

Hydrogeological Risk Assessment for Groundwater Conservation

by Herry Riswandi

Submission date: 22-May-2023 04:44PM (UTC+0700)

Submission ID: 2099102389

File name: b.1_f_J_Indonesian_Journal_of_Geography_23522010.pdf (6.43M)

Word count: 5474

Character count: 31551

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

Sari Bahagiarti Kusumayudha¹, Puji Pratiknyo¹, Herry Riswandi¹ and Eni Muryani²

¹Department of Geological Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia

²Department of Environmental Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia

Received: 2020-10-11

Accepted: 2021-01-06

Keywords:

Groundwater unbalance;
quality degradation;
risk assessment;
conservation.

Correspondent email:

saribk@upnyk.ac.id

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.

©2021 by the authors. Licensee Indonesian Journal of Geography, Indonesia.
This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC) license (<https://creativecommons.org/licenses/by-nc/4.0/>).

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 km² 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 ²⁰ represent either gross recharge or net recharge (Doble & Cross ¹⁵2017). 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 app¹³ropriately managed (Saha, 2013). Concerning water budget, 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 ¹⁶ects. 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

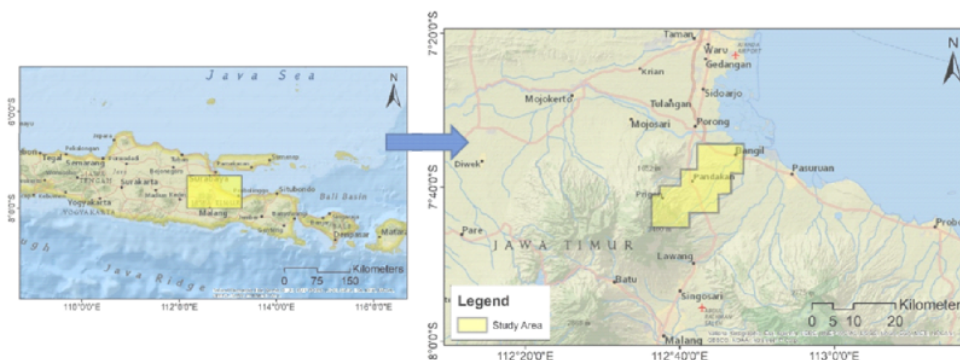
sealed to maintain the original properties of water samples. Samples were taken from dug wells of 1 to 10-meter depth for chemical testing and analyses.

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

⁹ Based on the physiographical map (Van Bemmelen 1949), the study area is positioned in the eastern part of the Kendeng Zone and Se¹²Subzone. 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.



⁴ Figure 1. Location of the study area on NatGeo-World-Map.

