Catchment Area Analysis of Guntur Karst Spring Gunung Kidul Regency, Java, Indonesia

M Widyastuti¹, I A Riyanto², M Naufal³, F Ramadhan³, N Rahmawati³

¹Lecturer in Faculty of Geography, Universitas Gadjah Mada
²Master in Planning and management on Coastal Area and Watershed (MPPDAS), Faculty of Geography, Universitas Gadjah Mada
³Bachelor Student in the Bachelor Program of Environmental Geography, Faculty of Geography, Universitas Gadjah Mada

m.widyastuti@geo.ugm.ac.id

Abstract. Karst area has abundant potentials and distinctive characteristics. Its prospective resources are associated with karst aquifer. This condition makes the local people highly dependent on karst groundwater sources, especially in dry seasons. However, in this landscape, water is stored abundantly in the hardly accessible underground flow system. Therefore, drought is a persistent hazard in a karst region. These conditions can be identified by examining the water recharge and delineating the catchment’s boundaries as the determinants of water resource potential in karst areas. The boundaries can be approached through the water balance method. The principle of water balance can be used to identify water distribution and storage in a catchment area. The primary data were the water level recorded automatically and the flow velocity Guntur Spring. The secondary data were rainfall statistics from 4 nearby rainfall stations and temperature records from 5 nearby meteorological stations. This study was conducted at a karst complex in Girijati Village, Purwosari District, Gunungkidul Regency. This study aimed to (1) identify the characteristics of Guntur Spring water recharge and (2) estimate the catchment area of the spring using the water balance approach. During the six months of the observation, the spring recharge zone received 1,658.6 mm of rainfall, lost up to 862.6 mm of water by evapotranspiration, and produced a discharge of 88.2 L/s at the spring. Based on the water balance calculation, the catchment area was 30.7 Ha. The nomogram and the topography-based delineation around Guntur Spring also affirmed this finding.

1. Introduction

Karst has abundant potentials and distinctive characteristics. It covers nearly 20% of the total area in Indonesia [1]. Its prospective resources include a copious amount of available groundwater. Accordingly, karst groundwater becomes the primary water source to meet the people’s needs not only in Indonesia but also in some countries in the world [2]. UN reports state that 25% of the world’s water supply is stored in karst areas [3]. The groundwater in karst needs to be considered as a potential aquifer [4]. Karst is continually filled with water and, therefore, it can provide a source to fulfill the water needs of the community. A study focusing on the identification of potential water availability can be helpful in determining groundwater capacity to meet the water demands in karst regions.

The hydrogeological characteristics of karst aquifers are distinctively more complex than other aquifers. Karst aquifer has three types of porosity (triple porosity, i.e., diffuse, fissure, and conduit),
high heterogeneity and anisotropy, and high hydraulic conductivity [5]. Karstification or carbonate rock dissolution is the primary geomorphological process that forms the subsurface morphology in karst. It creates unique hydrological characteristics, namely tunnels or caves that dominantly from the groundwater flow system and highly developed underground rivers. The high heterogeneity and the anisotropy [6] distinguish karst hydrology from the aquifer system in porous media that tend to be more homogeneous and isotropic.

Based on the geomorphological aspects, the southern part of the Special Region of Yogyakarta is mainly karst areas composed of limestone, one of which is located in Gunungkidul Regency. This condition makes the local people highly dependent on karst groundwater, especially in dry seasons [7]. It also indicates that karst is a potential catchment area in rainy seasons. However, in this landscape, water is stored abundantly in the hardly accessible underground flow system. Therefore, drought is a persistent hazard in karst regions.

These conditions can be identified by examining the water recharge and delineating the catchment’s boundaries as the determinants of water resource potential in karst areas. According to [8], the catchment area includes every point located above the elevation (or height) of the gauge stations and within the topographic divides that separate large-scale catchment areas with various underlying rock compositions and structures. These parameters control the amount of discharge at the outlet. A catchment area is higher than its outlet; therefore, the water captured therein accumulates in the mainstream and discharges through its single outlet.

