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Water quality of Pulejajar Underground River, Karst of Gunung Sewu as the basis of karst management

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Abstract

Karst area has a crucial role in providing water resource. However, due to the intrisic characteristic, water resource in the karst area is highly susceptible to the pollution and relatively hard to manage because the complexity of the aquifer. Karst of Gunung Sewu as one of the main karst areas in Indonesia has abundant water resource inside the cave but the utilization is very limited due to the technical constraint to lift the water and distribute it. One the main water resources in Karst of Gunung Sewu is the Pulejajar Underground River at Jepitu Village. As one of the main water resources, a management to maintain its water quality is very important. We examine the water quality of the Pulejajar Underground River and study the factors that affect it. We employ water sampling using purposive sampling in 4 locations and analyze it using Pollution Index (PI) calculation and view the spatial context of the underground river using GIS tool. As the result the PI for the sampling location consists of lighlty polluted in the water intake and the small junction of the Pulejajar Underground River and heavily polluted in the big junction and the Puring Spring. The pollution comes from the Calcium and E. Coli parameter which originates from the dissolution of limestone and the feces of the livestock because the poor filtration at the karst area. The management strategies supposed to comply with the SDGs number 6 as the main framework dan must cover both side of human side and the nature side including land cover management, water accessibility, and conservation of the catchment area.

Keywords:
Water quality; karst; sustainability; environmental management

Introduction

Karts of Gunung Sewu known as UNESCO Geopark changed the explosion of tourism activity around the 2010s. Previously, the conditions were dry and deforested, lack of water resources, and poverty in the community. It is caused by the soil being unable to hold water due to its impermeable but porous and fractured limestone (Ford &Williams, 2007). Then accumulate spring or an underground river. Finding water on the surface is only found in ponds or *logva* but it will be reduced during the dry season. Another concerning condition is that poor water infiltration in the soil and underground is severed by the low quality of water (Riyanto, et al., 2020; Khansa, et al., 2019; Ahmad et al., 2019; Bakalowicz, 2011). Examples are caused by human activities such as farming, livestock, and the effects of bacteria from septic tanks.

Droughts that appear every year cause this phenomenon. The Community in Karst of Gunung Sewu needs to adjust their crops to adapt to the conditions on the ground (Suryanti, et al., 2010), such as saving water use (Fatchurohman, et al., 2013), and creating social networks (Cahyadi & Setyaningrum, 2013). In addition, the increase in temperature due to climate change aggravates the situation (Misbahuddin, 2021) where the intensity of rain increases in the rainy season and decreases (Ahmad, et al., 2021) during the dry season. The factors of Weather and climate greatly affect the economic situation of the community, especially in livelihoods to earn income.

In the 2000s the government then provided a major infrastructure project. Its location is in Bribin and Seropan Caves where it can accommodate the discharge of underground river water flow. The aim is to overcome the environmental problem of drought in Karst Gunung Sewu. Through the Drinking Water Regional Company (Perusahaan Daerah Air Minum PDAM), this project manages 4 districts in the North-Eastern Part of Gunung Sewu for the attainment of water demand. However, many villages are not yet accessible by water from PDAM due to the elevation and geomorphology of polygonal karts making it difficult for PDAM to distribute water. Several villages communities' initiative to lift cave water using their infrastructure. For example, Pego Caves of Girisekar Village and Pulejajar Cave in Jepitu Village. PAMDes was later formed by the government as an institution that manages water resources in remote village communities.

The government and the community formerly create a buffer zone for sinking streams, karst spring, logva, and ponor, land use strategies, and cultivate catchment areas to preserve water quality (Selak et al., 2020). The conception of buffer zones and land-use strategies is depleted by making the distance of activity from water sources that have the potential to pollute water sources. Cultivating the catchment area is terminated by revegetation and reducing limestone mining activities. The strategy requires a commitment of cooperation between the community and the government to raise awareness of environmental problems in the karst area.

