IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Potential of Groundwater to Supply Domestic Water Necessity in Evacuation Shelters of Merapi Volcano Eruption

To cite this article: W Riasasi and S P Sejati 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **271** 012014

Potential of Groundwater to Supply Domestic Water Necessity in Evacuation Shelters of Merapi Volcano Eruption

W Riasasi[1], S P Sejati[1]

[1]Study Program of Geography, Faculty of Science and Technology, Universitas Amikom Yogyakarta, Indonesia

wiriasasi@amikom.ac.id

Abstract. Since the occurrence of eruption in 2010, volcanic activity of Merapi volcano increased several times. Cangkringan district was the most affected area with highest level of damage. Learned from the 2010 eruption, mitigation action was developed by preparing more and adequate evacuation shelters. During period of staying in evacuation shelter, primary necessity of clean water for the refugees needed to be fulfilled. Groundwater was considerated to be the alternative source to fulfill the needs of clean water for the refugeess in evacuation shelters. However, the amount of groundwater sources on the area of evacuation shelter had to be able to meet the domestic water necessity of all refugeess. This research aimed to measure the potential's amount of groundwater on the surrounding area of evacuation shelter, particularly in Cangkringan district, and to identify the capability of groundwater to fulfill the refugees's domestic water necessity in the evacuation shelter in Cangkringan district. Dynamic groundwater discharge method by Darcy model was used to measure the prediction of potential groundwater. The result showed potential of groundwater in Cangkringan were as much 88,417.2 m^3/day or 88,417.200 liter/day. Total water necessity of refugees in Cangkringan was 335,700 liters /day. Compared to the prediction value of groundwater potential, the total water necessity of refugees in Cangkringan was able to be fulfilled.

1. Introduction

One of the most active volcanoes in the world and located in Indonesia is Merapi volcano, precisely in Java Island. More than 70 eruptions occurred since 1548 [1] and killed over 7000 people [2]. In 2010, Merapi volcano erupted explosively then caused area within radius 20 km from the summit had to be emptied. It means 1,335,885 inhabitants that lived within the radius 20 km from the summit [3] must be evacuated to safe places. Evacuation is challenging process because "moving" many people during disaster occuring might be very chaotic. Evacuation is considered to be one of the most difficult action of response operations, it could be worse if preparedness level was inadequate [4]. At that time, when the zone of hazard was extended to 20 km, from initially 15 km, there was no refugee shelter prepared within the radius to accommodate the refugees [3].

Learned from the 2010 eruption, mitigation action was developed by preparing more and adequate evacuation shelters. Based on data from BNPB (Badan Nasional Penanggulangan Bencana/ National Agency for Disaster Management), there were many evacuation shelters on area around Merapi volcano. The refugees stayed in evacuation shelters during volcanic activity increased and instruction from the government to empty the disaster affected area was applied.

A place is capable for evacuation shelter if it meets the requirements of safety from disaster risk, capability to accommodate numbers of refugees, and availability of resources to fulfill human's necessity, among others is clean water. Human needs clean water for personal needs, or called domestic water necessity, such as for drinking, showering, washing, and cooking. Clean water is primary necessity for human, hence it must be fulfilled.

The certain condition during evacuation span, which is addition numbers of newcomers (refugees) at a certain time, surely affects on demand of the clean water in the area. In 2010 eruption, clean water for refugees in Sleman regency was supplied from groundwater through wells. In quantity and quality, groundwater is suitable to supply clean water for domestic needs [5]. To fulfill the domestic water necessity of all refugees in the evacuation shelter, it needs sufficient potential of groundwater. Consequently, the potential of groundwater in the eruption affected area, particularly in Cangkringan district, and the capability of the groundwater to supply refugees's domestic water necessity have to be identified.

Based on Merapi volcano's disaster hazard map and eruption affected area in 2010, Cangkringan district was the most affected area with highest level of damage. It was caused by material of the eruption flowing towards southern slope of Merapi volcano [5][6]. Cangkringan district lied on eruption hazard area level III, II and I (Fig 1.) that passed through by Gendol river [6]. Lahar from Merapi eruption flowed downward through Gendol river. Once the material overflowed, Cangkringan was the most affected area.

