previously a swamp [22] (see figure 7).

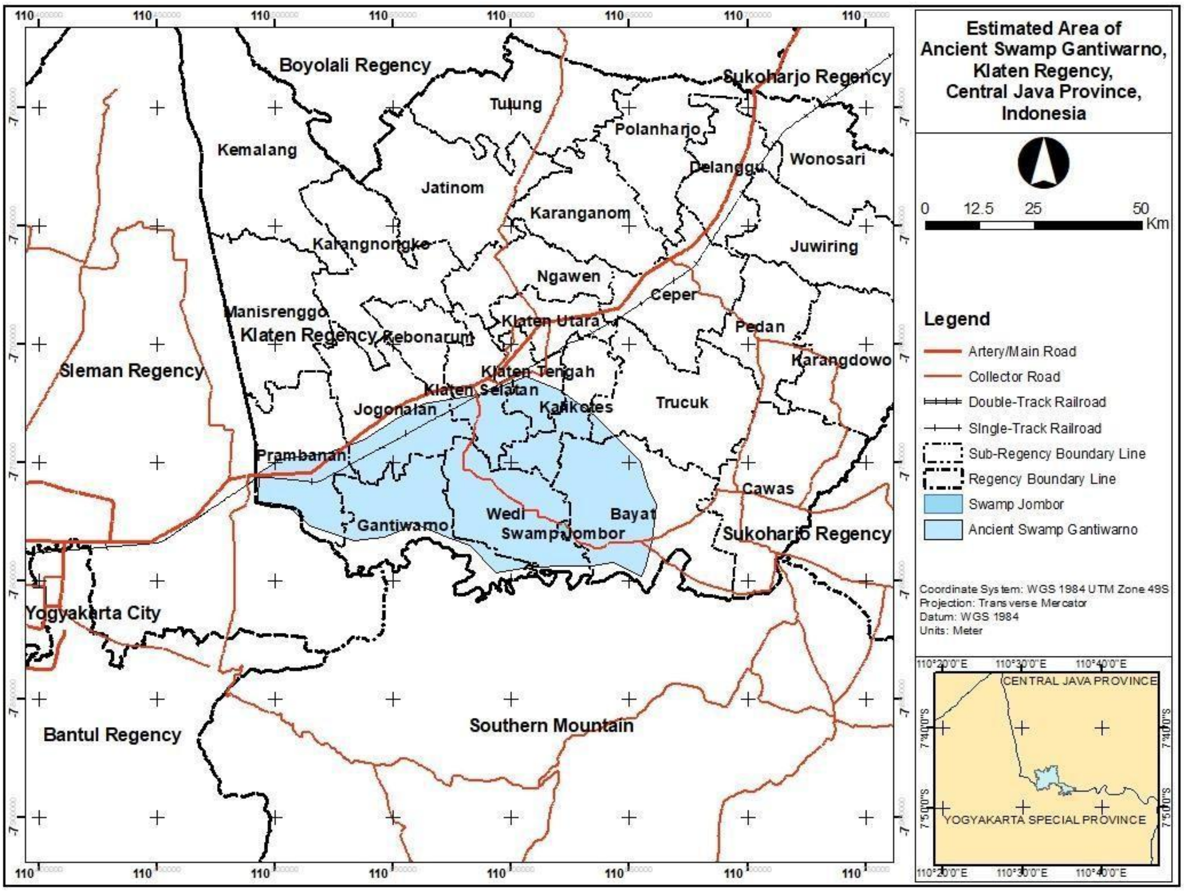

Fig. 7. Estimated area of Swamp Gantiwarno around the 10th century
Source: [16]

As a result of the periodic Merapi Volcano eruptions and fluvial and alluvial forces, a unique deposition pattern formed in Gantiwarno. There is a periodic change in the deposition between volcanic material and black clay from fluvial and alluvial processes in the swamp area. The deposition of these two kinds of deposit allows for interfinger relations. Thus, some depressed aquifers were formed from Merapi deposits sandwiched between clay layers [16].

