Groundwater Quantity and Quality of Springs of Karst Region in Pacitan Regency, East Java

Tri Anggraeni[1,2,*] Doni Prakasa Eka Putra[1] Ahmad Taufiq[2]

[1] *Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada, Indonesia*
[2] *Ministry of Public Works and Housing, Indonesia*
[*] *Corresponding author. Email: trianggraeni1995@mail.ugm.ac.id*

ABSTRACT

The emergence of springs and underground rivers is one of the characteristics of a karst landscape that is formed due to the karstification process in which carbonate rocks are dissolved by water to form cavities or channels. Karst Pacitan is an area located in parts of Donorojo, Punung, and Pringkuku sub-districts. Geologically, the area is included in the Wonosari Formation unit, which is composed of limestone. The hydrogeology of the Pacitan karst is part of the Wonosari Groundwater Basin. Similar to other karst regions, in the surface is difficult to find water. Naturally, the emergence of springs is used by the local community to help them meet the water needs for daily life. This research was conducted by measuring several groundwater samples from springs in the karst region of Pacitan Regency. The purpose of this study is to determine springs groundwater quantity and quality in the research area. In order to achieve above objectives, groundwater observation includes measurement of springs discharge, checking physico-chemical parameters including pH, Total Dissolved Solid (TDS), Electrical Conductivity (EC), and temperature. Based on the measurement results, the springs in the Karst Pacitan area have a discharge range between 0.01 to 89.28 L/s. According to WHO standards and the Regulation of the Minister of Health Republic of Indonesia the groundwater in the Pacitan Karst area is accepted as drinking water based on their physicochemical parameters.

Keywords: *Karst, Springs, Pacitan.*

1. INTRODUCTION

One of the more consumable and high-quality water sources is groundwater. People use groundwater for agriculture and daily needs [1][2]. However, the condition of Pacitan Regency is known as an area that often experiences drought, especially when entering the long dry season [3]. This is related to the area's geology is composed of limestone lithology, so the fulfillment of domestic needs cannot be done using dug wells like in other areas with good aquifers. Dug wells are only rainfed wells, which will store high intensity water during the rainy season and dry up when rain intensity decreases [4].

The majority of people in the area use PDAM to sufficient their daily needs, but when entering the dry season, the PDAM water supply is insufficient to be distributed to all areas, so that the community gets water allocation in turn [5]. In this situation, springs are necessary to increase the availability of clean water for residents [6].

Karst morphology has a hydrological system resulting from the development of soluble rocks, which is a combination of the tunnel resulting from the dissolving process (conduit) and the flow of water through the inter-grain cavity (diffuse) [7][8]. Life activities around underground rivers and springs will have an impact on the condition of water resources both in terms of quantity and quality [9]. This hydrological system causes karst areas to have a higher level of vulnerability to pollution compared to other landforms, because contaminants in groundwater are not filtered out by the rock [10].

The dissolution of limestone or dolomite increases the concentration of $CaCO_3$ and $MgCO_3$ in water compared to other hydrogeochemical conditions [11][12]. The dissolution of rock is related to the total dissolved solids and ion content in the water conditions, so it can be measured by the parameter value of TDS and the value of Electrical Conductivity (EC)[13]. Aside from domestic purposes, water's main use in life is to provide

A. D. Saputro et al. (Eds.): ICOSEAT 2022, ABSR 26, pp. 360–367, 2023.
https://doi.org/10.2991/978-94-6463-086-2_47

drinking water. So it must be of high physical and chemical quality.

In karst regions, underground rivers and springs are water sources that can supply some of life's necessities. Particularly for drinking water, it is important to research and evaluate the quantity and quality analyses. This research was conducted on the emergence of springs in the Karst region of Pacitan Regency.

Qureshi et al. determined water quality parameters in several areas of Pakistan based on their physicochemical properties. Using the WHO standard, it was found that only the boron concentration met the requirements, while other parameters such as pH, TDS, and EC exceeded the WHO guidelines[14]. In Indonesia, Irshabdillah and Widyastuti analyzed the quality of water sourced from PDAM Baron-Ngobaran. The results showed that the physical parameters (temperature and TDS) and chemical (pH) met the requirements according to the Regulation of the Minister of Health Number 492/MENKES/PER/IV/2010. However, the biological parameters (coliform bacteria) are not suitable for direct consumption and need processing first [15].