Places that used for evacuation shelter in Cangkringan were mostly big building with wide open spaces, such as school or village hall. Based on effusive scenario of evacuation shelter, five spots in Cangkringan district were used for evacuation shelter to accommodate refugees from Cangkringan district [7], as seen on Table 1.

Table 1. Evacuation Shelter in Cangkringan District [7]

No	Village	Hamlet	Evacuation Shelter
1	Kepuharjo	Kopeng Kaliadem Batur Jambu Manggo, Kepuh, Pagerjuang	Barak Pengungsian Kuwang/ Balai Desa Wukirsari
2	Glagaharjo	Kalitengah Lor Kalitengah Kidul Singlar Gading	Barak Gayam/ Mudal/ SD Banaran Balai Desa Glagaharjo
3	Umbulharjo	Palemsari/Kinahrejo Pangukrejo Balong/Karangkendal Gambretan Plosorejo Gondang	Barak Plosokerep SMP (di Watuadeg) / Barak Brayut

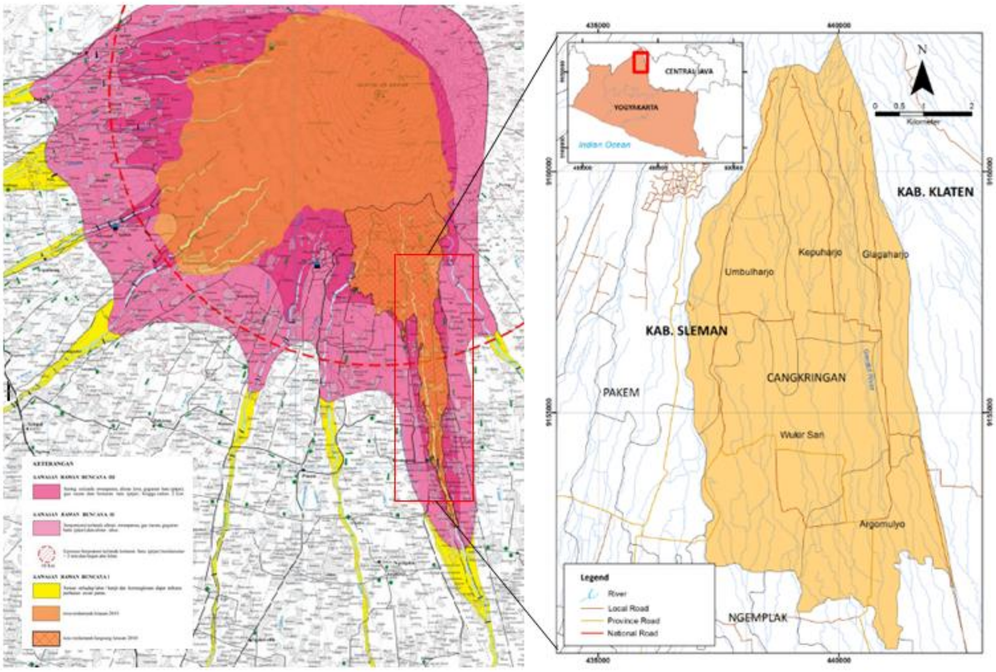

Figure 1. Merapi eruption hazard map [6] (left); Administration map of Cangkringan District (right) (Writer, 2018)

2. Method

2.1 Potential of Groundwater

Potential of groundwater in an area could be measured by dynamic groundwater discharge method [5][8][9][10]. The method uses basic mathematic equation that invented by Henri Darcy or widely known as Darcy Law [11][12]. The equation of Darcy Law is :

$$Q = KIA$$

Based on the equation, groundwater dynamic discharge (Q, unit of measure m^3/day) is the result of multiplication from three components, are aquifer hydraulic conductivity (K, unit of measure m/day), hydraulic gradient (I, constant), and area of cross-section aquifer (A, unit of measure m^2). Each component is calculated by different data. Specification of data to calculate value of Q is explained detail in Table 2.

