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Unconfined Aquifer System of Volcanics in the Northern Part of Bandung Basin, West Java, Indonesia

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Abstract

The foot slopes of the volcanoes along the margin of the Bandung basin area is interesting for the study of groundwater resources. A better understanding of the volcanic succession of the Cikapundung Formation is a key to identifying the distinct aquifer system in the study area. Five types of unconfined aquifer have been classified on the basis of hydrogeological mapping, e.g., the volcanic breccia aquifer, the lapilli tuff aquifer, the clinker and gravel under lava flow aquifer, the fractured lava aquifer and the fractured lahar aquifer. The clinker lava and gravel-under-lava aquifer system indicated a better network of openings, and as a consequence, this system has higher permeability than other aquifer systems. The physical groundwater of each aquifer through springs indicates that the groundwater has pH 6.16-6.99 and electrical conductivity (EC) 70.7-415 mikromhos/cm. During two seasons, the seasonal variation in EC and pH of aquifer is not significant. The groundwater temperature of springs decreases with spring elevation increase. At an altitude around 800 m above mean sea level (amsl), the groundwater temperature ranges from 24.1℃ to 24.9℃, whereas along elevation 1100 m amsl the range is 21.5℃ to 21.7℃.

Key-words : Hydrogeological study, volcanic succession, geological properties, physical groundwater, unconfined aquifer system.

1. Introduction

The study area is known as the Bandung region which is about 150 km south from Jakarta, the Capital City of Indonesia (Fig. 1). The northern part of the Bandung basin occupies about 91 km^2 and lies partially within paddy fields, vegetable gardens and only a little of forest. This area is an important which contains groundwater resources for not only water supplies but also for the irrigation system.

Due to the hydrogeological setting of the Bandung basin, some studies have focused on the groundwater occurrences. Recharge from precipitation varies from about 30 to 50 percent and reaches shallow or deeper aquifers (Pulawski and Obro, 1976; IWACO-WASECO, 1991). Numerous hydrological and hydrogeological studies have also been undertaken in the northern part of Bandung basin (German Water Engineering, 1982; DHV and IWACO, 1985; Iwaco-Waseco, 1991; Directorate of Environmental Geology of Indonesia, 1996). However, the foot slopes of the volcanoes along the margin of the Bandung basin, mainly in the northern part, are still of interest in the study of groundwater resources, not only for their regional results, but also because they are related to the problem of groundwater supply in the Bandung area.

The purpose of this paper is to establish the aquifer system within the undifferentiated volcanic products of the Cikapundung Formation. This study may provide the detailed hydrogeological framework of the northern part of the Bandung basin, west Java, Indonesia.

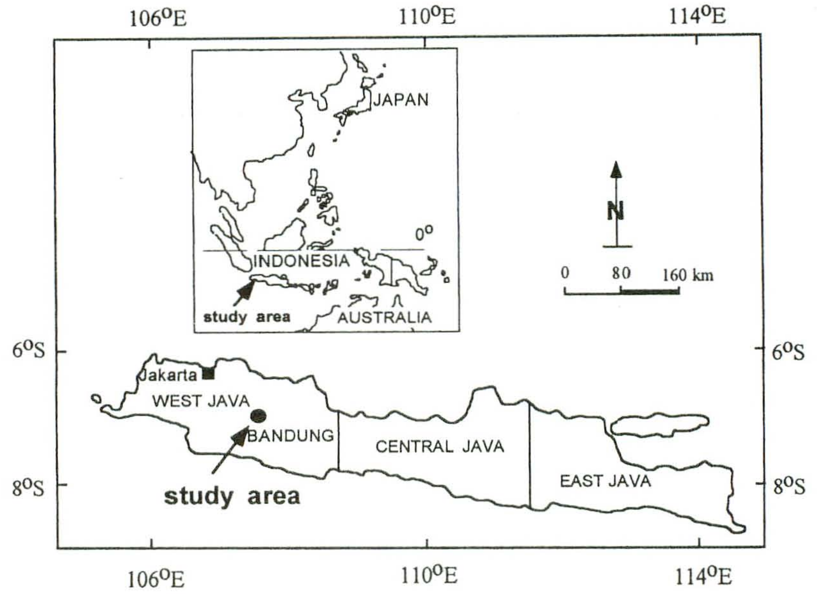


Fig. 1 Location index of the study area.

2. Methodology

Because the study area consists of undifferentiated rock, the geological and hydrogeological mapping had to be carried out to identify the stratigraphic sequence and the groundwater occurrence. Furthermore, wells for geological exploration and hydraulic head data are seldom available in the study area. Hence this study had to utilize the outcrop of rock and spring.

The data was collected during the dry season, July-August 2000, and the rainy season, January-February 2001, in order to detect maximum possible variations of groundwater temperature, electric conductivity (EC), and pH. The measurements were conducted at the end of the dry season, with precipitation 22.75 mm (August 2000), when maximum annual air temperatures are expected, and also at the end of rainy season with precipitation 270.45 mm (January, 2001), when maximum water is anticipated. The groundwater temperature, electric conductivity (EC) and pH were measured by portable tool of Cyber Scan PC 10 model. The tool was calibrated before each use for EC, and pH of groundwater. Buffer solutions of pH 4 and 7 were used for the pH measurements, calibrating everyday against standard buffer solutions of 4.01 and 7.00.

The measurements of spring discharge were employed by bucket and by construction weir of a thin plate with a notch which water flowed was determined. The thin plate is V-Notch (90°). Further, the amount of discharge by equation:

$$Q = 1.343\ H^{5/2} \text{ (USGS, 1980)},$$

where Q = discharge, m^3/sec and H = head of the water above the apex of the V-Notch, m.