The boundaries of the catchment area in karst are different from the non-karst region. In non-karst regions, the boundaries are based on topographical divides (as represented by ridges), whereas in karst areas, they are determined by analyzing surface morphology, such as the appearance of karst hill and karst valley network, on topographic or contour maps. The topographic divides can only be used when the delineation of the catchment’s boundaries also considers karst development conditions in the corresponding karst region [9]. In addition to topographic divides, the delineation has to take into account the information of other landforms like the spatial distribution of ponor and surface slope aspect. It also needs to factor in the differences between karst and non-karst catchment areas like the hydrological system. The extent of a catchment area in the karst landscape relies on complex subsurface hydrological systems, whereas the one in the non-karst landscape is apparent in the characteristics of the surface hydrological system.

The boundaries of catchment areas in karst region can be approached not only using topography but also the water balance method. The principle of water balance can be used to identify water distribution and storage in a catchment area. This method is also one of the easiest approaches to pinpointing the boundaries of the catchment area of a water body by considering several meteorological factors. The size of the catchment can also be estimated using a nomogram that displays the correlation between the size, spring discharge, and annual recharge [10].

The study was conducted at Guntur Spring complex in Gunungsewu Karst, particularly in Girijati Village, Purwosari District, Gunungkidul Regency. This hilly region has an underground river system, as well as the emergence of Guntur Karst Spring that is utilized by the local people for domestic purposes and irrigation water. There has been no research on flow potentials in the study area. Therefore, there is no comprehensive information regarding the quantity of the water flow potential and the size of the catchment area in Guntur Spring complex. Based on these considerations, this research aimed to (1) identify the characteristics of Guntur Spring recharge and (2) estimate the size of the catchment area of Guntur Spring using a water balance approach. The results are expected to provide the basis for further studies of the water management effectiveness in the study area, especially regarding water resource conservation in a karst region.

2. Methods
Guntur catchment area (DTA) is located in two regencies, namely Gunungkidul Regency (in Dringo Hamlet) and Bantul Regency (in Sorotopo Hamlet). Its coordinates are 911650 - 911660 m Northing and 428000 – 428250 mEasting in Zone 49 S (Figure 1). The catchment area has 7 classes of slope in
the catchment area, namely 0-2%, 2-4%, 4-8%, 8-16%, 16-35%, 35-55%, and >55%. Based on USDA soil textural classification, it is composed of soils from Typic Tropaquepts and Typic Eutropepts [11]. Geologically, it is part of Wonosari Formation (limestone) [12]. Wonosari formation consists of 2 compositions, bedded chalky limestone in the northern part and massive coral limestone in the southern part [1].

Furthermore, Guntur Spring also part of Karst Gunungsewu [13]. It is also part of PanggangHydrogeological Subsystem [14]. The rainfall ranges from 2,300 to 2,400 mm/year [15], and the average annual temperature is 27°C [7]. The conditions of Guntur Spring in rainy and dry seasons are presented in Figure 2.

**Figure 1.** Map of Guntur Spring and Its Surrounding Areas

**Figure 2.** Guntur Spring in Rainy Seasons (left) and Dry Seasons (right)
The research equipment included notebooks to record the field survey results, loggers to record water level automatically, a GPS to determine the absolute location during the field survey, a stopwatch to measure the time length of the discharge measurement, drones to capture the aerial overview of the areas around Guntur Spring, and digital cameras for field documentation. The research used both primary and secondary data. The primary data were the water level recorded automatically by the logger with a 10-minute interval in 6 months (December 2017 - May 2018) and the flow velocity obtained from direct measurement in the field using a current meter through-flow area method. Both of these data were used as the basis for creating a rating curve. The aerial photos of the study area provided basic information for topography-based catchment area delineation. The secondary data were rainfall statistics from 4 nearby rain stations (i.e., Pundong, Kretek, Panggung, Purwosari) and temperature records from 5 nearby meteorological stations (i.e., Barongan, Wates, Plunyon, Playen, Tegal). Rain and temperature data were the basis in water balance calculation. This study also employed literature studies of karst development characteristics in the study area to validate the size of the catchment area deduced from the nomogram.

