Springs discharge variation in the karst region of Mount Sewu based on elevation and rock transmissivity

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Abstract. Identification of springs that as sources of clean water based on the spatial pattern of spring discharge in the karst region of Mount Sewu, Gunung Kidul Regency, Special Region of Yogyakarta was performed. This karst region is prone to drought. In June 2018, a drought occurred in at least 11 sub-districts of the Regency. It means that new sources of clean water are urgently needed. Variations in discharge were obtained using data on spring elevation, rock transmissivity and water balance. The result shows that springs located at lower elevations have relatively lower water discharge compared to springs at higher elevations, while the transmissivity of aquifer rocks is directly proportional to the amount of spring discharge.

Keywords: Elevation, karst, Mt. Sewu, rock transmissivity, springs

1. Introduction
Water is a very essential natural resource for human life. The availability of water resources becomes a common problem faced by a society living in the karst region. The source of surface water in the karst region can only be obtained from the lake, river or emerging subterranean river, and spring. As a result, during the dry season, severe drought and lack of water supply to meet the needs of the community often occur. According to Summerfield, karst region has unique landscapes and hydrological characteristics [1].

Karst landscapes, in general, have characteristics of typical drainage system and relief which are affected by its high solubility properties [2]. The karstic aquifer is karst that presents a high level of heterogeneity. The more developed shaft in a karstic aquifer is, the older the age of the karst region is and the higher the rate of karstification is [3]. The rate of karstification of an aquifer will greatly affect groundwater recharge, the capacity of storage, and system of groundwater discharge by the aquifer [3].

The groundwater discharge in the form of the emergence of springs in the karst region is affected by several factors, namely rainfall, topography and hydrogeology of karstic aquifer [4]. Moreover, the hydrology system of unique karst is highly affected by the flow of groundwater through solutional fractures that cause water to enter the groundwater flow system. Therefore, drought occurs on the ground [5]. This becomes the characteristic of the Regency of Gunungkidul as a part of Mount Sewu karst region, which makes the region a drought-prone area.

According to Pusat Krisis Kesehatan Kementerian Kesehatan Republik Indonesia and Badan Penanggulangan Bencana Daerah Daerah Istimewa Yogyakarta (BPBD DIY), in June 2018, droughts in the karst region of Mount Sewu hit 54 villages in 11 sub-districts in the Regency of Gunung Kidul.
Alternative water sources such as springs need to be utilized to overcome the effects of drought. Therefore, the study of spatial patterns of variations in spring water discharge is required to locate springs with sustainable discharge.

Based on these considerations, this research intends to conduct a spatial investigation related to variations in spring discharge to spatial distribution patterns in altitude areas and properties of rock transmissivity in the karst region of Mount Sewu. This research aims to spatially analyze the correlation between the variation of spring discharge in the karst region and topography and hydrogeology, as well as to estimate the volume of spring discharge based on the location and the elevation of the spring.

2. Method
This research was conducted in the karst region of Mount Sewu covering 7°54’21.6576” S – 8°12’15.3936” S and 110°20’20.5728” E – 110°50’4.6782” E. The data used in this study are the precipitation data from 2012 to 2017 collected from Badan Meterologi, Klimatologi, dan Geofisika (BMKG), rock transmissivity data collected from hydrogeological map of Yogyakarta issued by Badan Geologi, and digital elevation model collected from Badan Informasi Geospasial (BIG). The data is processed using the Thornthwaite water balance by considering rock transmissivity and spring elevation to identify the theoretical discharge variation of the spring [5, 7]. The discharge condition is then processed based on three scenarios, which are discharge during the dry season, the rainy season, and the average annual discharge.