This study aimed to determine the quantity and quality of the Pacitan Karst springs in East Java on the parameters of physico-chemical properties and based on WHO standards and the Regulation of the Minister of Health Republic of Indonesia Number 32 the Year 2017. This research was carried out by collecting samples directly from springs and is expected to contribute to studying the region's groundwater use.

2. STUDY AREA

Pacitan Regency is a region in East Java Province whose administrative borders are Wonogiri Regency in the west, Wonogiri and Ponorogo Regency in the north, Trenggalek Regency in the east, and the Indonesian Ocean in the south[16].

The research location is the southern section of the Pacitan Regency. Concentration on the Wonosari Formation, which extends west of Pacitan City to Central Java Province's border, covers Donorojo, Punung, and Pringkuku Subdistricts [17]. The research location is shown in Figure 1.

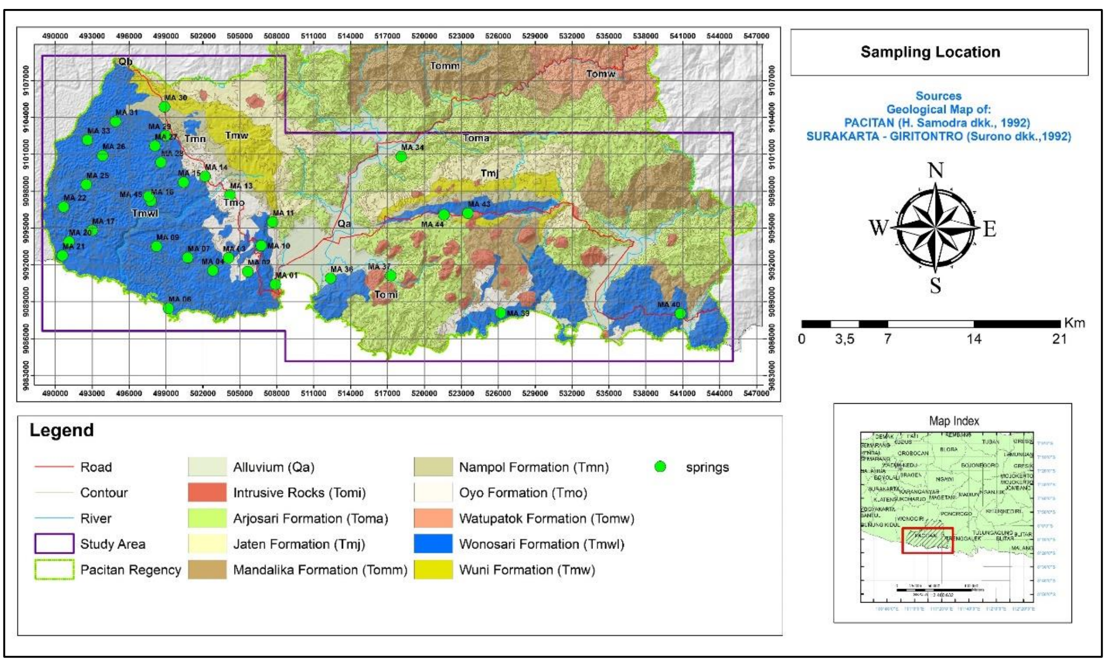

Figure 1 Study area and samplings location

The research location is mainly composed of the Wonosari Formation, which consists of reef limestones, bedded limestones, fragmental limestones, sandy limestones, and marl from the Late Miocene to Pliocene ages. The Oyo Formation is composed of calcareous sandstone, tuffaceous sandstone, calcareous siltstone, tuffaceous limestone, sandy marl, and tuffaceous marl from the Late Miocene age. The Nampol Formation is composed of tuffaceous sandstone, siltstone, tuffaceous limestone, claystone, and lignite, with intercalation of conglomerates and breccias from the Middle Miocene age. The alluvium is composed of cobble, pebble, sand, silt, clay, and mud with a Quarter age, and the Arjosari Formation is composed of polymit conglomerate, sandstone, siltstone, limestone, claystone, sandy marl, pumice sandstone, intercalated by volcanic breccia, tuff, and lava from the Oligocene to Early Miocene age [18], [19].