3. Result

3.1 Geologic setting

Both the geological and hydrogelogical analyses are based on outcrop observed in the field and also refer to the results of lava dating by Sunardi (1997). Fig. 2 illustrates the stratigraphy of this area. The geological map of the study area is also supported by the regional geological map after Koesoemadinata and Hartono (1981), Alzwar et. al (1989), Dam (1994), and Sunardi (1997), as shown in Fig. 3. The complexities of the geology revealed in the study area are due to undifferentiated volcanic product deposits, such as intercalations of lava and breccia, and also intercalations of lapilli tuff and volcanic ash layers.

The Cikapundung Formation is the oldest unit that crops out in this area. Overlying the Cikapundung Formation is the Cibeureum Formation in southwestern part, which is separated from the former by an erosion level. The Cibeureum formation comprises repetitions of alternating tuff-breccia beds with fragments of scoria, basalt, andesite and pumice.

The field observations of the Cikapundung Formation and the young volcanic product indicate that there are at least five volcanic rock units within the slope of the study area (Fig. 4). The Cikapundung Formation includes lahar, lava flow, intercalations of

Period	Epoch		Age	Units	Lithology
QUATERNARY	HOLOCENE			Flood plain deposits	Alluvium
				Alluvial fan deposits	Alluvium
				——erosion level——	
	PLEISTOCENE	UPPER	?	Young volcanic product	Intercalation of volcanic ash and lapilli tuff
				Cibeurcum Formation	Repetition of alternating tuff-breccia beds with fragments of scoria, basalt, andesite and pumice
				——erosion level——	
		LOWER	0.04-1.1 Ma	Cikapundung Formation	Conglomerate, lava, volcanic breccia and lapilli tuff
					Lahar, lava, and volcanic breccia

Fig. 2 Stratigraphic scheme for the study area (compilation after Koesoemadinata and Hartono, 1981; Dam, 1994; Sunardi, 1997).

volcanic ash and lapilli tuff, and intercalations of volcanic breccia and lapilli tuff. However, the Young Volcanic Product deposit consists of intercalations of lapilli tuff and volcanic ash layers only.

The lower part of the unit consists of lahar. The characteristics of the lahar in the western part and the eastern part are quite different. In the western part, as shown in section A-B, the lahar is characterized by whitish gray, pebble to cobble andesitic fragments with 0.5-19 cm size and sub-angular to sub-rounded shape. Some minerals, such as augite, pyroxene minerals and scoria are visible. The matrix is medium-coarse sand, indicating a highly consolidated rock with developing fractures. The thickness is from 6.9 to more than 10 meters of outcrop. The rock is considered to have been deposited by high temperature flows. In the eastern part (sections C-D-E and F-G), the lahar consists not only of breccia apparently at deposited high temperature, but also some conglomerates. The conglomerates occur as thin layer, approximately 10-25 cm, normally graded from cobble to pebble size and yellow-whitish color. Andesitic and basaltic igneous fragments are the principal components, and are subrounded to rounded and hard. The matrix is brownish and whitish yellow, fine-grained to coarse-sandy tuff. From north to south, the fragments become smaller and less. The thickness of this lahar is more than 50 meters.

The lahar is also in contact with clay and silt of Bandung Lake deposits, which form interfingering layers in the foot slope of the south. The direction of clay and silt layers indicates N 226E /12-17° S. In addition, the underlying lahar is largely unknown in this area. However, according to the results of geophysical survey, under the lahar is a repetition of volcanic deposits (Krisdoharto et. al, 1978).

Overlying the lahar is lava flow in the middle to northern part and a volcanic breccia in the southern part. The lava flow is aphanitic with color gray blackish. Some minerals, such as pyroxene (e.g. augite), amphibole are visible. According to the results of petrographic analyses, the lava is named as cpx, opx andesite (Sunardi, 1997). The thickness of this unit is 4 m to less than 30 m. Most of the upper part of lava flow shows massive texture without joints, whereas columnar jointing is visible in the middle part of the study area. Some outcrops indicate that the lower part of lava flow consists of gravel beds. The different characteristic of lava appears along northern part in which clinker beds are typically developed. On the basis of survey in the field, the lava in northern part is distinguished from that by the presence of olivine mineral in eastern part. The age of the lava flow in the northern part is 1.10 Ma (Sunardi, 1997). This may suggest that the lahar and lava within the middle part are probably older than 1.10 Ma.

The volcanic breccia is poorly sorted with subangular fragments up to block and boulder size. Generally, the volcanic breccia is characterized by scoriaceous tuff-breccia, very poorly sorted, with a whitish brown, sandy tuff matrix. Volcanic breccia is very thick, that is more than 35 meters, and extends throughout the ridge in the study area. This unit, including lava and lahar is quite thick. The geophysical survey indicates that the thickness is approximately 350 m

