

HYDROCHEMICAL ASSESSMENT OF UNCONFINED AQUIFER SYSTEM IN BAYAT MELANGE COMPLEX, KLATEN, INDONESIA

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ABSTRACT: The geological setting of Bayat that has a complexity in structural geology as well as a variety of lithology because this region is interesting to be investigated from the hydrogeological point of view. Hydrogeological assessments were conducted based on the hydrogeological and geological mapping, as well as hydrochemical analysis. Groundwater level measurements were carried out at 51 measurement points. There were 25 groundwater samples to be analyzed the ion content by using Ion Chromatography and ICP-OES. There are seven (7) lithology units i.e. Schist-phyllite-marble, Nummulities limestone, Diorite intrusion, Pebbly sandstone, Layered limestone, Colluvial and Alluvial deposit based on the surface geological mapping. The geological structure investigation in Temas Hill conduct the trends of structural orientation that are northeast to southwest. They become the point of infiltration and circulation pathways in the crystalline bedrock. Hydrochemical analysis obtain five (5) groundwater facies. They are Ca-Mg-HCO₃, a mix of Ca-Na-HCO₃-Cl, Na-HCO₃, Ca-SO₄ and Na-Cl. The concentration abundances of cation are Na⁺>Ca²⁺>Mg²⁺>K⁺ while HCO₃⁻>Cl⁻>SO₄²⁻>NO₃⁻ represent anion content. A Gibbs diagram shows that the dissolved ions are dominated by rock weathering process. Na⁺ ion is derived from the weathering of feldspar-rich mineral, Ca²⁺ and Mg²⁺ indicate through limestone dissolving. The high Cl⁻ ion content in some samples is predicted from the mixing of upwelling fossil water through Trembono strike-slip fault.

Keywords: Bayat, Groundwater level, Hydrochemical, Groundwater facies, Upwelling

1. INTRODUCTION

Bayat District is geographically located at coordinates of Longitude 110°38'25.8"E to 110°41'9.24"E and Latitude of -7°47'55.32"S to -7°45'48.6"S in Klaten Regency, Central Java Province/Indonesia (Fig. 1). Bayat has a complete type of rocks exposed at the surface. In geoscience, originally rocks divided into three major groups, i.e. igneous (crystallised from molten magmas), sedimentary (lithified from eroded surface materials), and metamorphic (compacted from other existing rocks). All of those rocks are widespread in a short distance in Bayat, exposure past processes of rock deformation (fracturing, faulting, and folding) and present-day processes of rock uplift, weathering and erosion [1]. The complexity of geologic setting in Bayat is interested to be investigated from the hydrogeological point of view.

Hydrochemical assessments are focused on an unconfined aquifer system in this area due to its dynamic condition and also affected by the fluctuation of the seasons. A tropical region such as Bayat (Indonesia) has two seasons, the rainy and dry seasons. A short hydrologic cycle generates a groundwater flow mechanism, as well as the physical and chemical property of groundwater in this aquifer system, is easily changed. It can be affected by the infiltration of surface water,

groundwater interaction with rocks, as well as human activities such as excessive groundwater exploitation and the use of chemicals contain for agriculture and industry.

The local residents withdraw groundwater in unconfined aquifer via dug wells. This aquifer is one of the main water resources that used to meet the needs of daily drinking water. A hydrogeological study in this aquifer is necessary to determine the condition of groundwater level, groundwater flow patterns, as well as hydrochemical. Thus, the utilisation of groundwater resources in this area can be done optimally while maintaining the stability of groundwater itself.

2. GEOLOGIC SETTING OF BAYAT

The study area is a melange zone that geologically located in the Southern Mountains Basin. [2] divides the stratigraphic settings in the Southern Mountains into three periods that sorted based on the chronology of geological time. A time before the intense volcanism activity is called the pre-volcanism, a period of intensively volcanism activity is called volcanism period and a period after volcanism activity is called post-volcanism or carbonate period. Based on the correlation to the regional stratigraphy of Southern Mountain Basin [3], the study area is divided into seven lithological units (Fig. 1). Sorted by the geological age from old