Apart from being a result of natural processes, the shrinkage of inundation is also caused by human activities. In the 19th century, the swamp still existed in the southern half of Gantiwarno Plain. The Dutch (the longest Indonesian colonizer) was draining the swamp during this time. Drainage was accomplished by constructing raised drying channels in the southern part of the plain so that the marshland could be reclaimed and utilized as a fertile plantation and agricultural area. Meanwhile, the water is discharged through the Dengkeng River in the Jiwo Hills gap. The drainage left only Rawa Jombor, which is in Bayat Sub-regency, Klaten Regency, and is used for fishery and irrigation purposes [16]. The process of geomorphological dynamics around Gantiwarno Plain from the Late Pleistocene to the present can be seen in figure 8.

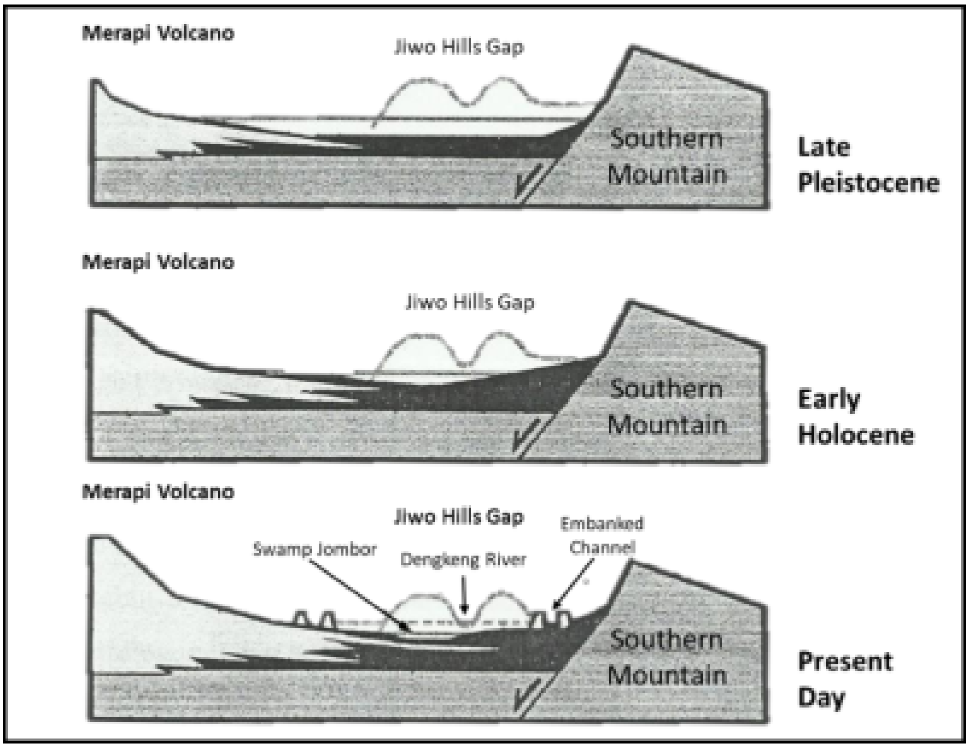

Fig. 8. Illustration of the geomorphological dynamics of the Gantiwarno Plain from the Late Pleistocene to the Present Source: [16]

The groundwater in Gantiwarno shows a high salinity value (very salty – brackish) with a resistivity value of 0 -15 Ω meters. Besides, from groundwater electric conductivity (EC) level measurements conducted in 155 wells of the study location, there were two wells with groundwater classified as "very saline (>4500 μmhos/cm)," with the highest EC of 4730 μmhos/cm. This highly saline groundwater results from the trapped Pliocene seawater within the clay layer. The clay used to be Swamp Gantiwarno clay deposits formed after paleogeomorphological processes insulated the Pliocene Sea during the Pleistocene Epoch. According to the subsurface geological structure, this clay occurs from the soil surface to a depth of more than 50 meters under ground level [19].

3.2 Groundwater hydrogeochemical analysis

Hydrogeochemical studies emphasize efforts to trace the evolution of groundwater, which is strongly influenced by the genesis of landform and geomorphological processes. There is a close relationship between the genesis of landforms and the dynamics of paleogeomorphological processes of Gantiwarno with the hydrogeochemical characteristics of its groundwater. Therefore, the hydrogeochemical model is very appropriate as a model for studying the influence of the genesis of past landforms and geomorphological processes on the evolution of groundwater, by emphasizing landforms as a spatial and temporal analysis approach [25].