Table 2. Components and Data to Calculate Groundwater Dynamic Discharge

No	Component	Data	Data Source
1	hydraulic conductivity (K) (m/day)	aquifer material	drilling log profile
2	hydraulic gradient (I)	contour of groundwater level	groundwater flownet map
3	area of cross-section aquifer (A) (m^2/day)	area of cross-section aquifer and aquifer thickness	groundwater flownet map and drilling log profile

Drilling log profile data was collected from two sources. One was provided by Ministry of Public Works through Water Resources Office division of Raw Water Supply. Other data source was from research publication on potential of unconfined aquifer in partly Klaten Regency [13]. Spatial distribution of drilling log profile in

IOP Conf. Series: Earth and Environmental Science **271** (2019) 012014 doi:10.1088/1755-1315/271/1/012014

Cangkringan is presented on Figure 2, and the composition materials of each location is presented on Table 3.

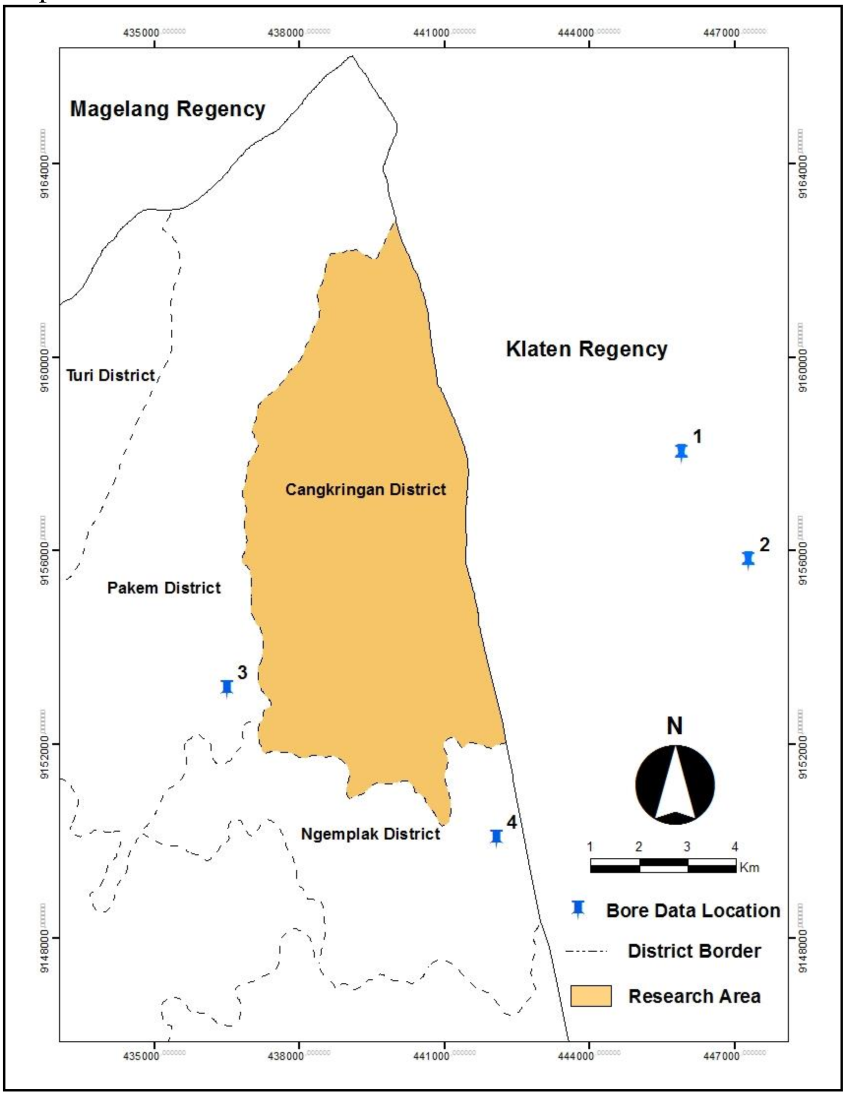

Figure 2. Spatial Distribution of drilling log profile in Cangkringan

Table 3. Composition Materials on Drilling Log Position

Point	Location	Material	Thickness (m)
1	Tangkil, Klaten[13]	Soil	5
		Volcanic Breccia	23
		Coarse Sand	4
		Volcanic Breccia and Lava	32
		Coarse and Medium Sand	7
		Volcanic Breccia and Lava	2
		Coarse and Medium Sand	56
		Volcanic Breccia	31
2	Ngemplak, Klaten [13]	Soil	2.5
		Volcanic Breccia	17.5
		Sandstone	20
		Volcanic Breccia and Lava	9
		Coarse and Medium Sand	51
		Coarse and Medium Sand, Tuff	50

