Groundwater Aggressiveness In Jonggrangan Karst, West Progo Area

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Abstract. The Jonggrangan Karst is located in the center of the West Progo Dome area. This karst landscape is less developed, but phenomena of karstification are still common. The aggressiveness of groundwater generally controls the dissolution of carbonate rocks in karst areas. This paper aims to analyze the characteristics of groundwater aggressiveness in the Jonggrangan Plateau based on the level of groundwater aggressiveness of the seven springs in the dry and rainy seasons. The saturation indices value was obtained based on groundwater chemistry data and processed using PHREEQC software. The results showed that all springs have groundwater which tends to be aggressive in the dry season (SI = -0.82 to -0.08), while in the rainy season varied (aggressive and saturated water) with an SI value of -0.44 to 0.47. This indicates that groundwater tends to be aggressive in the dry season and able to dissolve limestone more intensively. In contrast, during the rainy season, the dissolution rate is quite high, and saturation is reached immediately. The different characteristics of groundwater aggressiveness are more influenced by the condition of the pH of groundwater. Aggressive groundwater conditions in the dry season indicate that local groundwater flows are more developed in the study area.

Keywords— Jonggrangan, Karst, Groundwater, Saturation Indices, Aggressivity

INTRODUCTION

The karst landscape in the physiography of the West Progo dome is found in the center of the dome and forms a highland morphology known as the Jonggrangan plateau which reaches a height of more than 800 m [1]. This karst landscape has less than perfect stadia, at least when compared to the Gunungsewu karst. The phenomenon of endokarst and exokarst can be found in several places, including the presence of karst springs and caves. The karst development of this area can be assessed by assessing the aggressiveness of groundwater that appears in the spring.

Karst areas can be viewed as a system consisting of two integrated components, namely the hydrogeological sub-system and the hydrochemical sub-system, so that certain characteristics or mechanisms of groundwater flow will be reflected by certain hydrochemical characteristics [2]. The nature of groundwater flow in karst areas is divided into diffusion flow (slow flow) through pore media or dense fracture networks and flow through cavities or conduit networks (fast flow) [3].

Karst landscapes can be formed due to the dissolution process by water with two conditions, namely the nature of the water is not saturated (undersaturated) to carbonate rocks, and able to transport the dissolving products to other places [4]. Water conditions that are suitable for dissolving these carbonate rocks are phreatic water and also rainwater (meteoric water) which is rich in CO_2. This water infiltrates the carbonate rock and is then able to form solutional tunnels. This unsaturated water is affected by changes in temperature, mixing with water with other characteristics, rapid recharge (floods) and unsaturated nature, and increasing acidity of water along the groundwater flow. The aggressiveness of the karst groundwater is influenced by thermodynamic factors, namely the content of acidity and temperature which causes differences in the content of dissolved $CaCO_3$ in the water [2].

Reaction of groundwater to limestone is a critical process that forms the chemical composition of groundwater in karst aquifers and can further determine the rate and extent of karstification [5]. The karstification process that takes place depends on the ability of water to dissolve rocks, which is expressed in the aggressiveness characteristics of groundwater.

The level of interaction between water and CO_2, the important thing is to know the magnitude of the partial pressure of CO_2 (Pco_2) which theoretically can be calculated from the hydrochemical analysis of groundwater [2]. The aggressiveness of groundwater is influenced by the content of Pco_2. The higher the Pco_2 concentration, the stronger the water's ability to dissolve rock minerals [6].

The aggressiveness of groundwater in the karst landscape is very important in determining the dissolution and sedimentation stages that occur in the aquifer. This property is indicated by the saturation index (SIc) and is related to three phases, namely (1) the condition of the water is not saturated (undersaturated), so it is still able to dissolve rock minerals (2) the condition is balanced (equilibrium), the dissolving process has stopped, and (3) the condition of the water is saturated (supersaturated) there is a process of depotition (precipitation) [7]. The level of groundwater aggressiveness varies both temporally and spatially [5,8,9,10]. Spatially, the aggressiveness of groundwater in springs varies depending on the development of karst aquifers underlying it [9].