Based on the finding by Lisan & Adji (2017), we conducted a hydrogeochemical analysis of groundwater and an analysis of the feasibility of Gantiwarno groundwater for human consumption. In order to analyze the chemical content of the groundwater, groundwater sample was taken from a well that had the highest EC values according to the study by Lisan & Adji (2017). Groundwater taken from the well comes from the unconfined groundwater layer. The well is in Gentan Village, Gantiwarno at coordinate UTM 49 M, x = 455529 and y = 9138554. A well with the highest EC value possibly contents more ions so

that it better represents the hydrogeochemical characteristics of the groundwater from the study location.

After taking the groundwater sample, the sample was tested through a series of tests at the Center for Environmental Health Engineering and Disease Control (BBTKLPP) Yogyakarta with test parameters in the form of seven major elements (Mg+, Ca2+, Na+, K+, Cl-, SO42-, and HCO3-) and the addition of two elements, total Fe and CO -. The results of this laboratory test can be seen in table 1.

Table 1. Content of chemical elements of groundwater sample at study location.

No	Parameter	Unit	Test results	Test Method
1	Fe total	mg/L	<0.0162	Indonesian National Standard 6989. 4-2009
2	Ca2+	mg/L	364	Indonesian National Standard 06-6989. 12-2004
3	Mg^{2+}	mg/L	216.27	Indonesian National Standard 06-6989. 12-2004
4	Na^{+}	mg/L	2268	APHA 2012, Section 3500-NA
5	K^{+}	mg/L	9	APHA 2012, Section 3500-K
6	Cl^{-}	mg/L	162.4	Indonesian National Standard 6989. 19-2009
7	SO4	mg/L	2278	Indonesian National Standard 6989. 20-2009
8	CO3	mg/L	Not detected	APHA 2012, Section 2310 & 2320-C
9	HCO3	mg/L	659.8	APHA 2012, Section 2310 & 2320-C

Source: Laboratory Test

Data on the chemical content of groundwater from laboratory tests were used in a series of groundwater hydrogeochemical analyzes using three methods – Ion Dominance, Square Piper Diagram and Stuyfzand. These three methods have been widely used to analyze the characteristics of groundwater in various places. The resulting groundwater hydrogeochemical models can describe the origins and processes that affect the characteristics and evolution of groundwater. Hydrogeochemical processes greatly affect the chemical composition of groundwater, in addition to being closely related to the rock minerals that contribute to that composition [25].

Groundwater hydrogeochemical analysis will show the classification of groundwater hydrogeochemical types. Classification of groundwater hydrogeochemical types is intended to analyze the dominant compounds composing groundwater, which can be used as a basis for tracing the origins of groundwater and past geomorphological processes [25]. Following are the results and discussion of the four hydrogeochemical analyzes that have been carried out.

3.2.1 Compound (ion) dominance

The result of Compound (Ion) Dominance Analysis can be seen in table 2 below.

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Table 2. Compound (ion) dominance analysis of groundwater sample.

Element	mg/L	BA	mmol/L	meq/L	%
Ca^{2+}	364	40.08	9.08	18.16	13.47
Mg^{2+}	216.27	24.31	8.9	17.79	13.19
Na^{+}	2268	22.99	98.65	98.65	**73.16**
K^{+}	9	39.1	0.23	0.23	0.17
				134.84	100
Cl^{-}	162.4	35.45	4.58	4.58	7.29
$SO4^{2-}$	2278	96.06	23.71	47.43	**75.5**
$HCO3^{-}$	659.8	61.02	10.81	10.81	17.21
				62.82	**100**

Note: Dominant Compounds (Hydrogeochemistry): Na2SO4 Source: Laboratory Analysis Results and Calculations

The Compound (Ion) Dominance Method is applied to determine the main cations and anions that dominate the chemical composition of unconfined groundwater, so that it can be known the possibility of the main compounds making up the chemical type of groundwater [25]. The table 2 shows that the groundwater sample has the dominant compound (ion) in the form of Na2SO4.