The Sustainable Development Goals, in particular goal number 6 "ensuring the availability and sustainable management of water and sanitation for all" underestimate this activity. This purpose is following water problems in the karst area regarding the vulnerability and availability of water (Fiorillo, 2015; Stevanovic & Stevanovic, 2021). Sustainable water management can ensure good water quality in all seasons. Karst environmental problems can be solved by sustainable development with compatible governance from all stakeholders. The government urgently needs to involve research and higher education institutions for the implementation of sustainable development ideas. This will help to overpass between the concepts and policies therefore they can be customary by the community.

This study aims to examine the water quality in the Pulejajar Underground River catchment area and how the water quality reflects the water resource problem in the karst area. Furthermore, we link the water resource problem with the sustainable development concept to formulate the solution to overcome the water resource problem in the karst area.

Literature Review

Addressing the water quality issue is the main concern in the karst are (Biondi´c, Meaški, et al., 2021; Stevanovic and Stevanovic, 2021). The objective of karst management is to maintain the sustainability and minimizing the human activities under the carrying capacity (Beynen, 2011) or as minimum as possible especially in karst area which is well-known for its vulnerability (Iván, Mádl-Szőnyi, et al., 2017). Also, because the water resource is considered to be the most vital resource for human, the water management is the backbone of the karst management (Kazakis, Chalikakis, et al., 2018; Klaas, Imteaz, et al., 2020; Gondwe, Merediz-Alonso, et al., 2011). Study for water quality in karst of Gunung Sewu discovers how the water is mainly polluted by the activity of the human such as settlement and agriculture (Ahmad, Widyastuti, et al., 2020; Khansa, Widyastuti, et al., 2020)

To be precise and effective, the karst management has to be built above a firm and precise hydrological characteristic basis. Fathoming the hydrological characteristic in karst area faces many challenges including the complexity and multi-level aquifer system (Guo, Qin, et al., 2019; Setiawan, Yoseph, et al., 2020) and determining the catchment area. To overcome this obstacle, several methods has been developed such as tracing using dye and radioactivity (Ahmad, Haryono et al., 2012), climatology using the rainfall (Widyastuti, Riyanto, et al., 2019) to delienating using remote sensing approach [Luo, Wang, et al., 2016; Moreno-Gómez, Liedl, et al., 2019; Maria, Purwoarminta, et al., 2020].

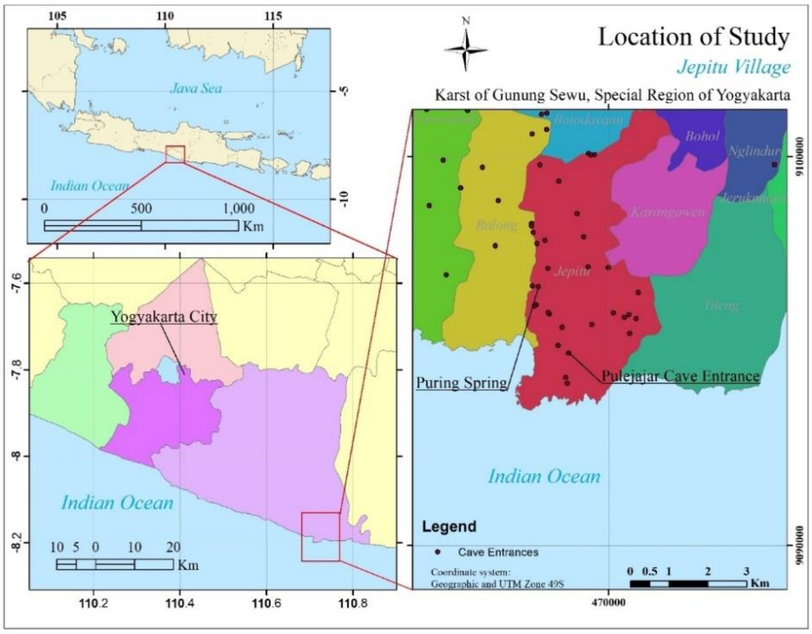
The result of the water quality is mostly compared with the policy prevails. However, it is also important to build a linkage with other framework such as Sustainable Development Goals (Reinhart & Rifani, 2019). We offer the relation concept between the water quality issue and the SDGs by studying the effect of the land use to the water quality and how the SDGs could be the context within it. This study will strengthen both issues particularly the SDGs implementation in karst management as the vulnerable landscape. Furthermore, the geopark status of the Karst of Gunung Sewu increases the urgency to mainstreaming the SDGs on its management framework.