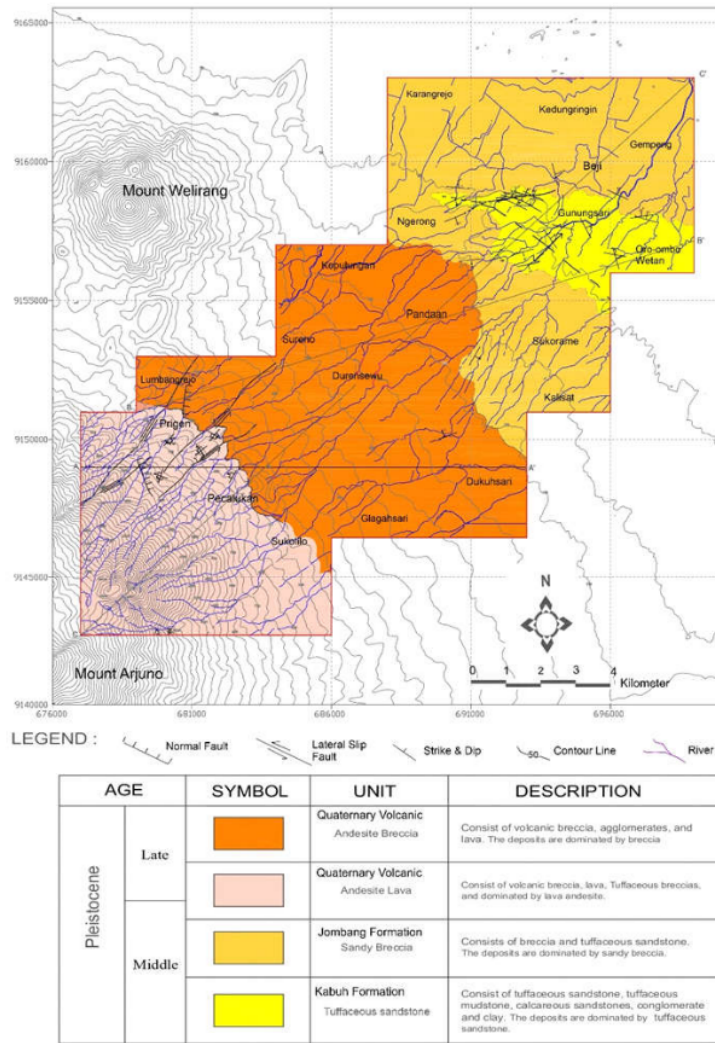


Figure 2 . Geologic map of the study area showing the distribution of rock units and geologic structures

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, ¹⁷ 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-

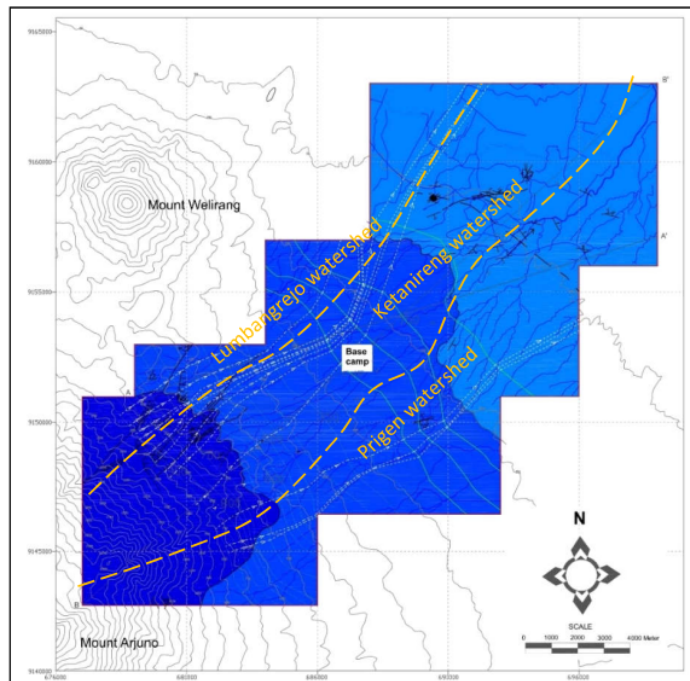
chemistry quality of groundwater can be categorized as clean water (Kusumayudha et al., 2013). Referring to the hydrochemical study by Newman et al. (2016) and Katsanou et al. (2017), the chemical compounds selected to be tested were: Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, NO₃⁻, NO₂⁻, HCO₃⁻, Fe, and Mn (Table 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 threatens 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, Kulusari, 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 (Ca²⁺, Mg²⁺, Na⁺, Fe³⁺, and SO₄²⁻) enrichment and CO₂ 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 (NO₃⁻) and nitrite (NO₂⁻) 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

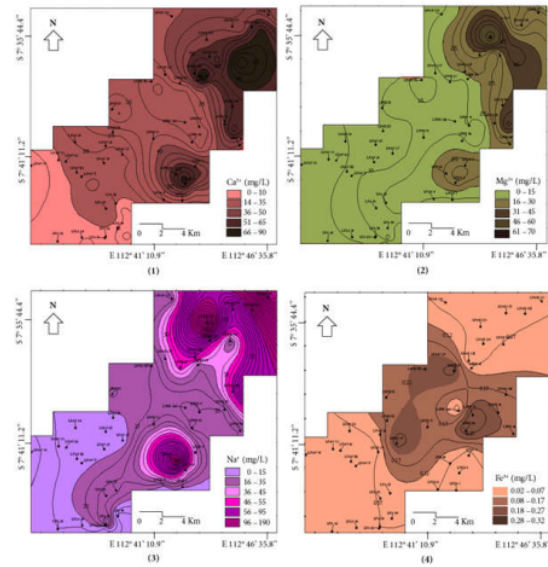


Figure 4. Distributions of cations in the unconfined aquifer system: (1) Ca²⁺, (2) Mg²⁺, (3) Na⁺, and (4) Fe³⁺.

