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Research Article

Geological spatial plan toward groundwater resources in Kertek, Wonosobo Basin, Central Java, Indonesia

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Abstract: Human activity affects both natural resources and spatial land use, including its utilization as sand mining sites. Sand mines, as a pillar of building construction, have been over excavated in certain areas, which has impacted the environment. In this research, the purpose of this study was to determine a spatial allocation of the mining designation area that will not damage the groundwater flow. Therefore, it is imperative for understanding the depth of groundwater at the study site, understanding the direction of groundwater flow, and the impact of mining activities on groundwater based on the combination of geophysical and geological approaches to improve the current government policy. A geological-geophysics approach, vertical electrical sounding (VES), was followed at 12 different locations surrounding the Kertek District, which has a general geological formation of igneous volcanic rock sediment. The result of the geophysical measurements (possibilities) indicates the presence of shallow, medium, and deep groundwater aquifers, which tended to follow the slope direction to the south. This may be due to the unsaturated soil conditions as the geoelectrical measurements were taken at the beginning of the rainy season. Finally, the goals of this research were to integrate resources with spatial characteristics to allow proper resources management.

Keywords: *groundwater, legislature policy, sub-surface, flow model, spatial plan*

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Introduction

Urban expansion occurs due to the increasing human population of metropolitan areas, which is a cause of high population density, especially in Indonesia. The increasing population size has resulted in the more intense climate-related and climate change hazards currently experienced by Indonesia. Based on a case-study in Indonesia, 60% of the population live in coastal areas, therefore, such areas are affected by the development of urban areas and water resources (Handayani and Kumala, 2015; Taylor, 2015; Djalante and Tomalla, 2012; Kumar et al., 2016; Handayani et al., 2017). Dieng Regency is included in the mining allotment area in the spatial plan of Central Java Province, Sindoro-Sumbing. Similarly, the derivation of the spatial plan of Wonosobo Regency (Figure 1) mentioned the existence of a gravel rock mining area in some areas of the district. In several places in Indonesia, there are some contradictions in policy implementations. In Wonosobo Regency, Public Document Policy No. 2/ 2011 section 30 contradicts section 39, which discuss whether the area is a groundwater basin or mining area. Kertek District, our case-study, is both a groundwater conservation basin and a volcanic gravel mining area. Therefore, it is necessary to determine the depth and flow direction of groundwater aquifers in the area to anticipate the harmful impacts of future mining activity and propose better spatial planning in this region (Wonosobo Regency Public Documents, 2011).

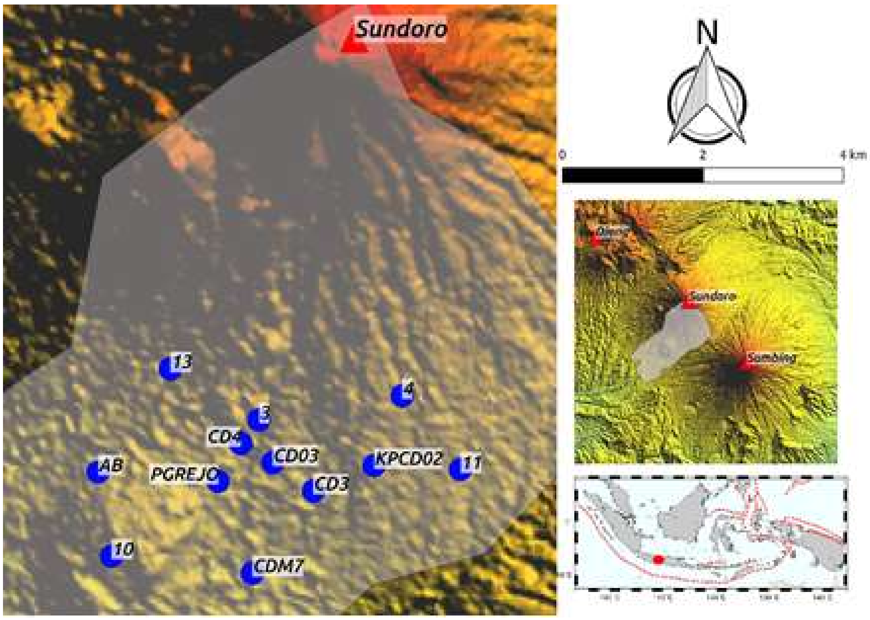

Figure 1. Study Area in Wonosobo regency, Central Java, Indonesia

The mining activity that occurs on the slopes of Mount Sindoro, located in Kertek District, is harmful to the environment, especially for groundwater conservation. Sand mining in Kertek District may affect the underground water resources, which could be demonstrated using the geophysical vertical electrical sounding (VES) approach. The geoelectric resistivity method is one of the most widely used methods of exploration, especially for groundwater exploration, because the resistivity of rocks is very sensitive to their water content. The basic concept of this method is very simple. The Earth can be considered as a resistor due to rapid advances in electrical technologies and the development of numerical solutions (Kearey and Brooks, 1991; Olayinka, 1991; Metwaly et al., 2009; Ndlovu et al., 2009). Groundwater investigations were conducted to estimate the depth between the forming facies (such as gravel or sand) and the physical characteristics of groundwater, (such as porosity and permeability). The aim of this research was to identify and generate underground aquifer maps to establish zonation policies for areas that may be mined, mined under certain conditions, and should not be mined at all. The maps will provide various geological information, such as the locations of sedimentary beds, sub-surface structures, and other associated features (Steward, 1982; van Overmeeren, 1989; Telford et al., 1990; Dahlin et al., 1999; Nowroozi et al., 1999; Meju, 2005; Helaly, 2017).