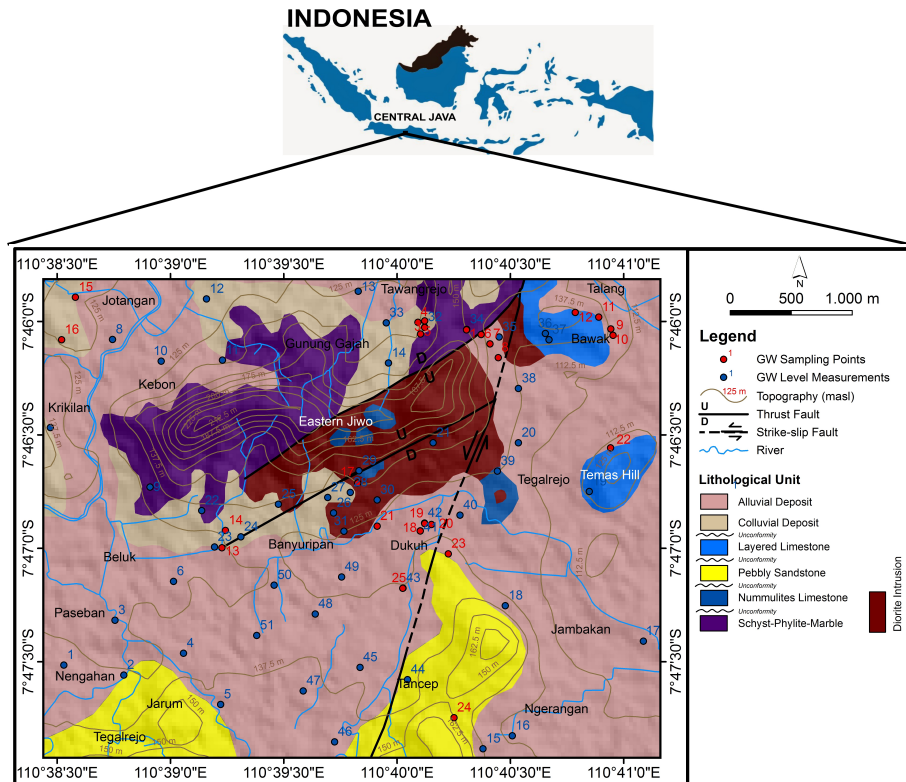


Fig 1. Location of study area showing geological map [1], groundwater sampling locations, and groundwater level measurement points

to young are Schist-phyllite-marble, Nummulites limestone, Diorite intrusion, Pebbly sandstone, Layered limestones, Colluvium and Alluvial deposit.

The basement complex mostly composes of metamorphic rocks, such as Schist-phyllite-marble. Phyllites are the most widespread among other metamorphic rocks, generally in weathered condition with some quartz veins and calcite veins aligned with their [1]. The basement rocks age is around Cretaceous (older than 66 million years ago/mya) by a finding of Orbitolina [4]. Moreover, to predict more accurate of the basement rock age, an application of K-Ar absolute dating of two samples of quartz-mica schist was applied [5]. It resulted in around 98 mya, which belongs to Late Cretaceous epoch. The metamorphic rocks form during a regional metamorphism that involved along with an ancient subducting lithospheric plate and the plates collision afterwards [6]. Subsequent erosion took place for millions of years had uplifted and peneplain those metamorphic rocks, and placed them as the basement rocks for the next oncoming sedimentary sequences [1].

Unconformably overlying the metamorphic basement rocks are Wungkal-Gamping Formation. It has two distinct members, Wungkal and Gamping Members occupies the lower and upper parts, respectively. Wungkal Member deposited during Early to Middle Eocene (55-40 mya) consists of

quartz conglomerates, polymict breccias, quartz sandstones, calcareous sandstones, calcareous siltstones, and some intercalation of Nummulitic limestones. Gamping and Wungkal Members are interfingering each other deposited during Middle to Late Eocene (approximately 48-34 mya) compose of mainly Nummulitic limestones, micritic sandstones, and quartz-arenite sandstones. The Wungkal-Gamping Formation gradually become Kebo-Butak Formation deposit around Late Oligocene to Early Miocene (28-20 mya), which at the lower part composed of sandstones, gravelly sandstones, siltstones, claystone, tuff, and shales. The middle part consists of pebbly sandstones, whilst the upper part is of polymict breccias, sandstones, pebbly sandstones, claystone, siltstones, and shales. Numerous igneous intrusions are producing diorite, diabase, andesite, and basalt intrusion in the period of Late Oligocene [3]. After, volcanic activities had gradually decreased; it forms shallow marine carbonate sequences to be developed at the end of Early Miocene compose of well-bedded limestones (Wonosari Formation). The deposition of Wonosari Formation occurs approximately since 16 to 5 mya. Colluvial and alluvial deposits is the recent product due to erosion and weathering activities.

