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RESEARCH ARTICLE

Hydrogeological Risk Assessment for Groundwater Conservation in the Northeastern Slope Area of Mount Arjuno, Pasuruan Regency, East Java, Indonesia

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Abstract .The northeastern slope of Mount Arjuno, Pasuruan district, East Java province, Indonesia represents a vast and good groundwater resource quality, generally be exploited by some companies for drinking water industries. Water unbalance and quality degradation is presumed to arise because groundwater extraction volume is getting bigger but less control by the regency authority. This study is to figure out the geologic condition and hydrogeological system, conduct groundwater exploitation risk assessment, and develop a conservation program. The study results show that the study area's geomorphological units can be divided into the volcanic summit, volcanic slope, fluvial plain, and anticlinal hills. The lithology comprises sandstone, breccia, and andesite lava of Mount Arjuno and Mount Welirang. The geological structures are anticline, normal fault, and lateral slip fault. Hydrologically, there are three watersheds, including Lumbangrejo, Ketanireng, and Prigen watersheds. The aquifers comprise unconfined to semi-confined aquifers with fissures and intergranular porosity. Based on risk assessment valuation, Pecalukan village of the Ketanireng watershed and Lumbangrejo village of the Lumbangrejo watershed are categorized as very high groundwater vulnerability zones, Karangrejo and Sukoreno villages of the Lumbangrejo watershed, Kedungringin, Kepulungan, and Gunungsari villages of the Ketanireng watershed are categorized as medium vulnerability zone. While, Ngorong village of the Lumbangrejo watershed, Gempeng, Oro-Ombo, Kalisat, and Dukuhsari villages of the Prigen watershed belong to the low vulnerability zone. The proposed conservation programs involve profitable water use safety campaigns, domestic waste, and industrial wastewater management, agricultural activities controlling, sandstone mining regulation, and reforestation.

1. Introduction

The northeastern slope of Mount Arjuno that belongs to Pasuruan district, East Java Province, Indonesia, is hydrogeologically performs potential groundwater resources, both in quantity and quality (Sukobar, 2007; Dianasari, 2008). This high potency attracts many companies to exploit groundwater from this area, which, among others, is used for commercially bottled water (Cahyahadi, 2010). The groundwater of the study area is taken for industrial usage and for fulfilling domestic and agricultural water needs. (https://wiretes.wordpress.com/2010/01/14/pasuruan-dan-air/).

Naturally, groundwater abstraction should not exceed the recharge area's capacity to fulfill (Supriyatno, 2019). However, unfortunately, the study area's groundwater supply and exploitation seem unbalanced (Yudianto, 2013). In the study area, 24 companies extracted groundwater in 2015, 27 companies in 2016, 31 companies in 2017, and 24 companies in 2018 (Supriyatno, 2019). Due to the large scale and uncontrolled groundwater exploitation, some problems presume to arise associated with the disturbance of water balance in the northeastern slope area of Mount Arjuno. Concerning this problem, such an assessment and measures for developing water conservation programs need to be done. The conservation is necessary to be conducted to maintain the sustainability of water resources, based on environmental perspectives. Investigations conducted by previous researchers (Reza et al., 2020; Bahri et al., 2017; Wandowo et al., 2015; Waspodo, 2011) were limited to aquifers types, and groundwater flows identification, did not discuss pollution and environmental risks that capable of disrupting groundwater quality.

This study evaluates the geologic condition and hydrogeological system, conducts a risk assessment related to groundwater exploitation, and develops a conservation program for sustainable groundwater development in the northeastern slope area of Mount Arjuno. The study area is approximately 251 km^2 with coordinate boundaries of 7° 34' 22.6" South 112 ° 48' 13.3" East to 7° 45' 16.5' South 112° 36' 18.1" East. The study area covers five sub-districts, namely Pandaan, Beji, Bangil, Sukorejo, and Prigen districts, included in Pasuruan Regency, East Java Province, Indonesia. (Figure 1).

2.Method

The study was conducted by an analytical approach, referring to field hydrogeology methodology (Moore, 2002). The data that were examined consisted of secondary data and primary data obtained from field surveys, geologic investigation, hydrogeological mapping, and laboratory analyses. The laboratory analyses and testing included petrology, geologic structures, and water samples of groundwater and surface water.

Hydrogeological system assessment was completed by concerning some previous research results either in the same and adjacent locations or other places. In this study, it was essential to determine and delineate recharge and discharge areas. The recharge area can represent either gross recharge or net recharge (Doble & Crosbie 2017). Gross recharge is the water volume that infiltrates through the unsaturated zone and crosses the water table, while net recharge is gross recharge minus Evapotranspiration (Ward & Trimble, 2004). Recharge areas generally display a high profile of topography with relatively inclined slopes and a deep groundwater table. In contrast, discharge areas show a low topography profile with a gently inclined slope to flat and shallow groundwater level elevation (Fetter, 1994). On the other hand, catchment areas, commonly involving hills and mountains, are characterized by relatively young aged groundwater with low chemistry content concentrations (Heath, 1987; Kusumayudha & Sutejo, 2008).