Methods

A. Research Location

We conduct the study at Pulejajar Underground River, one of the huge underground water systems in the Karst of Gunung Sewu (**Figure 1**).

Figure 1. Research Location Maps



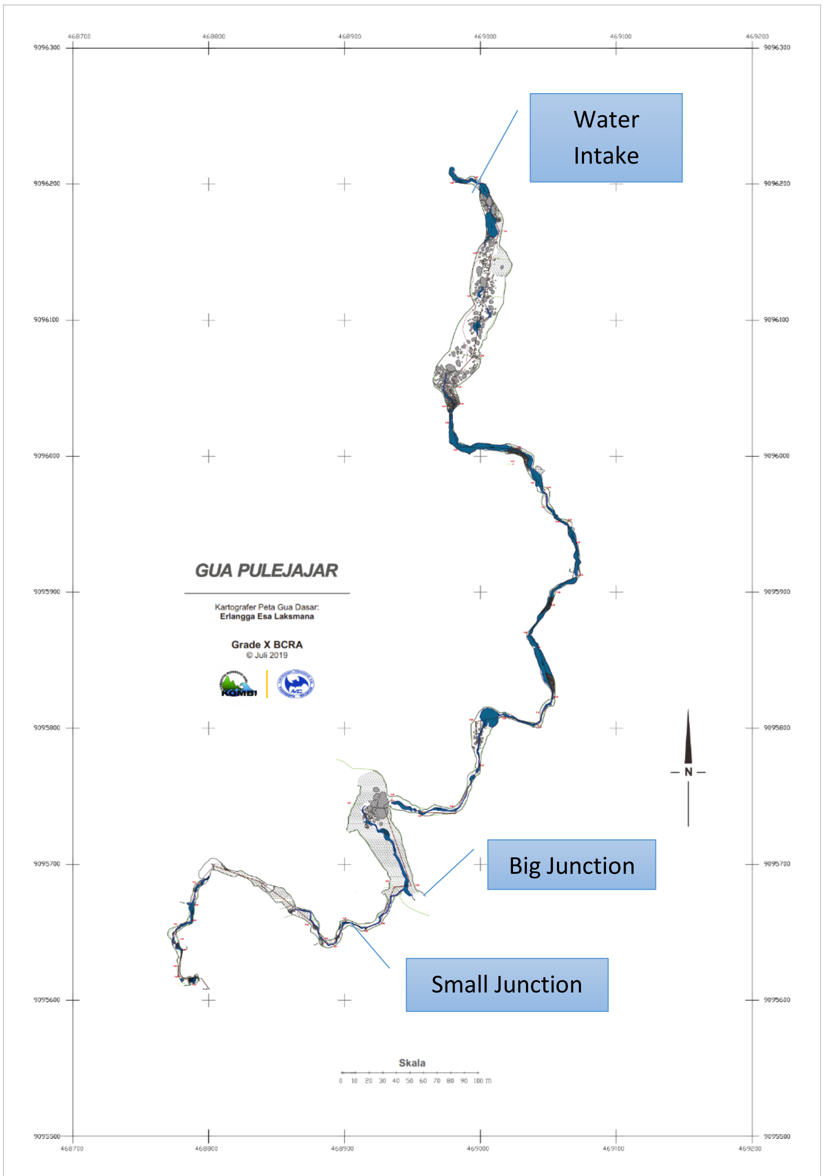
This cave is situated in the limestone of Wonosari Formation and administratively is located at Jepitu Village, Girisubo District, Gunung Kidul Regency, Special Region of Yogyakarta with the coordinate at UTM 49S 468816 9095598, near the famous Wediombo Beach. Pulejajar Underground River System has a considerably small entrance at the bottom of doline. With an average of 1.5 L/s, the water in the underground system is lifted to be used by the people and the community near the cave. The effort to utilize the water resource is initiated by the KOMBI, a local community supported by fellow cavers, speleologists, and collectives from Yogyakarta, Solo, and Wonogiri. We also check the water quality at the Puring Spring, a communal water resource and used to fill the water tank for the water dropping.