The Wonosari Formation contains an aquifer with moderate productivity that flows through fissures, fractures, and channels. With layered and localized limestones as their constituent lithology, reef limestones with variable degrees of karst formation have low to high graduations [20].

3. RESEARCH METHODOLOGY

This research was carried out in 3 steps, the first step is the determination of the sampling location, the second is the springs discharge measurement, and the third is the physico-chemical properties of the groundwater.

3.1. Determination of sampling location

The determination of the sampling location is conducted on the water source utilized by residents as their daily water supply. Particularly during the dry season, when the springs discharge continues to flow throughout the year in the Donorojo, Punung, and Pringkuku sub-districts. From the results of field observations, 33 springs were found scattered in the research area, as shown in Figure 1.

3.2. Springs discharge measurement

The springs discharge measurement used the reservoir volume and flow velocity method.

Based on SNI 8066:2015, the principle of measuring the flow of a river is to measure the wet cross-sectional area, and the flow velocity at a certain river water level [21]. The following formula can calculate the discharge in Equation (1):

$$Q = A \times v \quad (1)$$

where Q is the groundwater discharge (m^3/second), A is the wet cross-sectional area (m^2), and v is the average of flow velocity (m/second).

The volumetric method directly measures the flow by accommodating the flow of water in a measuring cup or bucket of known volume, according to Equation (2).

$$Q = \frac{V}{t} \quad (2)$$

where Q is the groundwater discharge (m^3/second), V is the container volume (m^3), and t is the time (second)

Springs with vertical flow can use the reservoir volume method. Springs with horizontal flow use the way of measuring flow velocity by using a buoy connected to the channel area, while springs that are seepage are measured by approximation and estimation.

3.3. The physico-chemical of groundwater

Measurement of the physico-chemical properties using the Water Test Kit to obtain data on pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS), and temperature from water samples at the time of collection in the field. Measurement by taking 50 mL of water, then dipping the tool electrode into it, and waiting for the reading of the results after the value shows a stable number. After completing the measurements, the electrodes were fed with distilled water to keep them clean and free of contaminants for further measurements.

Groundwater quality can be determined by its physical and chemical characteristics [22]. Using a Hannameter, the physical-chemical parameters of groundwater are measured directly in the field. In this investigation, the physical-chemical characteristics of groundwater are pH, Total Dissolved Solids (TDS), Electric Conductivity (EC), and temperature.

The composition of water is described by its pH. The pH of a solution indicates the effective concentration of Hydrogen ions, whereas a pH of 7 indicates neutrality. A pH value lower than 7 indicates acidic water, while a higher value than 7 indicates alkaline water [23].

Total Dissolved Solid (TDS) is the amount of dissolved or precipitated substances in water. TDS was analyzed by evaporating several volumes of the filtered water sample to dryness and weighing the results of the dry precipitate formed after the evaporation process of the water sample, and expressed as milligrams per liter of solution. The typical TDS concentration in groundwater in the karst region is less than 1.000 mg/L[24].

Electrical Conductivity (EC) is proportional to the concentration of dissolved ions in the solution and can give an idea of the total dissolved solids (TDS). For groundwater, the EC value at 25 °C is 50% greater than the TDS value. Electrical Conductivity (EC) is expressed in units of microsiemens (µS)/centimeter [24].

The temperature measured in the springs or well will increase with the source's depth. Groundwater is generally equivalent to the temperature of the aquifer. The temperature measured in springs or wells reflects the temperature at the depth of the aquifer. The temperature was measured in Celsius (^{0}C) [23].