The structural geology is a thrust fault which cut the block of Schist-phyllite-marble and Diorite intrusion. While the fractures can be found in

several places, one of them is in Temas Hill. The trends of structural orientation are northeast to southwest. Temas Hill is composed of layered limestone lithology. The study area is composed of crystalline basement rocks that are impermeable rock type. The feature of faults and fractures in the rocks can become a point of infiltration and groundwater flow circulation path in this aquifer.

3. METHODS

3.1 Data and analysis

The field campaign was conducted during the period of a dry season (August 2015). The measurement of groundwater level at 51 (fifty-one) stations. Twenty-five (25) selected groundwater samples (Fig.1) were taken by using bottle polyethylene for analyzing hydrochemistry content in the laboratory of Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University, Germany. Hydrochemistry contents consist of cations i.e. Na^+ , K^+ , Ca^{2+} , Mg^{2+} , and anions such as Cl^- , SO_4^{2-} , HCO_3^- , NO_3^- . Ion Chromatography [7] performed anions content. Cations were analyzed by Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-OES) [8]. Data were visualized into some graphics by using Aquachem 2012.1.

3.2 Groundwater Quality Assessment

The evaluation of groundwater quality was analysed by Ion Balance Error (IBE) based on cation and anion content for determining groundwater facies. Raw data were available in [15]. Indeed, the present of cation and anion content of groundwater from several lithologies performed a rock-groundwater interaction. Total Dissolved Solid/TDS represents as a sum of cations and anions value. Electrical Conductivity/EC and pH were measured by WtW Cond 3110 and WtW pH 3210, respectively. Saturation Indice and pH were analyzed to identify some minerals from several lithologies under saturated conditions.

3.3 Analysis of Spatial Data

The spatial data such as groundwater level, pH, and EC were analyzed by using Surfer 9 and ArcGIS 10 to determine the distribution and spatial correlation of each data. Two types of interpolation methods applied in this study. Data that has no significant value between adjacent data such as groundwater level was mapped using Minimum Curvature interpolation. This method uses the slope calculation that changes based on the distance to

estimate the shape of the surface. For data that has a significant value between adjacent data such as pH, EC was mapped using the Inverse Distance to Power (IDP). IDP method assumes that each input point has local influence that reduced toward the distance.

4. RESULT AND DISCUSSION

4.1 Aquifer and Groundwater Flow

The aquifer that becomes the focus attention in this study is an unconfined aquifer. It is easily affected by seasonal fluctuations because the hydrology cycle is relatively short. During the rainy season, the groundwater level will be shallower than in a dry season.

Unconfined aquifers in the study area can be classified into two types of aquifer based on its lithology characteristics. The first type is primary unconfined aquifer where the lithology of this aquifer has a primary porosity and permeability. Thus, groundwater can circulate through the pores. The lithologies that grouped into this aquifer are pebbly sandstone, colluvial and alluvial deposit. The second is an aquifer that composed of a little amount of water. This aquifer consists of fractured crystalline rocks. Water can circulate in these rocks through the secondary porosity and permeability. Lithology that grouped into this aquifer consists of Schist-phyllite-marble, Diorite intrusion, Layered limestone.

Groundwater flows from Eastern Jiwo Hills area (isolated hills) towards the plain of alluvial deposit (Fig, 2). The eastern Jiwo Hills area is a recharge zone where meteoric water could infiltrate through the fractures and fill the aquifers up. While the alluvial plains area that has a lower elevation acts as a discharge zone. The rivers in the study area are effluent streams and found in dry conditions caused by the decline of groundwater levels in this area.