3	Pakembinangun, Sleman [5]	Soil	1.5
		Coarse sand and Fine Gravel	4
		Fine Gravel	2.5
		Coarse and Fine Sand	13
		Fine Gravel	1.5
		Andesit	22.5
4	Kenthingan, Sleman [5]	Soil	5
		Fine and Medium Sand	8
		Fine Sand, Medium Sand, Clay	13
		Fine and Medium Sand	14
		Find Sand, Coarse Sand, Clay	2
		Fine and Medium Sand	2
		Fine and Coarse Sand	8
		Fine and Medium Sand	3
		Clay	2

Due to lack of drilling log profile data in the research area, then it used neighbour approach. Therefore from the map can be seen that location of spots to take drilling log profile data were at the outside of research area. Secondary data of drilling log profile taken from surrounding research area that were used to represent existing condition in research area. Since identical landform characteristic in Cangkringan and its surrounding, then the drilling log profile in the area were considered similiar.

Groundwater flownet map have two main components, namely equipotential line or countur line of hydraulic head and groundwater flowline. Equipotential line is interpolation line of hydraulic head data. The hydraulic head data that structured as point is resulted from watertable depth data and elevation data (altitude). Substraction the value of elevation data with watertable depth equals value of hydraulic head. Direct measuring on some wells as samples was done to get watertable depth and elevation data. Location of wells were determined with systematic random sampling method and grid method.

Data distribution and result of data processing in form of groundwater flownet map was presented spatially with software of geospatial data processes, specifically ArcGIS 10.3 and Surfer 11. The maps of data distribution in research area are presented in Figure 3. The flownet map was used to determine components of hydraulic gradient (I) and area of cross-section aquifer (A). Furthermore, after all components were collected, then the value of groundwater dynamic discharge (Q) can be measured.