As proposed in this study, groundwater and surface water problems have to be appropriately managed (Saha, 2013). Concerning water budged, the relative recharge amount from such water bodies would vary significantly depending on the water bodies' characteristics and spatial distributions (Kuroda et al., 2017). Groundwater quality assessment was also done in this study based on physical and chemical aspects. Groundwater chemistry values vary much, reflecting the combined effects of recharge and transport through different lithology and geological structures (Newman et al., 2016). The results of groundwater quality assessment were then figured on maps of compound distributions, including Ca^{2+}, Mg^{2+}, Fe^{3+}, Mn^{3+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, and NO_2^-. Water samplings were done using glass bottles and then sealed to maintain the original properties of water samples. Samples were taken from dug wells of 1 to 10-meter depth for chemical testing and analyses.

The geological and hydrogeological studies were continued with risk assessment and valuation, completed by considering groundwater-related parameters involving existence, continuity, quantity, and quality (Purnomo, 2007). Aspects to be taken into account for risk assessment were both natural and human factors. Natural factors involve floods, landslides, volcanic eruption, and erosion, while human factors consist of domestic waste, industrial waste, sand and stone mining activities, and deforestation. Each of the parameters and factors is qualitatively classified into low to very high risks depending on its influence intensity to groundwater environment degradation (Ward & Trimble, 2004). The detail of classification and scoring and weighting and scoring of the risk factor intensity to groundwater existence are discussed.

3. Result and Discussion

Geology

Based on the physiographical map (Van Bemmelen 1949), the study area is positioned in the eastern part of the Kendeng Zone and Solo Subzone. Based on Van Zuidam's classification (1983), the study area's landforms can be divided into four units: the volcanic summit unit, the volcanic slope unit, the fluvial plain unit, and the anticlinal hills unit. The volcanic summit unit covers the top part of Mount Arjuno, extends over about 1% of the study area. This unit's drainage system shows a radial pattern, while the lithology consists of andesite and basalt igneous rocks. The volcanic slope unit includes parts of Mount Arjuno's body, occupying about 24% of the study area, a radial drainage pattern at the top, and parallel at the bottom. At the same time, the lithology consists of andesitic lava and volcanic breccias. The fluvial plain unit occupies 71% of the study area, with a sub-dendritic drainage pattern. Lithology composing this unit is a thick soil as a weathering product of andesite-lava, volcanic breccias, and tuffaceous sandstones. The anticlinal hills unit covers 4% of the study area, is controlled by a geologic structure of anticline, with a sub-dendritic drainage pattern, while the lithology consists of tuff sandstone, volcanic breccias, and conglomerate.

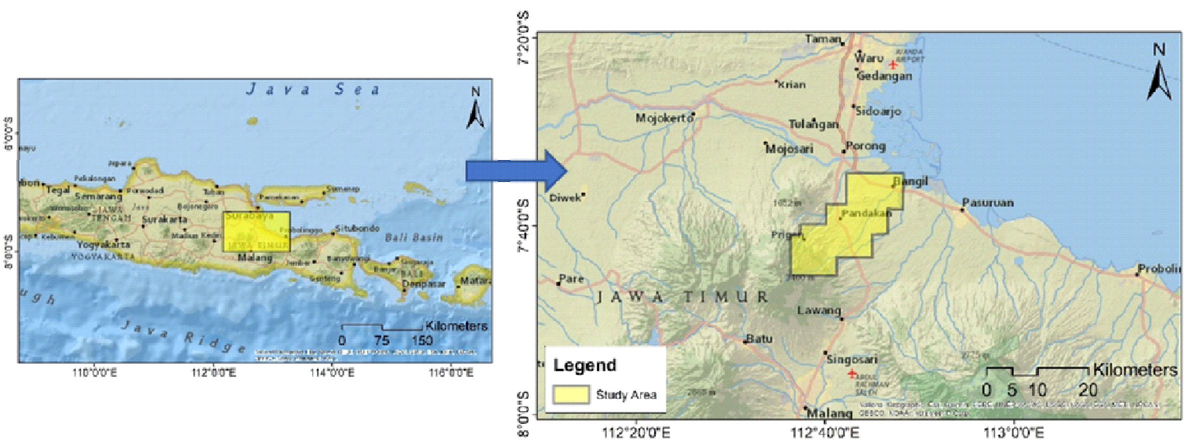


Figure 1. Location of the study area on NatGeo-World-Map.