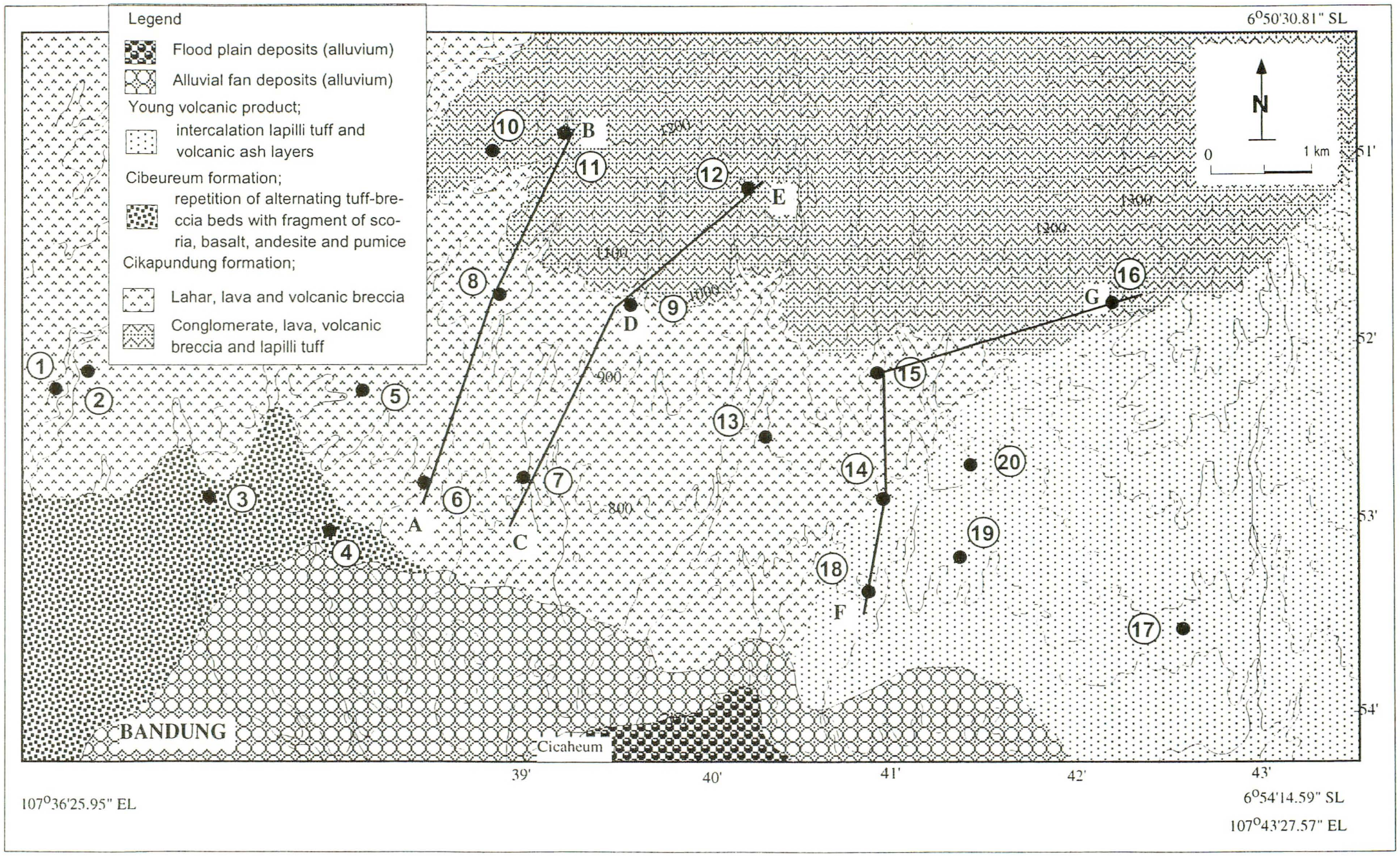


Fig. 3 Simplified geological map of the study area based on outcrops and adapted from Koesoemadinata and Hartono, 1981; Alzwar, 1989; Dam, 1994; Sunardi, 1997.