Based on previous studies, understanding flow pathways is a key issue for groundwater protection and development planning, essentially the types of sedimentary and tectonic homogeneous aquifer rocks (Lawrence et al., 2006; Rivett et al., 2011; Qin et al., 2013; Medici et al., 2016). Other studies have attempted to investigate contamination in aquifer areas, predict septic failure, or use geophysical prospecting for other purposes (Santos et al., 2006; Lee et al., 2006; Donohue et al., 2015; Gottschalk et al., 2017). Studies on local geology indicate that common silicate minerals were found throughout the study area. The distribution of groundwater facies is related to local geology, which may cause differences in the hydrochemical processes and lithologies of groundwater in the study area (Thin et al., 2018). To establish better policies, the government of Wonosobo Regency considers it necessary to conduct a geoelectric survey and subsurface identification. The other purpose of this study is to determine a spatial allocation of the mining designation area that will not damage the groundwater flow. Therefore, this research is imperative for understanding the depth of groundwater at the study site, understanding the direction of groundwater flow, and the impact of mining activities on groundwater. The result of the combined geophysical and geological approaches may protect groundwater aquifers and improve the current government policy for the mining area in Kertek, Wonosobo.

Geological Settings

Geomorphology

Wonosobo is located in the mountain range of Central Java within 98.468,38 ha, heading northwest-southeast along the Dieng-Sindoro and Sumbing Mountains. Wonosobo regency divide for 15 sub-districts with topographic elevation around 270~2250 asl. Banjarnegara, which is located on the eastern side of Wonosobo, is surrounded with more dense mountains along the east-west orientation. Dieng-Sindoro-Sumbing is the product of Holocene-Recent volcanic activity. The Quaternary volcanic arc was formed as a result of the orthogonal subduction of the Indo-Australian plate beneath the Eurasia plate, which has been active since the Early Cenozoic period. The major structures elongate east-west, parallel to the strike of subduction, forming the E-W-trending thrust faults of Kendeng-Barabis. Under this stress regime, major strike-slip faults that trend NE-SW and NW-SE were developed (van Bemmelen, 1949; Hamilton, 1979; Simanjuntak and Barber, 1996; Harijoko et al., 2016). The distance between active volcanoes is relatively close, similar to the nearby Merapi-Merbabu-Telomoyo-Ungaran active volcano row, which is also oriented northwest-southeast.

Stratigraphy of geology

There are several rock formations, mostly volcanic formations, that can be classified as the older Jembangan formation, Sumbing formation and younger Sundoro formation (Figures 2 and 3) based on the geological map of Banjarnegara and Pekalongan by Condon et al. (1996). The Jembangan volcanic formation consists of andesite lava and clastic volcanic rock, especially the local andesite with hypersthene-augite, which contains hornblende and olivine basalt. This formation is deposited over the slopes slightly further from the eruption centre. The Sumbing formation is composed of olivine-augite-rich andesitic lava, flow breccia, pyroclastic breccia, and lahar. The younger Sundoro formation consists of hypersthene-augite andesite and olivine-augite basalt, flow breccia, pyroclastic breccia, and lahar.

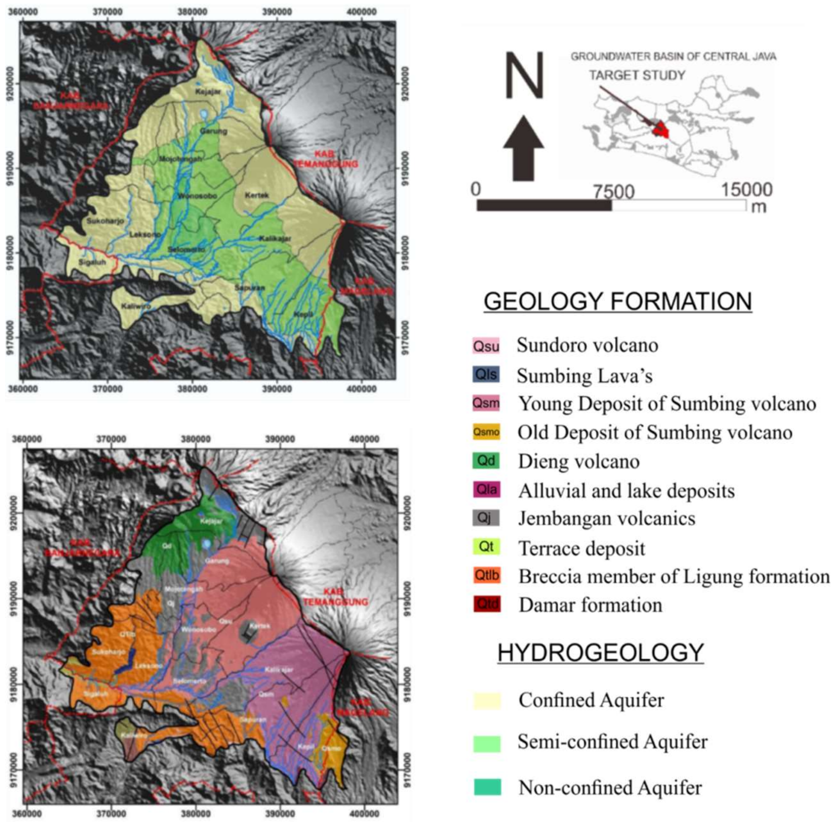

Figure 2. Hydrogeology and geology map of Wonosobo regency, Central Java, Indonesia (modified from Putranto et al., 2016)