4. RESULT AND DISCUSSION

4.1. Spring Discharge

The measurement of discharge at 33 springs sample points obtained data as shown in Table 1. below. The discharge measurement data shows varying results with a range of >0.01 to 89.28 liters/second.

Table 1. Springs discharge and distribution data

No	Sample Code	Location		Discharge (L/s)
		Easting	Northing	
1	MA 01	507884.81	9090413.75	2.40
2	MA 02	505648.61	9091448.42	0.80
3	MA 03	504089.80	9092558.76	89.28
4	MA 04	502814.29	9091538.02	0.15
5	MA 06	499201.87	9088468.82	82.50
6	MA 07	500766.59	9092592.11	1.20
7	MA 09	498231.52	9093500.05	> 0.01
8	MA 10	506729.52	9093565.58	0.50
9	MA 11	507668.50	9095479.86	1.50
10	MA 13	504200.32	9097686.73	2.00
11	MA 14	502168.14	9099200.45	2.92
12	MA 15	500428.84	9098721.26	1.50
13	MA 16	497772.58	9097195.14	> 0.01
14	MA 17	493002.75	9094807.70	0.50
15	MA 20	491115.22	9093882.59	0.10
16	MA 21	490578.28	9092757.28	48.23
17	MA 22	490677.79	9096708.12	> 0.01
18	MA 25	492510.86	9098528.82	0.10
19	MA 26	493845.64	9100884.46	> 0.01
20	MA 27	498098.78	9101671.42	0.25
21	MA 28	498595.44	9100329.22	2.40
22	MA 29	498962.56	9102516.51	> 0.01
23	MA 30	498879.21	9104855.35	> 0.01
24	MA 31	494898.59	9103660.67	> 0.01
25	MA 33	492620.75	9102155.62	> 0.01
26	MA 34	518126.53	9100812.99	2.45
27	MA 36	512373.81	9090913.41	2.11
28	MA 37	517277.70	9091125.79	7.80
29	MA 39	526196.51	9088082.39	> 0.01
30	MA 40	540814.38	9088035.76	1.50
31	MA 43	523534.00	9096201.00	2.44
32	MA 44	521589.00	9096078.00	0.50
33	MA 45	497595.00	9097576.00	> 0.01