This study aims to determine the characteristics of groundwater aggressiveness and to analyze it spatially and temporally. The karst development of the research area can be predicted based on this groundwater aggressiveness study. The research area is located in the center of the West Progo dome, which geographically belongs to the Girimulyo Sudistrict (Kulon Progo District, Yogyakarta Special Region Province) and Kaligesing Subdistrict (Purworejo District, Central Java Province) (Figure 1).

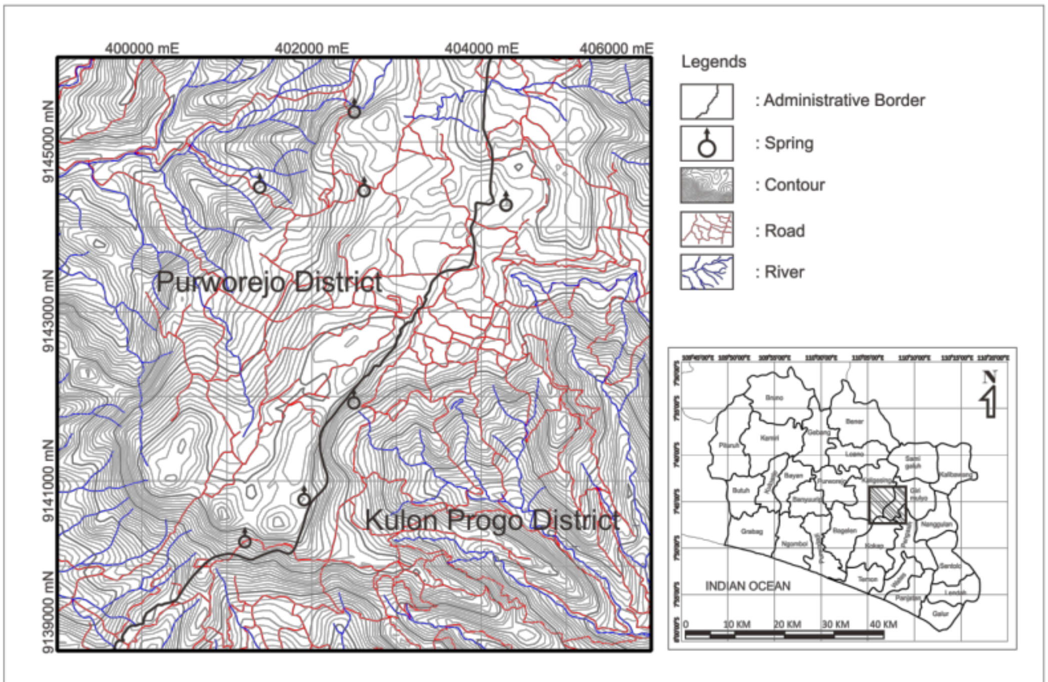

FIGURE 1. Location of the research area and sampling locations.

MATERIAL AND METHODS

The hydrogeological survey has been done in Jonggrangan karst accompanied by rock and groundwater sampling. The samples has been taken from seven springs with medium – large discharge (Table 1). Each spring has been sampled in two seasons, namely dry and rainy seasons. The next stage is the petrographic analysis of rocks and hydrochemical testing in the laboratory.

The groundwater samples has been tested at the Yogyakarta BBTKLPP laboratory to determine pH, TDS and chemical content in the form of major ions, especially Ca^{2+} and HCO_3^- ions. Furthermore, the value of the mineral calcite saturation index (SIc) was determined using PHREEQC software. The aggressiveness of water in this study was assessed from the value of the mineral calcite saturation index (SIc).

The chemical reaction between water and carbonate rock ($CaCO_3$) is a reversible partial equilibrium reaction between dissolution and precipitation. To determine the level of reaction between water and limestone ($CaCO_3$), the saturation index parameter for the mineral $CaCO_3$ (SIc) is used which is formulated as follows [11].

$$SI_C = Log \frac{(Ca^{2+})(HCO_3^{-})K_2}{(H^+)\,K_{CaCO_3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 1)$$

TABLE 1. Location of groundwater sampling and spring discharge measurement.