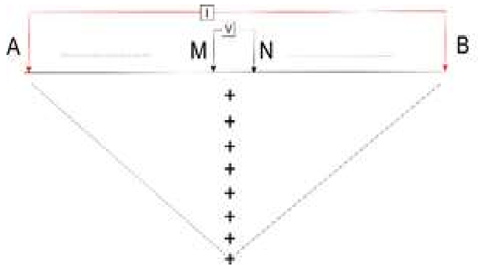

Figure 3. Schlumberger array configuration (modified from Telford, 1976)

Hydrogeology of Wonosobo

Wonosobo is divided into three regions based on its potential groundwater aquifers, i.e., confined, semi-confined, and non-confined aquifers (Figure 2), and is dominated by a confined aquifer system. This suggests that there is a high potential for water recharging areas in Wonosobo, which may be connected to another groundwater basin system in the proximity of the Sundara-Sumbing-Dieng volcanic deposits. The determination of groundwater conservation zones aims to classify the changes in the groundwater level and the environment caused by natural processes or human activities. There are two types of groundwater conservation zones, i.e., protection (inflow) and utilization zones (outflow). The utilization zones are determined based on the degree of damage to groundwater and environmental conditions (Putranto et al., 2016). The protection zones include groundwater recharge zones, natural springs, and groundwater outflow production wells. The mining activities are started since 2001 which is the sand-gravel mining in Indonesia is classified as C Class, whereas non-strategic or vital mining that the market is a non-direct global market without necessary mineral processing. The mining activities will impact a change of socio-economic culture in the local society surrounding the mine deposits (Nurdin, et al., 2000; Hakim 2015). Based on data presented in Tables 1 and 2, the mining activities in this sub-district impacted the groundwater debit since established in 2001.

Table 1. Groundwater debit before and after mining activities in Kertek sub-district (Source PDAM Wonosobo; Water Resources Dept.)

Year	Sidandang Spring (L/s)	Muncar Spring (L/s)	Mlandi Spring (L/s)	Total Production (L/s)	Average Production (L/s)	Description
1991	29.24	62.82	23.12	115.18		
1992	29.18	63,28	22.77	115.23		
1993	28.92	64.55	21.82	115.29		
1994	23.97	64.69	21.74	115.40		
1995	28.17	68.35	18.96	115.48	105.89	Before Mining
1996	29.11	65.01	21.49	115.61		
1997	29.35	62.24	25.70	117.29		
1998	29.26	62.78	24.30	116.34		
1999	29.30	62.54	24.51	116.35		
2000	29.28	62.61	24.81	116.70		
2001	29.24	62.82	25.71	117.77		
2002	29.51	66.32	20.74	116.57		
2003	30.73	70.00	18.50	119.23		
2004	29.99	43.48	36.83	110.30		
2005	30.80	42.08	28.56	101.44		
2006	26.48	42.09	26.58	95.15		
2007	26.47	41.45	26.09	94.01		
2008	26.11	41.40	25.89	93.40	98.6	Mining Activities
2009	25.99	41.17	25.66	92.82		
2010	28.83	41.07	25.51	92.41		
2011	25.39	40.65	24.99	91.03		
2012	27.53	41.03	24.44	93.00		
2013	25.11	39.46	24.01	88.58		
2014	23.64	39.11	23.89	86.64		
2015	24.76	38.76	23.13	86.65		

L/s – Liter per second

Table 2. Spring debit in Kertek (Source PDAM Wonosobo; Water Resources Dept.)

No	Spring Name	Before Mine (X1) (L/s)	After Mine (X2) (L/s)	*d* (X2-X1) (L/s)	d^2 (L/s)
1	Sidandang	29.08	27.18	1.9	3.61
2	Muncar	63.90	46.06	17.84	318.2656
3	Mlandi	22.92	25.37	2.45	6.0025

Materials and Methods

The concept applied as a geophysical approach to our case is based on the response of the Earth to electrical current. In VES, an electrical current is induced through current electrodes, and two other potential electrodes are used to measure the potential difference between them. The electrodes are spaced at a certain distance from each other (Ward, 1990; Telford et al., 1990; Burger, 1992). Current electrodes are placed with L distance, while potential electrodes are placed with the shorter a distance, and the measurement point is located in the middle using the Schlumberger Array with the spreading technique from the centre to the top target. For example, the measurement point is 300 m from current electrodes A to B, and the result data are generated as the logarithmic depth of approximately 60-100 meters, which is why this method is also referred to as vertical electrical sounding (Figure 3). The potential difference can provide information about the geological formation beneath the measurement point. The greatest eccentricity used is 1/3 of the ratio between the current (A-B) and potential electrodes (M-N) to obtain a better signal strength according to the comparison distances between current and potential electrodes. This VES method is particularly robust for exploring subsurface aquifers owing to the characteristics of water in geological formations, as it serves as a conductivity agent for transferring electrical current. A full explanation of this method can be found in Telford (1976).

The potential difference was measured using the VES method from 2015-2017 at the location shown in Figure 3 and Table 3. There were 12 measurement points to represent the Kertek Dub-district, and measurements were taken using OYO McOhm Mark 2.