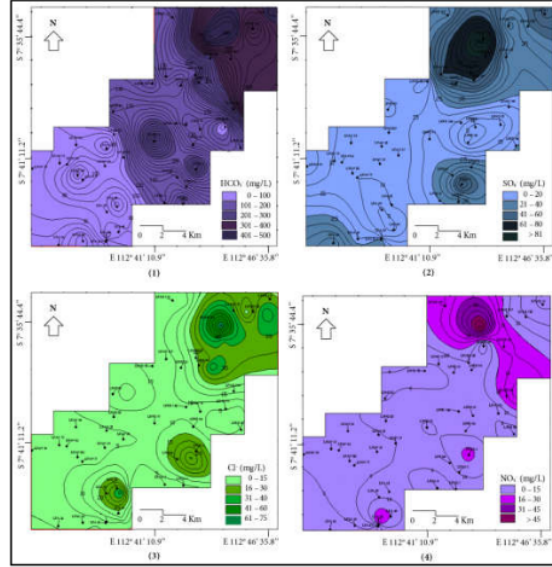


Figure 5. Distributions of anions in the unconfined aquifer system: (1) HCO₃⁻, (2) SO₄²⁻, (3) Cl⁻, and (4) NO₃⁻.

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	3	0	0	0	4
	Landslide	0	0	0	0	4
	Erosion	0	0	-	0	3
	Volcanic Eruption	0	0	0	0	4
	Industrial Exploitation	0	0	0	1	3
Human Factors (Weight = 60%)	Industrial Waste	-	-	0	0	2
	Domestic Waste	-	-	-	0	1
	Deforestation	0	0	0	0	4
	Sandstone Mining	0	0	0	0	4
	Farming Activity	0	-	-	0	1
	Uncontrolled Groundwater Use	3	0	0	0	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,	1	60%	2.8	Medium	
		pesticide, flooding	1	40%			
	Ngerong	domestic wastes	1	60%	0.6	Low	
		domestic waste,	1	60%	3.0	Medium	
	pesticide, industrial wastes	2					
	Lumbangrejo		domestic waste	1	60%	9.4	Very High
			pesticide	1			
			forest logging	4			
			industrial exploitation	3			
	Kedungringin		sandstone mining	4		2.8	Medium
landslide			4	40%			
domestic wastes,			1	60%			
pesticide, flooding			1	40%			
Kepulauan		19 domestic waste,	1	60%	3.4	Medium	
		industrial wastes,	2				
		landslides	4	40%			
		Domestic waste,	1	60%			
Ketanireng	Gunungsari	industrial wastes,	2		3.4	Medium	
		landslides	4	40%			
		domestic wastes,	1				
		pesticide,	1				
Pecalukan		forest logging,	3		9.4	Very High	
		industrial exploitation,	3	60%			
		sandstone mining,	4				
		landslides	4	40%			
Prigen	Gempeng	domestic wastes	1	60%	0.6	Low	
		Oro-ombo Wetan	domestic wastes	1	60%	0.6	Low
	Kalisat	domestic wastes,	1	60%	3.4	Medium	
		industrial wastes,	2				
Dukuhsari		landslides	4	40%	0.6	Low	
		domestic wastes	1	60%			

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 expansion of 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
Volcanic eruption	Public awareness Hazardous map/mapping	Deforestation	Reboization, offering alternative jobs
		Farming activities	Organic farming, fertilizer, and pesticide usages control
		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	<ul style="list-style-type: none"> a. Soil: low infiltration and low permeability b. Human resource & finance: construction and maintenance 	<ul style="list-style-type: none"> a. Giving more chance for water to infiltrate b. Controlling the speed of runoff water c. Controlling runoff water erosion 	<ul style="list-style-type: none"> a. Reducing the land (ordinarily used by the farmers, when the land is limited) b. Need more human resources and finance
Recharge well	<ul style="list-style-type: none"> 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. 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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	<p>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</p>	<ul style="list-style-type: none"> a. Improving soil structure b. Increasing crops productions c. Increasing weeds growth d. Reduce evaporation 	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> e. Agriculture irrigation f. Water storage g. The water source for irrigation h. Reduce the potential of flooding and sedimentation 	<p>The government needs to intervene in handling plans and costs</p>

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 Fe³⁺, Mn³⁺, and NO₂⁻. 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.