4.2 Hydrochemical analysis

Groundwater samples are grouped into six groups based on the type of lithology. In alluvial deposit, there are five samples as well as layered limestone. There are two samples of gravelly sandstone while diorite intrusion has four samples. Six samples represent colluvial deposits, and around three samples represent in schist-phyllite-marble. Chemical analysis of data correction is analysed by calculating IBE based on the main content of cations and anions. From the calculations obtained the IBE values ranged from 0.1 to 7.3%.

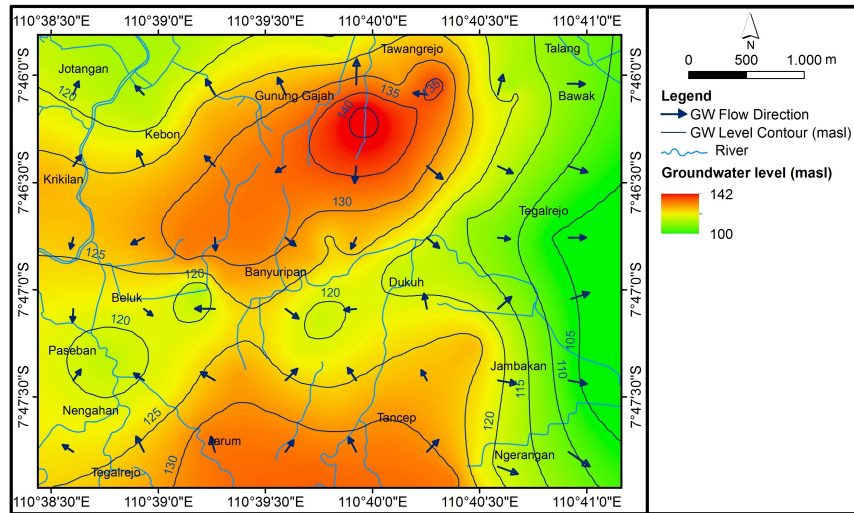


Fig. 2 Groundwater level and its flow direction

The pH values are around 6.81-7.86 with an average of 7.22. It indicates groundwater is neutral. An EC value has a range from 507 to 5,500 $\mu\text{S}/\text{cm}$ with an average of 1,341 $\mu\text{S}/\text{cm}$ that indicates the water comes from groundwater and seawater [9]. Total Dissolved Solid (TDS) has a range from 240-4,473 mg/L with an average of 2,030 mg/L that indicates the water is fresh to salt [10]. Geographically, the study area is quite far from the coastal zone and there are no hydrothermal, industrial or mining activity, so the possibility of salt-water origin is not affected by those factors.

The high number of EC and TDS are predicted from mixing of upwelling fossil water through Trembono strike-slip.

The Na^+ ion contents are in a range from 6.44 to 882 mg/L. Cl^- ion is around 8.55-669 mg/L, and SO_4^{2-} varies between 5-1,769 mg/L (Table 1). The high content of Na^+ , Cl^- , and SO_4^{2-} represent the characteristic of seawater or fossil water origin. The abundance of cations contains $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ while anions is $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$.