The results of the analysis show that the groundwater sample is of the sulfate type, with the dominant cation composition being Na+. Water containing large amounts of sulfate can form boilers, corrode piping, and cause odors. The sulfate content in water that is still within safe limits for consumption and for bathing, washing and toileting of 250 mg/l [26].

3.2.2 Square piper diagram

The result of calculation for Square Piper analysis can be seen in table 3, while the Piper Diagram result can be seen in figure 9.

Table 3. Hydrogeochemical type of groundwater in study location based on the Square Piper Diagram Method.

Kation Concentration (meq/liter)				%	Anion Concentration (meq/liter)				% Cl	Hydrogeochemi
Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Na + K	Cl^{-}	$SO_4^{=}$	$CO_3^{=}$	HCO_3^{-}	+ SO_4	cal Type
18.16	17.79	98.65	0.23	73.33	4.58	47.43	0.00	10.81	82.79	IV Mixed

Source: Laboratory Analysis Results and Calculations

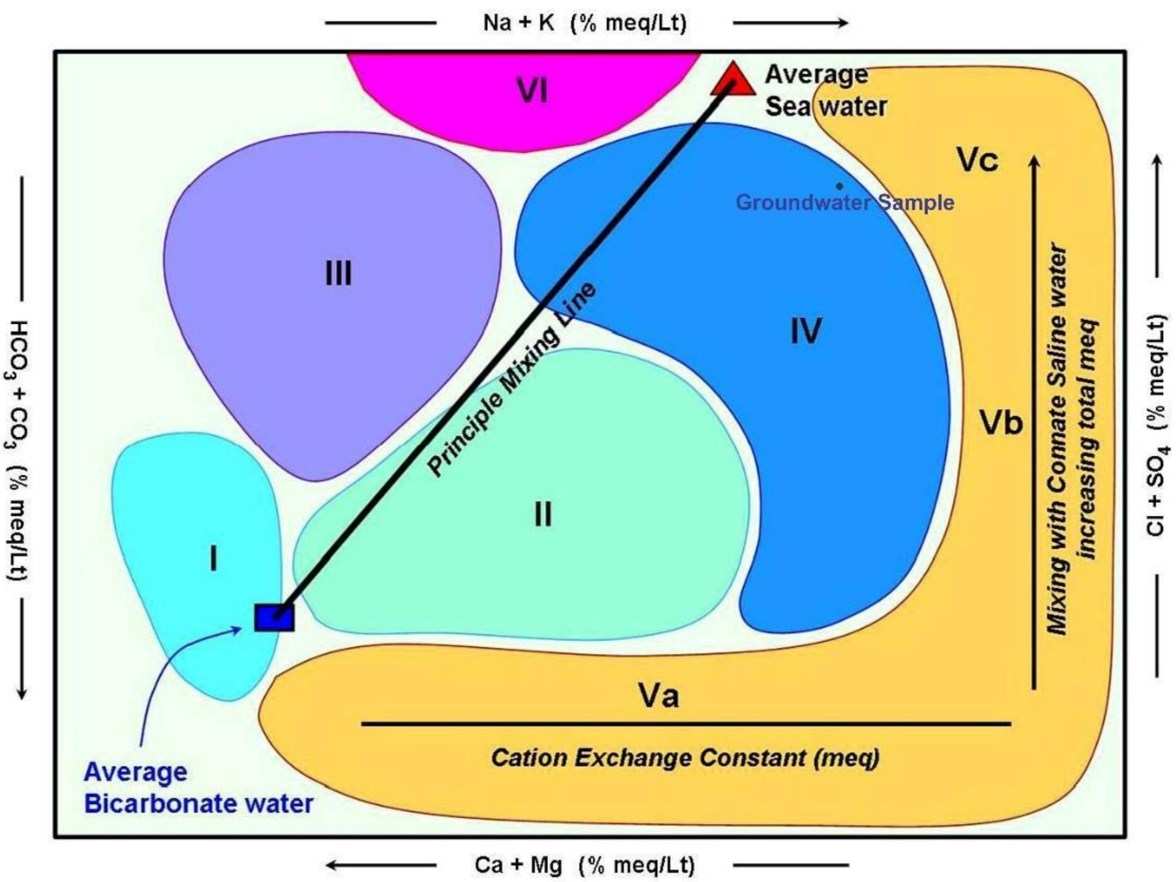

Fig. 9. Hydrogeochemical types of unconfined groundwater at study location based on the Quadrilateral Piper Diagram Method

The Square Piper Diagram method is aimed more at analyzing the genesis and the main geomorphological processes that form the hydrogeochemical types of groundwater. The analysis process using this method requires data on the percentage of Na+ + K+ compared to the total cations as the abscissa, and the percentage of Cl- + SO 2- compared to the total anions as the ordinate [27].