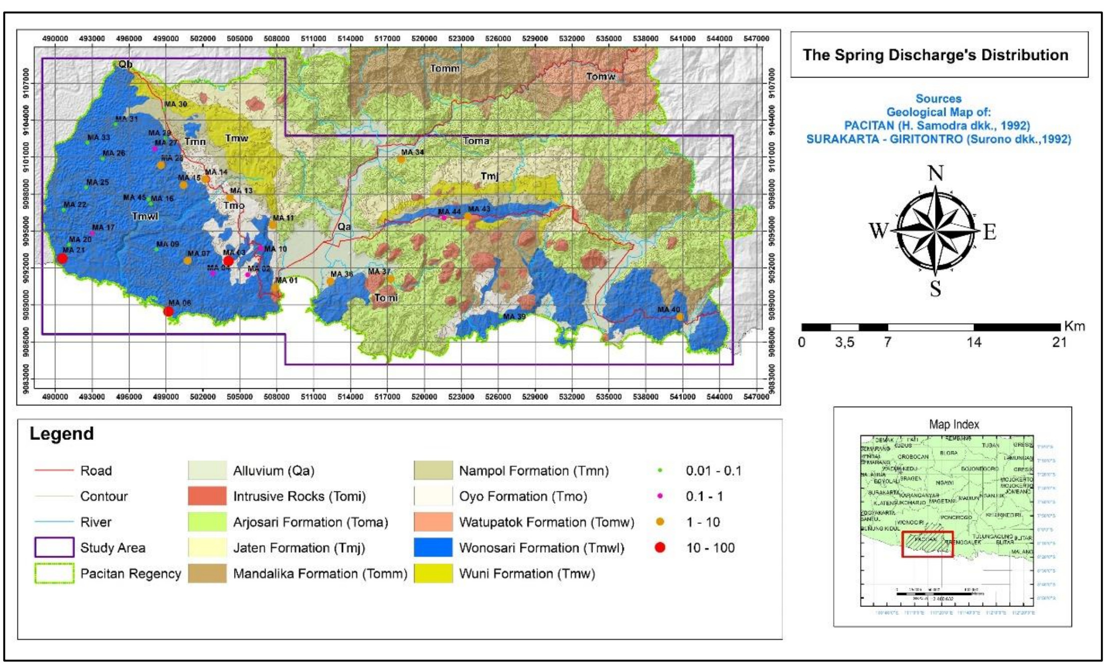

Figure 2 The distribution of spring's discharge

Small discharges in springs with seepage output include samples of MA 09, MA 16, MA 22, MA 26, MA 29, MA 30, MA 31, MA 33, MA 39, and MA 45 where measurements are taken using an approximation. The most significant discharge was 89.28 liters/second in the MA 03 sample.

MA 03 has been used for municipal waterwork in Pringkuku Subdistrict. However, MA 06 and MA 21 have a considerable discharge potential, but the springs have not been utilized properly

4.2. Physico-chemical of Groundwater

Measurement of the physico-chemical properties of groundwater at 33 samples using a Hannameter covering the parameters of pH, TDS, EC, and temperature. The results are shown in Table 2.

Table 2. Physico-chemical value of springs

No	Sample Code	pH	TDS (ppm)	EC (µS/cm)	Temperature (^{0} C)
1	MA 01	7.42	320	650	28,2
2	MA 02	7.08	340	700	27.0
3	MA 03	7.22	210	450	26.0
4	MA 04	7.46	260	530	26.4
5	MA 06	7.11	310	630	27.4
6	MA 07	7.35	270	560	27.4
7	MA 09	7.13	270	560	27.7
8	MA 10	7.08	350	720	27.5
9	MA 11	6.97	400	820	28.1
10	MA 13	7.02	310	640	26.9
11	MA 14	6.97	340	700	26.9
12	MA 15	7.00	290	600	27.3
13	MA 16	7.08	320	650	27.9
14	MA 17	7.29	300	610	27.6
15	MA 20	7.68	280	570	27.4
16	MA 21	7.07	360	730	28.8
17	MA 22	7.22	310	630	27.5
18	MA 25	7.69	230	470	29.3
19	MA 26	7.23	150	320	28.9
20	MA 27	7.42	310	640	27.2
21	MA 28	7.40	310	640	27.1
22	MA 29	6.93	290	590	29.1
23	MA 30	7.69	280	580	29.3
24	MA 31	7.10	290	600	27.2
25	MA 33	7.43	280	580	26.2
26	MA 34	7.80	70	160	27.3
27	MA 36	6.99	320	670	28.8
28	MA 37	7.03	260	540	27.7
29	MA 39	7.15	350	720	29.1
30	MA 40	7.38	320	660	28.3
31	MA 43	7.29	90	190	25.9
32	MA 44	7.56	250	510	25.7
33	MA 45	7.37	270	570	26.9

With parameters or standards that refer to the World Health Organization (WHO) regarding Guidelines for Drinking Water Quality [25] and Regulation of the Minister of Health Republic of Indonesia Number Number 32 the Year 2017 concerning Drinking Water Quality Requirements [26] it was found that: As shown in Figure 3. the pH distribution of the 33 spring samples varied from 6.93 to 7.80, with an average pH value is 7.26 which still shows the degree of neutrality. The MA 34 sample with the highest pH was located in the eastern section of the research area, not in the karst region.

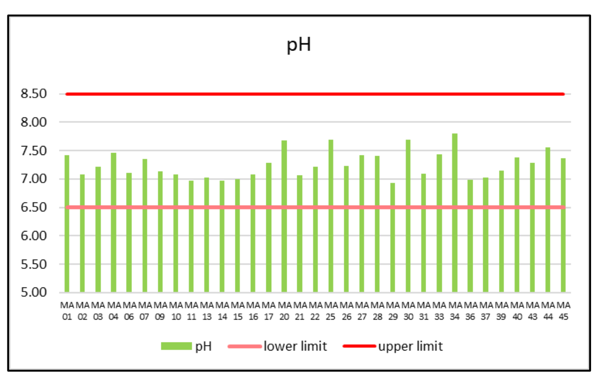

Figure 3 Distribution of pH value

According to WHO standards and Minister of Health Regulations, the pH range for potable water are between 6.5 and 8.5, so 33 spring samples meet the requirements.

