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Recharge Area on the Slopes of Volcano Based on Geological Setting, Content of Deuterium and Oxygen Isotopes of Groundwater Chemistry: Case Study on the Slopes of Salak Mountain, West Java

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ABSTRACT

Indonesian is huge areas that have the highest precipitation in the world, therefore water deficit of groundwater is often happened at anywhere. This study was related to determination of recharge area with approached by combining geological setting, stable isotopes and chemical content of groundwater. Case study was carried out at surrounding the Cicurug area, Sukabumi Prefecture, West Java Province. The area is the slopes of Salak Mountain that have elevation of 400 until 1,200 m mean sea level (msl). While, much groundwater supplies industry activities on elevation 450-500 m msl. Based on data and result analysis of the studies, the recharge areas was not around peak of mountain or near, but water infiltrated on elevation of 700-800 m msl for groundwater exploited by industries. Therefore, the accurate determination of recharge area becomes a key for the groundwater sustainability.

Keywords: Geological condition, groundwater isotopes and chemical content, recharge area, slope of volcano area

INTRODUCTION

The volcanic terrain has many worthwhile natural resources for the sake of human life. One of this natural resource content is water, either surface water or groundwater. Volcanos with forming geomorphological hilly and slopes in nature have potential for distributing recharge area as well as large issuing water in the discharge zones such as springs. As along with using groundwater in the downstream or in the flat areas of volcanic slopes, concern for recharge area is very important for keeping groundwater sustainability.

In Indonesia, the recharge area is generally determined by conventional approach through only high-law topography sistem, profiles of soils and rocks from surface until underground. Some previous studies have provided to use groundwater isotopes in defining inflow water and to delineate recharge zones such as Juanda and Sunarwan (1998) surrounding the Cimahi area, around high land of Bandung Basin (Geyh 1990). Beside, Lubis *et al* (2008) tried to use groundwater temperatures and isotopes compilation for recharge area on the Jakarta Basin. However, the previous studies using stable isotopes are still scare and there are many difficulties to predict due to non periodic sampling for isotope data with season in Indonesia. In the other side, amount of water inflow into soil/rock layers or aquifer is determined by the position and width of the recharge properly, so thus water balance calculation may be overestimate or underestimate. It is not surprising in Indonesia when the safe yield in calculation is not critical but the case is actually decline of water resources. Even phenomena of water deficits happened on some big cities in Indonesia. Ironically, Indonesia has the highes mean rainfall about 2700 mm yr^{-1} (UNESCO 2003).

In general, volcano areas where water flows and recharge places into aquifers, supply water for the need of agriculture areas and big cities in Indonesia. Therefore, this study has relevancy for those the illustration as mentioned previously as associated with water on the volcano areas. The case study was carried out on the southern part of Salak Mountain, Cicurug area and vicinity, Sukabumi,

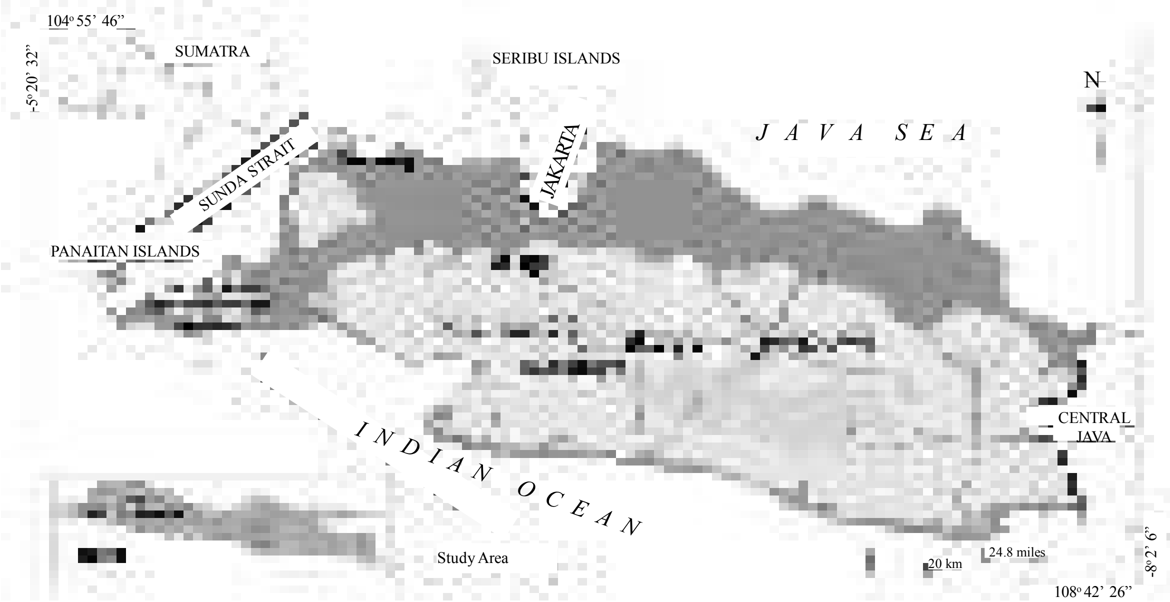

Figure 1. Location of study area surrounding the Salak Mountain.

