ISSN 1907-0322

Subsurface Flow and Surface Water Interactions Quantification in Gunung Kidul Karst Area Using Hydro-Chemical and Stable Isotopes Data Variations

Interaksi Sungai Bawah Tanah Dengan Air Permukaan di Daerah Karst Gunung Kidul Menggunakan Variasi Data Hidrokimia dan Kandungan Isotop Stabil

Paston Sidauruk, E. Ristin Pujiindiyati dan Satrio

Center for Isotopes and Radiation Application, BATAN
Jl. Lebak Bulus Raya No. 49, Jakarta12440
Email : pastons@batan.go.id

Diterima 03-03-2015; Diterima dengan revisi 18-03-2015; Disetujui 25-05-2015

ABSTRACT

Subsurface Flow and Surface Waters Interactions Quantification in Gunung Kidul Karst Area Using Hydro-Chemical and Stable Isotopes Data Variations. Subsurface flow is one of the available water sources in the Karsts area such as in Gunung Kidul. The study of the pattern of the variations of stable isotopes content as a function of time and its interaction with other water sources such as rain waters, groundwater, river water will be a very good tool to assess the potential of the subsurface flow as a water source. For this purpose, the variations of stable isotopes content of subsurface flow around Gunung Kidul Karsts area and its interactions with other local water sources have been studied for the last two years. From the comparison of stable isotopes variations pattern of the subsurface flow with monthly rain water, the interaction of the subsurface flow with other water sources in the area has been quantified. Based on hydro-chemical data, it was found that the recharge area of subsurface flow were relatively further than other samples and it was also found that Seropan and Bribin subsurface flow systems originate from different geologic structures. Based on stable isotopes relative contents, it was found Ngobaran and Baron Caves have been mixed with domestic sewerage water or other surface water.

Keywords : Karsts area, stable isotopes, subsurface flow

ABSTRAK

Interaksi Sungai Bawah Tanah Dengan Air Permukaan di Daerah Karst Gunung Kidul Menggunakan Variasi Data Hidrokimia dan Kandungan Isotop Stabil. Aliran sungai bawah tanah adalah salah satu sumber air yang tersedia di daerah Karst seperti halnya di daerah Gunung Kidul. Penelitian pola variasi kandungan isotop stabil sebagai fungsi waktu dan interaksinya dengan sumber air lainnya seperti air hujan, air tanah, dan sungai dapat digunakan sebagai alat untuk memperkirakan potensi aliran sungai bawah tanah dalam pengembangan selanjutnya. Untuk tujuan ini, pengamatan kandungan isotop stabil dan variasinya dan interaksinya dengan sumber air lainnya telah dilakukan pada dua tahun terakhir. Dari pola variasi kandungan isotop stabil aliran sungai bawah tanah dan perbandingan dengan pola variasi sumber air lainnya khususnya air hujan, besaran interaksi sungai bawah tanah dan sumber air lainnya telah dilakukan. Berdasarkan data kimia air, telah ditemukan bahwa daerah imbuh aliran bawah tanah adalah lebih jauh dari sumber air lainnya dan juga telah ditemukan bahwa air bawah tanah di Goa Seropan dan Bribin berasal dari struktur batuan yang berbeda. Berdasarkan data kelimpahan relatif isotope stabil, ditemukan bahwa aliran bawah tanah di Goa Ngobaran dan Baron telah mengalami percampuran dengan air buangan setempat atau air permukaan lainnya.

Kata kunci : *Daerah Karsts, isotop stabil, aliran sungai bawah tanah*

Jurnal Ilmiah Aplikasi Isotop dan Radiasi
A Scientific Journal for The Applications of Isotopes and Radiation
Vol. 11 No. 1 Juni 2015
ISSN 1907-0322

INTRODUCTION

The location of study area is in Gunung Kidul Regency as given in Figure 1. Gunung Kidul Regency that is located about 39 Km south east of Yogyakarta has the area around 1485 km^2 and the population around 700,000 people [1]. The rain intensity in the area was relatively high that is around 2000 mm/year. Due to geologic structure of the region, however, the availability of groundwater for domestic use is very limited. Hence, residents in karst area are more likely to experience water scarcity especially during dry season [2].