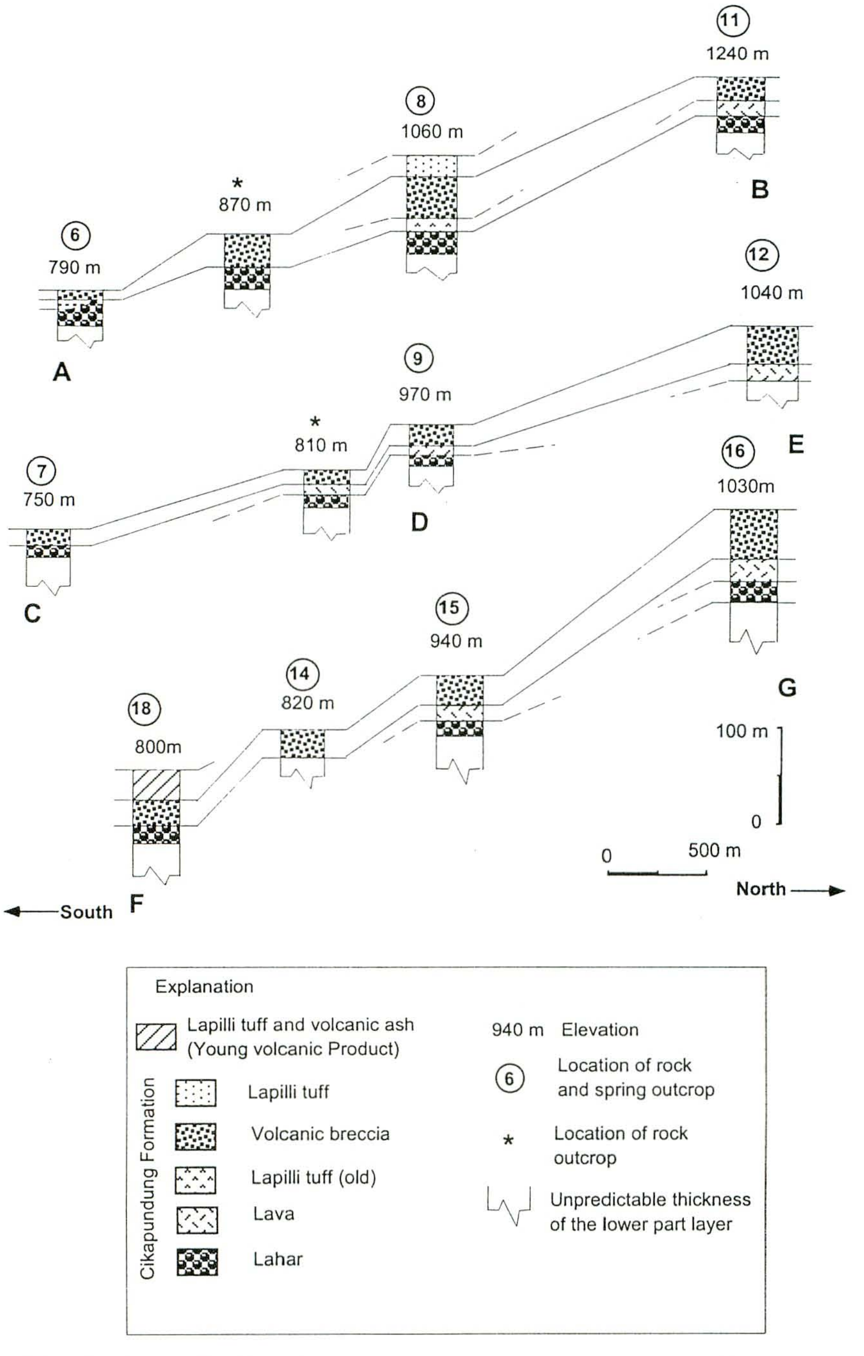


Fig. 4 North-South columnar sections based on outcrops in the study area.

(Krisdoharto et. al, 1978). Koeseomadinata and Hartono (1981) interpreted that the general facies of deposits in this formation as being a repetition of mass flow deposits with intercalated fluvial sandstone beds. The eruption of these rocks occurred in the Early Pleistocene (Sunardi, 1997). In addition, the andesitic lava flow and lahar are extruded from a system of northeast-southwest.

In southeastern part, the volcanic complex consists of intercalated lapilli tuff and volcanic ash layers. This unit belongs to the Young volcanic product (Silitonga, 1973). The lapilli tuff is generally brownish white, coarse ash-gravel-grained, scoria, poorly sorted and welded, whereas the volcanic ash layer is generally reddish white, well sorted, bedded, fine-coarse-grained. The thickness of the intercalated lapilli tuff and volcanic ash ranges from 5 to 43 cm. A detailed measured section of this unit is shown in Fig. 5.

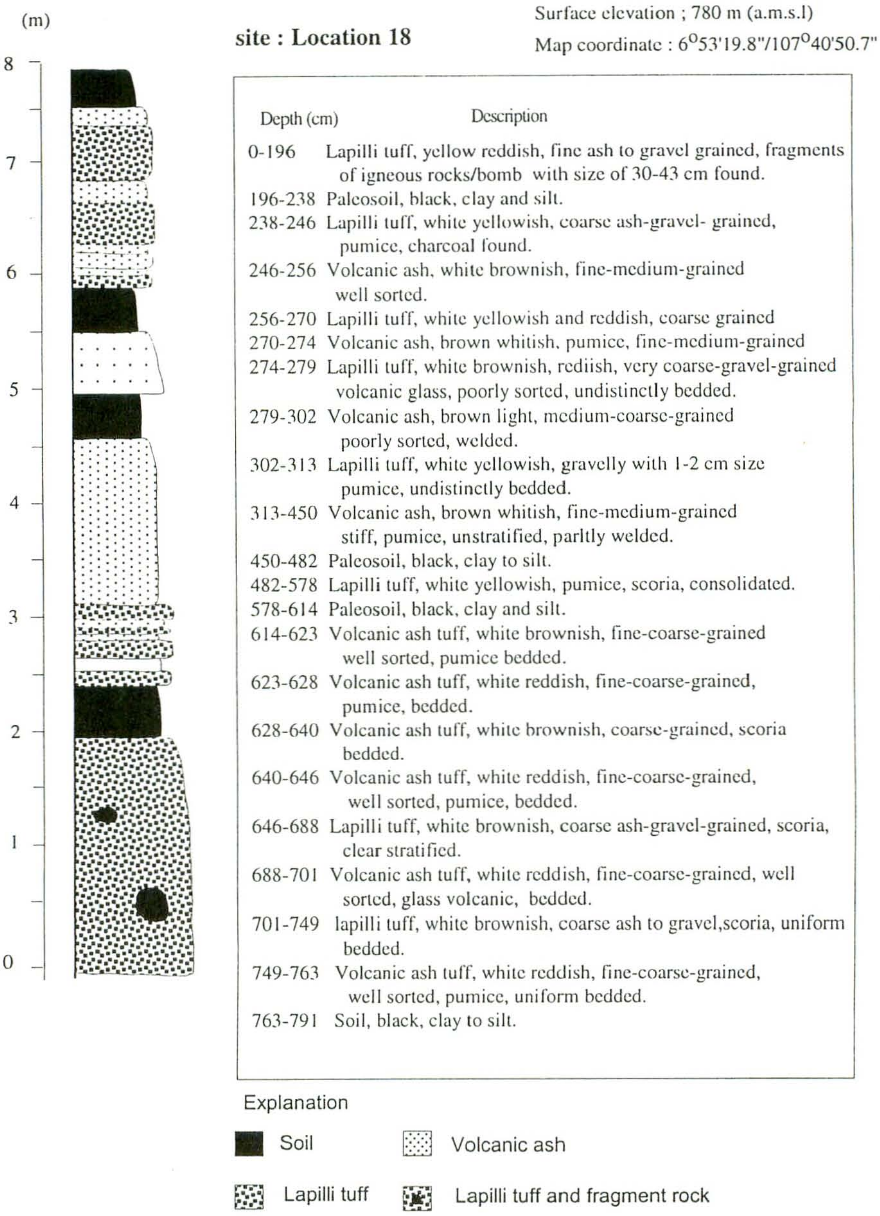


Fig. 5 The intercalation between volcanic ash and lapilli tuff as found in the south-eastern part of the study area.

3.2. Physical Groundwater

The results of physical parameters are shown in Table 1. All data were collected during the dry season from July to August 2000 and the rainy season from January to February 2001. A few springs ebbed in the dry season. Hence, the data are less than in the rainy season. The contours of groundwater temperature, EC and pH are drawn on the topographic map, indicating some trends of decrease or increase in values in spring. The contours of groundwater temperature tend to follow the elevation along the slope of the study area (Fig.6). For the groundwater EC and pH, the contours follow the same basic principles as contouring of water levels or topography (Sanders, 1998), as shown in Fig. 7 and 8.