Table 1. Hydrochemistry data

Sample Code	pH	EC ($\mu\text{S}/\text{cm}$)	K^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	HCO_3^- (mg/L)	NO_3^- (mg/L)	TDS (mg/L)	Lithology
1	6.94	697	3.53	102	7.56	10.7	148	18.1	200	2.5	492	Schist-Phyllite-Marble
2	6.99	622	1.22	103	12.0	15.4	5	13.6	371	2.5	524	Colluvial Deposit
3	7.58	884	0.50	80.1	26.5	36.6	29.8	28	419	2.5	623	Colluvial Deposit
4	7.05	1,046	1.72	84.2	54.5	28.9	14.7	55.2	530	21.5	791	Colluvial Deposit
5	7.24	989	3.66	138	21.6	32.8	41.6	73.1	438	5.75	754	Schist-Phyllite-Marble
6	7.59	882	1.18	93.9	33.1	61.5	20.8	31.7	513	2.5	757	Diorite intrusion
7	7.19	2,040	4.31	246	24.6	128	10.6	431	360	2.5	1,207	Diorite intrusion
8	7.40	935	0.50	76.0	59.5	60.3	5	31	548	14.1	794	Diorite intrusion
9	7.13	811	1.10	96.7	35.8	26.8	14.6	13.6	472	20.5	681	Layered Limestone
10	7.04	709	0.50	112	18.4	16	10.8	12.9	407	2.5	580	Layered Limestone
11	7.46	687	0.50	92.7	11.2	17.1	5	15.3	394	2.5	539	Layered Limestone
12	7.29	779	0.50	75.8	43.9	31.8	5	15	447	25.6	645	Layered Limestone
13	6.81	783	1.41	92.9	27.9	40.9	25.5	50.4	344	6.54	590	Colluvial Deposit
14	7.29	1,264	1.68	45.0	29.4	192	48.1	40	790	2.5	1,149	Colluvial Deposit
15	7.86	1,024	6.85	106	16.3	103	113	54.5	458	6.93	865	Colluvial Deposit
16	7.09	963	5.35	155	3.61	26.9	41.7	54	395	27.9	709	Schist-Phyllite-Marble
17	7.23	883	3.08	108	15.2	80.1	53.1	43.1	464	2.5	769	Diorite intrusion
18	7.19	2,740	1.58	180	88.6	356	592	223	694	2.5	2,137	Alluvial Deposit
19	7.29	1,951	1.86	83.7	18.2	384	506	56.4	696	2.5	1,748	Alluvial Deposit
20	6.88	699	0.5	137	3.71	6.44	5	8.55	406	2.5	570	Alluvial Deposit
21	7.18	1,434	4.32	76.5	23.7	200	204	24.4	688	2.5	1,223	Alluvial Deposit
22	7.64	1,282	1.42	48	23.8	238	45.7	37	730	2.5	1,127	Layered Limestone
23	6.83	507	1.56	47.8	14.3	43.3	19.4	14.3	257	2.5	401	Pebbly Sandstone
24	7.21	3,410	2.61	169	47.5	629	1,190	99.7	689	2.5	2,829	Pebbly Sandstone
25	7.20	5,500	5.10	356	144	882	1,769	669	646	2.5	4,474	Alluvial Deposit

4.2 Hydrochemical Facies

Several factors control the chemical composition of groundwater, such as the physical condition of the aquifer, the mineral composition of rocks and climate conditions. Based on the plot of Piper diagram [11] groundwater samples conducted various groundwater facies in the study area (Fig. 3). Ca-Mg-HCO₃ water type represents samples of diorite intrusion, layered limestone and schist-phyllite-marble. Two samples of layered limestone show Ca-SO₄ water type. Pebbly sandstone, alluvial and colluvial deposits indicate mixing of Ca-Na-HCO₃-Cl, Na-HCO₃, and Ca-SO₄ type.

Based on the groundwater facies group, Ca-Mg-HCO₃ type is the most dominant, up to 60%, of the groundwater samples. It then followed by facies of mixing Ca-Na-HCO₃-Cl with amount around 16%. Na-HCO₃ and Ca-SO₄ almost 8%, as well as the presence of Na-Cl up to 8%. Hydrochemical facies generally show the local distribution, so it has a close spatial correlation.

4.4 Rock-Groundwater Interaction

4.4.1 Gibbs diagram

The results on Gibbs diagram [14] (Fig. 4 and Fig. 5) shows that almost all groundwater samples are plotted in the rock dominance area except the samples of alluvial deposit and. It indicates that the concentration of ions in groundwater both cations and anions derived from the weathering and dissolution of minerals in the rocks. Weathering and dissolution are possible to come from dissolving layered limestone, weathering of pebbly sandstones and also weathering of silicate minerals from the crystalline basement such as diorite intrusion and schist-phyllite-marble. Some samples of alluvial deposit group are placed in the the evaporation area. It indicates the evaporation process is very high in the alluvial aquifer. This condition is supported by the of climatic conditions in the study area that has a tropical climate. Moreover, the measurements conduct in the period of dry season. The process of evaporation will increase the concentration of ions in groundwater because some of the water evaporate and leaves the dissolved solids. It is also supported by the relatively high value of TDS. The high value of TDS is also caused by the enrichment sodium and chloride ions that is generally derived from seawater or fossil water. On Gibbs diagram, no sample plotted on rainfall zone, because the field campaign is conducted during a dry season. However, the process of evaporation and precipitation are the secondary factors that affect the properties of hydrochemical in groundwater.

