Water Balance in Epikarst: Case study of Kakap Springs, the Eastern Karst of Gunungsewu

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Abstract. Kakap spring is one of the important springs in Eastern Karst of Gunungsewu. This study aims to determine the water balance in karst aquifer. The study was use three parameters to analysis the water balance in Kakap Spring. They are rain as main source, evaporation and discharge of Kakap Spring. The study was conducted by monitoring the water level for eight months in 30 minutes’ interval basis to analysis discharge. Temperature based evaporation analysis used Penman method, and water input conducted by monitoring rain basis typing bucket method used rain gauge. The result showed that the values of evaporation estimated as 1186 mm (71%), discharge estimated as 457 mm (27%) and 31 mm (2%) estimated get into the deep karst system.

1. Introduction

Karst is a landscape that has the distinctive characteristic and typical drainage caused by the degree of the limestone dissolution higher than other areas ([11], [2], [3]). The distribution of karst in the world reaches 9, 3 – 15, 9% ([3]), [4], [5], [6]) or 2.2 million km² Yuan and Chai, 1988 in [7] in which 25% of population in the world relies highly on the karst water [3].

Karst vertically was divided into 4 zones: 1) soil cover, 2) epikarst (subcutaneous zone), 3) vadose (unsaturated zone) and 4) phreatic (saturated zone) ([8], [9]). Epikarst is an unsaturated zone upper rock putrefaction in which porosity and permeability are homogeneously distributed [10], and has a biological and hydrological function ([11], [12], [13]). Epikarst grows close with the surface due to the higher level of dissolution by water infiltration with the higher concentration of carbon dioxide. This was seen as a storage place and temporary system distribution for the water infiltration into the karst system ([10], [14], [15], [16]). This temporary storage may develop so as to allow for the formation of larger lateral stream called as conduits ([12], [17]). Based on this fact, epikarst was stated as an important storage subsystem and believed that water deposits in it are more significant than the one in the phreatic zone [16]. The level of water reserve relies upon the characteristics of karts and determined by absorption, storage and rainwater [17]. As an unsaturated zone, in water balance calculations, epikarst plays its role towards the amount of water loss in the form of evapotranspiration depend on the thickness of the surface soil [18].

Gunungsewu Karst was the karst area located in the southern Java Island ranging from Gunungkidul Regency of Special District of Yogyakarta to Pacitan, East Java with the length of 85 km. It was a tropical karst with the type of cone karst [19] which was, in more detailed, classified into
the type of polygonal, labyrinth and residual karst dome [20]. It was formed in Wonosari Formation
with a thickness of 650 m composing of a layered limestone and a massive limestone in the northern
area with the variation of coral limestones ([21], [22], [23], [24]).

The land utilization of Gunung Sewu karst mostly dominated by mooring (31.56%), with the
seasonal plants such as corn, bean and paddy with rainwater irrigation system. Gunung Sewu Karst
has the climate type D and E based upon the method of Schmidt and Ferguson ([25], [26]) and with
the climate classification of AW and Am [27]. The rainfall level in karst area was categorized high in
every year (380l/sec), but it was prone to drought. Drought often occurs during the dry season so it
needs the supply of fresh water to fulfillment the needs of the local people in karst area. This related to
karstic geological and geomorphological conditions. This study aims to calculate water balance in the
karst area, so it can be used as a basis in determining the water management policy in karst area.

The Kakap spring located in the eastern part of Gunungsewu karst was the research site included of
residual karst classification with a water catchment area of 2703 ha (Fig. 1). Land use is dominated by
moorings and kailyard. Although it has a small catchment area, but the spring was perennial and has the
highest level of volume in Karst Wonogiri, thus providing a source of clean water for the local
people. Due to this reason the existence of Kakap Springs was very strategic. Today, the water use was
managed by PDAM (Local Water Company).