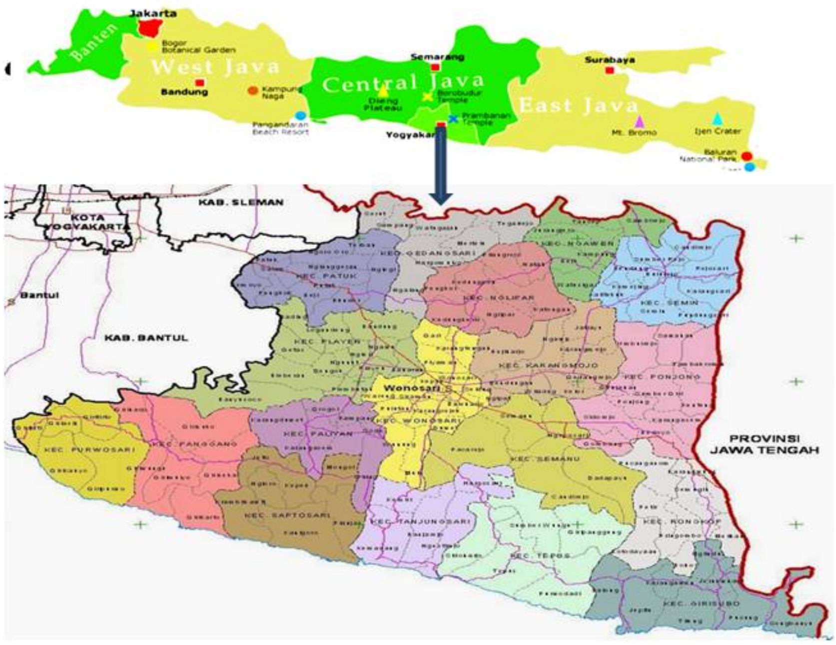

Figure 1. Location of study area

The rain water eventually becomes subsurface flow through the carbonate stone cracks passage. Hence, the obvious water supply that can be developed in the near future is to lift the subsurface flow to the surface. The construction of mini hydro turbine is undergoing in the area.

Numerous Karst features such assinkholes, swallow holes, solution lakes, have developed in the area because of the dissolution of the carbonate rocks that allows the water from the land surface moving directly into the subsurface flow. However, very little is known about the quality of the water moving downward through these karst features. The current study aim is to quantify the interaction of subsurface flow with other water sources such as surface water, river, rain water, and groundwater. The interaction quantification is very important information such as to asses of the susceptibility of the subsurface flow from contamination. One of the available techniques to achieve such goal is using naturally tracers such as stable isotopes of water. Water molecules were built by the hydrogen isotopes (^{1}H(H), ^{2}H(D, deuterium), ^{3}H(T, tritium)) and oxygen isotopes (^{16}O, ^{17}O, ^{18}O). Based on natural content of these isotopes, $H_2{}^{16}O$ (18), $H^2H^{16}O$ (19), and $H_2{}^{18}O$ (20) are the dominant water molecules in which the number in the bracket indicates corresponding molecule weight. Weight differences of the three molecules make them to respond differently

ISSN 1907-0322

to certain process. In evaporation process, for example, lighter molecules will tend to escape faster from the water body. In condensation process, in contrast, heavier molecules will tend to condensate faster. Hence, the content of $H_2{}^{16}O$ (H_2O), $H^2H^{16}O$ (HDO), and $H_2{}^{18}O$ in water body can be used as a tracer to identify what processes the water has undergone with. Due to over domination of $H_2{}^{16}O$ in natural water, the content of heavier molecules ($H^2H^{16}O$, $H_2{}^{16}O$) was expressed in relative content with respect to international standard as given in the following formula:

1. Relative content of deuterium (δ_D) in [3]:

$$\delta_D = \left(\frac{R_{D(\text{sample})}}{R_{D(\text{standard})}} - 1 \right) \times 1000\,‰; \quad R_D = \frac{N(HDO)}{N(H_2O)} \tag{1}$$

2. Relative content of oxygen-18 ($\delta_{O\text{-}18}$) [3,4]:

$$\delta_{O-18} = \left(\frac{R_{O-18(\text{sample})}}{R_{O-18(\text{standard})}} - 1 \right) \times 1000\,‰; \quad R_{O-18} = \frac{N(H_2{}^{18}O)}{N(H_2O)} \tag{2}$$

In which R_D and $R_{O\text{-}18}$ are the molecule ratio for deuterium and oxygen-18, respectively and $N(x)$ is absolute content of the molecule x.