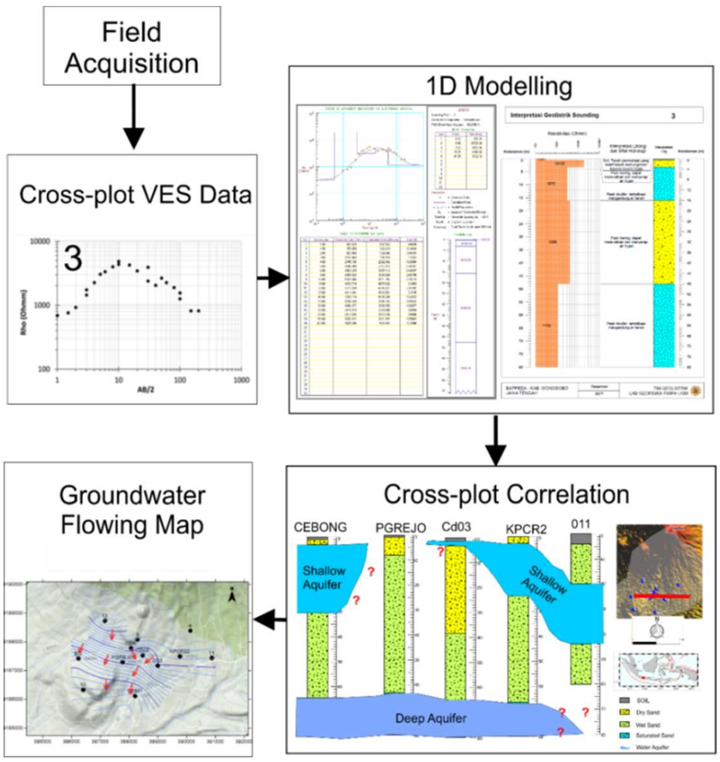

Figure 4. Research flowchart

Table 3. Location of VES measurement points in Kretek, Wonosobo Regency

No	Name of Point	X (UTM m)	Y (UTM m)
1	PGREJO	387771	9187293
2	CD4	388065	9187776
3	CD03	388470	9187533
4	11	390871	9187445
5	CDM7	388208	9186117
6	CD3	388990	9187170
7	KPCD02	398766	9187494
8	13	387159	9188731
9	AB	386235	9187412
10	10	386406	9186336
11	3	388293	9188080
12	4	390126	9188387

The measurement points were selected based on our concern that gravel mining would affect the water recharge system in the basin underneath the area. In addition to geophysical measurement, we also took geological observations in the study area to elucidate the origin and direction of the sedimentary process. Using geological data, such as structure bearing and geological formation, VES data can be used as a basis to determine both the depth and flow direction of groundwater. A flowchart for this research is shown in Figure 4.

Results and Discussion

The subsurface lithology and groundwater aquifers were detected through processing data and interpreting the true resistivity value at each measurement point. In general, the lithology obtained from the VES results indicates the resistivity of sandstone and volcanic materials. Shallow aquifers were identified at depths of approximately 3 m with a thickness ranging from 13 to 28 m. Mid aquifers were identified at approximately 20 m beneath the surface, with a thickness ranging from 22 to 24 meters. Deep aquifers were identified at a depth of 64 m. Lithocorrelation was conducted for several different lines of measured data, and the results are presented in Figures 5-10. Each measurement point was positioned according to its elevation in order to lithocorrelate the interpreted data, which also aids in determining the direction of groundwater flow.