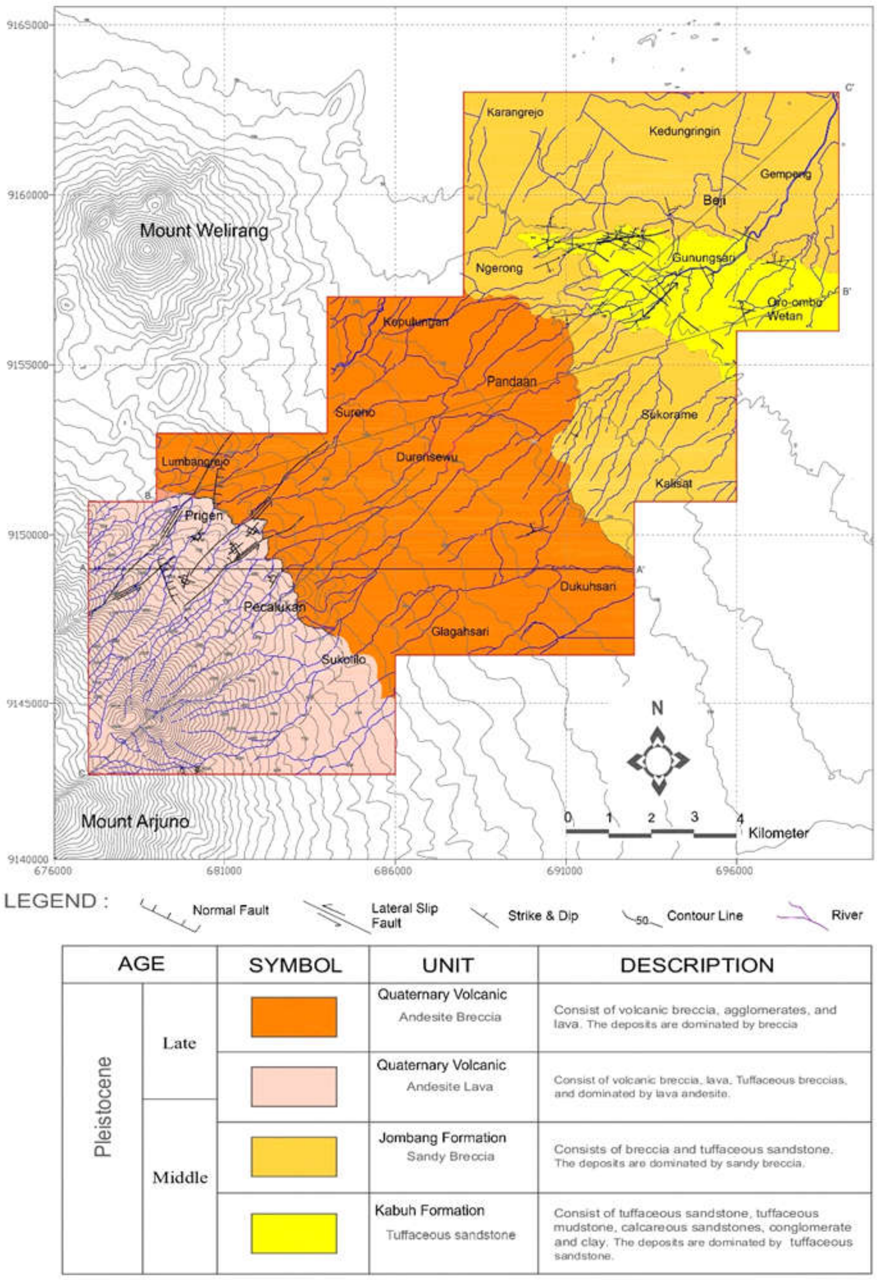


Figure 2 . Geologic map of the study area showing the distribution of rock units and geologic structures

The study area's stratigraphy from the oldest to the youngest involves the Kabuh Formation, the Jombang Formation, and the Quaternary volcanic rocks unit. The Kabuh Formation consists of tuff sandstone, tuffaceous claystone, calcareous sandstones, breccias, and conglomerates. Its age is Middle Pleistocene (Santoso et al. 1992). The presence of plagioclase minerals that makes up the rock units and aquifer layers interacts with groundwater and directly affects groundwater's chemical composition and quality to increase the concentration of anions and cations (Heath, 1987; Kusumayudha & Sutejo, 2008). The Jombang Formation consists of sandy breccias, volcanic breccias, tuff, and sandstone, deposited in the Middle Pleistocene, conformably overlay the Kabuh Formation (Santoso et al. 1992). The Quaternary volcanic rock unit consists of lava, volcanic breccias, brecciated lava, tuffaceous breccias, tuff, and sandstone. They were deposited during the Middle Pleistocene to the Late Pleistocene. This unit is sourced from Mount Arjuno and Mount Welirang. The study area's geographic structures are anticline in the northeast part and normal and lateral slip faults in the southwest part. The study area's lithological and structural distributions are represented in the geologic map (Figure 2).