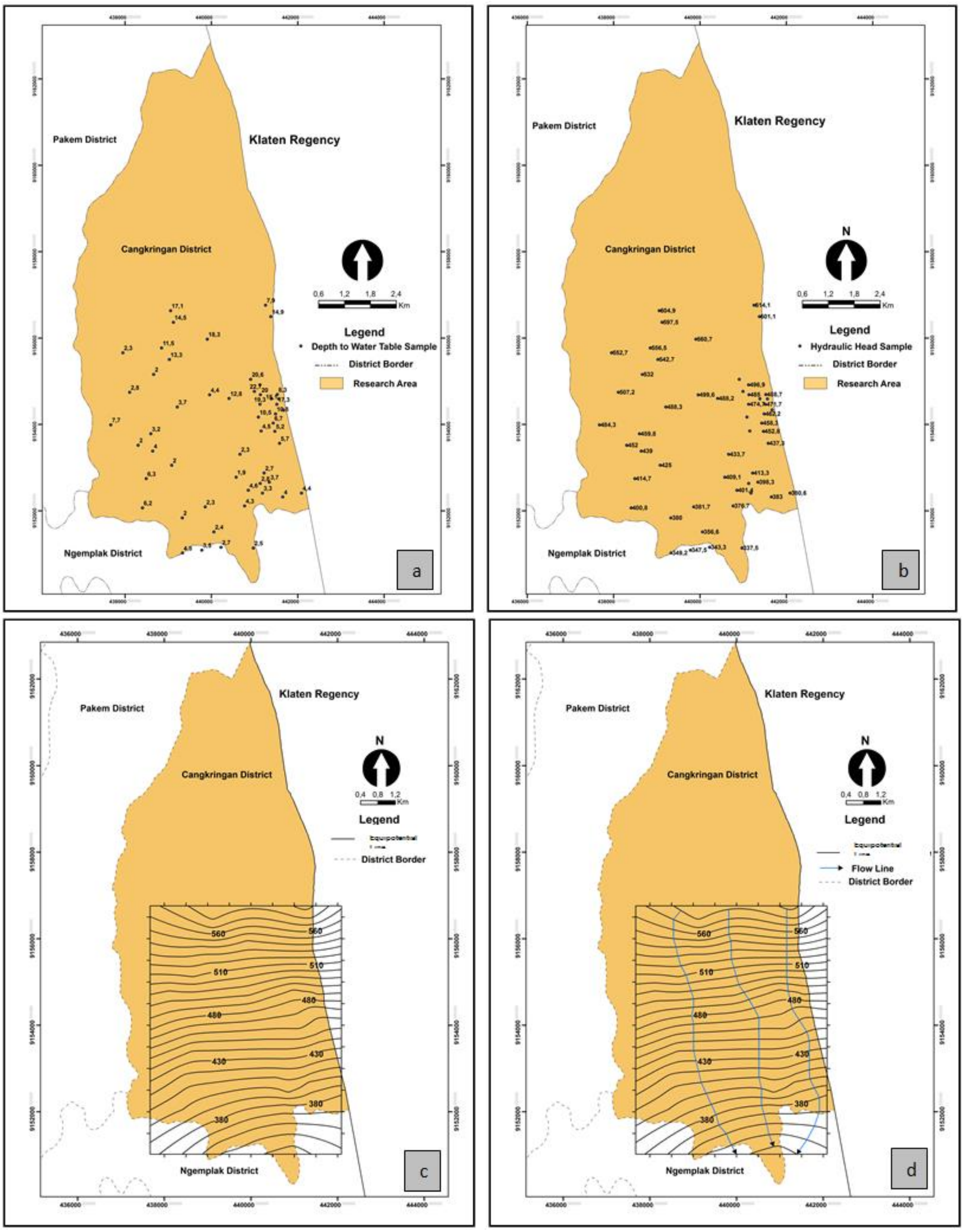

Figure 3. a) Watertable Depth Sample Map; b) Hydraulic Head Sample Map; c) Equipotential Map; d) Flownet Map

2.2 Domestic Water Necessity

Information of the value of groundwater was needed to measure groundwater availability in the research area to supply clean water for refugees during staying in evacuation shelter. The clean water was important for the refugees to fulfill their personal needs, or called domestic necessity, such as drinking, cooking, showering, and washing. Capability of the existing groundwater to supply the domestic needs can be assessed by comparing the value of potential groundwater (Q) with total needs of domestic water of all refugees staying in the area.

Numbers of refugees data were referred from Contigency Document of Merapi 2012 issued by Local Agency for Disaster Management (BPBD) of Sleman

Regency. Based on the document, information of the number of refugees and evacuation shelters in Cangkringan District was provided on Effusive Scenario of Evacuation Shelters data.

National Standardization Board [14] devided domestic water necessity into two characteristics, for village inhabitant and town inhabitant. Domestic water needs for town inhabitant was determined 120 liter/person/day, while for the village inhabitant 60 liter/person/day.

The value of domestic water necessity of the refugees was calculated by multiplicating total numbers of refugees that capable to be accomodated in all evacuation shelters in Cangkringan district with standard value of domestic water needs for village inhabitant, as much 60 liter/person/day.

Potential of groundwater in the research area was considered as capable to supply the refugees's domestic water necessity if the value of groundwater dynamic discharge was higher than total value of water that needed for domestic necessity of the refugees. Otherwise, if the prediction value of potential groundwater was lesser than total domestic water necessity of the refugees, then it determined as not capable. Unit of measure for groundwater dynamic discharge must be converted from m^3/day into liter/day.

3. Discussion

3.1 Prediction Value of Potential Groundwater

Potential of groundwater in the research area was calculated with groundwater dynamic discharge prediction method. In the research, the context of groundwater was unconfined groundwater. Unconfined groundwater was known as saturated water located beneath land surface that flowing on unconfined aquifer layer. Definition of unconfined aquifer was rock layer beneath land surface that capable to store and pass through water, moreover the layer was only separated by one impermeable layer. The existance of unconfined groundwater can be observed in wells that dug up by man [5] [15][16 [17].