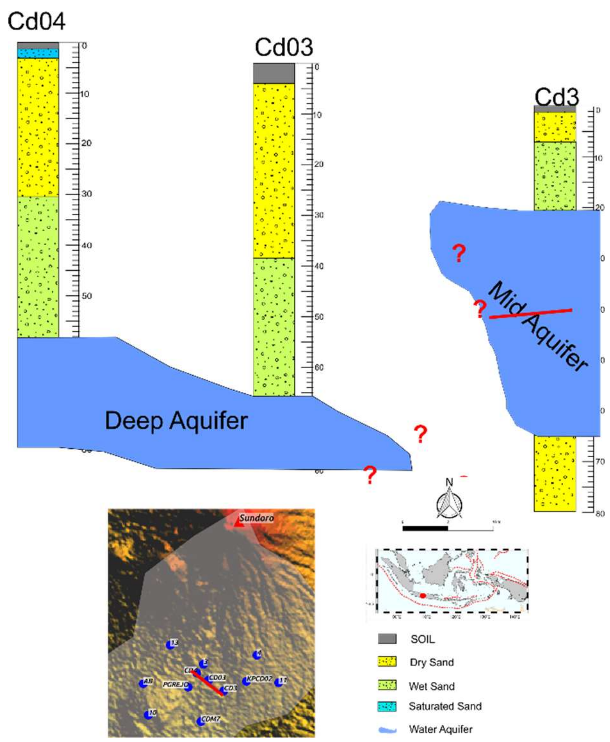

Figure 5. Correlation of groundwater aquifer between point 10-PGREJO-CD03

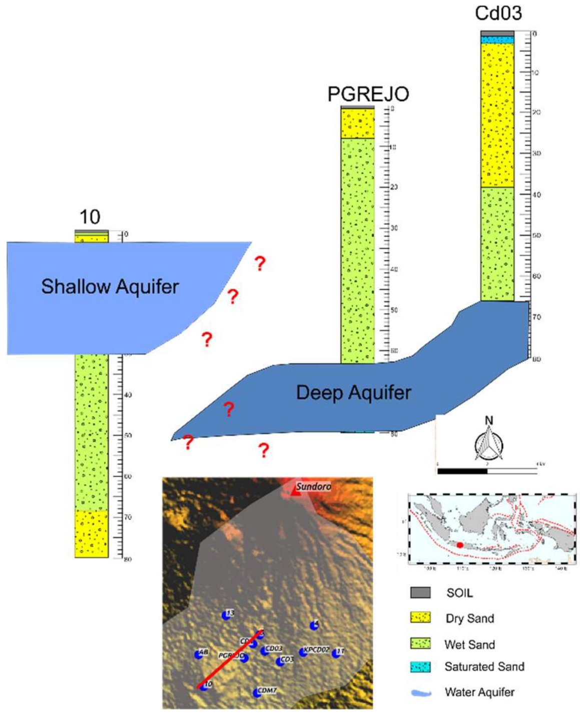

Figure 6. Correlation of groundwater aquifer between point CD04-CD3

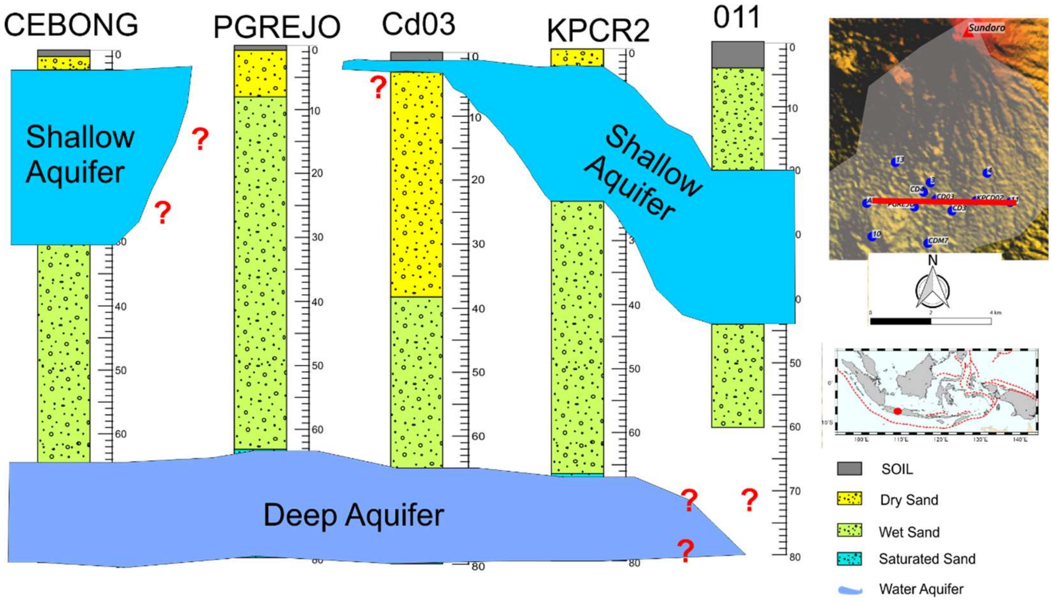

Figure 7. Correlation of groundwater aquifer between point AB-PGREJO-CD03-KPC02-11