Hydrogeology

By assessing the topographic and hydrogeological maps (Burhanul, 2002; Taufiq, 2002), the study area can be divided into three watersheds, i.e., the Lumbangrejo, t Ketanireng, and the watersheds. On the other hand, based on the stratigraphical position and type of porosity (Mechal et al., 2017), the study area's aquifer system can be classified into the unconfined aquifer with fissures porosity, unconfined to semi-confined aquifer with intergranular porosity, and unconfined aquifer with intergranular porosity (Figure 3). In the unconfined aquifer with fissure porosity, groundwater elevation ranges from 2400 m to 900 m. In the unconfined to semi-confined aquifer with intergranular porosity, groundwater height ranges from 900-150 m, while in the unconfined aquifer with intergranular porosity, groundwater head altitude is 30-150 m (Figure 3).

Recharge and discharge zones of the study area were mapped. The recharge zone occupies an area with topography from 2400 m to 500 m base on the maximum height of Mount Arjuno (Santoso and Suwarti, 1992), while the discharge zone occupies an elevation of fewer than 500 m above sea level. Groundwater flows from Southwest to Northeast direction.

Groundwater Quality

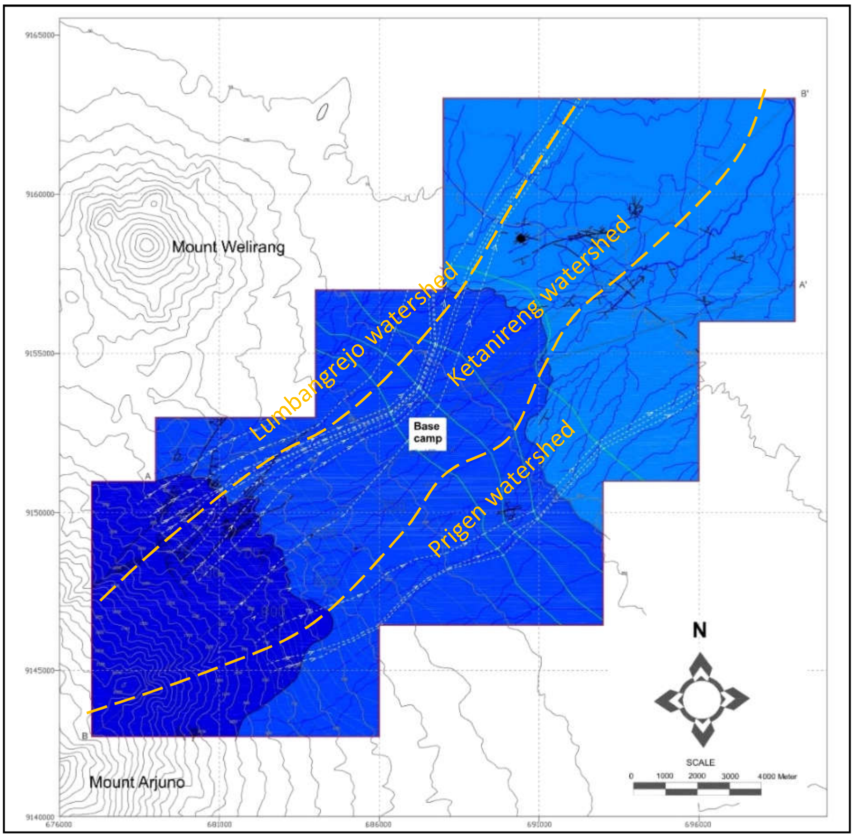
The study area's groundwater quality was determined by testing and analyzing water samples taken from dug wells. The quality analyses including physical parameters of color, odor, taste, turbidity, and temperature, physical-chemistry parameters such as electrical conductivity (EC), total dissolved solids (TDS), and hydrogen ion activity (pH), and chemical parameters. In general, the physics and physical-chemistry quality of groundwater can be categorized as clean water (Kusumayudha et al., 2013). Referring to the hydrochemical study by Newman et al. (2016) and Katsanou et al. (2017), the chemical compounds selected to be tested were: Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, NO_2^{-}, HCO_3^{-}, Fe, and Mn (Table 1). Their concentration distributions are shown in Figure 4 and Figure 5.

Risk Assessment

Risk assessment was done to recognize the potential hazards of the study area that may affect groundwater condition and distribution. It was based on two risk factors, including natural and human factors, as described below.