B. Data Collection

To answer the objective, we heavily rely on the water quality data with the spatial data to support the analysis. Sampling location could be seen in **Figure 2** below.

Figure 2.

Sampling Location at Pulejajar Underground River



Water quality is obtained by collecting water samples from 4 sampling locations which are selected using purposive sampling and comprises the water intake, the water junctions (big and small junctions), and Puring Spring as the daily water source for the people. 3 sample locations Water sampling was done using 2 types of the bottle to contain the sample: glass material for the e. coli parameter and the plastic for the rest of the parameters.

We also gather the spatial data from RBI Maps (*Peta Rupa Bumi Indonesia*) which were downloaded from in geoportal (https://tanahair.indonesia.go.id/portal-web). This web provides most of the spatial data we need such as land use, contour, and settlement as the main factor in impacting the water quality in the karst area.

C. Data Analysis

C.1. Water Quality Analysis

Water Quality Analysis is conducted by the pollution index analysis method in accordance with the Decree of the Minister of Environment and Forestry of the Republic of Indonesia Number 115 Year 2003 About Pollution Index. The principle of using pollution index method is to compare water quality data listed in Water Allocation Standard (j), and Ci from the concentration of water quality parameters (i) obtained from the analysis of water in a river flow, then each value Ci / Lij = 1,0 is a critical value, because this value is expected to meet a standard of water allocation quality. If Ci/Li> 1.0 for a parameter, then the concentration of this parameter should be reduced or set aside, if the main water is used for the allocation (j). If these parameters are parameters that are meaningful to the allocation, then management should be done for the water because it will contribute to the level of pollution of a body of water, this is as in the Decree of the Minister of Environment and Forestry of the Republic of Indonesia Number 115 Year 2003 About Pollution Index. In addition, another parameter reference is the Regulation of the Minister of Health of the Republic of Indonesia Number 492 / Menkes / PER / IV / 2010 about Drinking Water Quality Requirements and Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017 about Environmental Health Quality Standards and Water Health Requirements for Sanitary Hygiene, Swimming Pool, Aqua Solus and General Bathing. Meanwhile, for calcium parameter the reference quality standard is the Indonesian National Standard (SNI) number 01-0220-1987 on drinking water. Here is a table of IP analysis results on pulejajar cave water Equation in determining pollution index in **Equation 1** below.

$$PI_j = \sqrt{\frac{\left({C_i}/{L_{ij}}\right)_m^2 + \left({C_i}/{L_{ij}}\right)_R^2}{2}} \text{.......................................}(\textbf{Equation 1})$$

With:
PI_j= Pollution Index for allocation (j);
Li_j= Concentration of water quality parameters listed in the Water Allocation Standard (j);
Ci= Concentration of water quality parameters (i) the results of water sample analysis at a sampling site of a river flow.
$(Ci/Lij)_M$ = Ci/Lij Maximum Value; and
$(Ci/Lij)_R$ = Ci/Lij Average Value.

The following is a table on the evaluation of the value of PI (Pollution Index)

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Table 1.