![Figure 1. Catchment Area of Kakap Spring]
2. Methods
Water balance principally refers to calculate water between the inflow and outflow water in a
catchment area. This was an exploratory research using three parameters: rain, evapotranspiration and
spring discharge. Rain was the main input source in the system, while evapotranspiration and spring
discharge were the output ones. The data about rain was obtained by installing Rain Gauge using a
typing bucket system. Evapotranspiration used the Tronthwhite method based on the temperature
obtained from temperature record on Rain Gauge. The discharge was measured using a float method at
16 times during the dry and rainy season. The result of this (discharge properties was used to make the
stage rating curve - a curve that shows relationship between the discharge and water level. The water
level in the Kakap spring was obtained by installing AWLR to record the water level in every 30
minutes. In the end the discharge obtained was divided by the catchment area width to obtain the water
thickness in the unit.

3. Results and Discussion
The results of the research were presented based on the parameters of water balance calculation
rainfall, evapotranspiration and discharge converted in mm.

3.1. Rainfall
The rainfall amount recorded was as equal as the one distributed during the rainy season between
November 2014 and May 2015 by 1781 mm/year with the highest intensity occurred in December
2015 by 536 mm. The rain distribution of the research area presented in Figure 2.

![Figure 2. Rainfall Distribution in Kakap Spring Catchment Area](image)

3.2. Evapotranspiration
Based on the calculation result, it was found that the average of daily evapotranspiration was 3.3 mm,
the monthly average was 104.9 mm and reached 1186.9 mm for a year. The highest evaporation was
found at 3.6 mm occurred in November 2015, while the lowest evapotranspiration was 2.8 mm
occurred in February 2015. This shows that the season has an effect on the level of evapotranspiration
in which the dry season has the greater evapotranspiration value than the rainy season. The daily
variation of evapotranspiration was visually presented in Figure 3.

![Figure 3. Temporal Variation of Evapotranspiration of Kakap Spring](image)
3.3. Discharge

3.3.1. Validation of the determination of time recording in AWLR. The validation of recording time was conducted to see the feasibility of time determination in recording the data of water level (TMA). Based on the results of the calculation it was found that there was no any significant difference between the recording conducted in every 30 minutes and the one in every 15 minutes. The data resemblance was found at 99% indicating that no occurrence of peak discharge that was not recorded on AWLR. The difference between 30-minute and 15-minute recording can be seen in Figure 4.

![Figure 4. Validation of recording time of logger AWLR in research site](image)

3.3.2. Discharge Hydrograph

The discharge hydrograph in the research site was obtained based upon the relation between the water level and the discharge of direct measurement in field. Based on the discharge measurement in field, the maximum value of debit in December 2014 was 149.35 l/second (in rainy season) and the minimum one was in September 2014 at 17.86 l/secs (in dry season), meanwhile, for the stage discharge rating curve which was the relation between the discharge value and the water spring level was $y = 14.103e^{8.7333x}$ in which $y$ refers to the discharge and $x$ was the water spring level. This value was used to determine the discharge of spring based upon the level of water spring level recorded by AWLR in each 30 minutes to obtain a discharge hydrograph. Figure 5 shows the discharge hydrograph of the Kakap Spring.