1) Natural Factors

Natural factors that possibly affect groundwater and environmental conditions in the study area are identified as floods, landslides, droughts, volcanic eruptions, and erosion. Flood threats groundwater and environment due to its overflowing that generally implies high turbidity, sediment transport, and other materials that may be toxic. The occurrence of landslides can affect water quality because the transferred mass will increase water flows' turbidity. Volcanic eruptions generally produce pyroclastic materials, glowing clouds, toxic gases, and lava. Pyroclastic deposits of various



Symbol	Aquifer System			Groundwater Level (meter)
	Area	Porosity	Stratigraphic Position	
	Recharge – Runoff	Fissures	Unconfined	2400 – 900
	Recharge	Intergranular	Unconfined to semi-unconfined	900 – 150
	Discharge	Intergranular	Unconfined	30 – 150

Figure 3. Map of aquifer and groundwater distributions in the northeast slope area of Mount Arjuno.

Table 1. Distribution of chemical elements compared to drinking water standards from WHO in the groundwater study area.

Chemical compound	Concentration (mg/l)	WHO standards (mg/l)	Location, name of the village	Remarks (mg/l)
Ca^{2+}	66 – 90	75	Oro-ombo, Kolusari, Kiduldalem, Baujeng, Lekasari	-
Mg^{2+}	61 – 70	100	Pandaan and surroundings, Prigen	-
Na^{+}	95 – 190	200	Kalianyar, Kalirejo, Tambakan Ngadimilio,	-
Fe^{3+}	0,28 – 0,32	-	Wonokerto, Kenduran, Candibinangun.	Little bit exceeding the standard (Max. 0.3)
Mn^{3+}	0.6 – 1.45	-	Glanggang, Pagak, Kedungboto, Kalirejo	Exceeding the standard (Max. 0.4)
HCO_3^-	401 – 460	-	Beji district	-
SO_4^{2-}	81 – 105	250	Wonokoyo, Gunung Sari, Gununggangsir	Not exceeding the standard (Max. 250)
Cl^-	75	250	Beji district	Not exceeding the standard (Max. 250)
NO_3^-	40 – 49	50	Cangkringmalang	Not exceeding the standard (Max. 50)
NO_2^-	6 – 7	-	Kalirejo, Glanggang, Pagak, Kauman	Exceeding the standard (Max. 3)

grain sizes containing diverse compounds and minerals, when diluted by surface water or rainwater, and then slipped under the surface, will interfere with the groundwater quality in terms of chemical compounds (Ca^{2+}, Mg^{2+}, Na^{+}, Fe^{3+}, and SO_4^{2}) enrichment and CO_2 increasing (Domenico and Schwartz, 1990).

2) Human Factors

Human factors that possibly increase the risks of disruption on groundwater and the environment are industrial waste, domestic waste, deforestation or forest logging, sand and stone mining, farming activities, and groundwater exploitation. Industrial wastes and domestic disposals containing hazardous substances can contaminate and degrade natural water quality, threatening human health. In the farming area, groundwater is usually polluted by nitrate (NO_3^-) and nitrite (NO_2^-) from fertilizers and pesticides (Showers et al., 2008). In the study area, sand and gravel mining sites are indicated to disrupt the water flow system and groundwater infiltration. On the other hand, uncontrolled forest logging may trigger erosion, increase runoff, reduce rainwater infiltration, and threaten groundwater availability and sustainability.

In this study, four parameters are utilized to determine the groundwater system's risk factors' impact intensity, including existence, continuity, quantity, and groundwater quality. The risk factors can be classified into very high, high, medium, and low (Table 3).

During the valuation on the risk factor to groundwater existence, the natural factors are given the weight of 40%, while human factors are 60%, and every single factor scored as 1 to 4 (Table 4).

Identification of threat sources is made in the areas that include the three watersheds of Lumbangrejo, Ketanireng, and the Prigen, which mostly corresponds to human activities. The assessment results define the vulnerability zones towards the sources of the threat. Their vulnerability category includes domestic and industrial wastes, pesticide, flooding, forest logging, industrial exploitation, sandstone mining, and landslide. The source of the threats can be found in every village of Lumbangrejo watershed, Ketanireng watershed, and Prigen watershed, shown in detail in Table 5.

The value of Score (S) x Weight (W) represents the area's vulnerability toward groundwater problems. The lowest S x W = 0.6 while the highest = 9.4, therefore the range between the two values can be divided into four categories of a low, medium, high, and very high, like the following:

Table 2. Classification of the risk factors.

S x W	0 – 2.2	2.3 – 4.5	4.6 – 6.8	> 6.8
Category	Low	Medium	High	Very High

The risk assessment results are use as guidance for water conservation program development in the research area.