According to figure 9, △ symbol is a reference point that shows the average chemical composition of seawater types, while □ symbol shows the chemical composition of fresh water. The mixing between these two types of hydrochemistry, if it is without a chemical reaction due to other factors, then the result will lie in a straight line connecting the two [25]. The plot positions in the diagram for the cationic compositions of Na+ + K+ and Ca2+ + Mg2+ (meq/liter units) on the abscissa axis, with the equation:

$$Na^{+} + K^{+} (\%) = \frac{\Sigma (Na^{+} + K^{+})}{\Sigma \text{ Total Cations}} \times 100\% \qquad (1)$$

While the position of the plot in the diagram for the anion composition of Cl- +SO4= and HCO3- + CO3= (units of meq/liter) on the ordinate axis, with the equation:

$$\Sigma (Cl^{-} + SO_4^{=})$$

$$Cl^- + SO_4^= (\%) = \frac{\text{-------------------}}{\Sigma \text{ Total Anions}} \times 100\% \quad (2)$$

The results of the analysis of the groundwater sample (table 3 and figure 9) show that groundwater in the study location belongs to the mixed hydrogeochemical type IV. Hydrogeochemical classification IV shows that the groundwater in the study location is groundwater with a mixed composition characterized with low to high content of HCO - + CO 2-, low to moderate Ca2+ + Mg2+, moderate to high Na+ + K+, and moderate to high Cl- + SO 2-, and is often called sulphate groundwater. This is influenced by high sulfate admixture without much contamination by external factors, in addition to the occurrence of symptoms indicating the direction of cation exchange. Groundwater usually tastes brackish - salty, of moderate to poor quality, with high Cl- and SO42- contents. This condition causes groundwater to be permanently hard [25].

3.2.3 Stuyfzand

Stuyfzund Method aims to differentiate water types, determine dominant types and hydrogeochemical processes in groundwater [25]. Determination of the type of water using this method is carried out successively according to four levels of classification, namely the (1) main type based on chloride ion content (Cl-), (2) type based on total hardness (alkalinity) based on total hardness (Ca2+ and Mg2+), (3) sub-type (based on cations and major anions) and (4) class of water sample (based on correction of sea salts (Na++K++Mg2+)). Each of these classification levels contributes to the final Groundwater Total code (and name). There are 6 main types, 11 types, 16 sub-types and 3 classes in this classification. The results of the hydrogeochemical analysis of unconfined groundwater types in the study location can be seen in Table 4 to 8.

Table 4. Classification of main types of unconfined groundwater in the study location.

Cl concentrations (mg/liter)	Code	Classification
162.4	Fb	Fresh - Brackish

Source: Results of Analysis based on the Stuyfzand Method

Table 5. Type classification (alkalinity - hardness level) of unconfined groundwater of the study location.

Alkalinity (mmol/L)	Code	Classification
17.98	5	Extremely Hard

Source: Results of Analysis based on the Stuyfzand Method

Table 6. Classification of unconfined groundwater sub-types in the study location.

Cation	Concentration	(meq/liter)	Anion	Concentration	(meq/liter)
Ca^{2+}	5 **Mg^{2+}**	**K^+**	**Cl^-**	**$SO^=$ $_4$ $CO^=$$_3$**	**HCO^-**
18.16	17.79	98.65	0.23	4.58	47.43

Continued.

Total Anion	½ Anion	Total Cation	½ Cation	Type Condition	Sub-Type -

62.82	31.41	134.83	67.42	(S04+N03+N02)> 1/2Σa; SO4> (N03+N02)	**Na2SO4**
Source: Results of Analysis based on the Stuyfzand Method					

Table 7. Classification of unconfined groundwater class in the study locations.