Classification of Water Pollution Status

No	PI Value	Information
1	$0 < PI_j < 1,0$	Meet quality standards (good condition)
2	$1,0 < PI_j < 5,0$	lightly polluted
3	$5,0 < PI_j < 10$	moderately polluted
4	$PI_j > 10$	Heavily polluted

Source: The Decree of the Minister of Environment and Forestry of the Republic of Indonesia Number 115 Year 2003 About Pollution Index

C.2. Spatial Analysis

We employ the spatial analysis to comprehend the factors which influence the water quality. Water quality in the karst area is highly dependent with the land use above it because the porous characteristic enables the pollutants from the land use directly infiltrate the bedrock and enter the aquifer. By examining the land use in the catchment area, we expect to find an explanation toward the water quality.

We also use spatial analysis to delineate the catchment area. For this purpose, we run the flow direction-flow accumulation features in the ArcGIS to bound the basins which act as the catchment. Catchment area in the karst landscape is unique because the presence of the dolines, closed depression equipped with a ponor as the sinking path for the waterflow. Therefore, the catchment in the karst area is also known as micro-catchment and could be analyzed by the flow direction.

Results

A. Water Quality of Pulejajar Cave

To know the water quality sample, we analyze the parameter in *Balai Laboratorium dan Kesehatan Kalibrasi* Dinas Kesehatan/ Laboratory and Health Center Calibration Health Office Special Region of Yogyakarta and Hydrology and Climatology Laboratory of Faculty of Geography, Universitas Gadjah Mada. The laboratory examination result of water samples could be seen at the **Table 2** below.

Table 2.

Laboratory Result for Physical and Chemical Parameters

Parameter	Intake	Big Junction	Small Junction	Puring Spring	Standar Quality
	Laboratory Result (mg/L)				

Physical Parameter					
TDS	90	678	456	422	500*
Chemical Parameters					
COD	9,48	7,58	11,4	6,95	10**
DO	5,38	5,07	5,33	4,8	6**
Toughness	248	248	180	224	500*
Ammonia	0,01	-	-	0,01	0.5**
Nitrate	0,18	0,23	0,13	0,35	10*
Phosphate	0,09	0,09	0,09	0,09	0.2**
Sulfate	9,06	16,6	15	13,5	250*
Calcium	88	72	56	56	10**
Bicarbonate	20,8	18,2	13	13	125**
Biological Parameter					
Coliform	130	920	79	1600	50*

Source:
(*) Government Regulation of the Republic of Indonesia Number 22 of 2021 about the Implementation of Environmental Protection and Management on Appendix VI National Water Quality Standards
(**) the Regulation of the Minister of Health of the Republic of Indonesia Number 492 / Menkes / PER / IV / 2010 about Drinking Water Quality Requirements and Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017 about Environmental Health Quality Standards and Water Health Requirements for Sanitary Hygiene, Swimming Pool, Aqua Solus and General Bathing
(***) Indonesian National Standard (SNI) number 01-0220-1987 on drinking water

From the Table 2 above, we could see that the pollutant in the sampling location is the calcium and the E. Coli. These parameters are needed to be concerned because could impact human health. Accumulation of calcium in the body, especially the kidney triggers the kidney stone and leads to kidney failure. Meanwhile, E. Coli in the body causes diarrhea and for the children and infants the impact could be severed due to the imperfect health system. The calcium originates from the dissolution of limestone by the water as the host rock of the karst area. This dissolution increases concentration of the calcium ion in the water. E. Coli comes from organic material usually feces of animal. In Pulejajar Underground River, E. Coli could come from livestock in the catchment area and due to the poor filtration, directly enters the underground river. We also discovered the TDS at Big Junction and the COD at small junction that exceed the Standard Quality. TDS at Big Junction is relatively high due to the presence of many suspension, bedrock, and the sediment from the underground river current. The size, volume, and numbers of materials in this area affect the number of dissolved solid including ion, suspension, and colloid. For the COD in the small junction, the high chemical composition in the water becomes the main factor of the high value of COD.