Hydro-chemical data is very important to assess the potential of subsurface water because water is an excellent solvent to dissolve the material of the geologic system it has passed through [5]. Hence hydro chemical data is significantly improved our understanding about water movement, recharge mechanism, inter-aquifer connectivity, and chemical composition of the aquifer. For comprehensive discussion about the interaction of subsurface water and other sources of water, stable isotopes data will be used together with water hydro-chemical data.

The objective of this study is to investigate the potential of the subsurface flow in Gunung Kidul Karst area as a source of water for domestic use in the region by means of quantification of the interaction of subsurface flow and surface flow. The interaction of subsurface and surface flows was assessed through the stable isotopes content of collected samples and its variations as a function of time and space together with the age and hydro-chemical data of the water.

MATERIAL AND METHOD

The activities in this study were started by installing five rain collectors at five different locations with different altitudes in the area. Then, rain water samples for stable isotopes content analysis were collected regularly every month from each rain collector for duration of 12 months. The water samples for stable isotopes (δ_D, $\delta_{O\text{-}18}$), tritium, and hydro-chemical content analysis were also collected from various sources such as from subsurface flow and surface flow periodically. The samples from subsurface flow were mainly collected through caves and sinkholes, whereas surface flow samples were those collected from Kali Suci. For stable isotopes content analysis, 20 ml water was collected into well sealed bottle to prevent evaporation. One liter water was needed for either tritium or hydro chemical contents analysis. The samples were put into plastic sample jar. All collected samples were sent to Laboratory Center for the Isotopes and Radiation Applications – BATAN in Pasar Jumat, South Jakarta. Stable isotopes content of collected samples

(Deuterium and Oksigen-18) was analyzed by laser absorption method in which the absolute content of individual molecules can be quantified through the amount of absorbance at a specific wavelength [6, 7].

RESULTS AND DISCUSSIONS

Hydro-chemical data

The hydro-chemical data together with in-situ parameter of all collected samples from subsurface and surface waters are presented in Table 1 and the corresponding Piper diagram is given in Figure 2. The ranges of in-situ parameters pH, total dissolved solid (TDS), and temperature (T) are 6.23-7.26, 204-330 ppm, and 24.1-28.9 ^{0}C, respectively. In general all of the values of in-situ parameters are in acceptable values for drinking water [8].

Table-1 also shows that all collected samples had relatively high bicarbonate, calcium, and magnesium concentrations. Bicarbonate, calcium, and magnesium concentrations were in the range 180 – 300 ppm, 48 – 76 ppm, 4-20 ppm, respectively. Further, Figure 2 shows that all collected samples were grouped at the same area called bicarbonate and calcium-magnesium area. This is due to fact that Gunung Kidul Karst formation is dominated by limestone i.e., rudstones, packstones, and framestones [9-11]. Limestone is mainly composed of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) [12]. Therefore, the high concentration of bicarbonate, calcium, and magnesium in the samples indicates that the samples have been in contact with limestone formation for quite some time. Yan, Li, Ye, and Li (2012) found that the concentrations of the ions were normally affected by the rainfall i.e., higher concentration in dry season compared to wet season [13]. In this study, however, the samples were collected once in August 2012. Therefore the variations of the ion concentration in this study were not caused by the variation of the rainfall but it might indicate to residence time of the corresponding sample. It is also found from Table 1 that bicarbonate contents of those samples collected from subsurface flow (SSF) are generally higher than those collected from other sources. This indicated that the contact time of subsurface water with limestone structure was longer than other samples. Hence, this phenomenon could indicate that the recharge area of subsurface flow were relatively further than other samples. It is interesting to compare two subsurface flow namely Seropan and Bribin (Sindon) subsurface flows. These two subsurface flows are very important because the development of hydropower plant in Gunung Kidul Karst area has been focused in these two subsurface flows (caves) [14]. It

Table 1. Hydro-chemical data of collected samples around Gunung Kidul Karst area

Sample Name	K (ppm)	Na (ppm)	Ca (ppm)	Mg (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	TDS (ppm)	pH	T (°C)
Petung (SP)	1.03	3.85	48.49	13.80	2.60	2.29	252.11	301	6.77	26.4
Baron (SSF)	0.98	4.14	51.25	19.23	4.29	1.97	303.39	355	6.36	28.4
Kalisuci (SW)	0.80	4.16	53.31	7.48	6.85	2.21	181.14	204	7.05	28.9
Selonjono (SP)	0.57	3.15	62.99	7.85	2.81	2.15	249.8	231	6.55	25.4
Bribin 2 (SSF)	0.99	2.72	68.58	14.91	3.00	1.62	290.94	319	6.66	27.8
Seropan (SSF)	0.89	3.09	75.72	6.00	3.20	1.29	282.77	312	6.57	24.1
Ponjong (SP)	0.96	2.17	63.94	4.45	2.75	1.26	189.44	329	7.26	25.4
Ngreneng (SP)	0.87	3.09	60.67	9.40	3.08	1.47	219.94	330	6.13	27.3