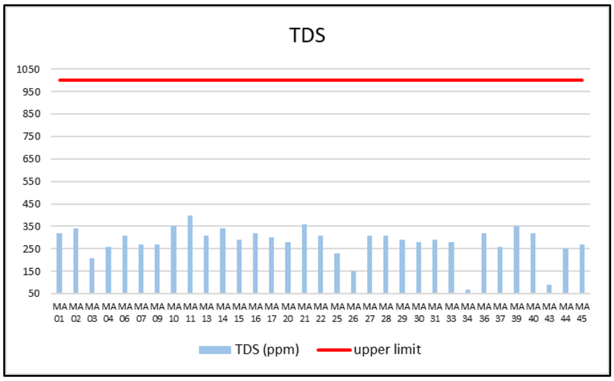

Figure 4 Distribution of TDS value

As illustrated in Figure 4, the TDS distribution of the 33 spring samples varied from 70 to 400 mg/liter. MA 11 is a sample of springs found in the rice field region in the center of the research area, which is the boundary between the Wonosari Formation and the Oyo Formation.

Two spring samples, MA 34 and MA 43 have a low TDS value (less than 100 ppm). It is assumed that rainwater is still present at the time of measurement.

In accordance with the WHO standard and the Minister of Health's Regulation, the maximum TDS value for consumable water is 1000 mg/liter, so the springs meet the TDS value parameter requirements for consumption.

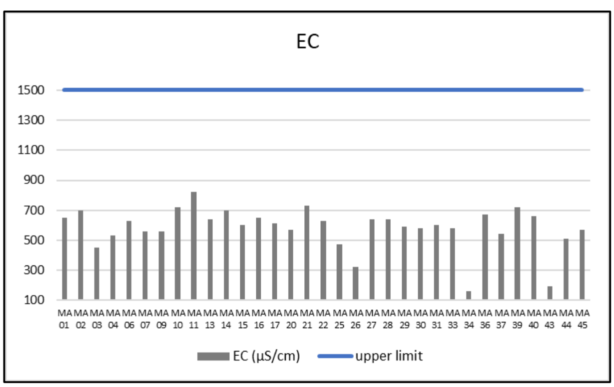

Figure 5 Distribution of electrical conductivity value

Electrical Conductivity (EC) is proportional to the concentration of dissolved ions and can be used to estimate the amount of total dissolved solids in a solution (TDS). High TDS indicates a high mineral concentration. Therefore, minerals containing cation and anion components can conduct electricity.

As depicted in Figure 5, the distribution of EC values for 33 spring samples varies from 160 to 820 µS/cm. MA 11, the sample with the highest EC value, is also the sample with the highest TDS value. It is a springs sample from the rice fields in the middle of the research area, at the boundary between the Wonosari Formation and the Oyo Formation.

According to the WHO standard, the maximum EC value for potable water is 1500 µS/cm [27]. So the springs match the consumption EC value parameter criteria.

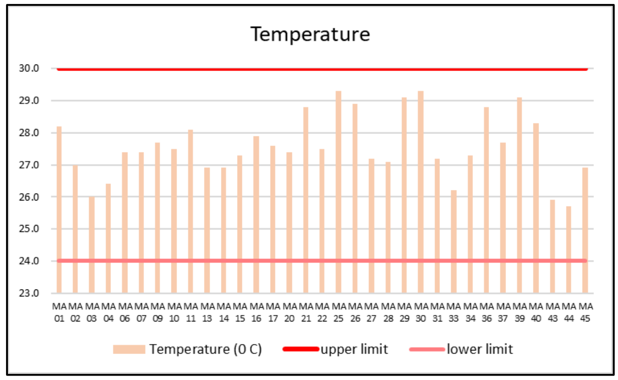

Figure 6 Distribution of temperature value

As shown in Figure 6, the temperature distribution values for 33 spring samples range from 25.7 to 29.50 ^{0}C. The sample of springs in the morphological region to the west, near the Wonogiri border, has the greatest temperature value. It is thought that the high temperature is caused by measuring while the sun is bright and samples stored there have been exposed to direct sunlight.