West Java (Figure 1). In this area, land for agriculture is developed as well as industries activities.

The purpose of this study was to define delineating recharge areas properly for springs and groundwater wells in varition of altitude that was distributed around southern part of the Salak Mountain. At least, this result can attract for other study mainly in the volcano areas as water resources. This study may become as reference for clarifying land used in Indonesia.

MATERIALS AND METHODS

Study Area

Geographically, The study area lies between latitude of 6°42'23" and 6°49'8" S and longitude of 106°42'53" - 106°47'49" E (Figure 1). Field surveys were carried out during August 2006 until August 2007 and data analysis was performed until February 2008 after the result was approved by experties from PT. Tirta Investama Danone, France. Geological seting of study area is approached by geological mapping through traversing method or outcrop described activities in the field (Barnes dan Lisle 2004). This method used some tools such as geological compass, GPS, hammer of igneous and sedimentary rocks, loupe and topography map. The rock outcrops were observed on 56 sites with the sampling representative 10 rocks sliced in the study area for analysis of mineral content. Similarity and distinguised rocks were mapped and described in the form of geological map.

While for observation of stable isotopes, 4 rainfall stations (Babakan Pari, Cidahu; Pasir Reungit, Jaya Bakti Village, Cidahu; Kuta Girang Village, Kuta Jaya, Cicurug: and Tenjolaya Village, Cicurug) were installed at places with altitude variation (Figure 2).

Sampling rainwater used the special appliance of steel stainless. Sampling was also conducted at least 11 sites of water source with 3 among them

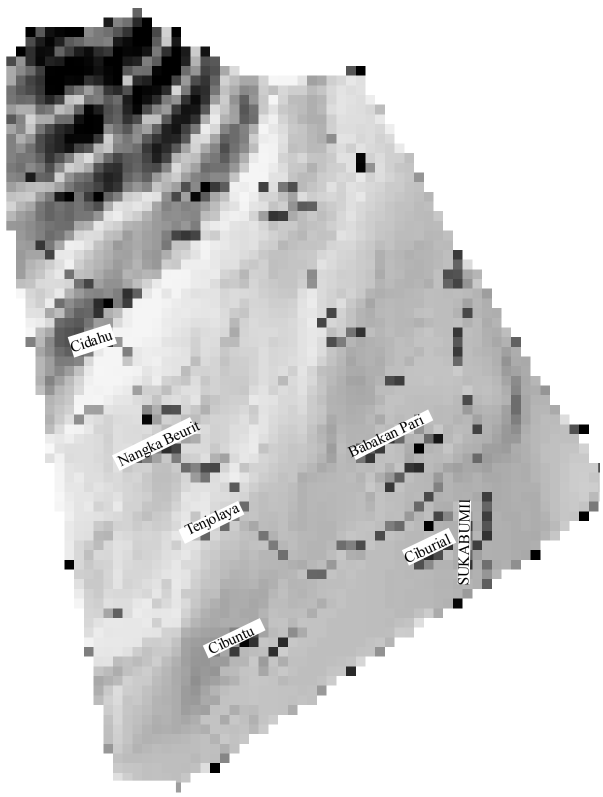

Figure 2. Location of sampling for water isotope content.

taken from wells of factory which had about 36 m depth. Technical sampling was performed random and periodic from springs, wells and rainfall every 2-3 months and particularly every month for rain water. Obstetrical Analysis of ^{18}O and ^{2}H (deuterium) isotopes was used by mass spectrometer appliance beforehand done by preparation (Fritz dan Fontes 1981; IAEA–Vienna).

Analysis of ^{18}O Isotope

Isotope ^{18}O analysis was conducted by reacting 2 ml water sample with gas of CO_2 and shake during 4-6 hours till reached the isotope balance. In this reaction, transfering the isotope ^{18}O from water sample into gas of CO_2 happened as reaction of the following,

$$H_2{}^{18}O + CO^{16}O \dashrightarrow H_2{}^{16}O + CO^{18}O$$

Gas of CO_2 result from this reaction, then flowed into mass spectrometer appliance to be measured for the ratio $^{18}O/^{16}O$.

Analysis of ^{2}H Deuterium

Analysis of Deuterium was through reaction of water sample with Zn powder (shoot) at temperature of 450°C in a condition yield gas of H_2, the reaction as follows;

$$H_2O + Zn \text{ à } ZnO + H_2$$

Gas of H_2 resulted from above reaction was then conducted into mass spectrometer appliance to be measured by ratio of D/H. Calculation result for ^{18}O and deuterium isotopes analysis refers to international standard that is called as the SMOW (Standard of Mean Ocean Water). Standard of SMOW as reference with the ratio value ^{18}O / ^{16}O and D/H is zero (0). Calculation result for ratio analysis ^{18}O / ^{16}O and D/H is expressed in the ratio relative (d) with set of per mill as the following

$$d = [\ ^{18}O/^{16}O\ ]\ \text{sampel} / [\ ^{18}O/^{16}O\ ]\ \text{standar} \times 1000^{o}/_{oo}$$

After calibrated by Standard of SMOW, result can be constructed as following isotopic index (mean-weight), local meteoric line and relationship between isotope composition and elevation. Isotopic index (mean-weight) of ^{18}O and ^{2}H in each rainfall station can be calculated based on equation below

$$MW = C_1X_1 + C_2X_2 \ldots. + C_nX_n \ldots X_1 + X_2 + X_n$$

Where: C_1, C_2, ... C_n is composition in 1st, 2nd, … n-th month precipitation, X_1, X_2, .. X_n is amount of precipitation in 1st, 2nd, … n-th month of monitoring.