Based on spatial distribution of wells sample map, shown that wells did not exist in whole area of the research area. The existance of the wells were getting rare toward area on above 600 masl (meters above sea level). The collected watertable depth and elevation data from well measurement, and also drilling log profile data were formulated to measure the prediction value of groundwater dynamic discharge.

The first component to be calculated was hydraulic conductivity (K), that defined as the capability of aquifer material to passing through water. In the research calculated five drill data. The result showed value of K was 48.12 m/day and value of mean thickness of the unconfined aquifer layer was 93.4 m. The material of unconfined aquifer in the research area was dominated by material of sand with various classifications. Sand was included in type of uncosolidated material or tended loose, mean it have space inter grains that capable to pass the groundwater to any directions, vertically or horizontally. The sand capability to loosen water made it as one of the best material to form unconfined aquifer layer.

The hydraulic gradient (I) and area of cross-section aquifer (A) components were discussed concurrently because both used groundwater flownet map and aquifer thickness data. Two segments were determined in flownet map to measure the value of the both components. Segments were determined randomly that the segments' border was two adjacent flownet, as presented on Figure 4.

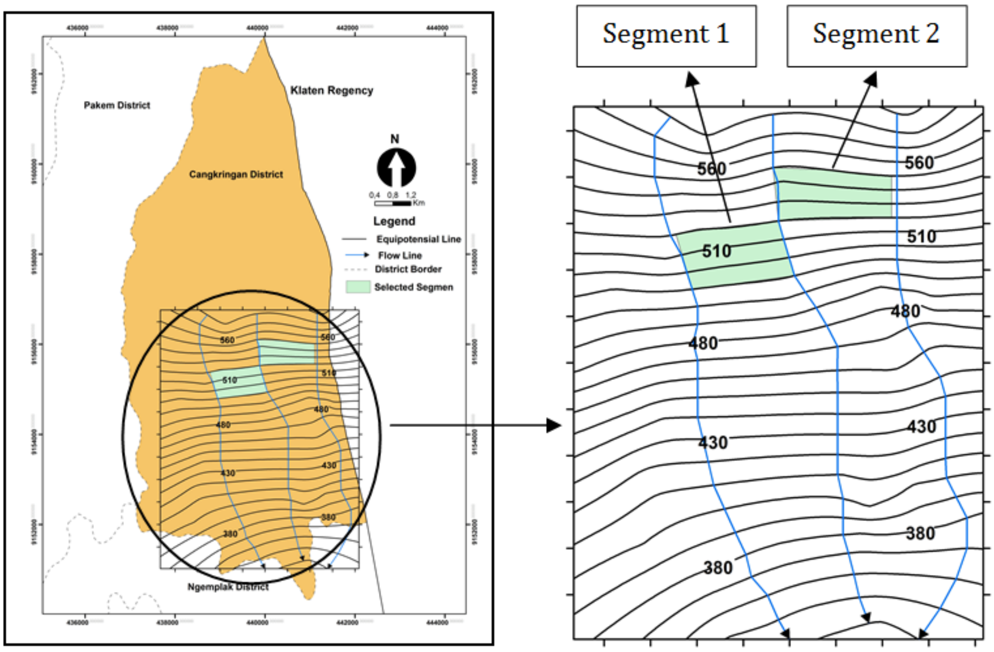

Figure 4. Segments of Aquifers in Research Area

Based on data calculation, the value of hydraulic gradient of the both segments was similiar, 0.16 with flow direction southward from north. Furthermore, the value of aquifer's surface area on segment 1 was 106,195.8 m^2 and segment 2 was 11,936.8 m^2. Final value of groundwater dynamic discharge (Q) was average value of Q from the two segments. Result shown the value of Q in the research area was 88,417.2 m^3/day or 88,417.200 liter/day. Detail calculation on the Q value is presented on Table 4.