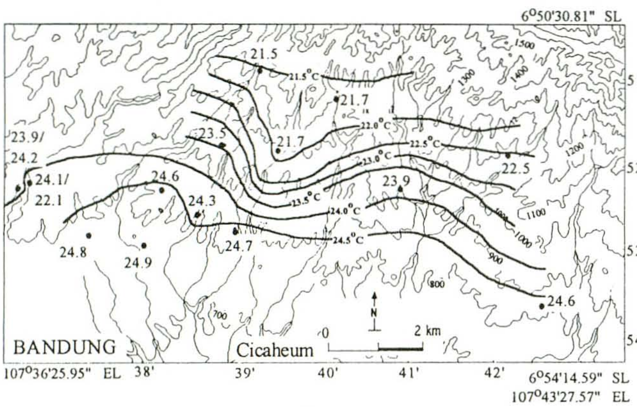
3.3 Hydrogeological Setting

In general terms, the climate of West Java is described as humid-tropical (Köppen type Af to Am) and is characterized by a wet period from October to May and a relatively dry season from June to September. The average calculation of average annual rainfall during 1986-1994, derived from Coblong station, is 2297.5 mm/year, and from Cisarua (Lembang) station is 2293.7 mm/year. The evapo-transpiration is 1126 mm/year and infiltration coefficient is 0.15 (IWACO, 1990). At location 12, spring discharge indi-

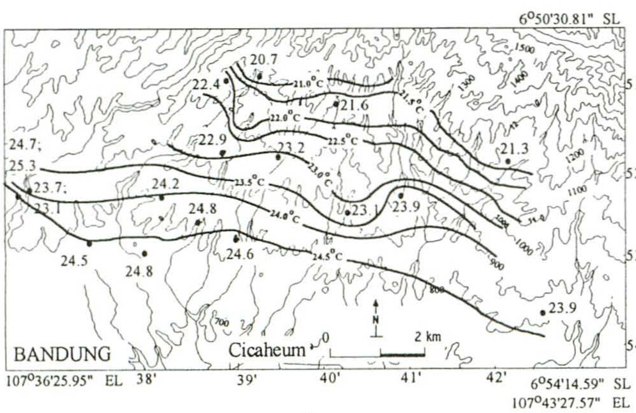
Table 1 Physical groundwater results derived from spring measurements.

Location	aquifer	dry season			rainy season		
		Temperature (°C)	EC µmhos/cm	pH	Temperature (°C)	EC µmhos/cm	pH
1	Lahar fracture and lapilli tuff	23.9 24.2	335	6.36	24.2 25.5	415	6.99
2	lava fracture and lapilli tuff	22.1 24.4	402	6.32	23.1 23.7	209	6.4
3	lapilli tuff	24.8	366	6.27	24.5	258	6.62
4	lahar fracture	24.9	405	6.33	24.8	372	6.96
5	volcanic breccia	24.6	127.4	6.31	23.9-24.2	138.7	6.05
6	volcanic breccia	24.3	243	6.25	23.9-24.8	183	6.13
7	volcanic breccia	24.7	118.1	6.33	24.6	118.7	6.54
8	volcanic breccia	23.5	64	6.28	22.9	64.4	6.16
9	Lahar fracture and lava fracture	21.7	138.8	6.35	23.2	173.9	6.67
10	lapilli tuff	*			22.4	156.8	5.36
11	clinker lava	21.5	59.4	6.34	20.7	76.3	5.3
12	clinker lava	21.7	134.4	6.36	21.6	141.8	6.8
13	volcanic breccia	*			23.1	145.3	6.62
14	lava fracture	*			24.2	177.4	6.36
15	lava fracture	23.9	112.1	6.34	23.9	112.7	6.54
16	gravel under lava	22.5	70.7	6.23	21.3	70.7	6.48
17	lava fracture	24.6	ET	ET	23.9	143.5	6.12

note: * ebbing spring
ET:error tool

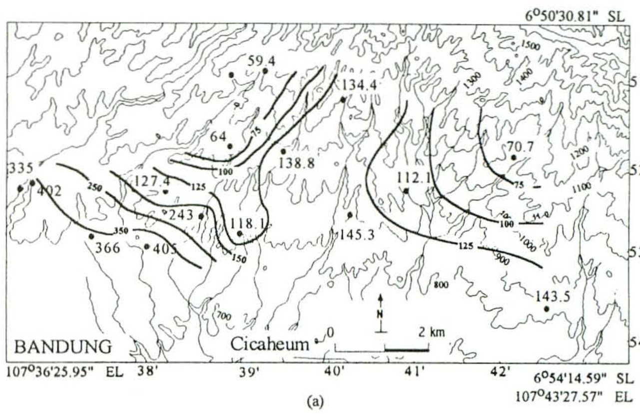


(a)

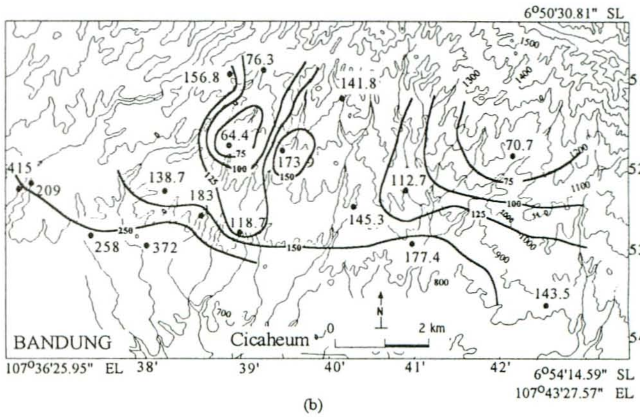


(b)

Fig. 6 Shallow groundwater temperature contours based on spring temperatures, (a) in the dry season and (b) in the rainy season.