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Other parameters that need to be addressed are the nitrate and phosphate. Nitrate contamination in wells is caused by a fairly close distance between the well and the source of the contamination. One of the areas that are the source of water contamination is the rice fields. According to Glanville (1993) said, the distance between the well as a provider of clean water and the recommended rice fields is 150 feet or about 50 m. The radius of nitrate carried by soil flow reaches 30 to 150 m depending on the amount of nitrate concentration that contaminates, type and postherniation of the soil. Phosphates in orthophosphate-shaped waters (PO4). The content of orthophosphate in the waters indicates the fertility of these waters (Mustofa, 2015). Phosphates in the waters generally come from agricultural fertilizers, human and animal waste, soap, vegetable processing, and industry. The use of detergents in households is also a significant contributor to phosphate levels in the waters. Aquatic organisms need phosphate for their lives, but if in excessive concentrations will cause dangerous impacts. High amounts of phosphate will result in very large algae growth and result in a lack of sunlight entering the waters. When algae die, bacteria will break it down using dissolved oxygen in the water (Green, 2018).

B. Water Pollution Index

We calculate the pollution index using equation 1 to obtain the pollution status in each sampling point. The pollution index analysis shows how the Pulejajar Underground System, including the Puring Spring is polluted ranging from lightly polluted at the Water Intake and the Small Junction, to heavily polluted at the Big Junction and Puring Spring (**Table 3**). The pollutants are the parameters that exceed the Standard Quality, and the pollution is dominated by the calcium, coliform, bicarbonate, and partly the TDS. Calcium and bicarbonate are pairing ion as the result of the interaction between the water and the limestone hence these two inevitably exist in large number particularly in underground river in the karst area. The pollution is urgently needed to be managed, especially because the Puring Spring as the main source of water for the nearest neighborhood is heavily polluted.

Table 3.

Results of IP Analysis of Pulejajar Cave Water

Sample Name	Categories	Pollution Index	Polluting Materials
Intake Air	Lightly polluted	4,12	Calcium, Bicarbonate, dan Coliform

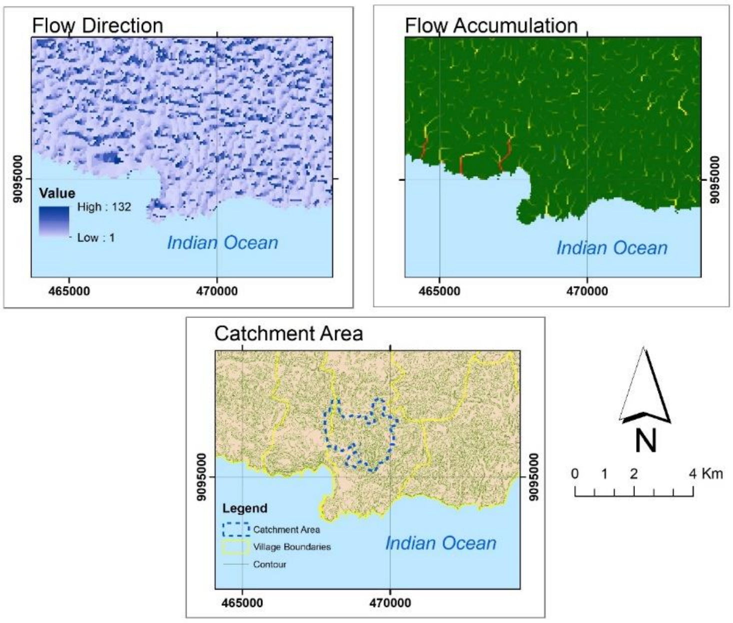
Big Junction	Heavily polluted	5,30	TDS, Calcium, Bicarbonate, dan Coliform
Small Junction	Lightly polluted	3,43	COD, Calcium, Bicarbonate, dan Coliform
Puring Spring	Heavily polluted	6,13	DO, Calcium, Bicarbonate, dan Coliform

C. Spatial Analysis

The spatial analysis is used to estimate the catchment area of the Pulejajar Underground River based on the flow direction and the flow accumulation tools. As the result, the estimated catchment area is 350 ha and reflects the smallest or the minimum area. The catchment area can be seen in **Figure 3**.