Acknowledgment

This study has conducted with the sponsorship of PT Danone-Aqua. Therefore deep gratitude is handed to the company. Appreciation also expresses to the Institute of Research and Community Service of UPN Veteran Yogyakarta to support the research process.

References

- Bahri AS, Widodo A, Utama W, Warnana DD, Aripin PR, Banuboro A, Abdillah RA (2017). 3D Resistivity Data Modeling to Identify Aquifer Geometry - Field Study of PDAM Groundwater Conservation Pandaan. Regional Conference in Civil Engineering, 166-174. doi: 10.12962 / j23546026.y2017i6.3249.
- Burhanul M (2002). Hydrogeological map of Pasuruan regency. Directorate of Geologic Resources, Environmental Geology, Bandung.
- Dianasari, Q (2008) Water Balance in the Pasuruan Groundwater Basin. Malang: Universitas Brawijaya. Retrieved from <http://repository.ub.ac.id/id/eprint/139316>. Time Accessed: Dec 01, 2020 07:55 AM Jakarta.
- Doble RC & Crosbie RS (2017). Review: Current and emerging method for catchment-scale modeling of recharge and evapotranspiration from shallow groundwater. *Hydrogeol J* 25:3-23. doi: 10.1007/s10040-016-1470-3.
- Domenico, PA, Schwartz, FW (1990) Physical and chemical hydrogeology. Michigan: Wiley.
- Cahyahadi, W (2010). Pasuruan and water. Retrieved from <https://wiretes.wordpress.com/2010/01/14/pasuruan-dan-air/>. Time Accessed: Dec 02, 2020 08:45 AM Jakarta.
- Fetter, CW (1994) Applied Hydrogeology. 3rd ed. Macmillan Publishing College Company Inc.
- Gebremicael, TG (2019). Understanding the Impact of Human Interventions on the Hydrology of Nile Basin Headwaters, the Case of Upper Tekeze Catchments. 1st ed. Taylor-Francis CRC Press. 24.
- Heath RC (1987). Basic groundwater hydrogeology. U.S. Geological Survey Water-Supply Paper 2220.
- Jiang Y, Wu Y, Groves C, Yuan D, Kambesis P (2009). Natural and anthropogenic factors affecting the groundwater quality in the Nandong karst underground river system in Yunan, China. *J. of Contaminant Hydrology* 109(1-4):49-61. doi: 10.1016/j.jconhyd.2009.08.001.
- Katsanou K, Lambrakis N, Alessandro WD, Siavatas G (2017). Chemical parameters as natural tracers in hydrogeology: a case study of Louro's karst system, Greece. *Hydrogeol J* 25:487-490. doi: 10.1007/s10040-016-1492-x.
- Kuroda K, Hayashi T, Do AT, Canh V.D., Nga TTV, Funabiki A, Takizawa S (2017). Groundwater recharge in suburban areas of Hanoi, Vietnam: effect of decreasing surface-water bodies and land-use change. *Hydrogeol J* 25:727-742. doi: 10.1007/s10040-016-1528-2.
- Kusumayudha SB & Sutejo B (2008). Proses-proses Hidrogeologi (Hydrogeologic Processes). Wimaya Press. Yogyakarta.
- Kusumayudha SB, Pratiknyo P, Riswandi H, Muryani E (2013). Hydrogeology and conservation programs of Mount Arjuno slope area, Pasuruan Regency, East Java. Proc National Seminar "Kebumian", Faculty of Mineral Technology, UPN "Veteran" Yogyakarta
- Mechal A, Birk S, Dietzel M, Leis A (2017). Groundwater flow dynamics in the complex aquifer system of Gibalbo Rivel basin (Ethiopian Rift): a multi-proxy approach. *Hydrogeol J* 25(2): 519-538. doi: 10.1007/s10040-016-1489-5.
- Moore JE (2002). Field Hydrogeology. Lewis Publishers by CRC Press LLC, U.S.
- Newman BD, Havenor KC, Longmire P (2016). Identification of hydrochemical facies in the Roswell Artesian Basin, New Mexico (USA), using graphical and statistical methods. *Hydrogeol J* 24:819-839. doi: 10.1007/s10040-016-1401-3.