Table 4. Calculation of Q Value

Component	unit	Segment 1	Segment 2
Hydraulic conductivity (K)	m/day	48.12	48.12
Unconfined aquifer thickness (b)	m	93.4	93.4
Euipotential line interval (Ci)	m	10	10
Surface area (A')	m^2	685224.42	772984.8
Average rate of equipotential line length (L)	m	1132	1269.5
Length of highest equipotential line in selected segment (AB)	m	1137	1252
Area of cross-section aquifer (A)= b. AB	m^2	106195.8	116936.8
B= A'/L	m	605.3	608.8
Hydraulic Gradient (I)= Ci/B	-	0.016	0.016
Dynamic groundwater discharge (Q) = K.I.A	m^3/day	84,420.2	92,414.17
Dynamic groundwater discharge (Q) = K.I.A	L/day	84,420,200	92,414,170

3.2 Capability the Potential of Groundwater to Supply Domestic Water Needs

Definition of clean water according to Decree of Minister of Health of the Republic of Indonesia number 1405/Menkes/sk/xi/2002 on health requirement in office and industrial work environment, was water that used for daily needs and the quality met the health requirement of clean water according to applicable regulation and drinkable after cooked [18]. Clean water was primary necessity for human because it absolutely needed for living. Human needed clean water to fulfill life necessity, particularly the least for drinking, washing, showering, and cooking, that called as domestic necessity.

Condition in evacuation was a certain condition, in terms of unusual daily basic needs. Addition numbers of people in certain time surely affected on amounts of water necessity compared to usual daily needs in the evacuation area. In that some days of evacuation span, there would be increasing of water demand to fulfill domestic water of all refugees in the area.

Natural condition post disaster also affected on surface water condition. Surface water, such as river or lake, probably was used for consumption by the community to fulfill their daily necessity. Consequently, the only clean water sources to supply the community was from groundwater.

The calculation of total numbers of refugees was used data from local government of Sleman Regency. Data of evacuation shelters in Cangringan was stated in Contigency Document of Merapi Eruption 2012. There were five evacuation shelters in Cangkringan with various capacity to accommodate the refugees, the data shown in Table 5. In average, each person needed 60 liters/day to fulfill domestic necessity.

Table 5. Numbers of Estimated Refugees in Evacuation Shelter in Cangkringan District

No	Shelter	Capacity (person)
1	Barak Pengungsian Kuwang/ Balai Desa Wukirsari	1,493
2	Barak Gayam/ Mudal/ SD Banaran	824
3	Balai Desa Glagaharjo	619
4	Barak Plosokerep	1,405
5	SMP Watuadeg / Barak Brayut	1,254
	Total	5,595

Total domestic water necessity = 5,595 persons x 60 liters/person/day
= 335,700 liters /day

The number showed total water necessity of refugees in Cangkringan was 335,700 liters /day that needed to be supplied. Compared to the prediction value of groundwater potential, 88,417,200 liter/day, it showed that total value of refugees's water necessity in Cangkringan was able to be fulfilled.

For the note, numbers of the evacuation shelters listed in Contigency Document of Merapi 2012 was effusive scenario, which mean directly affected by lahar flow. Apart from the scenario, at the real condition probably there were more evacuation shelters in Cangkringan.

Based on the value of Q in Cangkringan, the groundwater was still capable to supply more refugees. The calculated result on refugees's domestic water necessity could be basic information to predict the numbers of refugees that can be accommodate in Cangkringan district.

4. Conclusion

1. Cangkringan District stores abundant of groundwater potential. Based on calculation used groundwater dynamic dischage (Q) approach, there is potential of groundwater as much 88,417.2 m^3/day or 88,417.200 liter/day.
2. Total water necessity of refugees in Cangkringan was 335,700 liters /day that needed to be supplied. Compared to the prediction value of groundwater potential, total value of refugees's water needs in Cangkringan was able to be fulfilled.
3. The Q value could be basic information to predict the numbers of refugees that can be accommodated in Cangkringan district.