Measured	√12 Cl	1,061 x	Corrected Na+K+Mg =	Classes
Na+K+Mg (meq/liter)	(meq/liter)	√12 Cl (meq/liter)	Measured Na+K+Mg – 1,061 √12 Cl (meq/liter)	
116.67	15.87	16.84	99.84 +	Surplus

Source: Results of Analysis based on the Stuyfzand Method
Note: Surplus: often pointing at a (former) freshwater encroachment

Table 8. Hydrogeochemical type of unconfined groundwater in the study location based on the Stuyfzand Method.

Main Type (Cl)	Type (Hardness)	Sub-type	Class		Hydrogeochemistry type
mg/lt Code	mmol/ lt Code		Garam koreksi	Kode	
162.4 Fb	17.98 5	**Na2SO4**	99.84	+	Fb5 – **Na2SO4** +

Source: Results of Analysis based on the Stuyfzand Method

According to the first classification based on the Main Type based on chloride ion content (Cl-), the groundwater is included in the 'fresh - brackish' Fb category (fresh - slightly brackish groundwater) with a Cl- content of 150-300 mg/L.

The second classification level (Type) based on the value of alkalinity (hardness) shows that the sample has very high total hardness values with an alkalinity value of 16 – 32 mmol/L (code 5). According to Said (2008), hardness is a term used for water containing cations that cause hardness. Generally, hardness is caused by the presence of metals or cations with a valence of 2, such as Fe, Sr, Mn, Ca and Mg. However, the main causes of hardness are calcium (Ca) and magnesium (Mg). Calcium in water has the possibility of combining with bicarbonate, sulfate, chloride, and nitrate. Meanwhile, magnesium in water possibly combines with bicarbonate, sulfate, or chloride.

Hardness in water is highly undesirable for both domestic and industrial uses. For households, water with a high level of hardness results in more soap consumption because the soap becomes less effective due to one part of the soap molecule being bound by elements of Ca or Mg. For industry, the Ca element can cause scale on the walls of heating system equipment so that it can deteriorate to industrial equipment. Besides, it can also inhibit the heating process. Water hardness can be divided into 2, temporary hardness (temporary) and permanent hardness (permanent). Temporary hardness is caused by carbonate (CO3-) and bicarbonate (HCO3-) salts of calcium and magnesium. This hardness can be removed by heating or by adding quicklime. Meanwhile, hardness remains due to

the presence of chloride salts (Cl-) and sulfates (SO42-) of calcium and magnesium. This hardness is called non- carbonate hardness which cannot be removed by heating, but can be removed by ion exchange [28].

Based on the hardness classification according to Said (2008), the type of groundwater hardness in the study location is permanent hardness. This is caused by the presence of chloride (Cl-) and sulfate (SO42-) salts of calcium and magnesium which are dominant in the study location. This condition is in accordance with the results of groundwater analysis using the Square Piper Diagram Method which shows that the groundwater in the study location is included in category IV – Mixed and has permanent hardness. In addition, the hardness of groundwater in Gantiwarno can also be proven by the formation of scale on various cooking utensils owned by residents. This is one of the complaints expressed by residents in the study location.

The third level of classification in the Stuyfzund Method is Sub-Type. In this classification, the cations and anions which have more (predominant) influence in the ionic balance will determine the combination of the name of the water sub - type. However, in this classification a cation or anion with a partial meq/L does not always determine the name of the sub-type. Based on this level of classification, the groundwater has the Na2SO4 type. This is in accordance with the classification of groundwater based on the Compound (Ion) Dominance Method.

The last classification level in the Stuyfzund Method is Class. The results of the analysis show that the groundwater is included in Class + (surplus). The “surplus” category often indicates (former) freshwater encroachment. This indicates that there is additional fresh water in the groundwater [25].

Overall, the types of hydrogeochemistry according to the Ion dominance, Square Piper Diagram, and Stuyfzand Methods are presented in Table 9.