(a)



(b)

Fig. 7 Distribution electric conductivity values (a) in the dry season (b) in the rainy season (μmhos/cm).

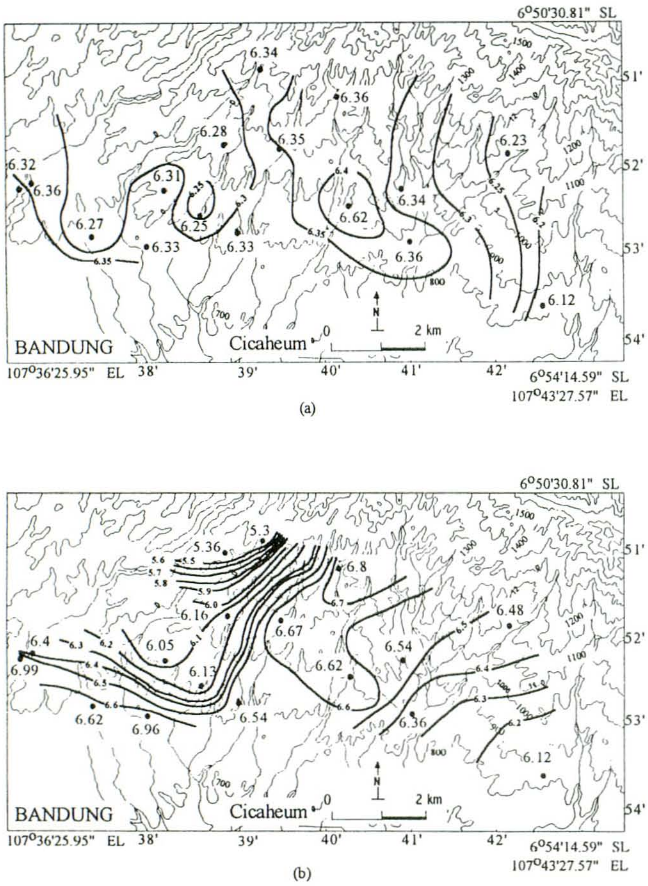


Fig. 8 Illustration of groundwater pH (a) in the dry season (b) in the rainy season.

cates 15.395 liter/second or 1330 m3/day. The simple equation of water balance as described by Domenico and Schwartz (1990) is applied to calculate the amount of recharge storage, as follows

$$P - E - T - R_o = S$$

$$P - (E + T) - R_o = S$$

$$R_n + Q_i - T - Q_o = S$$

Where P is precipitation; R_n is total run off; R_n is natural input; Q_o is effluent or gaining stream; Q_I is influent or losing stream; S is the lumped change in all subsurface water. The result indicates that in water balance equation, the amount of infiltration water to aquifer is around 20.39% and 5.05% as water discharge of spring, 15.34% as storage to the shallow or depth aquifers, and proportion of evaporation and transpiration 49.03%. This configuration of the water budget occurs inside the small sub-catchment area of the study area. This proportion may be expected to illustrate recharge in the study area.

In the study area, the water springs are supplied by free water moving under control of the water-table slope and also by the different hydraulic conductivities of the water-bearing formation. Generally, the springs are perennial and they discharge throughout the year, and only a few are intermittent.

Some springs issue from volcanic breccia and from intercalations of tuffaceous and lapilli tuff, where the water-table intersects the ground surface. Secondly, springs issue from consolidated lahar fractures. The fractures can create the flow of water where they intersect the land surface. Thirdly, springs issue from lava fractures. Lastly, springs issue from the clinker bed of lava and the gravel under lava.

The hydraulic conductivity of the each formation is the result of the regional formation. In particular, the permeability of the lava aquifer was measured in the field (location 12), using the Dupuit formula for calculation. The permeability of all units is shown in table 2.

Table 2 Permeability of lithologic units in the study area.

Units	Lithology	Permeability (cm/sec)
Young volcanic product	Intercalated volcanic ash layers and lapilli tuff	4.87×10^{-3} to 5.89×10^{-3}
Cibeureum Formation	Gravelly sand to sandy gravel with scoria and primary volcanic, pyroclastic flow deposits	8.68×10^{-3}
Cikapundung Formation	Lahar, lava, volcanic breccia and lapilli tuff.	5.52×10^{-3} *(lava clinker bed)* 6.86×10^{-1}

4 Discussion

4.1 Groundwater temperature, EC and pH

The maps shown in Figs. 6,7 and 8 may lead to an interpretation of character change in the aquifer system. The groundwater temperature maps show that contour anomalies occur within the lahar aquifer, along an altitude range of 900 to 1000 meters above mean sea level (location 9). The groundwater temperatures are 21.7℃ and 23.1℃. This phenomenon can be interpreted as a spring inflow from lava aquifer above the lahar aquifer. Another consideration is that the lahar and lava aquifers are likely to be supplied from a recharge area with the same altitude. However, study of detailed groundwater flow is required to explain this circumstance. The other contour patterns are generally similar to the increase of elevation with decreasing groundwater temperature. The correlation gives approximately -83.9 m/℃ of slope in linear regression with a correlation coefficient of 0.882.

The groundwater EC reflects either activity of the electrically charged ions or a rapid determination of total dissolved solids. The EC values suggest that higher conductivity will be the potential for electrochemical action. Generally in the study area, the groundwater EC within aquifers A and B are higher than in aquifers C, D and E (Table 3). The hardness of lithology may probably control total dissolved solids during groundwater flow path. This behavior is indicated by lahar, lava aquifer (aquifer C, D and E) with low EC of 59.4-134.4 μmhos/cm. Except for location 8, despite volcanic breccia and lapilli tuff (aquifer B), the EC value is quite small, i.e. 64.4 μmhos/cm. It is rather similar to aquifer D or C. In this location, the presence of an old volcanic ash layer may lead to less dissolved solids, related to small permeability. Hence, the groundwater flow path is slow in this aquifer system and can create small EC values.