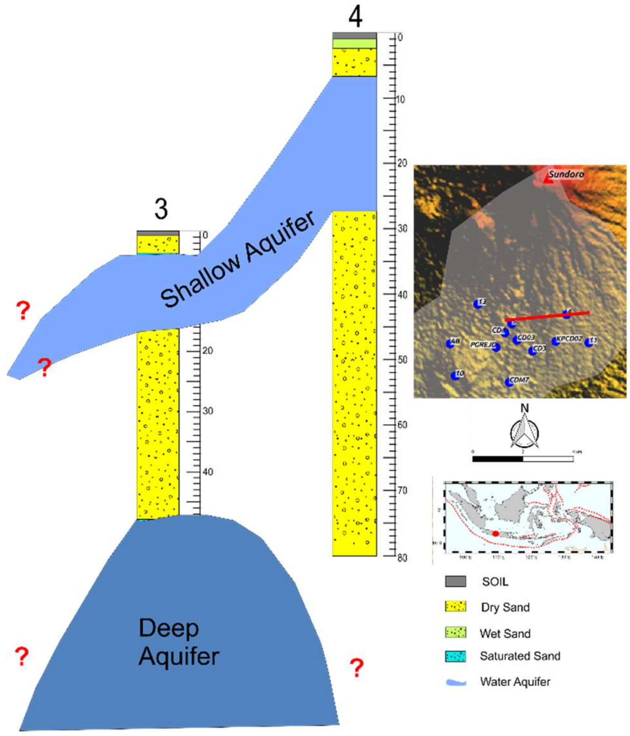

Figure 8. Correlation of groundwater aquifer between point 3-4

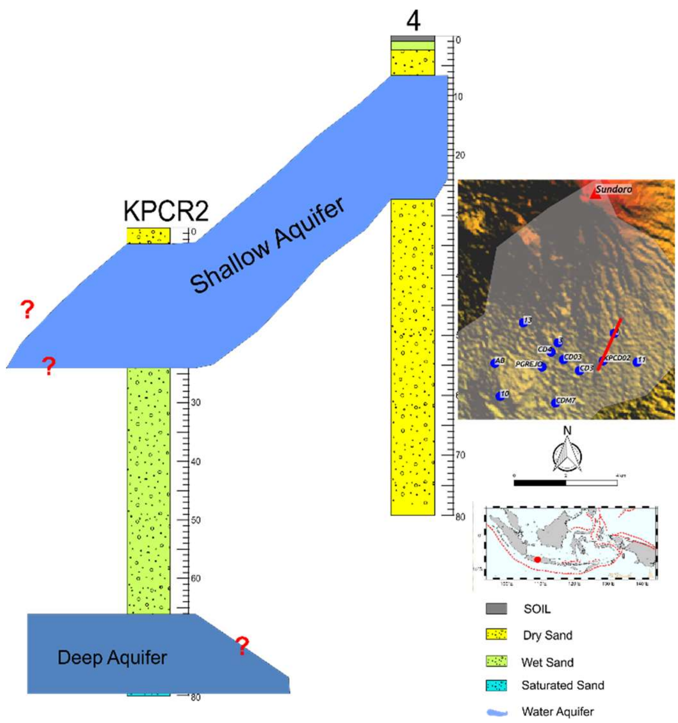

Figure 9. Correlation of groundwater aquifer between point KPCR2-4

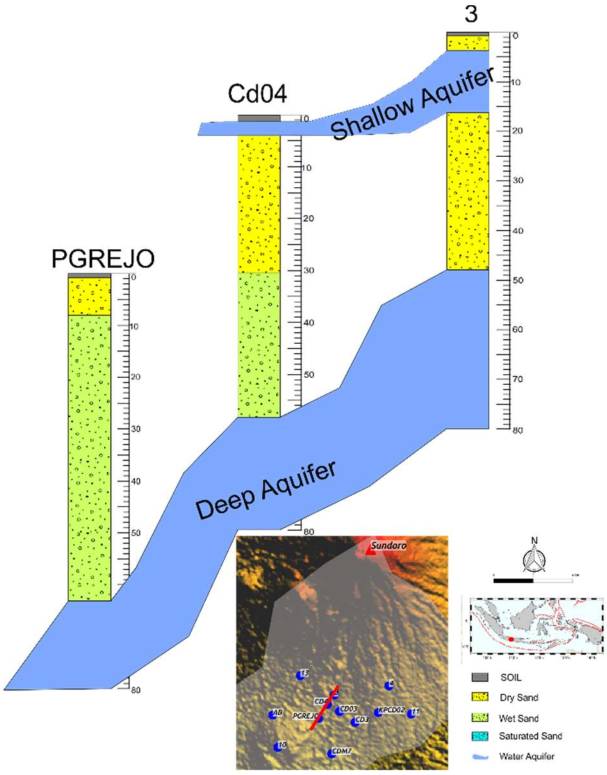

Figure 10. Correlation of groundwater aquifer between point PGREJO-CD4-3

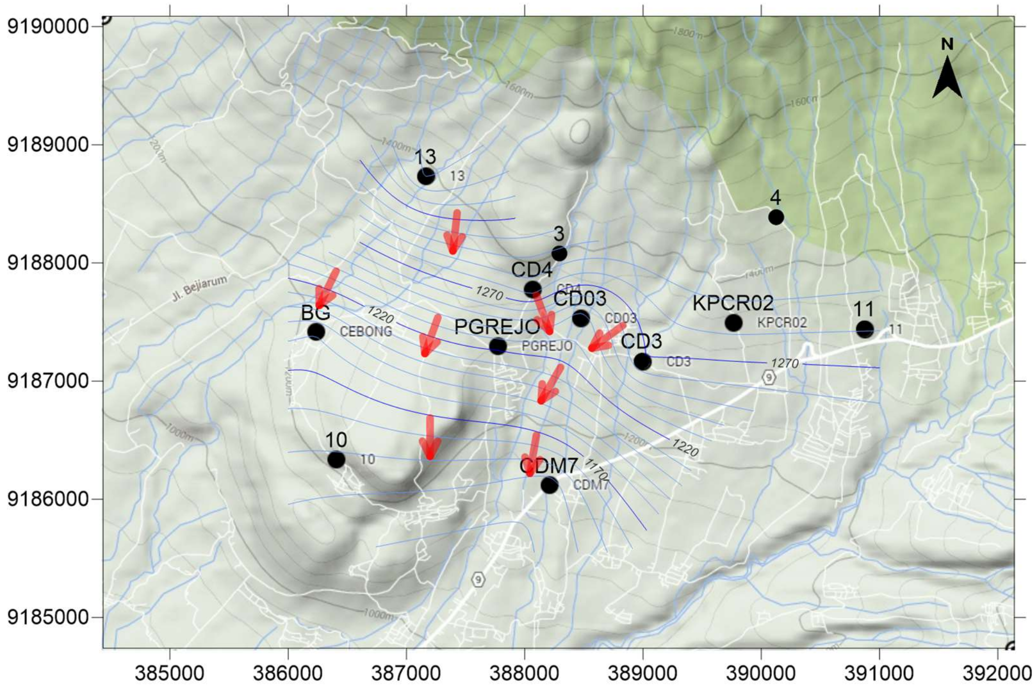

Figure 11. Contour map of groundwater elevation (contour interval 10 m)