During sampling in the field, physical parameters such as pH, Electrical conductivity, temperature and dissolved oxygen, were measured by portable tool. Testing for samples of spring, at least 14 samples from different altitudes and aquifers were perfomed. Water samples were tested at laboratorium to obtain the major ion content such as Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, $CO_3^=$, HCO_3^- dan $SO_4^=$. Domination of cation and anion is defined by trilinear Piper's diagram (1944) in order to obtain the groundwater facies. This facies will support in predicting groundwater flow system as well as predicted by geological approach and validation from isotope content.

RESULTS AND DISCUSSION

Although detailed map was not available yet, but geological setting of Salak Mountain has been mapped regionally with quite small scale of 1: 100.000 (Efendi 1974). Therefore, it is important to conduct detailed mapping on the basis of geological regional map. Mapping result indicated that there were some modification in rock variation and geological setting. The rock units were changed in short distance (in order of 10 to 100 m), and can be divided into some units such as shown in Figure 3.

The study area generally had radial stream system where develop to be parallel stream system in middle part of the Salak Mountain. Direction of stream flow indicate northwest-southeast relativelly as corresponding to direction of long ridge. The study area consists of 6 units of rock which are laharic breccia unit, welded tuff unit, tuff unit pumiceous tuff unit, paleosoil unit, lapilli tuff unit, lava unit as associated with vertical succession as shown in Figure 11.

Combining field and laboratorium description indicated that laharic breccia unit was composed of silica and ferry oxide, component of andesitic igneous (*porfiri andesite*) with grained 2 mm to 8-20 cm and very compact. Pumiceous tuff unit belongs to vitric tuff with composed of clorite mineral, ferry oxide, clay mineral and some associated with opaque minerals. Disclosed paleosoil was separated between tuff unit and lapili tuff layer in lower part. Lapilli tuff unit itself indicated grained 0.05 – 0.26 mm with plagioclas mineral content. Lava unit had color of blackish gray with fractures and piroxine mineral content. This unit indicated andesitic igneous.

Four aquifer systems were identified from drilling well, consisting of laharic breccia aquifer, pumiceous tuff aquifer, lapilli tuff aquifer and lava aquifer. Groundwater flows through pore between grain and also through fracture system.