Spring	Location	Longitude / Easting	Latitude/ Northing	Elevation (m asl)	Q (L/s)		T(°C)	
					Dry	Rainy	Dry	Rainy
Anjani	Tlogoguwo	402501	9145353	665	32.74	75.48	25.2	25
Pagertengah	Middle page, Tlogoguwo	401387	9144466	409	0.1	0.7	24.6	24
Sikantong	Tlogoguwo	402617	9144425	705	56.98	58.91	26.1	26
Ngelo	Purwosari	404289	9144257	710	10.3	12.5	26.3	26.1
Mudal	Mudal River Park, Girimulyo	402496	9141923	664	236.77	315.44	23.8	24
Seplawan	Seplawan Cave, Tlogoguwo	401910	9140782	728	15	58.44	24.1	24
Jatimulyo	Teganing Dua, Jatimulyo	401212	9140284	706	0.6	0.75	22.5	22

The solution will be in equilibrium with respect to $CaCO_3$ if SIc = 0 which means that the dissolving process for $CaCO_3$ has stopped. The negative SIc value indicates that the condition of the solution is undersaturated with respect to $CaCO_3$, so that water is still able to dissolve $CaCO_3$. A positive SIc value means that the condition of the solution is supersaturated with respect to $CaCO_3$, so $CaCO_3$ will be precipitated.

RESULTS AND DISCUSSIONS

The karst landscape in the Jonggrangan area forms a hilly morphology with gentle to moderately steep slopes, but the conical hills are not well developed in this area (Figure 2). The doline phenomenon as an exokarstic formation was also not found. This imperfect karst development may also be caused by the presence of impure carbonate rock layers. The Jonggrangan Formation that forms this landscape also contains conglomerates and tuffaceous sandstones [12] which of course can obstruct the development of karstification. However, caves and spring karsts were found in several places, for example the Seplawan and Anjani springs (Figure 3).

FIGURE 2. The appearance of the Jonggrangan plateau that forms a karst landscape.

Limestones that make up the karst landscape in the study area vary, including mudstone, wackestone or packstone (Figure 4). Limestone is generally composed of fossils, micrite, sparite. Impurity minerals such as quartz are sometimes found in very small amounts (<1%).

The data from groundwater chemistry laboratory tests and the value of saturation indices resulting from data processing using the PHREEQC program can be seen in Table 2.

FIGURE 3. Anjani and Seplawan springs; two examples of karst phenomena in Jonggrangan plateau.

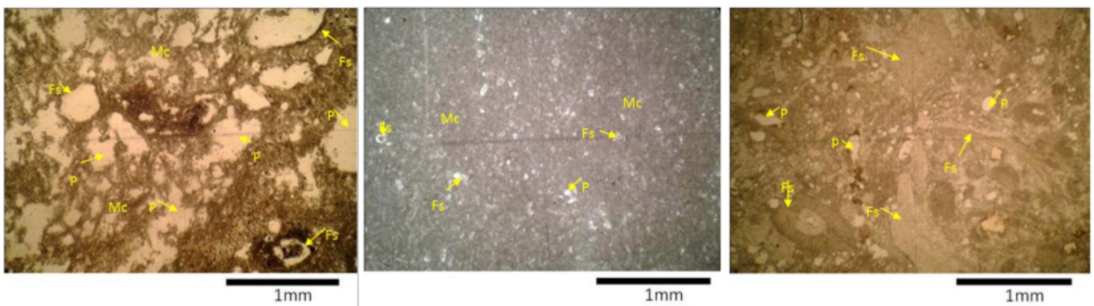

FIGURE 4. Microscopic photo of rock samples in the form of (a) wackestone taken from Pagertengah, (b) mudstone from Anjani and (c) packstone from Seplawan.

TABLE 2. Hydrochemical data and saturation indices of calcite.