4.4.2 Scatter Plot Cl⁻ vs Na⁺

From the results of scatter plot between Cl⁻ ions vs Na⁺ ions with the value of equiline 1:1 (Fig. 6), groundwater samples are plotted above the equiline. It shows the population of the Na⁺ ion is more dominant than the Cl⁻ ion. Na⁺ ion likely comes from the weathering of Na-Silicate rich mineral such as sodium plagioclase from crystalline basement. In addition, Na⁺ ions can also be derived from seawater or fossil water that contain salt mineral (NaCl). Some samples of the alluvial deposit and pebbly sandstones show the Cl⁻ value is higher than the Na⁺ value, where the samples are plotted below the equiline. These conditions indicate the existence of Cl⁻ ion enrichment in some groundwater aquifers that indicate a fossil water mixing. [12] reported that fossil water likely comes from lenticular aquifers. Alluvial deposits in this area are volcanic materials carried out by fluvial activity during the Holocene age. Lenticular deposit may still occur in the floodplains because the deposition takes place in the terrestrial environment. It will not carry out the salt water. Fossil water comes from the Tertiary sedimentary rocks deposited in the marine environments. The existence of Trebono strike-slip fault can become an upwelling path for fossil water and it then mixing with shallow groundwater. Fossil water is located at a certain depth and the possibility to interact with shallow groundwater is slight. The presence of uplift basement (Schist-Marble-Phyllite) that are exposed to the surface indicate the tectonic activity has raised the rock formations up that bring fossil water become shallow.

4.4.3 Scatter Plot (HCO₃⁻ + SO₄²⁻) vs (Ca²⁺ + Mg²⁺)

The Ca²⁺ and Mg²⁺ are the cations that are affected by the dissolution of carbonates minerals. A scatter plot between (HCO₃⁻ + SO₄²⁻) vs (Ca²⁺ + Mg²⁺) show the dominant weathering process occurred (Fig. 7). Chemical data of groundwater samples taken in alluvial deposit, gravelly sandstone, diorite intrusion, schist-phyllite-marble and colluvial deposit are plotted below the equiline 1:1. It indicates the weathering processes are dominated by the weathering of silicate minerals. Dissolved ions derived from the silicate mineral-rich rocks represent the possibility of weathering-derived from metamorphic rocks types and diorite intrusions. Pebbly sandstones, in this area come from the volcanic material destruction, contain high silica. It indicates an abundant feldspar mineral in the rocks (KAlSi₃O₈-NaAlSi₃O₈-CaAl₂Si₂O₈).