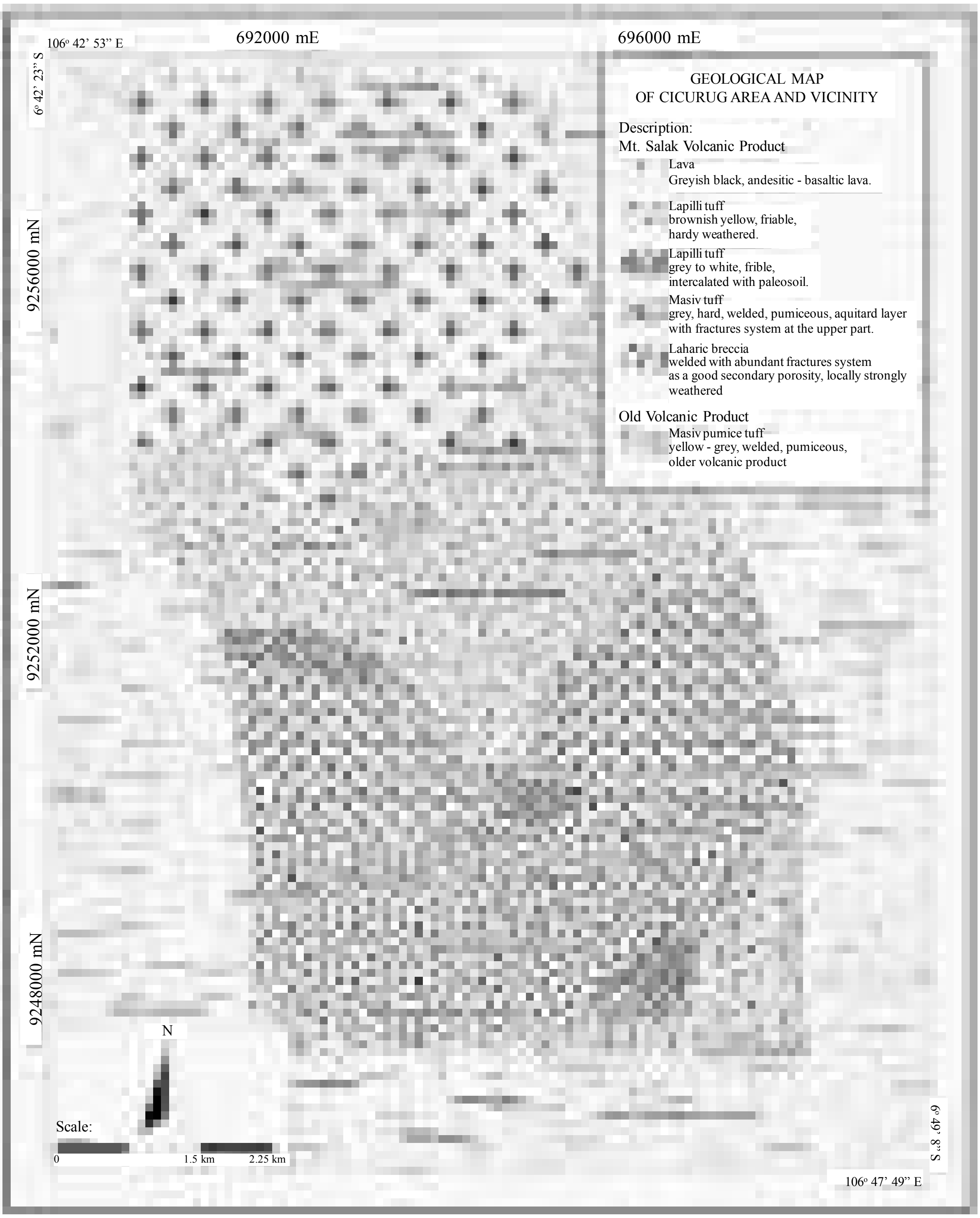

Figure 3. Result of geological mapping with distribution of rock units in the study area.

The results of ^{18}O and of ^{2}H, isotope analysis during the research period can be shown in Table 1 and 2, while Figure 2 shows location for sampling (see method). Based on this category, monitoring of rainfall and its isotope composition covered more than 95% of annual rainfall. The amount of rainfall in each station along the research period varied, between 33.3 – 287.1 mm. The intensity of rainfall was quite proportional to its isotopes composition. Generally, isotopes composition of rainfall will be more ^{18}O dan ^{2}H depleted if the intensity of rainfall was heavy, whereas will be more ^{18}O dan ^{2}H enriched if the intensity of rainfall was low (phenomena of amount effect).

Isotopic index (mean-weight) of ^{18}O and ^{2}H in each rainfall station can be calculated based on the equation as mentioned in method part. Isotopic mean-weight is shown in Table 3 for each rainfall station. This local meteoric water-line can be used as reference to relate between isotopic composition

Table 1. Data of rainfall on the 4 station of observation (mm).

[illegible]

Table 2. Analysis result of ^{18}O dan ^{2}H isotopes from rain water samples.

[illegible]

Tabel 3. Values of meanweigth of isotope content for each rainfall station.

Station	Elevation (m)	^{18}O (‰)	^{2}H (‰)
Babakan Pari	475	-5.56	-30.99
Pasir Reungit	628	-6.85	-41.54
Kuta Jaya	760	-6.74	-41.01
Tenjolaya	923	-7.20	-43.45

of precipitation and groundwater sources (springs and wells) to determine its origin and recharge area. Constructing simulation is also compared to research of Fan *et al.* (2008) in the Heishui Valley, indicating that the spatial variation of the stable hydrogen and oxygen isotopes from different tributaries was correlated with changes in altitude. Correlations between isotopes and elevation for the *mean weight* of isotopes indicate linear line as shown in Figure. 4, 5 and 6. Decrease of ratio values of ^{18}O dan ^{2}H (deuterium) isotopes were 0,43‰ dan 3,45‰, respectively as increase of every 100 meter in elevation.

Analysis result of ^{18}O and ^{2}H isotopes were resulted from three times monitoring in the study area *i.e.* springs and wells as shown in Table 4. Springs and wells consisted of 9 springs and 3 wells of PT. Tirta Investama Danone, that distributed in variation of altitude (Figure 2). Analytical error of simulation ranged from 0.08 to 0.20‰ and 0.39 to 2.22‰ for ^{18}O and ^{2}H respectively. It is well known that statistically 0.2‰ and 2.0‰ difference for ^{18}O and ^{2}H respectively are not significant. Figure 7 shows the relationship between ^{18}O and ^{2}H composition of springs and wells, compare to mean weight rainfall, local meteoric water line, and global meteoric water line Isotopic composition of groundwater is close to the line of local meteoric

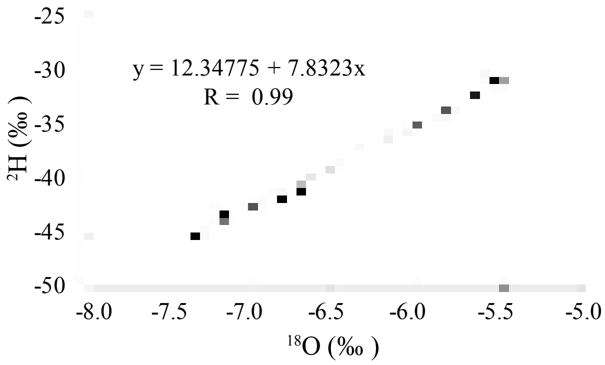

Figure 4. Relationship between ^{18}O and ^{2}H (deuterium) isotopes from meanweight of rain water.