Table 9. Hydrogeochemical types of unconfined groundwater in the study location according to the Dominant Ion, Quadrilateral Piper Diagram, and Stuyfzand Methods

Unconfined Groundwater Hydrogeochemistry		
Dominant Ions	**Piper Diagram**	**Stuyfzand**
Na2SO4	IV Mixed	Fb5 – **Na2SO4** +

Source: Analysis Results

Santosa (2009) explains that the evolution of groundwater can be traced following flow patterns and changes in its chemical properties. During its journey, groundwater flow will experience a change in chemical composition from upstream to downstream, which leads to the chemical composition of seawater. The chemical elements that dissolve in groundwater undergo evolution in the following pattern:

$$HCO3^{-} \rightarrow (HCO3^{-}, SO4^{=}) \rightarrow SO4^{=} \rightarrow (SO4^{=}, Cl^{-}) \rightarrow (Cl^{-}, SO4^{=}) \rightarrow Cl^{-}$$

The journey from upstream to downstream has increased in age

Referring to this concept, groundwater will undergo evolution as indicated by changes in the dominant ions; from bicarbonate – sulphate – to chloride under equilibrium conditions.

In accordance with this concept, groundwater in the study location is quite young as the main anion content is SO42-. In addition, the groundwater is not balanced enough so that it

is more reactive and can still experience changes in ionic/chemical properties through various processes.

Based on the formation process and the type of groundwater found in the study location, the groundwater originates from a mixed process with low to high content of HCO3- + CO32-, low to moderate Ca2+ + Mg2+, moderate to high Na+ + K+, and Cl- + SO4 is moderate to high; and is often called sulphate groundwater. This is influenced by high sulfate admixture without much contamination by external factors, in addition to some indications of cation exchange. The groundwater usually has moderate to poor quality, with high SO42- contents. This condition causes the groundwater to be permanently hard, shown by the domination of Na2SO4 groundwater type.

The presence of sulfate content (SO4) is caused by the reduction of SO4 from past organic materials [25]. These organic materials are very likely to be found because the ancient Gantiwarno Swamp was in a lower area and was the accumulation site of all the streams, particularly from the north direction of the study location. Water from the streams was difficult to escape and was accumulated in the study location because there was a strong water barrier in the form of the Baturagung Hills. As a result, various kinds of sedimentary materials including organic materials carried by the various streams were retained and settled in the study location. When these organic materials become more abundant and met the air in the atmosphere, a SO 2- reduction process occurs from these organic materials. This is what causes the groundwater in Gantiwarno rich in sulfate.

Based on its equilibrium, groundwater in the study location can be categorized as "surplus." The "surplus" condition has an indication of frequent encroachment / intrusion of freshwater.

3.3 Analysis of groundwater consumption feasibility

Water is a very vital thing for human life. Water is very necessary to maintain the survival of most living things. Utilization of water (including groundwater) for consumption must always consider health reasons. Drinking water is safe for health if it meets several requirements, one of which is chemical requirements. The following table 10 shows the results of the analysis of the chemical content of groundwater in the study location compared to the permitted chemical content requirements for consumption purposes.

Table 10. Analysis of Chemical Content of Groundwater According to the Maximum Threshold for Consumption Purposes.

No	Parameter	Unit	Test results	Max Threshold	Note	References
1	Fe total	mg/L	<0.0162	0.3	√	Regulation of the Indonesian Minister of Health No. 492 / 2010
2	Ca2+	mg/L	364	200	X	http://siat.bgl.esdm.go.id/
3	Mg2+	mg/L	216.27	150	X	http://siat.bgl.esdm.go.id/

4	Na+	mg /L	2268	200	X	Indonesian Government Regulation No.2 / 1990
5	K+	mg /L	9	12	√	Said (2008); EEC (1978)
6	Cl-	mg /L	162.4	250	√	Regulation of the Indonesian Minister of Health No. 492 / 2010
7	SO42-	mg /L	2278	250	X	Regulation of the Indonesian Minister of Health No. 492 / 2010
8	HCO3-	mg /L	659.8	500	X	Regulation of the Indonesian Minister of Health No. 492 / 2010

*Note
√ = does not exceed the maximum allowable threshold X = exceeding the maximum allowable threshold

Based on the table, the consumption of groundwater of the study location is potentially harmful to human health. This is because most of the parameters tested have values that exceed the permissible threshold for consumption. Besides, contaminants possibly exist in Gantiwarno groundwater that have caused high rate of disability in Gantiwarno. Contamination of groundwater from anthropogenic or natural sources with several social impacts has now become a primary environmental concern in many parts of the world [29]. Contaminant exposures via drinking water, even at low concentrations, may have significant consequences across the entire population [30]. Mineral chemicals, like major ions, minor ions, nutrients, and trace elements - influence the chemical quality of groundwater [2].