Seasonal variation in EC values of the study area during the dry and rainy season indicates that majority of the EC values increases in the rainy season. During the rainy season, the infiltration effect may enhance the aggressiveness of the water in dissolving solids. However, the variation of EC values is not significant and tends to show constant values.

Besides groundwater temperature and EC, the accurate in situ groundwater pH is necessary in order to define ion activity. Although water molecules are quite stable chemically, they still tend to break down or dissociate into their component parts, hydrogen and hydroxyl. This approach allows the author to predict that the percolation of rainwater enriched in carbon dioxide reduces the pH of groundwater.

The result indicates that groundwater pH variation is generally not significant during the dry and rainy seasons. However, some values of groundwater pH (location 5, 6, 8 and 11) indicate decreasing values in the rainy season. There are probably two considerations to explain this condition. These predictions are based on rough characterization of water chemistry. Firstly, the solution of CO_2 gas in soil in the rainy season is less than in the dry season. These sites consist of lapilli tuff with old volcanic ash layers, and the slow infiltration appears to affect the solution of CO_2 gas in the soil zone. Secondly, decreasing the non alkalinity leads to a decrease in pH. Another reason indicates that the decrease of the EC values (due to total dissolved solid) coincides significantly with decrease pH of in this location. This prediction is also a rough interpretation. Hence, data on groundwater chemistry must be collected for further study in order to determine processes.

4.2 Aquifer system

From the geological and hydrogeological data, the water-bearing bed is focused on the Cikapundung Formation. The characteristic lithology includes pervious layers such as volcanic breccia, bottom of lava and lapilli tuff, and the impervious layers consist of consolidated lahar and the upper part of the lava bed. The volcanic breccia and lapilli tuff layers are sufficiently thick and occupy all the land surface of the study area. Therefore, the volcanic breccia and lapilli tuff are also very important in controlling the occurrence and movement of the groundwater flow path.

Table 3 Characteristic of aquifer systems in the study area.

Aquifer system	Geologic Description	Groundwater Temperature (°C)	Groundwater EC (μmhos/cm)	Groundwater pH	Spring
A	This unit consists of breccia volcanic and lappili tuff. In particular, east-southernpart intercalation of lapilli tuff and volcanic ash layers.	23.1-25.3	209-415	6.12-6.99	The controlling feature is intersection of the water table with the ground surface (topographic control). Water discharges range from 0.588 l/sec. to 1.426 l/sec.
B	The lapilli tuff (old) and volcanic breccia overlie the lahar and lava flow.	22.9-24.6	64.4-183	6.03-6.16	The spring occurrence is caused by contact with impervious layer such as lahar. Discharge of spring is 0.173 l/sec to 0.514 l/sec.
C	This unit consists of lahar with developing fractures. The fractures may not be regular but interconnected, relatively.	21.7-24.7	18.7-173.9	6.54-6.67	The spring is fed by intersecting fractures with the upper part of volcanic breccia and lapilli tuff as supply reservoir with discharge ranging from 0.22 l/sec to 0.278 l/sec.
D	This unit composes lava flow with developing columnar joints	23.1-23.9	112.7-177.4	6.36-6.54	Fracture is important factor in developing the vertical permeability. Spring discharges range from 0.115 l/sec to 0.25 l/sec.
E	This unit consists of lava flow with characteristic of gravel under lava and clinker bed of lava.	20.7-22.5	70.7-141.8	5.3-6.48	The gravel bed and clinker lava bed control the issuing water, not only through vertical permeability due to fractures, also develop horizontal porosity with discharge ranging from 2.43 l/sec to 15.395 l/sec.

Geological description and the physical parameters of groundwater become basic consideration in order to create the division of unconfined aquifer system into units in the study area. Therefore, characteristic of minor aquifer can be identified e.g. one lithology unit may develop two or more aquifers that show distinguishable characteristics.

The aquifer systems within the Cikapundung Formation are expressed in some sections, as shown in Fig. 9. Names of aquifer systems are based on geographical local names and lithological types. Further,