2.1. Determining the Size of the Catchment Area Based on Water Balance.

The size of the catchment area was assessed using the water balance approach, consisting of three main components, namely flow discharge, rainfall, and evapotranspiration. The mathematical formula of the water balance is presented in Eq. (1).

\[ Q = P - E \pm \Delta S \]  

where:
- \( Q \): spring discharge (m\(^3\)/s or L/s)
- \( P \): precipitation (mm/year)
- \( E \): evapotranspiration (mm/year)
- \( \Delta S \): storage change (mm/year)

The rainfall data from the 4 nearby stations were interpolated to produce the regional rainfall (in mm/year) around Guntur Spring. The temperature data was processed using the Blaney-Criddle method [16] to generate evapotranspiration data. This research used potential evapotranspiration because it receives the most influence of meteorological factors [17], i.e., solar radiation, temperature, atmospheric humidity, and wind speed. This study collected a set of data containing air temperature, monthly percentage of daytime hours—which is associated with latitude and solar radiation—, the type of vegetation cover (coefficient of vegetation). These data were processed using the Blaney-Criddle Method to calculate the potential evapotranspiration in the study area [16]. The mathematical equation is presented in Eq. (2)

\[ PET = U = \Sigma k x \Sigma t x p / 100 \]  

where:
- \( PET/U \): potential evapotranspiration (inch)
- \( Kt \): \(0.0173t - 0.314\)
- \( t \): average monthly temperature (°F)
- \( Kc \): coefficient of vegetation
- \( P \): the monthly percentage of daytime hours in one year (%)
- \( \Sigma \): the total amount in one year

In the water balance calculation, discharge (Q) represents the total flow rate (discharge) over a predetermined time length. It is principally the water volume per unit of time that flows through an outlet. This research used the total volume of water emerging in and passing through Guntur Spring during the six-month observation. The total water volume calculation is summarized in Eq. (3).

\[ V_{6\, months} = \frac{Q_{6\, months} \times \text{Unit of time}}{1} \]
\[
V = \left[ \frac{Q(n) + Q(n+1)}{2} - Q(n+1) + Q(n+2) + \ldots - Q(m-1) + Q(m)}{2} \right] \text{Unit of time}
\]

where:

- \( V \): total water volume in one year (m\(^3\) or L)
- \( Q \): total water discharge in one year (m\(^3\)/year or L/year)
- \( Q(n) \): the first discharge data (m\(^3\)/s or L/s)
- \( Q(m) \): the latest discharge data (m\(^3\)/s or L/s)
- Unit of time: 10 min x 60 s (because the logger automatically recorded the water level of Guntur Spring every 10 minutes)

This study assumed that water fell on the ground, directly recharged the spring, and transformed into an outflow (i.e., discharge in one single outlet), making \( \Delta S \) negligible. Therefore, the water balance equation became \( Q = P - E \). In this case, the annual rainfall (P) and evapotranspiration (E) were measured in mm or dm, while the mean annual discharge was presented in L/s or dm\(^3\)/s. Accordingly, to obtain the size of the catchment area, the total water volume (outflow) in one year (V in dm\(^3\)) was derived from discharge data (Q), while the precipitation was subtracted by evapotranspiration before multiplied by area (A). These mathematical operations produced balanced measurement units on both sides of the equation, \((P-E) \times A = V\). The size of the catchment area (in m\(^2\) or ha) was obtained by dividing the 6-month water volume by effective rainfall (precipitation subtracted by potential evapotranspiration) using the water balance parameter.