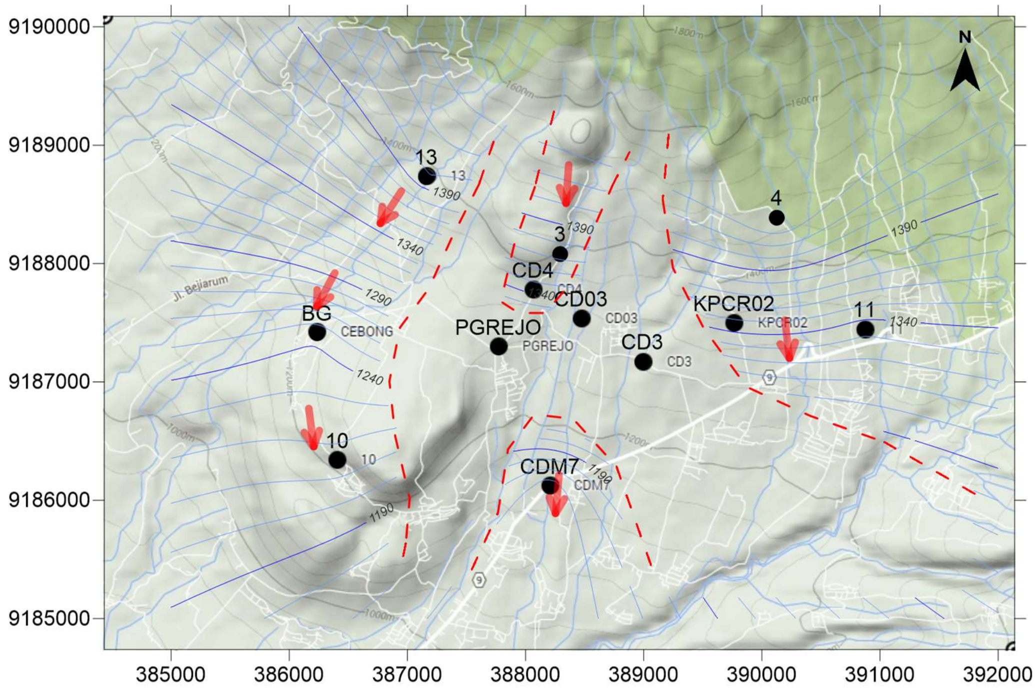

Figure 12. Contour map of shallow groundwater (contour interval 10 m)

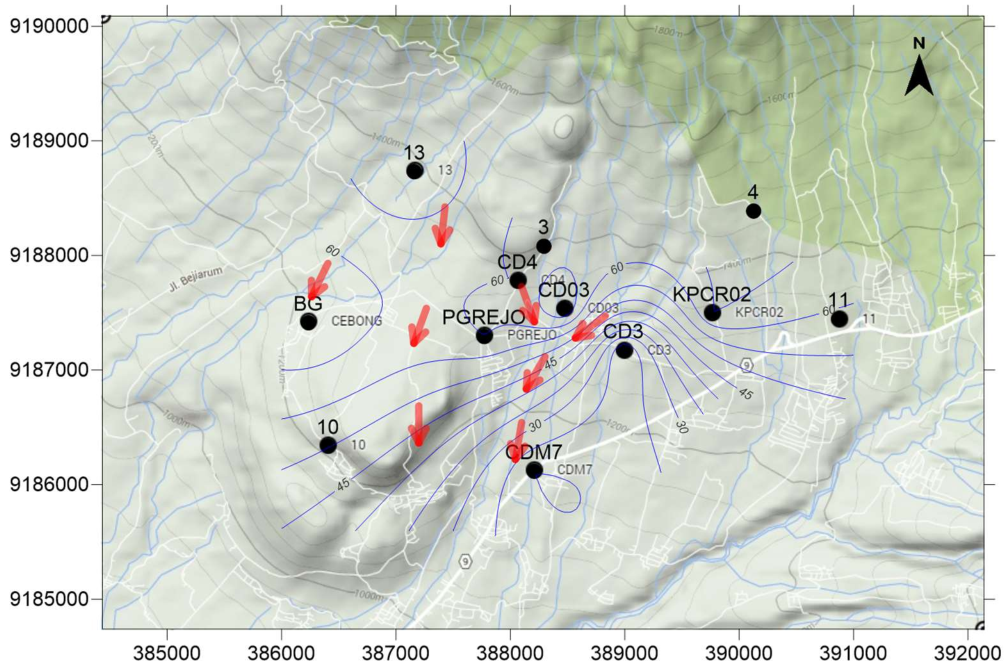

Figure 13. Contour map of depth aquifer and the direction the groundwater (contour interval 10 m)

Shallow aquifers were detected at several measurement points. The crossline in Figure 7 suggests that water formations beneath KPCR02 and 011 were connected as a shallow aquifer extending eastwards. However, the lithocorrelation of points 3 and 4 (Figure 8) suggests that the aquifer extends westwards. Figure 9 shows that the shallow aquifer beneath KPCR2 and 4 extends southwards. Observations of the shallow aquifer reveal that the shallow aquifer is strongly influenced by formation distribution; in this case, sandstone formations have different thicknesses at different points which influence the direction of groundwater flow.

A deep aquifer was observed at 10 measurement points, located in the mid-western region of the measurement area. As shown in Figure 5, PGREJO and CD03 indicated that the deep aquifer is connected and extends southwest. The NW-SE lithocorrelation of CD04, CD03, and CD3 suggested that the deep aquifer extends southeast. Figure 7 shows the lithocorrelation of five measurement points and suggests that the deep aquifer is distributed evenly in the central part of the study area. Point 3 in Figure 8 indicates the existence of a deep aquifer in the northern region of the study area. Figure 10 shows the deep aquifer beneath PGREJO, CD4, and 3, and the lithocorrelation suggests that the groundwater it contains flows towards the south-southwest. In general, the deep aquifer is assumed to be well connected in the central and western regions of the study area and groundwater is estimated to flow southwards based on the observations from the lithocorrelation.

A mid-depth aquifer is observed beneath CD 3 (Figure 6), which appears to be isolated and was not detected at other measurement points. This aquifer is estimated to be 40 m thick at CD3. It is difficult to correlate the mid-depth aquifer detected at CD3 with the nearby points, but the possibility remains. Other possible explanations as to why this aquifer is isolated are differences in lithology or an error during data processing. This aquifer could also connect the shallow and deep aquifers and serve as the bridge for groundwater in the shallow aquifer located in the eastern region of the study area to the aquifers (shallow and deep) in the southern region with a lower elevation.