2.1. Water balance
To estimate the volume of spring discharge, this research used the Thornthwaite water balance (equation 1 and equation 2). However, in a karst region, runoff water can recharge into the soil through fractures on the surface. Therefore, in general, the discharge of water balance in the karst region can be formulated as follow (equation 3 and equation 4) [8]. In the Thornthwaite equation:

\[
\text{Precipitation} = \text{Infiltration} + \text{Runoff}
\]

(1)

\[
\text{Infiltration} = \text{Precipitation} - \text{Runoff}
\]

(2)

the volume of recharge and discharge are:

\[
\text{Recharge} = \text{Infiltration} + \text{Runoff}
\]

(3)

\[
\text{Discharge} = (\text{Infiltration} + \text{Runoff}) - \text{Storage}
\]

(4)

2.2. Surface runoff and infiltration
The surface runoff can be estimated through a calculation using Lloyd-Davies method or rational method (equation 5) [9]. The correlation between surface runoff and precipitation highly depends on the value of infiltration of the soil [10]. According to Tarboton [11], when the soil becomes saturated, the excess water will be collected in a basin on the surface and then becomes runoff. The ability of soil to store water in its voids is called infiltration capacity, [11] described by Curve Number (CN) in which infiltration occurs and runoff does not occur as long as the threshold abstract (saturated) value is not reached. If we study the Thornthwaite concept of water balance further, the infiltration calculation can be implemented into the rational method with runoff coefficient as the comparison between rainfall and surface runoff (equation 5) [12]. According to Fetter and Walter, the value of runoff coefficient varies depending on land use and slope [10, 13]. The surface runoff is formulated as follows:

\[
R = 0.0028 \times I \times A
\]

(5)
hence, the volume of infiltration is,

\[ \text{Infiltration} = 0.0028 \times (1 - C) \times I \times A \]  

(6)
in which surface runoff \((R)\) is affected by precipitation \((I)\), runoff coefficient \((C)\), and area \((A)\).

2.3. Variation of spring discharge

In determining groundwater discharge, the aquifer is considered as a container filled with material that can be passed by water [14]. Based on the explanation above, the approach of balance between recharged and discharged water from groundwater aquifer system is used to analyze the variation of spring discharge in the karst region [15]. The calculation of spring discharge used data of spatial precipitation, runoff coefficient, and transmissivity in the form of raster dataset which was used to calculate the volume of recharge in the karst region of Mount Sewu. The data of rock transmissivity was used to estimate the storage by calculating the maximum volume of water that flows horizontally through rocks to the area. Results of the calculation of recharge and storage were then used to identify a theoretical discharge of the spring. Subsequently, the variation of discharge in the sample location of the spring was interpolated and correlated with the elevation in the karst region of Mount Sewu using regression.

3. Results and discussion

3.1. Topography

The topography in the karst region of Mount Sewu has the highest point of 490 meters above sea level. The karst region of Mount Sewu is divided into two regions, namely the northern region and the southern region. The northern region has an elevation ranging from 150 to 200 meters above sea level. This region includes the Districts of Playen, Wonosari, Karangmojo, Ponjong in the middle, and Semanu in the north. The southern region has an elevation ranging from 0 to 300 meters above sea level. This region includes the Districts of Saptosari, Paliyan, Girisubo, Tanjungsari, Tepus, Rongkop, Purwosari, Panggang, southern Ponjong, and southern Semanu (figure 1a).

The karst region of Mount Sewu has a slope of 0 to 320 percent rise. The northern karst region is relatively flat with slopes below 60% rise. This region includes the Districts of Playen, Wonosari, Karangmojo, Ponjong in the middle, and Semanu in the north. The southern area of Mount Sewu karst has a slope of more than 60% rise with a characteristic of conical hills (conical limestone). This region includes the Districts of Saptosari, Paliyan, Girisubo, Tanjungsari, Tepus, Rongkop, Purwosari, Panggang, southern Ponjong, and southern Semanu (figure 1b).

3.2. Hydrogeology

The formation in the karst region is highly affected by the process of karstification. Karstification causes changes that occur on the surface or near the surface of the rock, either on the surface (exokarst) or below the surface (endokarst). The geology in the karst region of Mount Sewu is composed of Kepek Formation consisting of limestone and marlstone with transmissivity value of 1.524 m²/day and Wonosari Formation consisting of layered limestone with transmissivity value of 6.096 m²/day. Based on the transmissivity values above, the aquifer in the karst region of Mount Sewu can be classified as mediocre productivity aquifer and high productivity fractured aquifer (figure 1c) [16].