2.2. Determining the Size of the Catchment Area using Nomogram.

The size of the catchment area can be estimated using a nomogram that correlates it with spring discharge and annual recharge [10], as presented in Figure 3. The yearly recharge was obtained from SNI 19-6728.1-2002 in 2002[18], as summarized in Table 1. Based on the table, the percentage of rainfall partitioning into recharge in limestone (the dominant rock in karst area) is 30-50%. Based on the karst development condition observed in the field, 50% was selected as part of the regional rainfall that transformed into recharge (RC) in Guntur Spring area. The mathematical formula is presented in Eq. (4).

\[
Recharge = 50\% \times Regional Rainfall
\]

Based on the recharge calculation and the average spring water discharge, the size of the catchment area was determined by correlating the discharge and recharge in the nomogram presented in Figure 3.

**Table 1. The Annual Water Recharge by Geological Formation**

| Geological Formation | Recharge RC (%) |
|----------------------|-----------------|
| Volcanic materials from the Recent epoch | 30-50 |
| Old volcanic; sediments or mixed sediments from the Recent epoch | 15-25 |
| Sediments, particularly marl or indurated rock | 5 |
| Limestone | 30-50 |
2.3 Determining the Size of the Catchment Area Based on Topography.

The boundaries of the catchment area were delineated spatially based on the topographic information processed in ArcGIS 10.2 software. This process also relied on the locations of hills, valleys, sinkholes, and cave entrances, which were obtained from field observation. The delineation considered not only the primary data but also the actual condition in the field. Therefore, the boundaries of the catchment area expectedly match or resemble the actual ones. As [19] has done in his research, which is limiting the catchment area one of them with a topographic approach. Other research conducted by [20] limits the karst system through several approaches, including using a topographic approach.

3. Result and discussion

The rainfall interpolation from the 5 nearby stations, as depicted in Figure 4, showed that the regional rainfall in the study area was 1,658.6 mm. The interpolation process involved a set of rainfall data in 6 months, i.e., from December to January, which was assumed to represent the rainy and dry seasons.

This study required evapotranspiration data to calculate the effective rainfall (i.e., precipitation subtracted by evapotranspiration). The evapotranspiration was estimated using the Blaney-Criddle approach. This method is widely used to determine the amount of evapotranspiration in vegetation cover (consumptive use). Moreover, according to Allen [21], evapotranspiration is a combination of water loss process from a cultivated land through evaporation and transpiration. The potential evapotranspiration during the 6-month observation was 862.6 mm (Table 2).

Figure 4. The Map of the Regional Rainfall around Guntur Spring
Table 2. The Potential Evapotranspiration Calculation in the Study Area Using the Blaney-Criddle Method

| No | Months     | Temp. (°C) | Temp. (°F) | Kc | Kt | P (%) | U (inch) | U (mm) |
|----|------------|------------|------------|----|----|-------|----------|--------|
| 1  | January    | 27.271     | 81.0878    | 0.75 | 1.08882 | 8.7898 | 5.82038 | 147.838 |
| 2  | February   | 27.651     | 81.7718    | 0.75 | 1.10065 | 7.8399 | 5.29207 | 134.419 |
| 3  | March      | 27.627     | 81.7286    | 0.75 | 1.0999  | 8.51   | 5.73746 | 145.732 |
| 4  | April      | 27.883     | 82.1894    | 0.75 | 1.10788 | 8.11   | 5.53846 | 140.677 |
| 5  | May        | 27.622     | 81.7196    | 0.75 | 1.09975 | 8.24   | 5.55403 | 141.072 |
| 6  | December   | 27.8       | 82.2       | 0.75 | 1.1     | 8.81   | 6.01    | 152.86  |
|    | Total      |            |            |     |      |       | 862.6   |        |

Table 3. The Water Level and Discharge Measurement Results in Guntur Spring

| No | Dates         | Water Level (m) | Discharge (L/s) |
|----|---------------|-----------------|-----------------|
| 1  | 24 January 2018 | 0.36            | 94.79467333    |
| 2  | 13 February 2018 | 0.25           | 97.19629444    |
| 3  | 23 February 2018 | 0.28           | 117.8618556    |
| 4  | 9 March 2018    | 0.26            | 87.10380631    |
| 5  | 28 March 2018   | 0.27            | 96.7157        |
| 6  | 7 April 2018    | 0.18            | 68.36062297    |
| 8  | 13 May 2018     | 0.09            | 12.86          |