Groundwater Conservation

Groundwater exploitation in the northeastern slope area of Mount Arjuno and surrounding is mostly used to support industrial activities and sold as bottled water. Excessive groundwater exploitation will threaten groundwater sustainability; therefore, a conservation

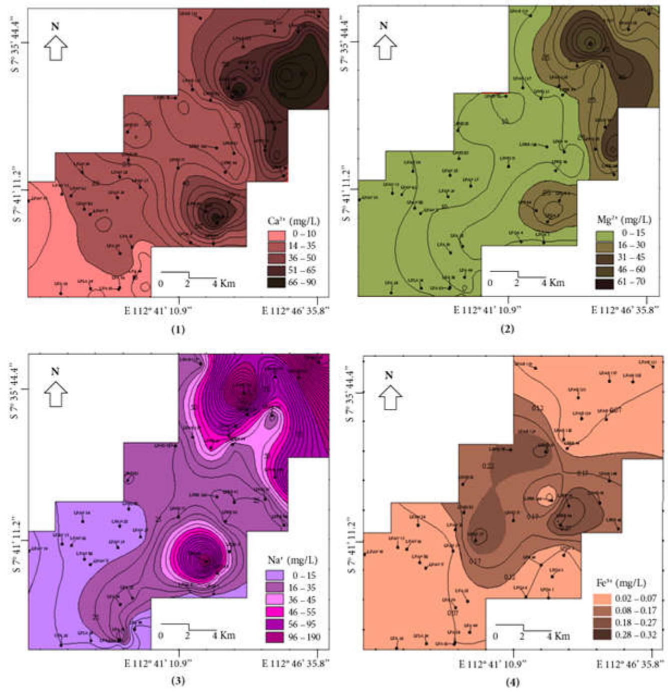


Figure 4. Distributions of cations in the unconfined aquifer system: (1) Ca^{2+}, (2) Mg^{2+}, (3) Na^{+}, and (4) Fe^{3+}.

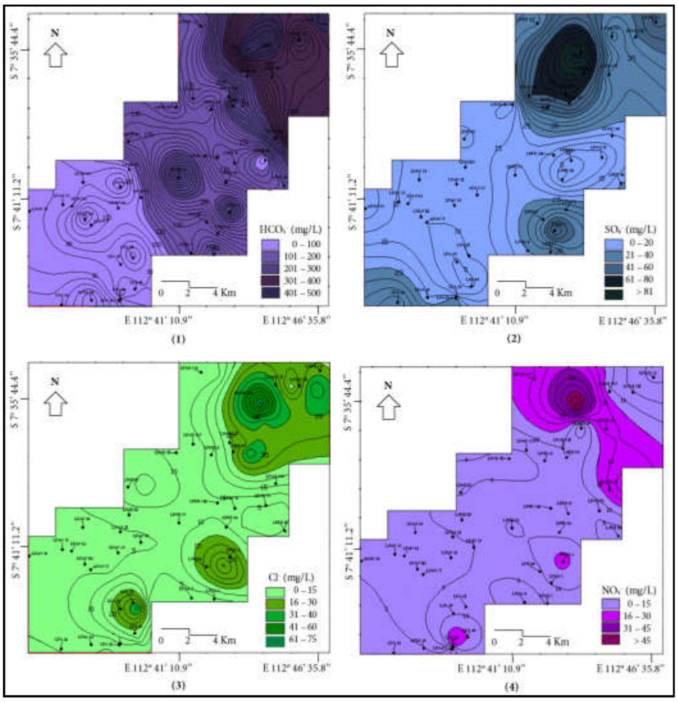


Figure 5. Distributions of anions in the unconfined aquifer system: (1) HCO_3^-, (2) SO_4^{2-}, (3) Cl^-, and (4) NO_3^-.

Table 3. Classification and scoring of the risk factor used in this study.

Number of parameters (existence, continuity, quantity, and quality of groundwater) affected by the risk factor	Risk factor classification	Score
All of the parameters are affected	Very high risk	4
3 of 4 parameters are affected	High risk	3
2 of 4 parameters are affected	Moderate risk	2
1 of 4 parameters are affected	Low risk	1

Table 4. Weighting and scoring of the risk factor intensity to groundwater existence.