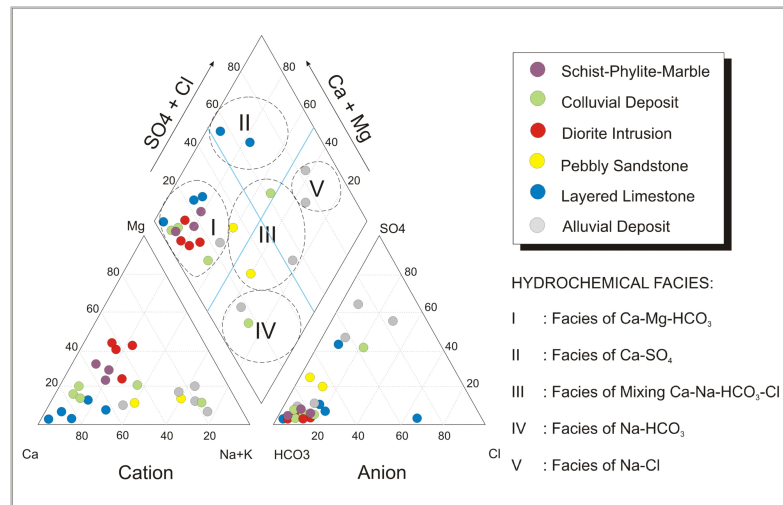


Fig. 3 Groundwater samples plot on Piper diagram

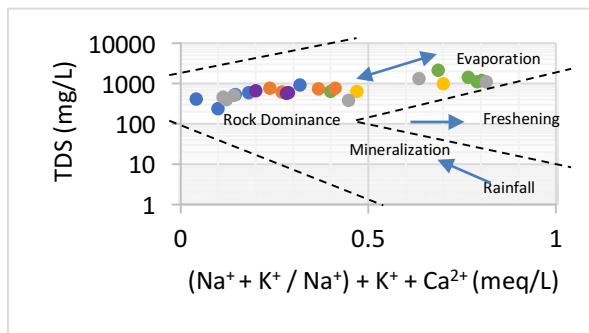


Fig. 4 Gibbs diagram (Na⁺, K⁺, and TDS)

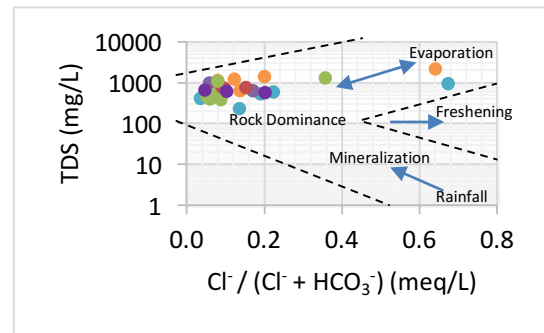


Fig. 5 Gibbs diagram (Cl⁻, HCO₃⁻, and TDS)

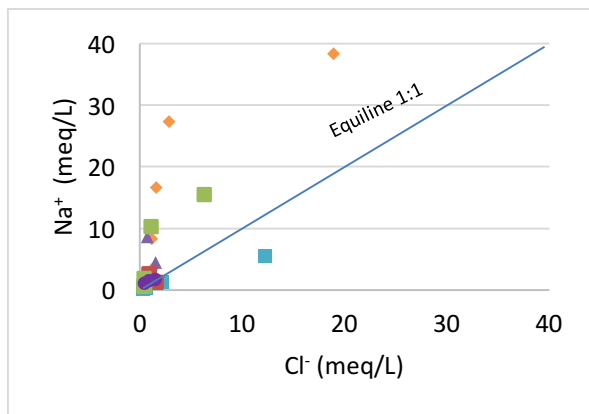


Fig. 6 Scatter plot Cl⁻ vs Na⁺

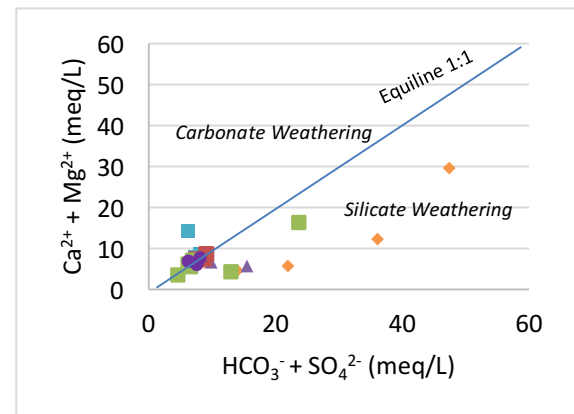


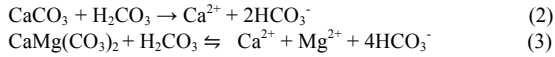
Fig. 7 Scatter plot (HCO₃⁻ + SO₄²⁻) vs (Ca²⁺ + Mg²⁺)

In addition, feldspar minerals weathering also produce a lot of sodium (Na⁺) and potassium (K⁺) ions in groundwater. Moreover, weathering of carbonate also can be found mainly in layered limestone and some samples of diorite intrusion, schist-phyllite-marble and colluvial deposit. It represents that lithology have pH with slightly more acid than alluvial deposits. The more acidic pH will increase the aggressiveness of groundwater in dissolving minerals, especially calcium and carbonate. Rainwater will be naturally slightly acid

because it reacts with atmospheric carbon dioxide into carbonic acid Eq. (1).



The meteoric water can infiltrate through the cracks and occurs chemical reaction between the carbonic acid with calcite Eq. (2) and dolomite Eq. (3) via some intensive fractures in layered limestone.