- Purnomo, BJ (2007). Hydrogeological assessment in the water shortage area, groundwater borehole location of Pasuruan Regency, East Java Province, Directorate of Geologic Resources, Environmental Geology, Bandung.
- Reza T, Alam BYCSSS, Hendarmawan (2020). Geological Control of Unconfined and Confined Groundwater Flow Patterns in Aquifer Potential Evaluation, Case Study of Pandaan and Surrounding Areas, Pasuruan Regency, East Java. *Bulletin of Scientific Contribution, Faculty of Geological Engineering, Padjadjaran University*, 18 (1) April 2020: 35 - 44.
- Saha, GC (2013). Analysis of groundwater-surface water interaction in the horizontal unconfined aquifer bound by a stream and groundwater divide using a non-linear numerical model. *J. of Hydrology Science and Technology* 3(3):193 - 205. doi: 10.1504/IJHST.2013.058309.
- Santosa S, Suwarti T (1992). Geologic map of Malang sheet, Java. Center of Geological Research and Development, Bandung.
- Santosa S, Suwarti (1992). Geologic map of Pasuruan. Center of Geological Research and Development, Bandung.
- Showers, W., Genna, B., McDade, T., Bolich, R., & Fountain, J (2008). Nitrate Contamination in Groundwater on an Urbanized Dairy Farm. *Environmental Science & Technology*, 42, 4683-8. doi:10.1021/es071551t
- Sukobar (2007). Identification of Potential Water Resources in Pasuruan Regency. *Jurnal Aplikasi Teknik Sipil*, 3(1), 28-33. doi:10.12962/j12345678.v3i1.2565.
- Supriyatno, H (2019). Eksploitasi Besar-besaran Air Tanah Picu Krisis Sumber Air, Birawa On Line, Retrieved from <https://www.harianbhirawa.co.id/eksploitasi-besar-besaran-air-tanah-picu-krisis-sumber-air/>.
- Taufiq NZ, Agus (2008). Quantification and groundwater modeling of Pasuruan basin, East Java. Ministry of Energy and Mineral Resources, Indonesian Geologic Survey, Center of Geologic Environment, Bandung.
- Van Bemmelen RW (1949). The Geology of Indonesia. Vol IA, Martinus Nijhoff, The Hague.
- Van Zuidam RA (1983). Guide to Geomorphic Areal Photographic Interpretation and Mapping, ITC, Enschede, Netherlands: 110-128.
- Wandowo, Abidin Z, Djijono (2015). Investigating Groundwater in Pasuruan Regency with Natural Isotopes. *A Scientific Journal for The Applications of Isotopes and Radiation*. 1 (1): 8-17.
- Ward AD, Trimble SW (2004). *Environmental Hydrology*, 2nd ed, Lewis Publishers.
- Ward FA, Velazquez MP (2008). Water conservation in irrigation can increase water use. *Proceedings of the National Academy of Science of the United States of America*. 105(47):18215-18220. doi: 10.1073/pnas.0805554105.
- Warsito D, Sukrisno (2001). Groundwater Conservation of Surabaya - Pasuruan area and surroundings. Ministry of Energy and Mineral Resources, Indonesian Geologic Survey, Center of Geologic Environment, Bandung.
- Waspo do RSB (2011). Groundwater Exploration in Pandaan. *Journal of Agricultural Engineering*. 25 (1): 29-35.
- WHO (2011). Guidelines for drinking-water quality. *World Health Organization* 216:303-304.
- Yudianto, DT (2013). Groundwater Exploration Balance in the Pasuruan Basin-East Java, retrieved from <https://atpw.files.wordpress.com/2013/03/a2-djoko-tri-yudianto-kedetimimbangan-eksplorasi.pdf>. Time Accessed: Dec 03, 2020, 08:23 AM Jakarta.