Risk Factors Weight		A parameter to be affected				Score
		Existence	Continuity	Quantity	Quality	
Natural Factors (Weight = 40%)	Flood	Ö	Ö	Ö	Ö	4
	Landslide	Ö	Ö	Ö	Ö	4
	Erosion	Ö	Ö	-	Ö	3
	Volcanic Eruption	Ö	Ö	Ö	Ö	4
Human Factors (Weight = 60%)	Industrial Exploitation	Ö	Ö	Ö	-	3
	Industrial Waste	-	-	Ö	Ö	2
	Domestic Waste	-	-	-	Ö	1
	Deforestation	Ö	Ö	Ö	Ö	4
	Sandstone Mining	Ö	Ö	Ö	Ö	4
	Farming Activity	-	-	-	Ö	1
	Uncontrolled Groundwater Use	Ö	Ö	Ö	Ö	4

program is necessary to be conducted. Changes in land use have implications for decreasing rainwater infiltration continuously with the diminishing groundwater availability. Identifying a complicated relationship between hydrology processes and the environment for excessive pressure on land resources to provide food, water, and shelter in a significant change of land cover, which consequently modifies the hydrological regimes, is always indispensable for improved water management (Gebremicael, 2019). The water management problem is also happening in the Geba catchment. Headwaters of the Upper Tekeze basin (Gebremicael, 2019) are known for their severe land degradation and sound good experiences in integrated

Table 5. Vulnerability zones due to groundwater problems in the watersheds of the study area.

Watershed Name	Village	Source of the Threat	Valuation			Vulnerability Category
			Score (S)	Weight (W)	Total Value (S x W)	
Lumbangrejo	Karangrejo	domestic wastes, pesticide, flooding	1 1 4	60% 40%	2.8	Medium
	Ngerong	domestic wastes	1	60%	0.6	Low
	Sukoreno	domestic waste, pesticide, industrial wastes	1 1 2	60%	3.0	Medium
	Lumbangrejo	domestic waste	1	60%	9.4	Very High
		pesticide	1			
		forest logging	4			
		industrial exploitation	3			
		sandstone mining	4			
		landslide	4	40%		
Ketanireng	Kedungringin	domestic wastes, pesticide, flooding	1 1 4	60% 40%	2.8	Medium
	Kepulungan	domestic waste, industrial wastes, landslides	1 2 4	60% 40%	3.4	Medium
	Gunungsari	Domestic waste, industrial wastes, landslides	1 2 4	60% 40%	3.4	Medium
	Pecalukan	domestic wastes, pesticide, forest logging, industrial exploitation, sandstone mining, landslides	1 1 3 3 4 4	60% 40%	9.4	Very High
Prigen	Gempeng	domestic wastes	1	60%	0.6	Low
	Oro-ombo Wetan	domestic wastes	1	60%	0.6	Low
	Kalisat	domestic wastes, industrial wastes, landslides	1 2 4	60% 40%	3.4	Medium
	Dukuhsari	domestic wastes	1	60%	0.6	Low

watershed management. This phenomenon should anticipate appropriate actions through groundwater conservation efforts, aiming to efficiently manage groundwater use and increase water infiltration into the soil.

By holding research completed with risk assessment and valuation, the water conservation programs for guidance can handle the threats—natural factors threats including flood, landslide, erosion, and volcanic eruption. It also works in the Upper Rio Grande Basin of North America by analyzing a series of water conservation policies for their effect on water used in irrigation and water conserved (Ward and Velazquez, 2008). Human factor threads include industrial exploitation, domestic and industrial waste, deforestation, farming activities, and sandstone mining. Human activities increase in population and expand farmland, causing increases in chemical concentrations in the Nandong karst system in Yunan, China (Jiang et al., 2009). The conservation guidance for handling the threats is shown in Table 6.

Water conservation techniques in recharge area for the channel, well, mulching, harvesting water. These conservation techniques developed from Warsito & Sukrisno (2001) and Ward & Velazquez (2008) need specific requirements to benefit and contain the implementation. Some techniques that implement describe with their benefits and constraints in Table 7.

The first conservation technique in the recharge channel needs soil with low infiltration and low permeability, human resource, and finance for construction and maintenance. This technique's advantages are giving more water to infiltrate, controlling runoff water's speed, and controlling runoff water erosion. The implementation constraints are reducing the land ordinarily used by the farmers (when the land is limited), needs more human resources, and finance. The recharge requirements are human resources and finance for construction and maintenance, adequate material availability. Recharge well is suitable for human settlement, not for the mountainous area; the groundwater depth should more than 1,50 m in the rainy season, while soil permeability is at least 2.0 cm/hour.

The second conservation techniques for recharge draw well benefits in decreasing runoff's speed, reducing the volume of runoff, limiting the speed of erosion and sediment deposition, increasing groundwater storage to minimize the fluctuation of flow rate, and avoiding groundwater dryness stay for longer. Implementation constraints are that the program is high cost, maybe not affordable, reducing the land area for ponds construction, and it should be accompanied with technical efficiency of water use.

The third conservation for the mulching techniques requires sufficient mulch materials available on-site, such as exchanging legume crops with food crops or planted on the contour or parallel strips of crop residues. This technique improves soil structure, increases crop productions and weeds growth, and reduces evaporation. Implementation constraints if the mulch is not enough can stimulate weeds' growth, so the closure is less, can sometimes be pests/plant diseases, and farmers would rather see the land clean.