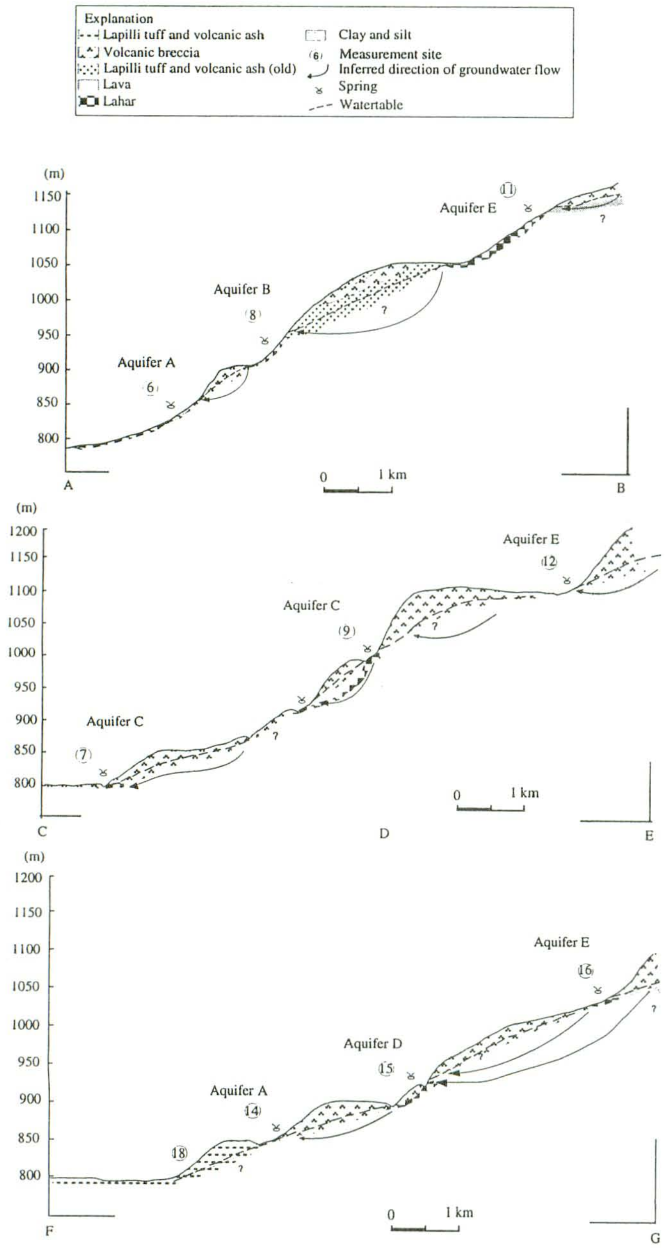


Fig. 9 Schematic representation of the aquifer systems in the study area; the cross-section refers to the section in Fig 3.

each aquifer includes physical parameters of groundwater and spring characteristics (see table 3), as shown below.

1. *The Cikapundung andesitic volcanic breccia and pumice lapilli tuff aquifer (aquifer A)*

The characteristic feature of this unit is that it is pervious and sufficiently thick. Several springs indicate that the seepage issues from layers in contact with impervious layers. The majority of the springs are perennial spring. However, during the dry season, some springs dry up (ebb spring), mainly those that are controlled by the intersection between water table and topography. The ebb spring may be caused by water-table decrease. Hence, the springs only occur at the foot of steep slopes as found around the southern part of the study area. The physical groundwater is characterized by groundwater temperatures ranging from 23.1℃ to 25.3℃, EC from 209 to 415 mikromhos/cm and pH from 6.12 to 6.99. Further, water discharges are 0.588 L/sec. to 1.426 L/sec.

2. *The Dago andesitic breccia and pumice lapilli aquifer (aquifer B)*

The characteristic lithology of this aquifer is quite similar to the A type. The aquifer is distinguished by the presence of old lapilli tuff and volcanic ash layer. The spring is controlled by contact with an impervious layer, such as consolidated lahar. The physical groundwater is characterized by groundwater temperature ranging from 22.9℃ to 24.6℃, EC from 64.4 to 183 μmhos/cm and pH from 6.03 to 6.16. The water discharge of the spring is 0.173 L/sec to 0.514 L/sec.

3. *The Cigadung augite andesitic pyroclastic flow aquifer (aquifer C)*

The rock is lahar with developing secondary permeability or fractures. The fractures may not be regular but are probably interconnected, and this is reflected the spring being perennial. The physical groundwater is characterized by groundwater temperature ranging from 21.7oC to 24.7oC, EC from 118.7 to 173.9 μmhos/cm and pH from 6.54 to 6.67. Seepage water or spring has low discharge, around 0.22 L/sec to 0.278 L/sec.

4. *The Ujungberung pyroxene andesitic lava fractures aquifer (aquifer D)*

In the field, the lava flow has much secondary permeability, such as columnar joints and cooling joints. These fractures are an important factor in the development of the vertical permeability characteristic of this lava. The upper part of the lava consists of pervious breccia and lapilli tuff. In the lower part, the lava is a massive bed. The spring has small discharge of 0.115

L/sec to 0.25 L/sec. This aquifer is very important for storage of water that inflow from the successive volcanic ash layers or volcanic breccia mainly in the dry season. The physical groundwater is characterized by approximately groundwater temperature of 23.1℃ to 23.9℃, EC 112.7 to 177.4 μmhos/cm and pH 6.36 to 6.54.

5. *The Ciburial pyroxene andesitic lava aquifer (aquifer E)*

Water-flows through the edges of the lava occur in the north part of the area. The spring has a large discharge of water. The big one is found around location 12 (see Fig. 2). On the basis of measurement of water discharge, yields range from 2.43 L/sec to 15.395 L/sec. The clinker layer of lava and gravel under the lava bed indicate that their function of water bearing are not only expected vertical permeability due to fractures, but also horizontal porosity and permeability. The physical groundwater is characterized by groundwater temperature ranging from 20.7℃ to 22.5℃, EC from 70.7 to 141.8 μmhos/cm and pH from 5.3 to 6.48.

5. Conclusions

This study establishes the aquifer framework of the Cikapundung Formation which consists of undifferentiated volcanic products. On the basis of observation of the springs, five types of aquifer systems within the unconfined aquifer are recognized in this area. The aquifer includes aquifer A (the Cikapundung andesitic volcanic breccia and pumice lapilli tuff aquifer), aquifer B (the Dago andesitic breccia and pumice lapilli aquifer), aquifer C (the Cigadung augite andesitic pyroclastic flow aquifer), aquifer D (the Ujungberung pyroxene andesitic lava fractures aquifer), and aquifer E (the Ciburial pyroxene andesitic lava aquifer). Aquifer E (clinker lava and gravel under lava aquifer) with permeability of 6.86 x 10^{-1} cm/sec has the highest permeability of all the aquifers. However, further studies are required to identify the other parameters of hydraulic conductivity, such as transmissivity and the storage coefficient for each aquifer system.

Seasonal variation in groundwater temperature, EC and pH are generally not significant and are quite constant. However, the trends of change in values during two seasons may suggest that the presence of an old volcanic ash layer, hardness of lithology and the infiltration factor may affect the EC and pH values in the study area.

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