Following the Minister of Health's Regulation, the temperature value for water that is suitable to drink varies around $\pm$ 3 ^{0}C from the air temperature. If the air temperature is estimated to be 27 ^{0}C, the temperature value received is between 24 - 30 ^{0}C.

Based on WHO guidelines, high water temperatures can increase flavor, odor, color, and corrosion problems because they encourage the growth of bacteria. So that the sample springs match the temperature value criteria.

5. CONCLUSION

From the results of the research that has been carried out, it can be concluded that:

1) The discharge measurement at springs in the karst region varies between 0.01 to 89.28 liters/second.
2) The measurements of the physico-chemical properties for groundwater in the Pacitan Karst region indicate that it is acceptable for consumption according to WHO guidelines and the Regulation of the Health Minister Republic of Indonesia.

ACKNOWLEDGMENT

The authors appreciate the River Basin Organization for Bengawan Solo 's permission to conduct this research. Additionally, the first author wishes to thank the Ministry of Public Works and Housing of Indonesia for its financial support.

REFERENCES

[1] H. I. Zamil Al-Sudani, A Review on Groundwater Pollution, *Int. J. Recent Eng. Sci.*, vol. 6, no. 5, pp. 13–21, 2019, doi: 10.14445/23497157/ijres-v6i5p103.

[2] Z. Kılıç, The Importance of Water and Conscious Use of Water, *Int. J. Hydrol.*, vol. 4, no. 5, pp. 239–241, 2020, doi: 10.15406/ijh.2020.04.00250.

[3] I. Nita, A. N. Putra, and A. Febrianingtyas, Analysis of Drought Hazards in Agricultural Land in Pacitan Regency, Indonesia, *Sains Tanah*, vol. 17, no. 1, pp. 7–15, 2020, doi: 10.20961/stjssa.v17i1.35688.

[4] T. Prayogo, Pemetaan Geohidrologi Daerah Donorojo Kabupaten Pacitan, in *Jurnal Teknologi Lingkungan*, 2016, vol. 10, no. 1, p. 54. doi: 10.29122/jtl.v10i1.1503.

[5] S. R. Sihkusuma and A. Suhardono, Debit Kebutuhan Pengembangan Pipa Air Bersih di Kecamatan Pringkuku, in *Jurnal Online Skripsi*, 2021, vol. 2, pp. 78–83.

[6] E. Haryono, Nilai Hidrologis Bukit Karst, in *Seminar Nasional Teknik Sipil UGM*, 2001, p. 5.

[7] D. Ford and P. Williams, *Karst Hydrogeology and Geomorphology*. West Sussex City: John Wiley & Sons, Ltd, 2007. doi: 10.1002/9781118684986.

[8] E. Haryono, D. H. Barianto, and A. Cahyadi, Hidrogeologi Kawasan Karst Gunungsewu: Panduan Lapangan Fieldtrip PAAI 2017, *Pekan Ilm. Tah. Ahli Airtanah Indones.*, no. December 2018, pp. 1–33, 2017, doi: 10.31227/osf.io/t5dgp.

[9] N. E. Peters, M. Meybeck, and D. V Chapman, Effects of Human Activities on Water Quality, *Encycl. Hydrol. Sci.*, no. June 2020, 2005, doi: 10.1002/0470848944.hsa096.

[10] E. Budiyanto, Muzayanah, and K. Prasetyo, Karst Groundwater Vulnerability and Risk to Pollution Hazard in the Eastern Part of Gunungsewu Karst Area, *IOP Conf. Ser. Earth Environ. Sci.*, vol. 412, no. 1, 2020, doi: 10.1088/1755-1315/412/1/012020.