The fourth conservation for water harvest techniques require intermediate to semi-arid climate (3-4 months without rain), the area with low availability of groundwater, sloping or hilly and wet area, but with such a critical water period. This technique benefits agriculture irrigation, water

Table 6. Conservation recommendation based on risk assessment and valuation.

Natural Factor		Human Factor	
Threats	Conservation Guidance	Threats	Conservation Guidance
Flood	Drainage improvement (construction and gutter enlargement), recharge channel, recharge well, and bio pores. When the location is on the river flood plains, bamboo tree plantation suggests, and embankment construction.	Industrial exploitation	Water safety campaign related to water use habit
Landslide	Soil enforcement by structural supports (retaining wall, buttress), recharge wells, horizontal drainage, cover vegetation with appropriate kind of plants.	Domestic waste	Need for appropriate sanitation and drainage, septic tanks, good construction of wells, a proper distance of well to the septic tank.
Erosion	Cover vegetation, terracing	Industrial waste	Appropriate drainage system
		Deforestation	Reboization, offering alternative jobs
		Farming activities	Organic farming, fertilizer, and pesticide usages control
Volcanic eruption	Public awareness Hazardous map/mapping	Sandstone mining	Offering alternative jobs
			Reclamation, revegetation with appropriate kind of plants/trees Converting the landuse for geotourism

Table 7. Water conservation techniques for recharge area.

Water conservation techniques	Requirements	Benefits	Implementation constrains
Recharge channel	a. Soil: low infiltration and low permeability b. Human resource & finance: construction and maintenance	a. Giving more chance for water to infiltrate b. Controlling the speed of runoff water c. Controlling runoff water erosion	a. Reducing the land (ordinarily used by the farmers, when the land is limited) b. Need more human resources and finance
Recharge well	a. Human resource & finance: construction and maintenance b. Adequate material availability c. Recharge well for human settlement, not for the mountainous area; groundwater depth >1.50 m rainy season d. Soil permeability ≥ 2.0 cm/hour.	a. Decreasing the speed of runoff water b. Reduce runoff water volume c. Limiting the speed of erosion & sedimentation d. Increase groundwater storage to minimize the groundwater availthe fluctuation of flow rate e. Avoid dryness because ability remains to stay for longer	a. The high cost of the program may be not affordable b. Reducing the land area for ponds construction c. It should be accompanied by technical efficiency of water use
Mulching	Sufficient mulch materials available on-site (example: exchange legume crops with food crops or they planted on the contour or parallel strips of crop residues	a. Improving soil structure b. Increasing crops productions c. Increasing weeds growth d. Reduce evaporation	e. If the mulch is not enough, it can stimulate weeds' growth, so the closure is less. f. The mulch can sometimes be pests/plant diseases g. Farmers would rather see the land clean.
Water harvest techniques	a. Intermediate to semi-arid climate (3-4 months without rain) b. The area with low availability of groundwater c. The area with slope or hilly area d. Wet area, but with such a critical water period	e. Agriculture irrigation f. Water storage g. The water source for irrigation h. Reduce the potential of flooding and sedimentation	The government needs to intervene in handling plans and costs

storage, the water source for irrigation, and reduce the potential of flooding and sedimentation. In the implementation, the government needs to intervene in handling plans and costs.

4. Conclusion

In the northeastern slopes of Mount Arjuno, the geomorphic units can be classified into four, including the volcanic peak unit, the volcanic slope unit, the fluvial unit, and the anticline hills unit. The lithology is dominated by sandstone, breccias, and andesite-lava of Mount Arjuno and Mount Welirang. The hydrogeological system comprises three watersheds of Lumbangrejo, Ketanireng, and Prigen, with recharge area, is located at an altitude of 500 meters up to the summit of Mount Arjuno, while the discharge area is at an altitude of fewer than 500 meters to the lowlands, 10 meters above sea level. Three aquifers can be classified into the unconfined aquifer with fissures porosity, unconfined to semi-confined aquifer with intergranular porosity, and unconfined aquifer with intergranular porosity. In terms of physical and chemical aspects, groundwater quality in the study area generally does not exceed the drinking water standard, except in some village for Fe^{3+}, Mn^{3+}, and NO_2^-. Based on the risk assessment that considers natural factors and human factors, some villages of Ketanireng watershed and Lumbangrejo watershed are categorized as very high vulnerability zones to groundwater problems, some villages of Lumbangrejo watershed and Ketanireng watershed are categorized as medium vulnerability zones, while some villages in the Lumbangrejo watershed and Prigen watershed are included in low vulnerability zone.

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