Notes:
SP: Spring water; SSF: Subsurface flow; DW: Dug well; SW: Surface water (river)

is seen from Table 1 that almost all hydro chemical data of two samples from Seropan and Bribin subsurface flows are about the same except for Magnesium (Mg). The concentration of Magnesium (Mg) in Seropan subsurface flow is much lower compared to the concentration of Magnesium (Mg) in Bribin subsurface flow. This may also suggest that the two subsurface flows originate from different geologic structures.

contents of deuterium an oxygen-18was -40 $^{0}/_{00}$ and -6.2 $^{0}/_{00}$, respectively [15].

At the same time, sampling from various water outlets such as water from sinkholes, caves, springs, dug wells, and surface water were also conducted from March 2010 until June 2011 and the results of deuterium and oxygen-18 relative contents analysis are presented in Table 2. The ranges of deuterium (δ_D) and oxygen-18 ($\delta_{O\text{-}18}$) were -53.2 to -37.4 $^{0}/_{00}$ and -8.18 to -5.28 $^{0}/_{00}$, respectively. In general, Table 2 showed that those samples collected from either spring water (SP), surface water (SW), or dug well (DW) had higher stable isotopes relative contents (more enrich) compared to those samples collected from subsurface flow (SSF). These phenomena were common since all spring water, surface water and dug well had interacted with the atmosphere for sometimes before collected. Some samples such as those samples collected from Baron dug well, Teleng spring water, and Sundak

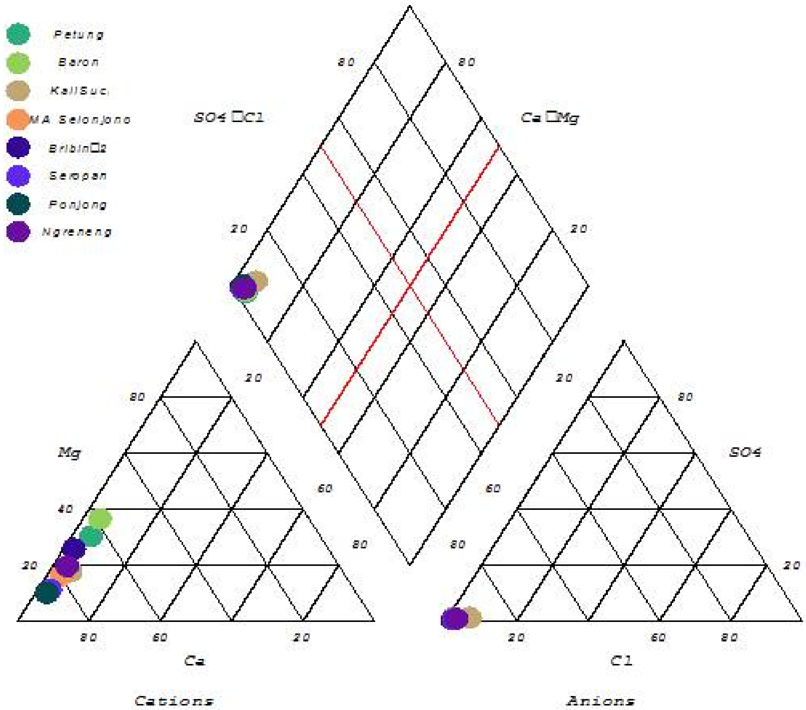

Figure 2. Piper diagram of cation and anion data of collected samples around Gunung Kidul Karst area.