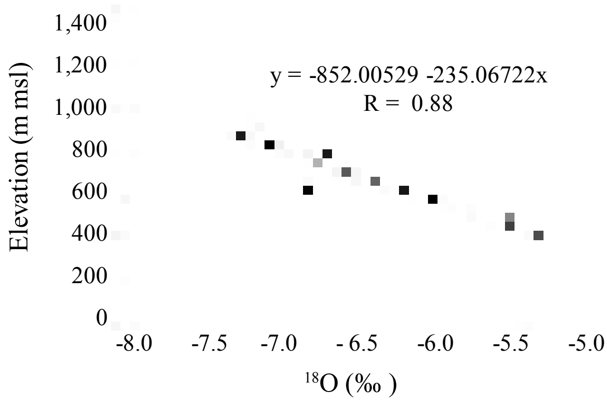

Figure 5. Relationship between ^{18}O and elevation from meanweight of water rain.

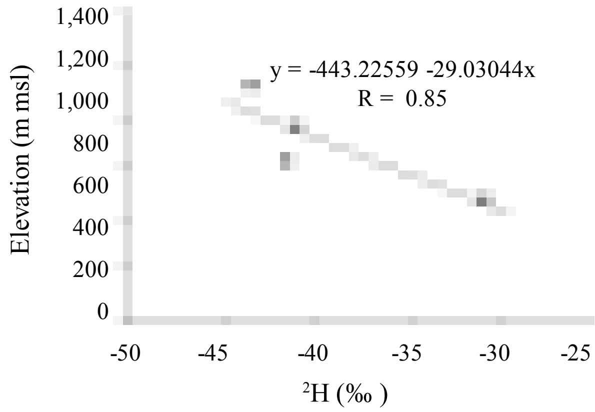

Figure 6. Relationship between deuterium and elevation from meanweight of water rain.

water, and there is no indication of evaporation process or mixing with other source. This condition shows that the source of groundwater is meteoric origin with different elevation of recharge places. ^{18}O and ^{2}H isotopic composition of Babakan Pari Discharge as associated with wells of PT. Tirta Investama Danone, correspond to the values of rainfall isotopic composition in the Kutajaya Girang (760 m) and Tenjolaya (923 m) Stations. Result of simulation is shown in Figure 8.

The elevation of recharge area can be determined by entering the values of ^{18}O and ^{2}H from water discharge into equations resulted from relationship between elevation and isotopic composition. Another way, it can be determined through graphic as shown in Figure 9. Based on linear equation and graphical solution, the elevation of Babakan Pari's recharge area is located at altitude of 800 ± 100 m asl.

Concerning groundwater chemistry, water was sampling from springs that emerge in varying altitudes and rocks. Data of groundwater chemistry content are shown in Table 5.

Table 4. Analysis result of ^{18}O dan ^{2}H from groundwater samples.

Location	Elevation	Sampling I		Sampling II		Sampling III		Average	
	(m)	^{18}O	^{2}H	^{18}O	^{2}H	^{18}O	^{2}H	^{18}O	^{2}H
		………	………	………	………	(‰)	………	………	………
Well 1 Aqua, Babakan Pari	475	-6.93	-41.4	-6.9	-41.2	-6.87	-41.40	-6.88 ± 0.03	-41.33 ± 0.39
Well 2 Aqua , Babakan Pari	475	-7.06	-42.8	-6.93	-42	-7.20	-44.10	-7.06 ± 0.14	-42.97 ± 1.06
Well 4 Aqua, Babakan Pari	475	-7.05	-42.6	-7.3	-43.6	-6.90	-41.12	-7.08 ± 0.20	-42.44 ± 1.25
Garuda Spring Tenjolaya, Cisaat, Cicurug	760	-7.21	-43.7	-7.2	-43.1	-7.43	-45.90	-7.28 ± 0.13	-44.23 ± 1.47
Cimumutan Spring, Tenjolaya, Cisaat , Cicurug	900	-7.50	-46.7	-7.35	-44.8	-7.44	-46.52	-7.43 ± 0.08	-46.01 ± 1.05
Well PDAM Cikombo	590	-7.54	-46.8	-7.56	-46.6	-7.63	-48.04	-7.58 ± 0.05	-47.15 ± 0.78
Cidahu Spring, Mount Salak	900	-6.07	-34.6	-7.14	-35.9	-7.22	-41.40	-7.18 ± 0.06	-37.30 ± 2.22
Nangka Beurit Spring, Cidahu Village	710	-6.73	-39.8	-6.44	-38	-7.16	-39.00	-6.78 ± 0.36	-38.93 ± 0.90
Cibuntu Spring, Pd. Kaso Tengah Village	520	-7.32	-44.8	-7.29	-44.3	-7.00	-44.20	-7.20 ± 0.18	-44.43 ± 0.32
Ciburial Spring, Babakan Jaya Village, Parung Kuda	472	-7.59	-46.7	-7.23	-43.8	-7.05	-46.20	-7.29 ± 0.27	-45.57 ± 1.55
Cimabuputan Spring	1023					-7.46	-48.18	-7.46	-48.18

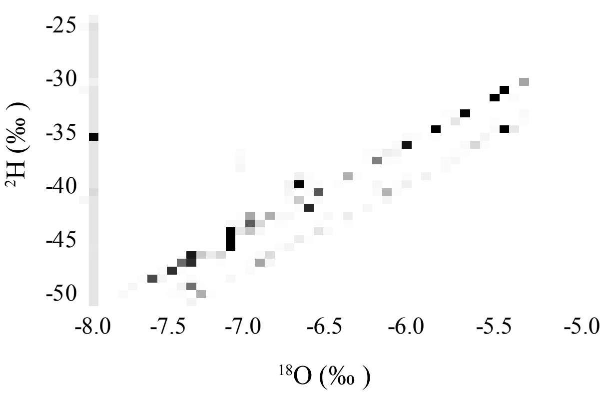

Figure 7. Relationship between ^{18}O dan ^{2}H from samples of groundwater and rainwater. ▪= mean of rainfall, ▫= mean of wells/source, = Line of local meteoric, and ▫▫= Line of global meteoric.