[11] B. B. S. and R. P. G. Singhal, *Applied Hydrogeology of Fracture Rocks*, Second. New York: Springer, 2010.

[12] H. Siswoyo, M. Bisri, M. Taufiq, and V. Pranantya, Karakteristik Hidrokimia Mata Air Karst untuk Irigasi di Kabupaten Tuban, *J. IPTEK*, vol. 23, no. 2, pp. 93–100, 2019, doi: 10.31284/j.iptek.2019.v23i2.546.

[13] G. Han and C. Q. Liu, Water Geochemistry Controlled by Carbonate Dissolution: A study of the river waters draining karst-dominated terrain, Guizhou Province, China, *Chem. Geol.*, vol. 204, no. 1–2, pp. 1–21, 2004, doi: 10.1016/j.chemgeo.2003.09.009.

[14] S. S. Qureshi *et al.*, Assessment of Physicochemical Characteristics in Groundwater Quality Parameters, *Environ. Technol. Innov.*, vol. 24, p. 101877, 2021, doi: 10.1016/j.eti.2021.101877.

[15] M. R. Irshabdillah and M. Widyastuti, Water quality analysis of the PDAM drinking water distribution network at the Baron-Ngobaran management unit, Gunungkidul Regency - Indonesia, *E3S Web Conf.*, vol. 200, 2020, doi: 10.1051/e3sconf/202020002027.

[16] Statistic of Pacitan Regency, Letak Geografis Kabupaten Pacitan, 2014. https://pacitankab.bps.go.id/statictable/2014/12/23/3/letak-geografis-kabupaten-pacitan.html

[17] Statistic of Pacitan Regency, Luas Daerah dan Jumlah Pulau Menurut Kecamatan di Kabupaten Pacitan, 2014. https://pacitankab.bps.go.id/indicator/153/108/1/luas-daerah-dan-jumlah-pulau-menurut-kecamatan-di-kabupaten-pacitan-.html

[18] S. Samodra, H., Gafoer, S., Tjokrosapoetro, *Peta Geologi Lembar Pacitan, Jawa Timur*. Pusat Penelitian dan Pengembangan Geologi, 1992.

[19] I. Surono., Toha, B., Sudarno, *1992. Peta Geologi Lembar Surakarta - Giritontro, Jawa*. 1992. [Online]. Available: Pusat Penelitian dan Pengembangan Geologi

[20] A. Djaeni, *Peta Hidrogeologi Lembar Yogyakarta*. Direktorat Geologi Tata Lingkungan, 1982.

[21] S. N. Indonesia, Tata Cara Pengukuran Debit

Aliran Sungai dan Saluran Terbuka Menggunakan Alat Ukur Arus dan Pelampung, SNI 8066:2015, 2015

[22] D. K. Todd and L. W. Mays, *Groundwater-Hydrology*, Third Edit. United States of America: John Wiley & Sons, Ltd, 2005.

[23] E. Mazor, *Chemical and Isotopic Groundwater Hydrology*, Third., vol. 23, no. 2. New York: Marcel Dekker, Inc, 1997. [Online]. Available: http://www.dekker.com

[24] I. Clark, *Groundwater Geochemistry and Isotopes*. New York: CRC Press, 2015. doi: 10.1201/b18347.

[25] W. H. Organization, *Guidelines for Drinking-Water Quality*. Swiss, 2011, p. 564.

[26] P. M. Kesehatan, *Standar Baku Mutu Kesehatan Lingkungan dan Persyaratan Kesehatan Air untuk Keperluan Higiene Sanitasi, Kolam Renang, Solus Per Aqua, dan Pemandian Umum*. Indonesia: Pemerintah Republik Indonesia, 2017, p. 31.

[27] J. K. Ondieki, D. N. Akunga, P. N. Warutere, and O. Kenyanya, Bacteriological and Physico-chemical Quality of Household Drinking Water in Kisii Town, Kisii County, Kenya, *Heliyon*, vol. 7, no. 5, p. e06937, 2021, doi: 10.1016/j.heliyon.2021.e06937.