The emergence of springs in the karst region is a result of solutional either on the surface or below the surface [17]. Groundwater is basically a balance between the flow of water in and out of a system. The balance is called water balance [6]. When rain occurs, some of the rainwater is caught by the vegetation and infiltrates the soil while the others run off on the ground surface and flow down to
the valley and river nearby [18]. Consequently, the characteristics of springs in the karst region greatly depend on the rate of karstification. The characteristics of each karst region are unique. Therefore, slightly different results are expected in other karst regions [19]. The volume of discharge of karstic spring is highly affected by its topography and geological structure [4]. Based on the result of data processing, distribution patterns come with three scenarios, which are discharge during the dry season, discharge during the rainy season, and average annual discharge, with a correlation of $R = 0.7582$ and $R^2 = 0.574868$, respectively, are obtained. This method is based on empirical evidence; hence it is not suitable for micro-temporal calculation. Therefore, other approaches are required to estimate the value of micro recharge and discharge abstraction.

3.3. Distribution of spring discharge variation during dry season
In this scenario, the data of precipitation between April and September is used. In the scenario of the dry season (figure 2a), the minimum discharge is 0–1.28 liter/second (L/s) on mediocre aquifer region and south coastal region with an elevation of 0–5 m a.s.l. This includes the Districts of Playen, Wonosari, Karangmojo, Ponjong in the middle and Semanu. Meanwhile, the maximum discharge is 3.359–4.889 L/s on fractured aquifer region: on the west and east part of karst region of Mount Sewu with an elevation of more than 100 meters above sea level (m.a.s.l.). This region includes the Districts of Saptosari, Paliyan, Girisubo, northern Tjanjungsari, northern Tepus, Rongkop, northern Purwosari, Panggang, southern Ponjong, and southern Semanu.

3.4. Distribution of spring discharge variation during rainy season
In this scenario, the data of precipitation on January-March and October-December is used. In the scenario of the rainy season (figure 2b), the minimum discharge is 0–6.798 L/s on mediocre aquifer region and south coastal region with an elevation of 0–5 m a.s.l. This includes the Districts of Playen, Wonosari, Karangmojo, Ponjong in the middle and Semanu. Meanwhile, the maximum discharge is 20.172–28.192 L/s on fractured aquifer region: on the west and east part of karst region of Mount Sewu with an elevation of more than 100 m.a.s.l. This region includes Saptosari, Paliyan, Girisubo, northern Tjanjungsari, northern Tepus, Rongkop, northern Purwosari, Panggang, southern Ponjong, and southern Semanu.
3.5. Distribution of spring discharge variation of average annual discharge

The data used is the data of precipitation throughout 2017. In the scenario of average annual discharge (figure 2c), the minimum discharge is 0–4.08 L/s on mediocre aquifer region and south coastal region with an elevation of 0–5 m.a.s.l. This includes the Districts of Playen, Wonosari, Karangmojo, Ponjong in the middle and Semanu. Meanwhile, the maximum discharge is 11.768–16.391 L/s on fractured aquifer region: on the west and east part of karst region of Mount Sewu with elevation more than 100 m.a.s.l. This region includes the Districts of Saptosari, Paliyan, Girisubo, northern Tanjungsari, northern Tepus, Rongkop, northern Purwosari, Panggang, southern Ponjong, and southern Semanu.

4. Conclusion

The topography in the karst region of Mount Sewu is divided into two regions, namely the northern region and the southern region. The northern region has an elevation of 150–200 meters a.s.l with slopes below 60 % rise. The southern region has an elevation of 0–300 meters a.s.l with slopes of more than 60 % rise and the characteristic of conical hills (conical limestone). The geology at karst region of Mount Sewu is composed of Kepek Formation and Wonosari Formation. Based on their transmissivity, the aquifer in the karst region of Mount Sewu can be classified as mediocre productivity aquifer and high productivity aquifer.

The distribution of spring discharge variation in karst region either on dry season, rainy season, or average annual discharge is affected by elevation and hydrogeology of the spring itself. Low-elevation springs have relatively lower discharge compared to high-elevation springs. Meanwhile, the transmissivity value of aquifer rocks is directly proportional to the discharge volume of the springs. Therefore, areas with high potential for spring discharge in the karst region of Mount Sewu are in the western part with an elevation of 100–250 m a.s.l. and classified as fractured aquifer areas. This region includes the Districts of Saptosari, Paliyan, Girisubo, northern Tanjungsari, northern Tepus, Rongkop, northern Purwosari, Panggang, southern Ponjong, and southern Semanu.
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