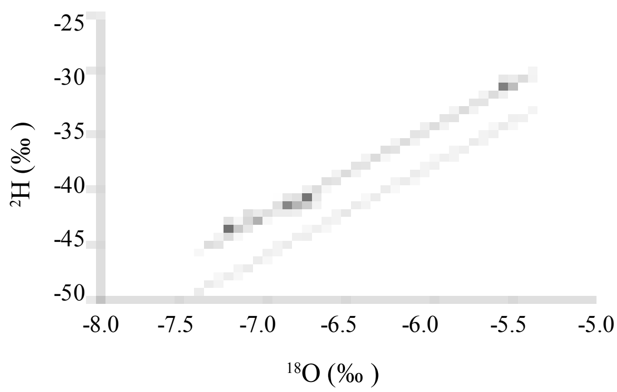

Figure 8. Relationship between ^{18}O and ^{2}H from Babakan Pari source and rain water. ▪= mean of rainfall, ▫= Source of Babakan Pari wells, = Line of local meteoric, and ▫▫= Line of global meteoric.

Sample numbers follow the site number of geological observation. Interaction between groundwater and rock can produce dissolution with certain features, therefore the water chemistry can be used to evaluate dissolution along the flow path. Then the long-term impact can be predicted. Groundwater facies as product from data processing of groundwater quality using Piper diagram, can support in verification and validation of groundwater being flow path.

Simulation result indicated 4 groundwater facies, consisting of fasies Ca, Na-K, HCO_3 in the sites of S-37, S-38, S-39, S-40, S-41, S-44, S-45, S-47, S-50, S-51, S-52, S-53, S-54; fasies Mg, HCO_3, in the site S-43; fasies Mg, SO_4 in the site S – 49; fasies Na-K, SO_4 in the sites of S-42, S-46, S-48 (Figure 10). This geochemical patterns tend to be related to variation of rock units in the study area as Glynn and Plummer (2005) suggested that many

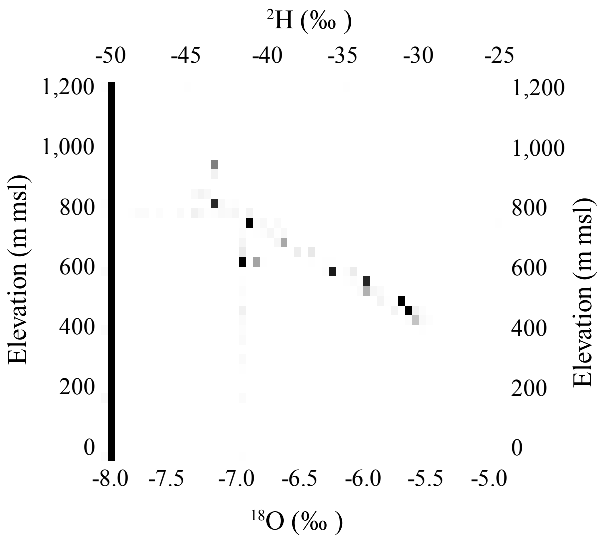

Figure 9. Graphic for determining elevation of recharge zones. = ^{2}H, = ^{18}O.

geochemical patterns observed in groundwater systems can also be related to heterogeneities in reactive mineral abundances and difference in hydrologic characteristics.

Based on identification of the emerged springs, wells in the field and their location, groundwater discharge can be divided into altitude of 800-900 m msl, 650-600 m msl dan 450-500 m msl, in particular groundwater from wells of laharic breccia aquifer (site of PT.Tirta Investama Danone at Babakan Pari). As mentioned in purpose of this study, where is the recharge zone from groundwater exploited by industries? Azzaz *et al.* (2008) suggested that it is difficult and the determination of recharge altitudes must be controlled by topographic and geologic criteria.

As distribution of rocks in the geological profile configuration (Figure 12), springs on altitude 800-900 m msl issuing water from lava aquifer are predicted that recharge water comes at the peak of Salak Mountain (1000-1200 m msl). This interpretation is supported by isotope composition, indicating that water infiltrated in short distance on the altitude of 900 - 1100 m msl. However, groundwater facies is composed Natrium in the Ca, Na-K, HCO_3 type, reflecting that water flows in the short distance with deep circulation flowpath (refers to groundwater evolution, Chebotarev (1955) cited by Hiscock 2005). This groundwater flow system belongs to local system (To'th 1963).