Stable isotopes data

During this study, there were 5 rain collectors installed in the area at different locations and altitudes. Based on the monthly sampling that was conducted from June 2010 – May 2011, it was found that rainfall intensity ranged from 0 – 310 mm/month with total annual rainfall was about 2600 mm. The relative contents of deuterium (δ_D) and oxygen-18 ($\delta_{O\text{-}18}$) were in the range, -60 to -25 $^{0}/_{00}$and -10 to -5 $^{0}/_{00}$, respectively. The overall average of relative

 ISSN 1907-0322

spring water had significantly higher in stable isotopes relative contents ($\delta_D, \delta_{O\text{-}18}$) compared to other samples. This phenomenon indicated that the three samples had experienced significant evaporation caused by ponded water around the spring. In addition, the collected sample from Baron dug well might also have mixed with the seawater because it was very close to shore line. Within subsurface flow samples, it was found that those samples collected from Ngobaran and Baron Caves were more fluctuated and enrich compared to those samples collected from Seropan Cave. Highly fluctuated samples indicated that either water was recharged locally or the samples have been mixed with intermittent sources. During field visits, some domestic organic and inorganic garbage has been observed in the main stream of subsurface flow. Hence, the fluctuation of deuterium and oxygen-18 relative contents in those samples collected from Ngobaran and Baron Caves suggested that these two caves (subsurface flows) have been mixed with domestic sewerage water or other surface water. The fact that Ngobaran and Baron Caves are the last caves before subsurface flows discharged to the sea intensifies the suggestion that the subsurface flows have been mixed with domestic sewerage water or other surface water.

Table 2. Deuterium (δ_D) and Oxygen-18 ($\delta_{O\text{-}18}$) relative contents of all collected samples around Gunung Kidul Karst area

Sampling Location	$\delta_{O\text{-}18}$	δ_D	$\delta_{O\text{-}18}$	δ_D	$\delta_{O\text{-}18}$	δ_D	$\delta_{O\text{-}18}$	δ_D
	($^0/_{00}$) SMOW		($^0/_{00}$) SMOW		($^0/_{00}$) SMOW		($^0/_{00}$) SMOW	
Sumber Ponjong (SP)	-6.99[a]	-51.2[a]	-8.06[b]	-51.3[b]	-6.27[c]	-44.5[c]		
Ngobaran (SSF)	-6.58[a]	-45.4[a]	-6.24[b]	-37.8[b]	-5.39[e]	-43.8[e]		
Baron (DW)	-5.47[e]	-37.4[e]	-5.87[f]	-39.5[f]				
Ngereneng (SP)	-6.53[a]	-46.3[a]	-6.88[b]	-43.6[b]	-6.27[c]	-44.5[c]	-6.93[d]	-46.7[d]
Baron (SSF)	-8.03[a]	-53.2[a]	-6.44[b]	-42.8[b]	-5.54[c]	-42.6[c]		
Seropan (SSF)	-7.57[a]	-42.9[a]	-7.15[b]	-42.6[b]	-6.33[e]	-45.2[e]		
Sundak (SP)	-5.32[a]	-50.4[a]						
Teleng (SP)	-5.28[a]	-48.6[a]	-6.79[e]	-45.3[e]	-6.71[f]	-44.5[f]		
Selonjono (SP)	-6.92[e]	-46.2[e]	-7.43[f]	-47.2[f]				
Gedong (SP)	-6.68[e]	-44.5[e]	-6.12[f]	-42[f]				
Beton (SP)	-8.18[a]	-44.8[a]	-6.83[e]	-45.6[e]				
Kali Suci (SW)	-5.72[f]	-45.2[f]						

Notes: a: sampling time March 2010; b: sampling time April 2010
c: sampling time June 2010; d: sampling time October 2010
e: sampling time June 2011; f: sampling time September 2011
SP: Spring water; SSF: Subsurface flow; DW: Dug well; SW: Surface water (river)

CONCLUSIONS

Higher bicarbonate concentrations of collected samples from subsurface flow indicated that the contact time of subsurface water with limestone structure was longer than other samples or this also suggested that the recharge area of subsurface flow were relatively further than other samples.

The different concentration of Magnesium (Mg) of Seropan and Bribin subsurface flow systems suggested that the two subsurface flows originate from different geologic structures. Based on oxygen-18 (δ_D, $\delta_{O\text{-}18}$) contents analysis, it is concluded that those samples collected from spring water, surface water and dug well had experienced either evaporation or mixing with surface water. Those samples collected from Baron dug well, Teleng spring water, and Sundak spring water had experienced significant evaporation caused by ponded water around the spring. In addition, the collected sample from Baron dug well might also have mixed with the seawater because it was very close to shore line.

The fluctuation of deuterium and oxygen-18 relative contents in those samples collected from Ngobaran and Baron Caves suggested that these two caves (subsurface flows) have been mixed with domestic sewerage water or other surface water.

AKNOWLEDGEMENTS

This research was partly funded by State Minister Research and Technology office through INSENTIVE PROGRAM 2011.