Figure 3.

Catchment Area and Flow Accumulation

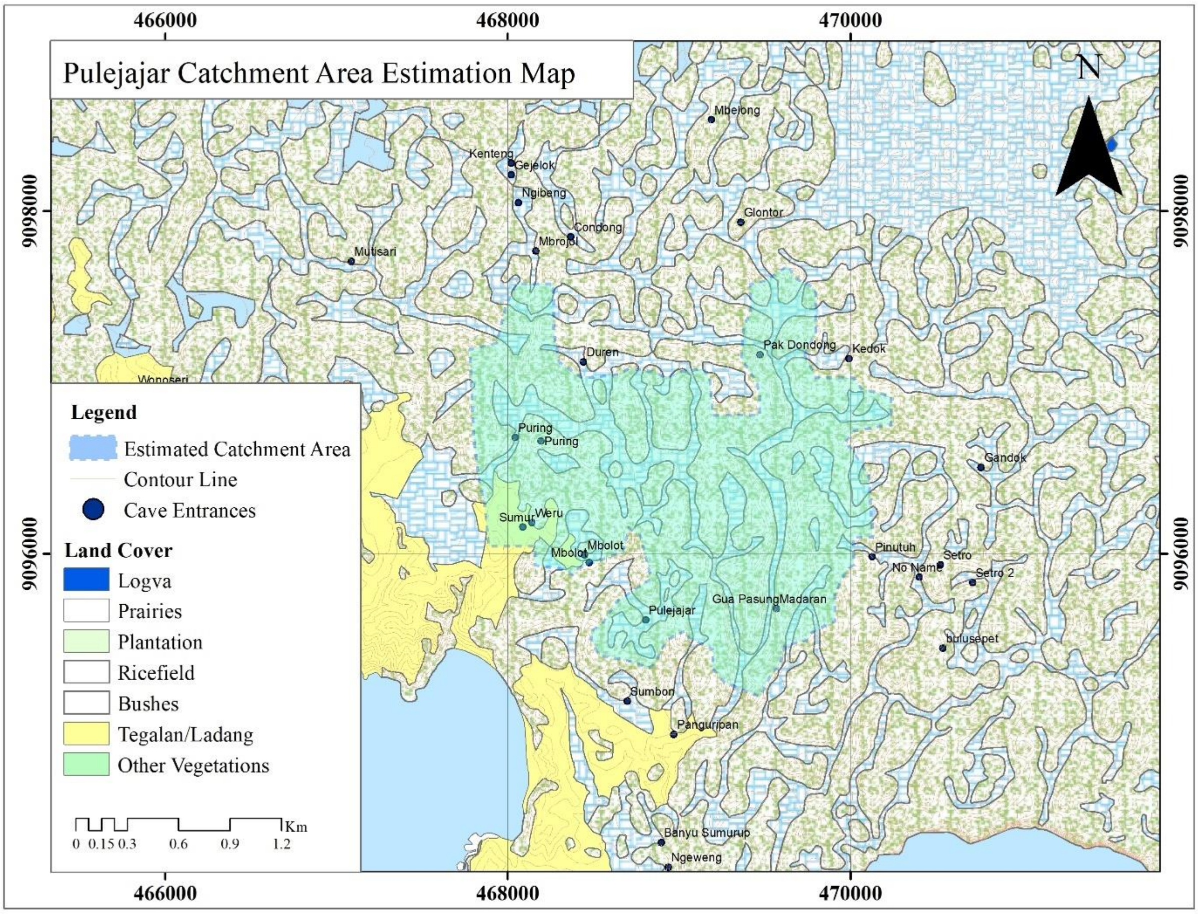


The type of catchment area of Pulejajar Underground River is the radial. Catchment area in the karst landscape is unique and different from other types of landscape, especially at the Karst of Gunung Sewu. Catchment area depends on the landform aspects as the physical boundaries for water to flow. Karst of Gunung Sewu landform can be categorized into three types of polygonal, cockpit and residual with addition of radial type landform (Haryono & Day, 2004; Tjia, 2013). This causes the form of micro-catchment area, convergence only in the doline with average diameter of 150 meters and interconnected below the ground passing the conduit from fracture-fissure in the limestone.