Figure 5. The Rating Curve of Guntur Spring

The flow discharge was assumed to be the only outflow from Guntur Spring. Therefore, to calculate the output of the water balance, the average discharge data within the 6-month observation, which represented the rainy and dry seasons, was required. This research used a rating curve to estimate the discharge per unit of time in 6 months. Based on the data presented in Table 3, the rating curve equation was $Q = 745.25x^{1.5851}$ (Figure 5), where $x$ = water level (m). When the water level changes, the discharge fluctuates accordingly without the need to measure it directly every time. This research also used this equation for calculating the average of the water discharge of Guntur Spring every 10 minutes. The calculation results for 6-month observation are summarized in Table 4. The average 10-minute discharge of Guntur Spring in one year is 88.27 L/s.

Based on the rating curve, the research acquired 10-minute discharge data in 6 months. Therefore, the total water volume flowing out of Guntur Spring within 6 months was estimated using the volume calculation formula, as presented in Table 4.
Using the rainfall, evaporation, and water volume data, the water balance calculation resulted in the size of the catchment area, i.e., 30.7 Ha (0.307 Km$^2$). The size is highly dependent on rainfall. If high precipitation is followed by a small annual volume of spring water, then the size is small. On the contrary, if high precipitation is followed by a large annual water volume, then the catchment area is also extensive.

Several studies affirm this finding. A survey in Grza Spring (Eastern Serbia) states that the size of the Grza catchment area varies between 30-50 km$^2$ and 36.6-43.6 km$^2$. It becomes smaller in dry years but broader in wet years [22]. Lestari [23] explain that during the runoff simulations (5, 6, and 7 months) the size of the catchment area of Pindul Cave system in Gunungkidul Regency varies according to the predetermined runoff. The size of the catchment area is wider when the runoff is larger, and vice versa, proving that rainfall is a determinant of the size of a catchment area.

The size of the catchment area resulted in the water balance method was reanalyzed using the nomogram introduced by Todd [10], which depicts the correlation between the size of the catchment area, spring discharge, and annual recharge. The average 10-minute discharge of Guntur Spring in one year was 88.27 L/s, while the average rainfall of the study area in 6 months was 1,700.5 mm/year. Based on the assumption of the rainfall partition in the study area, the water recharge was 1,219.5 mm. Therefore, a line was drawn to connect the spring discharge, the water recharge, and the generated catchment area. The line drawing on the nomogram showed that the catchment area was 30-40 ha (0.3-0.4 Km$^2$), as presented in Figure 6. There was no significant difference between the size of the catchment area obtained from the nomogram (i.e., 30-40 ha) and the one from the water balance calculation (i.e., 30.7 ha).