Quite difference for springs on altitude of 650-600 m msl, geological profile indicates that shallow groundwater flows in the lapilli tuff aquifer and being retained by laharic breccia as impermeable layer in the lower part. This circumtance of flowpath

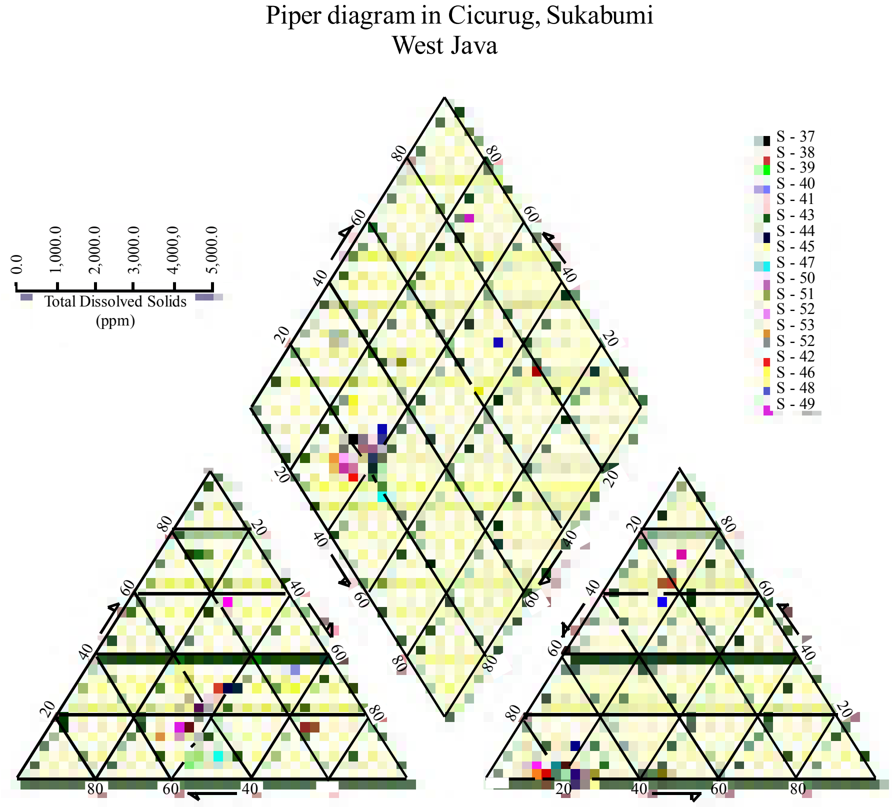

Figure 10. Groundwater quality processing used by piper diagram.

Table 5. Groundwater quality Data of some springs resulted from laboratorium test

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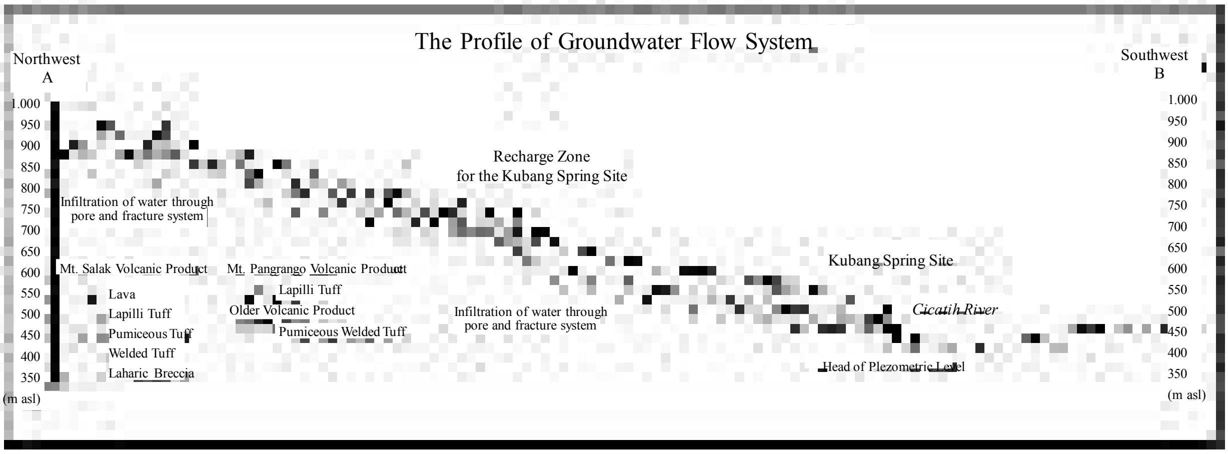

Figure 11. Geological profile in the study area.

is supported by isotope composition, indicating that recharge water happened at altitude of 800-900 m msl. While from groundwater facies, Mg, HCO_3 and Mg, SO_4 types may indicate that intensity of flow is in slightly long distace and mixing between shallow and deep water circulation. This groundwater flow system is classified into middle system or intermediate system.