Inside the catchment area is the land cover which affects the water quality. Because there are no settlements, most of the land cover or land use in the catchment area is the bushes in the karst hill foot. Nevertheless, the bushes in here are dominated by hard wood vegetation such as teakwood (*Tectona sp.*) or akasia (*Acacia sp.*). Meanwhile in the bottom of the doline, the land use is agriculture filled with paddy when rainy season, peanut, and casava when dry season. A little portion of the catchment area is filled with *tegalan*, a local term for area used to plant casava.

Figure 4.

Land Use of The Catchment Area



The usage of fertilizer in the *tegalan* for the crop and the presence of the livestock are the main source of pollutant from anthropogenic factor and need to be managed. Although the pollutant from the fertilizer has not been a threat, an effort to prevent the pollutant to enter the underground river remains crucial

Discussion

Management effort for the water quality management is desperately needed to ensure the water accessibility. Water scarcity in the karst area has become a high-level issue for years moreover, 25% of world population water needs hinges to the supply from karst area (Ford & Williams, 2007). Water and sanitation are also included in the Sustainable Development Goals number 6. Data from the UN (United Nations, 2021) shows the clean water problem consists of two threats: the accessibility from the people side and the shrinking wetlands from the nature side. In the Karst of Gunung Sewu, those problem also occur.

The accessibility of clean water, particularly at the dry season when there is no rainfall in the Karst of Gunung Sewu is mainly done using water dropping from water tank. To increase the water distribution, Regency Authority builds piping network, flowing the water from main water resources of Seropan Cave, Ngobaran Spring, Baron Spring, and the biggest one, the Bribin Cave. The treatment of this water is still poor, and the water still contains calcium ion. But again, the people have a very limited option. The quantity of the water is the most fundamental aspect to be satisfied before the water quality is addressed as the people feels lucky enough to have the water from the pipe network despite the quality of the water. From the nature side, Karst of Gunung Sewu has underwent massive land conversion due to agriculture and now, the tourism expansion (Sunkar, 2008). The land conversion would alter the infiltration of the water, causing more run-off to happen. Afterward, the more activities in the surface means more pollutant will be carried to the stream below the ground.

To comply with the SGDs number 6 about the water and sanitation, several management strategies must be included including increasing the water accessibility, maintaining land cover, and preservation of the catchment area (Reinhart & Rifani, 2019). This management have to envelope both side of the anthropological and the natural. Afterward, it is also important to promote the terminology of the wetland in the karst area. Indonesia's policy has included karst into Essential Ecosystem Area (Sahide, Fischer, at al., 2020) as the wetland and to raise the awareness of this function, such terminology will be fruitful.

Another obstacle in the water management in the karst area the delineation of the catchment area. With the micro-catchment type, delineating the catchment area is difficult and intricate. We have employed the GIS approach by considering the flow direction and the flow accumulation, yet it is still far from sufficient. A more exact method such as water tracing is inevitably required. The complex interconnection system makes the RS-GIS approach becomes the minimum and serves only as the preliminary or harsh estimation. A combination of RS-GIS and field survey will provide a better and firm boundary of the catchment area.

Conclusion

The water quality in the Pulejajar Underground River catchment area is heavily polluted due to the polluting materials especially in the Puring Spring. It's need water source management because as the main source of the water for the people. The result from spatial analysis showed that the type of catchment area of Pulejajar Underground River is the radial. Catchment areas confide in the landform aspects as the physical boundaries for water infiltration. People need to actualize water treatment management to serve good water quality.

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