Hydrogeological Risk Assessment for Groundwater Conservation

ORIGINALITY REPORT

9%

SIMILARITY INDEX

5%

INTERNET SOURCES

6%

PUBLICATIONS

4%

STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Universitas Negeri Jakarta Student Paper	1%
2	Submitted to Asian Institute of Technology Student Paper	1%
3	mediatum.ub.tum.de Internet Source	1%
4	Sari Bahagiarti Kusumayudha, Heru Sigit Purwanto. "Hydrogeological drives in mass transfers of Mount Telagalele and surrounding area, Banjarnegara Regency, Central Java, Indonesia", AIP Publishing, 2021 Publication	1%
5	Submitted to University of Nebraska, Lincoln Student Paper	1%
6	Submitted to Universitas Diponegoro Student Paper	<1%
7	A Buntoro, C Prasetyadi, R A Wibowo, Suranto, A H Lukmana. "Validation of shale brittleness index calculation from wireline log	<1%

of well BETRO-001 by using XRD test results and uniaxial test as parameters for determining potential of shale hydrocarbon - brown shale of Pematang Group Formation, Central Sumatra Basin, Bengkalis Trough", IOP Conference Series: Earth and Environmental Science, 2018

Publication

8

T.G. Gebremicael, Y.A. Mohamed, P. Van der Zaag. "Attributing the hydrological impact of different land use types and their long-term dynamics through combining parsimonious hydrological modelling, alteration analysis and PLSR analysis", Science of The Total Environment, 2019

Publication

<1 %

9

Qiang Wu, Wenping Mu, Yuan Xing, Cheng Qian, Jianjun Shen, Yang Wang, Dekang Zhao. "Source discrimination of mine water inrush using multiple methods: a case study from the Beiyangzhuang Mine, Northern China", Bulletin of Engineering Geology and the Environment, 2017

Publication

<1 %

10

Submitted to UNESCO-IHE Institute for Water Education

Student Paper

<1 %

11

hidrobiologie.granturi.ubbcluj.ro

Internet Source

<1 %

12

S B Kusumayudha, Y O Putra, P Pratiknyo. "Conservation zones in a cultural heritages area of Penanggungan Volcano, based on volcanic-hydrogeological assessment, Mojokerto Regency, East Java, Indonesia", IOP Conference Series: Earth and Environmental Science, 2018

Publication

<1 %

13

Keisuke Kuroda, Takeshi Hayashi, An Thuan Do, Vu Duc Canh, Tran Thi Viet Nga, Ayako Funabiki, Satoshi Takizawa. "Bổ cập nước ngầm tại khu vực ngoại thành Hà Nội, Việt Nam: ảnh hưởng từ việc suy giảm nguồn nước mặt và sự thay đổi sử dụng đất", Hydrogeology Journal, 2017

Publication

<1 %

14

fliphtml5.com

Internet Source

<1 %

15

Rebecca C. Doble, Russell S. Crosbie. "Revisão: Métodos atuais e emergentes para a modelagem de recarga e evapotranspiração de aquíferos livres em escala de bacia", Hydrogeology Journal, 2016

Publication

<1 %

16	Brent D. Newman, Kay C. Havenor, Patrick Longmire. "Identificação das fácies hidroquímicas na Bacia Artesiana de Roswell, Novo México (EUA), usando métodos gráficos e estatísticos", Hydrogeology Journal, 2016 Publication	<1 %
17	ijs.uobaghdad.edu.iq Internet Source	<1 %
18	edepot.wur.nl Internet Source	<1 %
19	"Algae Abstracts", Springer Science and Business Media LLC, 1973 Publication	<1 %
20	Robert G. Maliva. "Anthropogenic Aquifer Recharge", Springer Science and Business Media LLC, 2020 Publication	<1 %
21	Smith, Alastair D.. "Cognition in the Real World", Cognition in the Real World, 2023 Publication	<1 %
22	onlinelibrary.wiley.com Internet Source	<1 %
23	S. Vajirakachorn, W. Phoochinda. "An evaluation of Map Ta Phut Industrial Estate's air pollution reduction and elimination policy", WITPRESS LTD., 2014 Publication	<1 %

24

Sari Bahagiarti Kusumayudha, Puji Pratiknyo, N.A. Purwanto, Herry Riswandi, Ayu Narwastu Ciptahening, Nenden Hermawanti. "Fissure structure analysis to unravel groundwater inflow problem in gold mining site of Pongkor area, West Java, Indonesia", International Journal of Hydrology Science and Technology, 2018

Publication

<1 %

Exclude quotes On

Exclude matches < 5 words

Exclude bibliography On