5. References

[1] Voight B Young K D Hidayat D Subandrio Purbawinata M A Ratdomopurbo A Suharna Panut Sayudi D S LaHusen R Marso J Murray T L and Dejean M 2000 De- formation and seismic precursors to dome-collapse and Fontaine-collapse Nuées Ardentes at Merapi Volcano, Java, Indonesia 1994–1998 *J. Volcanology and Geothermal Research* **100** 261–287

[2] Lavigne F Thouret J C Voight B Suwa H and Sumaryono A 2000 Instrumental lahar monitoring at Merapi Volcano, Central Java, Indonesia *J. Volcanology and Geothermal Research* **100** 457–478

[3] Mei E T W Lavigne F Picquout A and Grancher D 2018 Crisis Management During the 2010 Eruption of Merapi Volcano https://www.researchgate.net/publication/266505128_CRISIS_MANAGEMENT_DURING_THE_2010_ERUPTION_OF_MERAPI_VOLCANO

[4] Carter W N 1992 Disaster Management : A Disaster Manager's Handbook Asian Development Bank

[5] Sejati S P 2013 Study on Groundwater Potential to Supply Domestic Water Necessity in Temporary Shelter (in Bahasa) Thesis Yogyakarta: Faculty of Geography Universitas Gadjah Mada

[6] Geological Agency 2010 Map of Merapi Volcano Prone Area and Eruption Affected Area in 2010 (in Bahasa) Jakarta: Ministry of Energy and Mineral Resources Indonesia

[7] BPBD 2012 Contigency Document of Merapi Eruption 2012 – Rehabilitation and Reconstruction Action (in Bahasa) Yogyakarta: Pemerintah Kabupaten Sleman

[8] Santosa L W and Tjahyo N A 2018 Aquifer Characteristic and Groundwater Potential in Bantul Graben (in Bahasa) Yogyakarta: UGM Press

[9] Aleke C G Okagbue C O Aghamelu O P and Nnaji N J 2016 Hydrogeological Potential and Qualitative Assessment of Groundwater from The Ajali Sandstone at Ninthmile Area Southeastern Nigeria *J. Environmental Earth Science* **75** 290-306 https://link.springer.com/article/10.1007/s12665-015-4843-3

[10] Rahman F 2016 Study on Aquifer Hydrostratigraphy and Groundwater Availability in Makassar City (in Bahasa) Thesis Yogyakarta: Faculty of Geography Universitas Gadjah Mada

[11] Todd D K 2005 Groundwater Hydrology New York: Willey and Son

[12] Coes A L Spruill T B Thomasson M J 2007 Multiple Method Estimation of Recharge Rates at Diverse Locations in the North Carolina Coastal Plain USA *J. Hydrogeology* **15** 773-788 https://link.springer.com/article/10.1007%2Fs10040-006-0123-3

[13] Utami A W 2008 Potential of Unconfined Groundwater in Area Among Somokaton River and Soran River on Southeast Slope of Merapi Volcano Klaten Regency Central Java (in Bahasa) Thesis Yogyakarta: Faculty of Geography UGM

[14] BSN 2002 Indonesia National Standarization: Making of Reseource Balance (in Bahasa) Cibinong: National Standardization Board

[15] Sejati S P 2018 Characteristic of Unconfined Groundwater in Cangkringan District Sleman Regency Yogyakarta Province (in Bahasa) Media Komunikasi Geografi **18**(2) 166-177 Singaraja: Jurusan Pendidikan Geografi Fakultas Hukum dan Ilmu Sosial Universitas Pendidikan Ganesha.

IOP Conf. Series: Earth and Environmental Science **271** (2019) 012014 doi:10.1088/1755-1315/271/1/012014

[16] Adji T N and Sadewa P S 2014 Identification of Groundwater Potential Zones within an Area with Various Geomorphological Units by Using Several Field Parameters and a GIS Approach in Kulon Progo Regency Central Java *Arabian J. Geosciences* **7**(1) 161-172 https://link.springer.com/article/10.1007/s12517-012-0779-z

[17] Rahmawati N Viullaume J F Purnama I L S 2013 Salt Intrusion in Coastal and Lowland Areas of Semarang City J. Hydrology **493** 146-159 https://www.sciencedirect.com/science/article/pii/S0022169413003259

[18] Effendi H 2003 Study on Water Quality for Water Resource and Environment Management (in Bahasa) Yogyakarta: Kanisius