The impact of the contaminants is devastating, as they create many health-related problems (abnormal growth, high risk of breast cancer, diabetes, obesity, etc.). The most common contaminants in water are heavy metals (Hg, Pb, Pd, Fe, Cd, Cr, Cu, Co, Mn, Ni, Zn, Al, As, etc.); toxic compounds (As, Se, CN- etc.); inorganic compounds (NO3–, NO2–, PO4–3 etc.); synthetic organic compounds (phenols, chlorinated hydrocarbons, detergents, pesticides, paint colors, petroleum products etc.); radioactive substances (radon caused by uranium and thorium series decay); and pathogenic microorganisms (bacteria and viruses) which can cause diseases, e.g., dysentery, diarrhea [5], [6], [13]. Further, non-essential metals may impair the human neuron system. Heavy metal toxicity may disrupt cell components, cellular organelles, mental and central nerve activities, cell membranes, nuclei, and blood compositions; and destroy lungs and kidneys. Long-term exposure to toxic metals can lead to multiple sclerosis, Alzheimer's disease, muscle degeneration, and various types of cancer. Moreover, metal ions interact with nuclear proteins and DNA, resulting in damage to DNA and thus causing cell cycle modulation, carcinogenesis, or apoptosis [5].

These contaminants are classified into two categories, based on the origin – carbon-based and non- carbon-based contaminants. Carbon-based contaminants are referred to as organic contaminants, while non-carbon-based materials are referred to as inorganic contaminants [5].

However, to determine the types of contaminants and their negative impacts on health condition of Gantiwarno people in more detail, further research must be carried out. This is an important step to do to find solutions to the high rate of disabilities in Gantiwarno that has caused numerous derivative impacts, including the deterioration of life quality of disability sufferers, and the development of the area in general.

4 Conclusion

It is very probable that there is something hidden within the groundwater and aquifers in Gantiwarno that has caused a high rate of many disabilities in this sub-regency that are classified as "retarded- mental disabilities – tuna mental retardasi," "physical & mental disabilities – tuna daksa & mental," "physical disabilities – tuna daksa," and "former mental disabilities – bekas penderita gangguan jiwa." Its paleogeomorphological dynamics possibly hide the answer to this condition as Gantiwarno was once under the sea that was then lifted and blocked from the north and the south, creating an ancient swamp. The groundwater in Gantiwarno originates from a mixed process with low to high content of HCO - + CO 2-, low to moderate Ca2+ + Mg2+, moderate to high Na+ + K+, and moderate to high Cl- + SO 2-; and is often called sulphate groundwater. Groundwater in Gantiwarno has moderate to poor quality, with high Cl- and SO 2- contents. This condition causes groundwater to be permanently hard, which is dominated by the types of Na2SO4. The presence of sulfate content (SO 2-) is caused by the reduction of SO 2- from past organic materials. These organic materials are very likely to be found because of the existence of the ancient Gantiwarno Swamp. The groundwater in Gantiwarno is potentially harmful to health, as most tested parameters from it exceed the permissible threshold for consumption. Besides, contaminants possibly exist in Gantiwarno groundwater that have caused high rate of disability in Gantiwarno. All of this is possibly caused by the paleogeomorphological dynamics in Gantiwarno, especially during and after the formation of Gantiwarno Swamp. The swamp has also experienced many other natural and anthropogenic events. This condition has maybe created groundwater that contains exsessive or deficient components needed for human metabolism which have drived the high rate of disabilities. This preliminary study has presented some possible factors that have caused high rate of disabilities in Gantiwarno. However, there are many more to answer. The authors do not give a firm statement in this study regarding the cause of the disabilities. However, they invite other researchers to conduct their study in Gantiwarno for more assessment of this condition and its driving factors. With more researchers studying the area, there will be more information and understanding on this matter, and solutions can be formulated to address the issue.

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