REFERENCES

1. ANONYMOUS, Profil daerah Kabupaten Gunung Kidul, BAPPEDA-Kabupaten Gunung Kidul (2013).

2. RETNOWATY, A., Culture and Risk Based Water and Land Management in Karst Areas: An Understanding of Local Knowledge in Gunung Kidul, Java, Indonesia, Dr. rer. Nat Dissertation, University of Giessen, 2014.

3. LUBIS, M.E.S, HARAHAP, I.Y., HIDAYAT, T.C., PANGARIBUAN, Y., SUTARTA, E.S., RAHMAN, Z.A., TEH, C., HANAFI, M.M., Stable Oxygen and Deuterium Isotope Techniques to Identify Plant Water Sources, *Journal of Water Resource and Protection*, **6**, 1501-1508 (2014).

4. STEWART, M. K., MEHLHORN, J., ELLIOTT, Hydrometric and natural tracer (oxygen-18, silica, tritium and sulphur hexafluoride) evidence for a dominant groundwater contribution to Pukemanga Stream, New Zealand, Hydrol. Process., 21, 3340–3356 (2007).

5. PRADHAN, B., PIRASTEH, S., Hydro-chemical analysis of the ground water of the Basaltic catchments: Upper Bhatsai Region, Maharastra, *The Open Hydrology Journal*, **5**, 51-57 (2011).

6. IANNONE, R. Q., ROMANINI, D., CATTANI, O., MEIJER, H. A. J., KERSTEL, E. R.TH., Water isotope ratio (δ^2H and δ^{18}O) measurements in atmospheric moisture using an optical feedback cavity enhanced absorption laser spectrometer, *J. Geophys. Res.*, 115, D10111,1-12 (2010), doi:10.1029/2009JD012895.

7. KERSTEL, E.R.TH., MEIJER, H.A.J., Optical isotope ratio measurements in hydrology, p. 109-123, in Aggarwal, P.K., et al. (Eds.) Isotopes in the Water Cycle: Past, Present, and Future of a Developing Science. IAEA/Springer, Dordrecht, the Netherlands (2005).

8. WORLD HEALTH ORGANIZATION, Guidelines for drinking water quality-4th ed., WHO Library Cataloguing-in-Publication Data, Malta (2011).

9. KUSUMAYUDHA, S.B., SETIAWAN, J., CIPTAHENING, A.N., SEPTIANTA, P.D., Geomorphologic Model of Gunung Sewu Karst,

Gunung Kidul Regency, Yogyakarta Special Territory, Indonesia: The Role of Lithologic Variation and Geologic Structure, *Journal of Geological Resource and Engineering*, 1, 1-7 (2015), doi:10.17265/2328-2193/2015.01.001

10. HARYONO, E., ADJI, TJ. N., WIDYASTUTI, M., TRIJUNI, S., Atmospheric carbon dioxide sequestration through karst denudation: Preliminary estimation from Gunung Sewu karst, Paper in International Seminar on Achieving resilience agriculture to climate change trough thedevelopment of climate based management, PERHIMPI, 17-19 Nov 2009, Bogor. http://www.academia.edu/ access date: July 25, 2015.

11. HARYONO, E., DAY, M., Landform differentiation within The Gunung Kidul Kegel karst, Java, Indonesia, *Journal of Cave and Karst Studies*, **66** (2), 62 – 69 (2004).

12. PIANE, C. D., BURLINI, L., KUNZE, K., BRACK, P., BURG, J. P., Rheology of dolomite: Large strain torsion experimental and natural examples, *Journal of Structural Geology*, **30**, 767 – 776 (2008).

13. YAN, J., LI, J., YE, Q. , LI, K., Concentrations and exports of solutes from surface runoff in Houzhai Karst Basin, southwest China, *J. Chemical Geology*, 304-305, 1-9 (2012), doi:10.1016/j.chemgeo.2012.02.003.

14. NESTMANN, F., OBERLE, P., IKHWAN, M., STOFFEL, D., SOLICHIN, Development of underground water extraction system for karst regions with adapted technologies and operating system pilot plant in Java, Indonesia, Procedia Engineering, 54, 58 – 68 (2013).

15. SIDAURUK, P., WIBAGIYO, SATRIO, PRATIKNO, B., Studi karakteristik dan potensi sungai bawah tanah di daerah Gunung kidul dengan teknik isotope, Laporan Teknis Blockgrant 2011, PAIR-BATAN (2011).