| Months          | Discharge (L/s) | Number of Days | Total Discharge (Q) in 6 Months (L/s) | Volume in 6 Months (L) |
|-----------------|-----------------|----------------|--------------------------------------|------------------------|
| December 2017   | 141.6535487     | 11             |                                       |                        |
| January 2018    | 122.937         | 31             |                                       |                        |
| February, 2018  | 97.08           | 28             |                                       |                        |
| March, 2018     | 78.921          | 31             | 448.03                               | 254,837,344.8          |
| April, 2018     | 67.436          | 30             |                                       |                        |
| May, 2018       | 21.651          | 27             |                                       |                        |
| Average Discharge| 88.28           |                |                                       |                        |
The catchment area was delineated based on the topographical divides and karst connectivity [24][25][26]. The results showed an elongated form and characteristics in line with the topographical divides. They also corroborated the assumption that underground river, spring, ponor, and swallow holes were interconnected (Figure 7). Kali Nongko Underground River and Guntur Spring are assumed to be connected, as evidenced by the information provided by some villagers who had performed a traditional tracing test using rice husk that eventually emerged in Guntur Spring. Also, the spring ceased to flow when the residents had to close the stream of Kali Nongko Underground River. This two information is sufficient to confirm the hypothesis that Kali Nongko Underground River and Guntur Spring are connected. A further assumption is that this underground river is also physically connected to Kali Kulon and Jambu Springs, ponor, and swallow holes inside the catchment area. This connectivity remains an assumption due to the absence of supporting tracer tests. The next research is expected to perform these tests to validate the karst connectivity above and the size of the catchment area [27][28].
The results showed that the catchment area’s boundaries identified from the water balance calculation were quite relevant and logical to the resultant size of the catchment area. The condition is also affirmed by the nomogram and the topography-based delineation of Guntur Spring catchment area. The water balance approach is also suitable because it considers both surface (input) and subsurface (hydrogeology) factors. Both factors are essential mainly because karst has different characteristics from other landscapes.

4. Conclusions
Based on the results, this research concluded that within 6 months, the rainfall of Guntur Spring was 1,658.6 mm, the average spring discharge was 88.27 L/s, and the evapotranspiration amounted to 862.6 mm. Based on the water balance calculation results, the catchment area was 30.7 ha. Rainfall influences the size of the catchment area. If high precipitation is followed by a small water volume in one year, then the size of the catchment area is small, and vice versa. The delineation of the catchment area using the water balance calculation is quite relevant and logical to the resultant size of the catchment area. This assertion is affirmed by the nomogram and the topography-based delineation around Guntur Spring. The water balance approach is also suitable because it considers surface (input) and subsurface factors (hydrogeology).

Acknowledgment
This research was funded by Hibah Penelitian Dosen, the Faculty of Geography, Gadjah Mada University (Scheme No. UGM/GE/1555/M/03/18). The authors would like thank to all surveyor, Environment & Geography Department and Faculty of Geography Gadjah Mada University for the support of this paper.

Reference
[1] Balazs D 1968 Karst Regions in Indonesia: Karszt-Es Barlangkutatás, V. Budapest, Globusnyomda, 61 p.
[2] Kaçarog'lu F 1999 Review Groundwater Pollution and Protection in Karst Area. Water, Air, and Soil Pollution 113: 337–356.
[3] Ko R K T 1984 Peranan Ilmu Speleologi Dalam Penyelidikan Fenomena Karstik dan Sumberdaya Tanah dan Air –Sebuah Informasi Soal Speleologi, (Ceramah Pada Pusat Penelitian Tanah– Bogor, Bogor).
[4] Bakalowicz M 2005 Karst Groundwater: A Challenge for New Resources. Hydrogeology Journal 13:148–160.
[5] White W B Elizabeth L W 2003 Conduit fragmentation, Cave patterns, and the localization of karst groundwater basins: The Appalachians as a test case. Speleogenesis and evolution of karst aquifer 1 (2): 1-15.
[6] Goldscheider N 2005 Karst Groundwater Vulnerability Mapping: Application of New Method in Swabian Alb, Germany Hydrogeology Journal 13 (4): 555–564.
[7] Haryono E and Day M 2004 Landform Differentiation Within The Gunungkidul Kegel, Java, Indonesia Journal of Cave and Karst Studies, 66(2) : 62-69.
[8] Lee R 1988 Hidrologi Hutan (Yogyakarta: Gadjah Mada University Press).
[9] Goldscheider N Drew D 2007 Methods in Karst Hydrogeology. (London:Taylor and Francis Group)
[10] Todd D K 1980 Groundwater Hydrology (New York: John Wiley and Sons).
[11] Gunungkidul Regency. Spatial Plan 2010-2030
[12] Tjia H D 2013 Morphostructural Development of Gunungsewu Karst, Jawa Island. Indonesian Journal of Geology, 8(2): 75-88.
[13] Haryono E Suratman.2010 Significant Features of Gunungsewu Karst As Geopark Site. 4th International UNESCO Conference on Geopark, April 12-15, 2010, Langkawi.
[14] Kusumayudha S B 2009 Detecting Springs in the Coastal Area of the Gunungsewu Karst
Terrain, Yogyakarta Special Province, Indonesia, using Fractal Geometry Analysis. The Journal of Technology and Sci. 2(4): 1 – 12.