Spring	pH		TDS		Facies (bicarbonate)		SIc		Explanation	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Anjani	7	7.9	131	128	Ca, Mg	Ca	-0.81	0.28	Undersaturated	Saturated
Pagertengah	6.4	7.1	302	234	Ca, Mg	Ca	-0.82	-0.3	Undersaturated	Undersaturated
Sikantong	7	8.1	165	126	Ca, Mg	Ca	-0.72	0.47	Undersaturated	Saturated
Ngelo	7.1	7.5	240	217	Ca, Mg	Ca	-0.64	0.44	Undersaturated	Saturated
Mudal	7	7.5	229	198	Ca	Ca	-0.08	0.2	Equilibrium	Saturated
Seplawan	7.2	7.6	186	216	Ca, Mg	Ca	-0.12	0.15	Undersaturated	Saturated
Jatimulyo	6.6	7.2	229	215	Ca	Ca, Na	-0.58	-0.44	Undersaturated	Undersaturated

Based on Table 2, it can be seen that in the dry season, groundwater tends to be more aggressive. The result of SIc calculation shows that groundwater is in equilibrium to undersaturated condition. This is different from the results of research in karst areas that have developed well [9]. Some things that can be interpreted from the hydrochemical field and laboratory data can be explained as follows.

a. Temperature

Groundwater aggressiveness is influenced by temperature [2], however, the groundwater SIc values studied do not show the influence of groundwater temperature on the water saturation index. This is possible because the weather conditions in the study area are not much different in the dry or rainy seasons. The measured temperature in the field shows a small difference, i.e. <1^{o}C (Table 1) Therefore, groundwater temperature does not significantly affect changes in the aggressiveness of the studied water.

b. Acidity (pH)

The level of groundwater acidity studied in the dry season tends to be lower, in line with the aggressiveness of groundwater which increases compared to the rainy season (Table 1). Thus, the pH condition of the groundwater greatly affects its aggressiveness.

c. Spring Discharge

Low/saturated water aggressiveness can occur in springs with small flow rates, where small water flow discharges are typical of base flow or diffuse systems [13]. However, both aggressive and non-aggressive conditions can occur in the studied groundwater, both at low and high discharge. It can be interpreted that in some places there is still a lot of diffusion flow developing.

d. TDS and Groundwater Facies

The TDS value for groundwater tends to be higher in the dry season. In the rainy season, this TDS decreases due to the dilution of rainfall. However, groundwater facies in dry season are dominated by Ca,Mg-carbonate facies. Therefore, the aggressiveness of groundwater as indicated by the calcite saturation index ($CaCO_3$) in the dry season is lower than in the rainy season. This shows that besides calcite minerals, there are other carbonate minerals that dominate the groundwater facies in the dry season. As a result, calcite saturation (SIc) is lower and groundwater is still able to dissolve calcite mineral (aggressive).

The characteristics of groundwater which are more aggressive in the dry season than in the rainy season can be interpreted as follows.

1. In the Jonggrangan karst landscape, groundwater flow is dominated by local flow systems [14]. Therefore, the flow time is relatively short and the flow distance is relatively close. This results in non-intensive water-mineral interactions, such that even though it is dry season, it is also possible for groundwater to be in an under-saturated condition.
2. Groundwater in springs with large discharges such as Anjani, Sikantong, Ngelo, Mudal and Seplawan shows a saturated nature in the rainy season, which means the dissolution rate of carbonates at that time is quite high. As a result, there is quite a lot of carbonate content in the groundwater, as evidenced by the growing facies that is Ca-bicarbonate.
3. The results of previous studies [14] indicate that groundwater flows are deeper in the Sikantong, Ngelo and Mudal springs. Therefore, even though it is rainy season, groundwater in the three springs is very likely to be saturated so that it is not aggressive because groundwater flow allows for greater time and distance so that water-rock interactions can be more intensive.

Thus, the aggressive characteristics of groundwater in the dry season compared to the rainy season support the existence of a local flow pattern in the groundwater system in the Jonggrangan Hills. This is also understandable because the karstification system of the area is not working well, which means that conduit expansion due to the aggressiveness of groundwater is also not fully occurring. This condition is of course also influenced by the rocks that make up the Jonggrangan karst landscape, which are not completely composed of pure carbonate rocks.

CONCLUSION

The Jonggrangan karst landscape is composed of carbonate rocks which form underdeveloped karst morphology, characterized by several spring karst phenomena. The hydrochemical changes in groundwater from this spring occur along with seasonal changes. The results of the hydrochemical analysis and the calculation of the calcite saturation index (SIc) show that groundwater in the dry season is actually more aggressive than in the rainy season. This supports the understanding that in these areas groundwater flow is more developed in local systems, so that even though it is dry season, water-rock interactions are not necessarily intensive.

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