Based on the reaction above, the result of the dissolution of calcite or dolomite will generate Ca^{2+} , Mg^{2+} , and HCO_3^- .

4.4.4 Saturation Indices (SI) of Mineral

Saturation indices (SI) shows that the pH value is directly proportional to the value of SI. The high pH value depicts the high of SI and vice versa (Fig. 8). The aggressiveness of the water in dissolving

minerals will be reduced so that water is not able to dissolve the mineral, especially calcium. SI will be equilibrium on the number of 0 [13]. SI over 0 indicates a condition of saturated mineral in water (super saturated) then the mineral will be precipitated. While if the SI is less than 0 indicates the dissolving process is still ongoing. Some samples i.e. the mineral of calcite, aragonite and dolomite are in saturated conditions based on the calculation of the SI. While the minerals of halite, anhydrite, and gypsum indicate under saturated conditions.

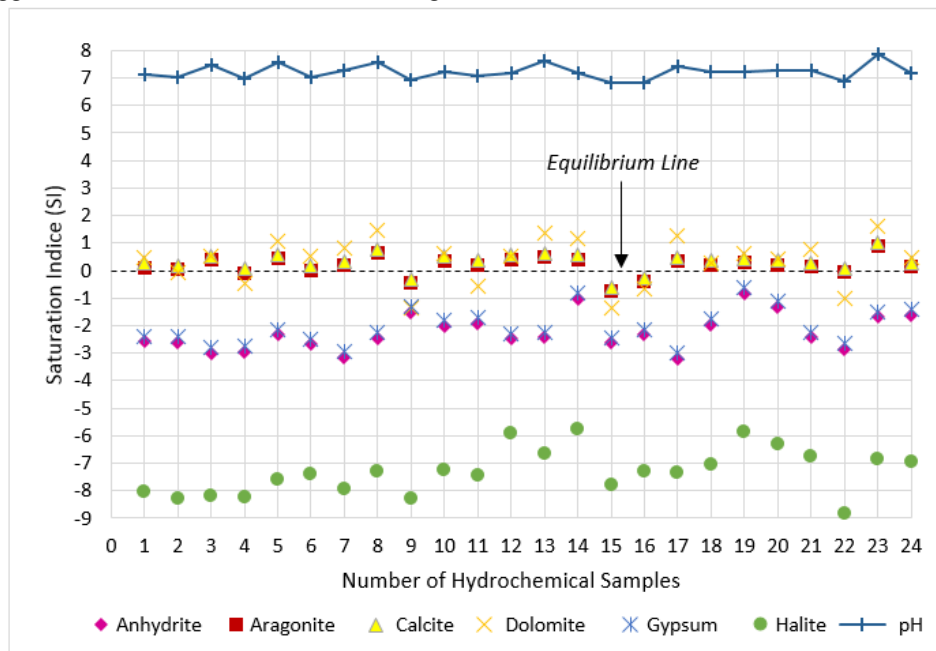


Fig. 8 Graphic of pH and Saturation Indices of Mineral (SI)

5. CONCLUSION

The study area is composed (from old to young) of Schist-phyllite-marble, Nummulities limestone, Diorite intrusion, Pebbly sandstone, Layered limestones, Colluvial and Alluvial deposit. The structural geology that can be identified is shear fractures and thrust fault.

The Eastern Jiwo hills is the recharge area while alluvial plain is discharged area. Groundwater flows from Eastern Jiwo Hills towards the alluvial plain. The alluvial plain is basin filling or zone of groundwater accumulation this area.

There are five (5) hydrochemical facies. Ca-Mg- HCO_3 is the most dominant water type, followed by mixing of Ca-Na- HCO_3 -Cl, Na- HCO_3 , Ca- SO_4 , and Na-Cl. The abundance of cations content can be sorted sequentially, namely $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ while anions is $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^-$.

Gibbs diagram shows the ions dissolved in groundwater are derived from the weathering and

dissolution of rocks that influence groundwater type. The presence of Ca^{2+} and Mg^{2+} indicates a very intensive limestone dissolving. Enrichment of Na^+ ions derive from the weathering of sodium silicate-rich rocks. The high numbers of Cl^- and SO_4^{2-} ions content in some samples are predicted coming from the mixing of fossil water.

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