[15] Brunsch A Adji T N Stoffe D Ikhwani M Oberle P Nestmann F 2011 Hydrological Assessment of A Karst Area in Southern Java Wi,h Respect to Climate Phenomena. Asian Trans-Disciplinary Karst Conf. 2011, Yogyakarta-INDONESIA.

[16] USDA SCS (U. S. Department of Agriculture, Soil Conservation Service) 1970 Irrigation Water Requirements. Tech Release 21 (rev.) 92 p.

[17] Asdak Chay 2010 Hidrologi dan Pengelolaan Daerah Aliran Sungai, Cetakan ke 5. (Yogyakarta: Gadjah Mada University Press).

[18] Badan standarisasi nasional (BSN) 2002 Penyusunan Neraca Sumberdaya : Bagian 1 Sumber Daya Air. (Jakarta :BSN).

[19] Agniy R F 2016 Kajian Hidrogeologi Karst Sistem Gua Pindul, Kecamatan Karangmojo, Kabupaten Gunungkidul. Skripsi. (Yogyakarta: FakultasGeografi UGM).

[20] Ramdhani A A 2014 Studi Neraca Air dalam Menentukan Daerah Tangkapan Air (DTA) Mataair Karst (Studi Kasus Mataair Ngeleng, Petoyan, Purwosari). Skripsi. (Yogyakarta: Fakultas Geografi UGM)

[21] Allen R G Pereira L S Raes D and Smith M 1998 Crop Evapotranspiration: Guidelines for Computing Crop Requirements. Irrigation and Drainage Paper No. 56. Food and Agriculture Organization of the United Nations. Roma.

[22] Vakanjac V R Prohaska S Polomcic D Blagojevic B and Vakanjac 2013 Karst Aquifer Average Catchment Area Assessment ThroughMonthly Water Balance Equation with Limited Meteorological Data Set: Application to Grza Spring in Eastern Serbia. Acta Carsologica 42(1) : 109-119.

[23] Lestari E P Widyastuti M 2013 Analisis Neraca Air Untuk Menentukan Daerah Tangkapan Air (DTA) Sistem Pindul, Kecamatan Karangmojo, Kabupaten Gunungkidul.

[24] Vakanjac V R Stevanovic Z Stevanovic A M Vakanjac B and Ilic M C 2015 An example of karst catchment delineation for prioritizing the protection of an intact natural area. Environ Earth Sci. 74: 7643–7653, DOI 10.1007/s12665-015-4390-y.

[25] Luo G J Wang S J Bai X Y Liu X M and Cheng A Y 2016 Delineating small karst watersheds based on digital elevation model and eco-hydrogeological principles. Solid Earth, 7: 457–468, DOI:10.5194/se-7-457-2016.

[26] Kovarik J L Van Beynen P E and Nledzekksim M A 2017 Groundwater vulnerability mapping for a subcatchment of the Rio La Venta watershed, Chiapas, Mexico. Environmental Earth Sci. 76: 797.

[27] Knoll P and Scheytt T 2017 A tracer test to determine a hydraulic connection between the Lauchert and Danube karst catchments (Swabian Alb, Germany). Hydrogeology Journal. https://doi.org/10.1007/s10040-017-1678-x

[28] Barbera J A Mudarra M Andre B and Torre B D 2018 Regional-scale analysis of karst underground flow deduced from tracing experiments: examples from carbonate aquifers in Malaga province, southern Spain. Hydrogeol J. 26: 23–40, DOI 10.1007/s10040-017-1638-5.