In particular for springs on altitude of 450-500 m msl that known as Ciburial spring, groundwater issue from laharic breccia aquifer, outflowing in some springs and the wells of PT.Tirta Investama Danone around Babakan Pari. This aquifer is confined aquifer and water flows through fracture system. Geologically, water resource comes possibly from places around altitude of 600 and 850 m msl (see profile). This prediction is supported by the presence of land subsidence or possible fault in rock layers and by developing fractures on the surface of soil and rock outcrop. The other possibility that water may come from places on altitude of 1,000 – 1,200 m msl. However, result of isotope analysis indicated that both water resources come from water infiltrated on altitude of 700-800 meter msl. Certainty of this water recharge is also supported by analysis of facies Na-K, SO_4. Alan *et al.* (2007) described that total dissolve Solid (TDS) can help to identify the different flow for one aquifer to other aquifers. TDS values of groundwater resource on this altitude is quite higher than other springs (Table 5 and 6). Based on those phenomena, water flow is characterized by coming from long distance and deep circulation flowpath. This groundwater flow system belongs to regional system (To'th, 1963). Therefore, summary from the third approach indicates that recharge area for water from laharic breccia in the wells exploited by industries is places on altitude of 700-800 m msl (Figure 12).

CONCLUSIONS

Based on third approach in the study area, it can be concluded recharge area the springs issuing water on altitude of 800-900 m msl came from places on the altitude of 900 – 1,100 m msl. While, springs issuing water on altitude of 650-600 m msl came from places on altitude of 800-900 m msl. In particular groundwater exploted by industries and some springs on altitude of 450-500 m msl, water can be origin from places on altitude of 700-800 meter msl.

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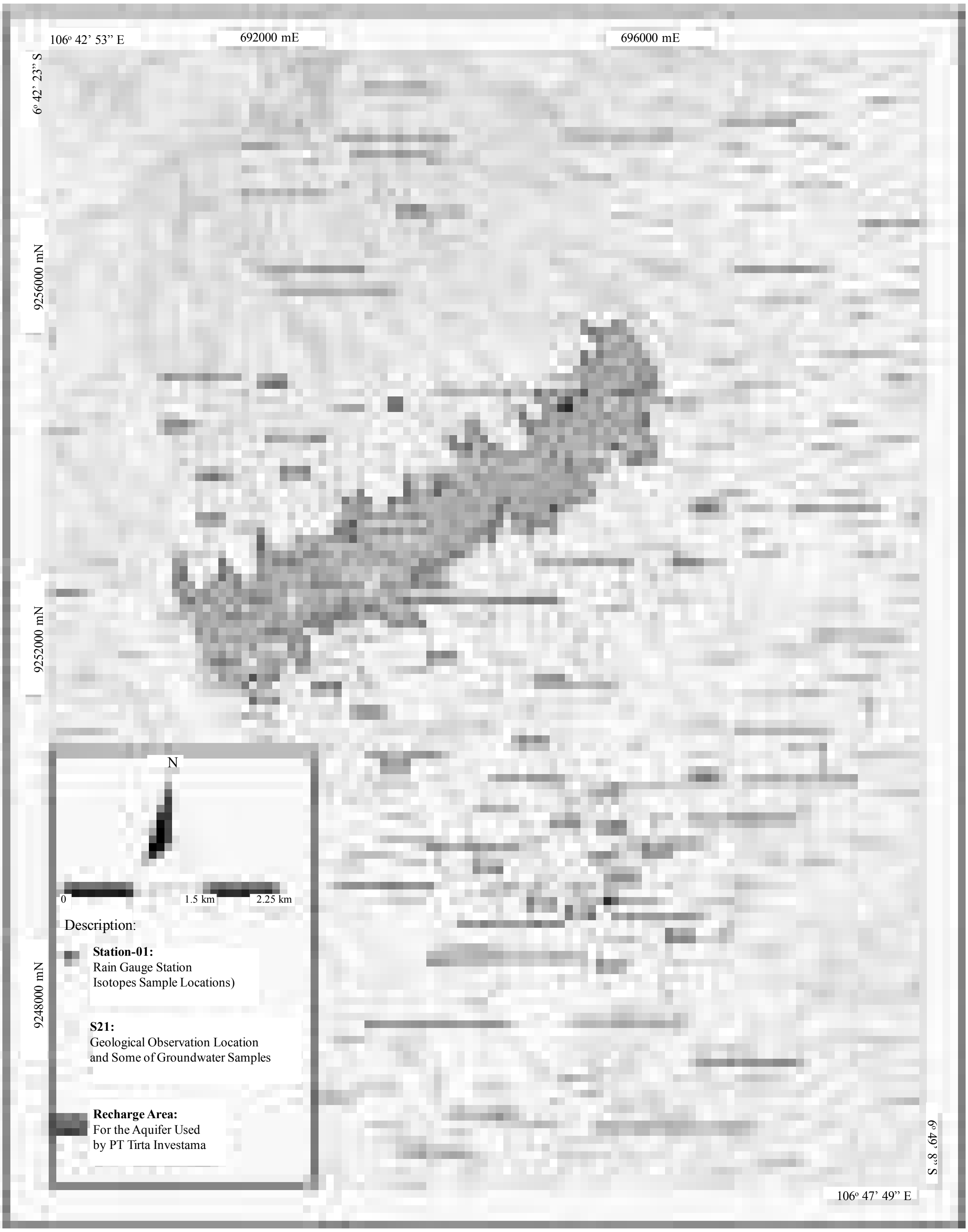

Figure 12. Recharge area for groundwater exploited by industries.

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