As shown in the Figure 5, it can be seen that the level of flow discharge was determined by the level of rainfall. This indicates that rain has a significant effect on the level of water spring discharge. The highest level of discharge occurred in March, while the lowest one was in November. The minimum discharge occurred in the end of the dry season. This occurred because flow discharge in the dry season was the base flow due to no rain at all in the dry season. Figure 6 shows the difference of discharge during the rainy and dry seasons.
3.3.3. Water Balance. As shown in Figure 7 it can be seen that the overall water response to the water spring depends on the rainfall in the research area. The rainfall in the beginning of the rainy season was used to moisturize the soil surface, thus indirectly increasing the water amount in the spring. In this condition the time used for rainwater reaches the hydrograph peak was relatively longer than the average during the rainy season. Based on a number of flood occurred, it was found that the time required to reach the flood peak was 4.5 hours. The time to the peak (Tp) indicates that the spring flow response to rain was not so fast, later indicating that the Kakap Spring is dominated by the diffused flow. As the rainwater was sufficient to moisturize the surface soil, the spring response to rain increases as indicated by the higher water coming out in the spring. In rainy season, evaporation is more varied, in which it is determined by the rain event especially during the day. Although had varied evaporation values, (but) it was lower than outflow water in the spring. In rainy season, water has a surplus in which the rainfall was higher than evapotranspiration and the water in the spring.
In contrast, during the dry season, the process was dominated by evapotranspiration. The discharge in the water spring was much smaller than the one in rainy season. The outflow in the spring was the base flow and flowing less compared to evapotranspiration. The absence of input during the dry season has resulted in a decrease in water reserves in the epikarst system. The water decrease in the water spring continues until the end of the dry season, although not making the spring getting dried. At this stage, the karst area will experience a water deficit, so it was not adequate to fulfil the need of people for the clean water. The water deficit will take place during the dry season until the beginning of the rainy season in which the rain was still rare and rainwater was still used to moisten the soil surface.

Based on the results obtained in water balance parameters, a model of water balance in Kakap Spring can be made. Figure 8 shows the water balance model in Kakap Spring, which was a representation of the inflow water and the outflow one in of Kakap Spring Catchment Area. Based on the model, it can be seen that the epikarst system in the research area was dominated by evapotranspiration at 1186 mm (71%), while the flow in the spring is 457 mm (27%). Meanwhile, the rest at 31 mm (2%) estimated get into the deeper karst systems. This value was not much different from a research conducted by Vestena L.R. and Kobiyama M., 2007 at Riberiao da Onca Catchment Area, Brazil. Even though it has a sub-tropical climate with almost equal width of catchment area (1611.8 Ha), in the study [28], the result showed that evapotranspiration dominated the output process (76.8%) while the spring flow was at 23.2%. This was due to the influence of the phreatic zone.

4. Results and Discussion
Karst Spring has an allogenic type where the outflow water in the spring comes from the rainfall occurred in catchment area of Kakap Spring, hence, there was no input from other catchment areas.
The aquifer system was dominated by a diffuse system characterized by a slow flow response to the rain (4.5 hours). Based on the model it was figured out that evapotranspiration was the highest output. In fact, this was a common condition in karst. It cannot be apart from the geological and geomorphological conditions of karstic formation, dominated by the secondary porosity, many open lands and thin surface soils. [18] stated that the epikarst role in evaporation was very high depend on the thickness of the surface soil and would be maximal on an open land. Such condition becomes the main problem in karst landform; hence it was prone for the occurrence of drought in dry season. On the other hand, there would be 31 mm (2%) that probably get into karst system, so it would be difficult to be utilized because it needs a further effort in terms of both technology and cost.

Based on these problems, some efforts should be made that could reduce the value of evapotranspiration, such as the re-election of land cover which was suitable with the karst area. Climatologically, the research area has sufficient water to meet the needs throughout the year [25], but the uneven distribution of temporal throughout the year has led the research area into drought-prone area. Certain effort to anticipate the drought-prone in the dry season was the more intensive rainwater harvesting in consideration that in rainy season there was a surplus water. Rainwater harvesting was done to make the surplus in the rainy season able to be stored and used to meet the water needs both for the population and for the crops. Thus, it can reduce the water shortages and crop failure in the dry season.

5. Conclusions
Kakap Springs was an autogenic spring in which the rainwater becomes the main supply source. The rainy season between February and May was the month of water surplus. Based on the water balance, it was found that the evapotranspiration value had the highest value (71%) compared with the output coming out of the water (27%), contributing to karst areas as the drought-prone area. The efforts to manage karst in the determination of plants that can reduce evapotranspiration and more intensive rainfall harvesting can be done to cope the water shortage in the dry season.

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