Based on the interpretation of each measurement point and lithocorrelations, a groundwater flow direction map was built, and the results are presented in Figures 11-13. Figure 11 shows the flow direction of the shallow aquifer at its elevation. In general, the flow travels southwards, but it is not present in the central part of the study area. The dominant sediments originated from Mount Sundoro; therefore, the geology of the Wonosobo Regency is controlled by volcanic activities from the Sundoro-Siung-Dieng Mountain. Figure 11 shows the groundwater flow of the deep aquifer, which is distributed in the central-western part of the study area and generally travels southwards to the south, gravity force of sedimentary process from volcanism in Mount Sundoro. Figures 12 and 13 also present the groundwater flow direction based on the cross-plot correlation of the measurement point. The groundwater protection zones of the study area include recharge areas and the spring protection zone. The recharge zone is identified by considering topography, drainage pattern, and springs, and is located in northern to eastern Wonosobo Groundwater Basin area, including the Kejajar, Garung, Kertek, Kalikajar, Sapuran, and Kepil Sub-districts, at an altitude above 1100-3050 m. The spring protection zone should be created within a radius of 200 m from the location of destructive activities (human activities), such as drilling, excavations, and other activities that may interfere with the presence of these springs (Putranto et al., 2016).

Generally, the aquifer flow travels southward, but that in the eastern region flows to the west. A shallow aquifer in the eastern region also flows southwards. The groundwater basins in Kertek, Wonosobo Regency, were identified as shallow and deep aquifers (mid-depth aquifers were also found in some regions) according to the cross-correlation model of the groundwater aquifer (Figures 5-10). The layering system of the groundwater basin found in the study area is common in Indonesia, especially within the vicinity of active volcanic sedimentary rocks, such as Yogyakarta City (Hendrayana, 2013). Other regulations in Indonesia state that open-pit mining, including gravel and limestone for housing construction, should consider and establish a maximum depth that reaches the groundwater level (there is no explanation of such a depth or the aquifer depth). Mining and special mining permit holders must also continue taking sustainable actions and maintain the carrying capacity of water resources under certain laws and regulations, data on the Tables 1 and 2 show the decreasing groundwater resources before and after mining activity in this sub-district (Law of the Republic of Indonesia No.4/ 2009; Ministry of Energy and Mineral Resources Regulation No. 34/ 2017; Ministry of Energy and Mineral Resources Regulation No. 555.K/26/M.PE/1995).

Understanding the relative importance of various inputs to a given surface body is crucial for proper management (Winter, 1998; O'Driscoll and Parizek, 2002). Pedrera et al. (2016) conducted a study on the preservation of groundwater aquifers using controlled-source audio magnetotellurics (CSAMT), time-domain electromagnetic sounding (TDEM), and gravity prospecting for evaluating the hydrodynamic impact of intensive water pumping from limestone aquifers. The geophysical methods to constrain the geometry of carbonate aquifers provide insights into the implications of proper spatial groundwater and land management. In groundwater resources management, efforts must be made to investigate the susceptibility of the delineated aquifers to pollution; therefore, these methods will assist in mitigating water contamination threats against human health and the environment (Oni et al., 2017). Geological and geophysical approaches to proper surface management are required to understand impacts to other aspects of life, such as underground water aquifers. The isotope ratio of δD (deuterium) in the water sample collected from Wonosobo is calculated as an elevation function by entering the value of δ18O (oxygen). Therefore, the isotopic composition of the rainwater line contains the information of the elevation at which the rainwater fell. If the isotopic composition of a water sample taken from the springs and coordinated wells is consistent with this, then the water samples are likely derived from meteoric water. The meteoric water source in this area is oxygen-rich, and the resulting groundwater is potent at an elevation of approximately 1395-1509 m above sea level (Drever, 1988; Wijatna et al., 2018). Groundwater conservation zones were studied to determine the degree of changes in conditions and environmental groundwater caused by natural processes and/or human activities. The implementation of a conservation zone aids in protecting groundwater from misuse and spatial planning. The determination of conservation areas is the responsibility of the government in accordance with PP. 43/2008 article 24 which states that groundwater resources are to serve societal prosperity and that direct supervision from the government is provided at the district, regency, province, or even national levels under the Ministry of Public Works (Public Document of Water Resources, 2008; Hendrayana, 2015). Groundwater conservation effort should be made to optimize the reservoir area in the groundwater basin system, restore, and protect groundwater from contamination by human activities, and improve the long-term environmental sustainability. This research indicates that there is a situation where resource deposits may be located in the same place as the groundwater basin system and may also conflict with the future spatial residential plan of this regency. The government should carefully establish legislation to address this.

Conclusion

In this study, the regulation of the groundwater recharge zone in Kertek, Wonosobo, was evaluated. The geoelectric survey on the southwestern slope of Mount Sindoro in the Kertek District indicates the presence of "shallow", "mid-depth", and "deep" groundwater aquifers, which incline along the slope direction to the south. However, the water in the deep aquifer in the east flows to the west. Shallow aquifers, which were detected by geoelectric surveys are not completely connected, particularly in the Pagerrejo area. This could be due to the unsaturated soil conditions, as geoelectric measurements were conducted at the beginning of the rainy season. The results of this study can be used to improve our understanding of geophysical approaches in hydrogeology to conduct more comprehensive research and improve water resources management. At the end of this research, we suggested that the Kertek Sub-district recharge area may conflict with the sand-gravel mine in the same location, according to the sub-surface modelling.

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