

# Temporal variation of water suitability for paddy irrigation needs at karst springs influenced by allogenic recharge in Gunungsewu Karst Area, Indonesia

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**Abstract.** Irrigation, a critical element in farming, can fulfill crop water needs and increase agricultural productivity during the dry season, provided that the two necessary factors are met, namely water supply and water quality. Water quality is a principal factor in assessing whether or not a water body is usable as a source of irrigation. Excess or lack of elements in irrigation water may affect irrigated crops and soil. For maximum harvests, studies scrutinizing the suitability of water supply for irrigation become necessary. Beton Spring has a large discharge, which the people of Ponjong District, Gunungkidul Regency, rely on for their irrigation and fish farming practices. Uniquely, this karst spring receives allogenic recharges from outside the karst area. This research was intended to assess the suitability of water quality of Beton Spring for temporal irrigation purposes by Sodium analysis (Na%), Sodium Adsorption Ratio (SAR), USSL, and Wilcox. The elements observed in the analysis were Ca<sup>2+</sup>, Na<sup>+</sup>, Mg<sup>2+</sup>, K<sup>+</sup> and electrical conductivity. Based on the overall analysis results of the water quality series—Sodium analysis (the water samples were classified as Excellent), SAR (Excellent), USSL (moderate to good), and Wilcox (Excellent to Good), Beton Spring produces good-quality water that is suitable for irrigation.

## 1 Introduction

The practices of irrigation for agriculture date back to 4000 BC in Mesopotamia, Iran [1]. In East Asia, the Pagan and Ayutthaya Kingdoms initiated the earliest known system of irrigation in China and Southeast Asia in 1044–1351 AD [2]. Irrigation is a water regulation technique aimed at lessening the effects of drought during the dry season [3]. It is crucial in maintaining food availability and can increase food productivity [4]. Groundwater and surface water (rivers and lakes) are two examples of irrigation water sources [5]. Usable water quality for irrigation can be measured from electrical conductivity, sodium adsorption, specific ions (sodium, chloride, sulfate, and nitrate), residual sodium carbonate (RSC), and trace elements (Fe, Mn, Zn, Cu, Pb, Cd, Cr, Ni, and F) [6]. Meanwhile, for proper irrigation, the water discharge must be within the range of 2.5 – 4 L.sec<sup>-1</sup> m<sup>-1</sup> [7]. Irrigation techniques can be differentiated into surface irrigation, localized irrigation, drip irrigation, and sub-surface drip irrigation [8].

Excessive or too little presence of elements is the foremost concern in irrigation [9, 10]. A plot of land can produce maximum yields only if they are present adequately in irrigation water [11]. Relevant analyses must test at least the major elements, namely Ca, Na, Mg, and K [12], and electrical conductivity [13]. Both

are the minimum parameters needed to analyze hardness and salinity and conclude whether or not the tested water is suitable for irrigating agricultural areas.

This study was conducted at Beton Spring (Figure 1). It is a resurgence of karst aquifers within the Gunungsewu Karst Area and has a distinctive characteristic, that is, allogenic recharges from outside the karst area [14, 15]. With water discharge varying between 505.9 and 11 111.17 L s<sup>-1</sup>, Beton Spring has a vital role in irrigating agricultural fields in its surroundings [16]. It emerges from developed karst aquifers and has great water resource potential [14, 16].

This research was designed to determine the temporal suitability of irrigation water sourced from Beton Spring. From the results, the necessity of irrigation water quality improvement can be evaluated. Also, this research can be applied to other sites in Gunungsewu Karst Area to assess the suitability of water quality for irrigation for a maximum impact on the agricultural sector.

## 2 Regional description

Beton Spring is situated in Sumber Giri Village, Ponjong District, Gunungkidul Regency, Yogyakarta. The absolute location is 469961 mE and 9121242 mN. It is found at 239 m above sea level and is surrounded by karst hill morphology. Its surrounding land is used

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for settlement and multiple-species plantation. A reservoir was built as part of the agricultural irrigation network, which consequently maximizes the function of Beton Spring (Figure 2).

Beton Spring receives, on average, 2.100 mm to 2.200 mm of rainfall per year [17]. Based on Oldeman Climate Classification, this site is categorized as C3 with more wet months than dry months [18]. In the C3 region, each dry and wet period can last for 5-6 months, in which the yields of paddy and CGPRT (i.e., secondary crops consisting of coarse grains, pulses, roots, and tuber crops) cropping are most favorable. Geologically, rocks abutting Beton Spring are the Limestone of Wonosari Formation [19], and geomorphologically, the karst landforms found surrounding the spring are categorized as Residual Cone Karst [20]. The soil is mainly composed of Lithic Udorthents and Aquertic Chromic Hapludalfs. Beton Spring is included in the Ponjong Hydrogeological Sub-System [21], which is characterized by the emergence of karst springs with large water discharge to the west.

### 3 Methodology

Beton Spring water was sampled in series from February 2019 until January 2020. The sampling instrument included 1L water sample bottles, water checker to test electrical conductivity, Global Positioning System (GPS), and Current Meter to measure water rates during sampling. Afterward, the water samples were tested in the laboratory for major ion presence, namely  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$ , and  $K^+$ . Then, the suitability of water quality for irrigation was computed using the equations of Sodium analysis (Na%) and Sodium Adsorption Ratio (SAR). Other analyses were performed using the graph equations of the USSL and Wilcox diagrams.



**Fig 2.** Beton Spring (top) and Beton Reservoir (bottom)

Na% and SAR were calculated in Microsoft Excel. The results of Na% and SAR calculations, as well as EC measurement, were plotted on the USSL and Wilcox

diagrams. From this procedure, the suitability of water quality grade for irrigation was able to be concluded.

#### 3.1 Sodium analysis

Sodium analysis was required to determine the degree of interaction between irrigation water and soil permeability. In this research, the Sodium concentration (in milliequivalent/liter) was calculated using equation 1. The classification of water quality for irrigation based on Na% is shown in Table 1.

$$Na\% = \frac{(Na+K)100}{(Ca+Mg+Na+K)} \quad (1)$$

Table 1. The Na% Classification for Irrigation

Classification	Na %	Water Quality Grades
S1	≤20	Excellent
S2	>20 - 40	Good
S3	>40 - 60	Permissible
S4	>60 - 80	Doubtful
S5	>80	Unsuitable

Source: Wilcox (1955) [12]

#### 3.2 Sodium Adsorption Ratio (SAR) analysis

SAR defines the direct relationship between irrigation water content and soil. SAR (in milliequivalent/liter) was calculated using equation 2. The classification of water quality for irrigation based on SAR is presented in Table 2.

$$SAR = \frac{Na}{\sqrt{\frac{1}{2}(Ca+Mg)}} \quad (2)$$

**Table 2.** The Classification of SAR for Irrigation

Classification	SAR	Water Quality Grades
S1	<10	Excellent
S2	10-18	Good
S3	18-26	Fair
S4	>26	Poor

Source: USSL (1954)[22]

#### 3.3 Wilcox diagram analysis

The Wilcox diagram represents the relationship between electrical conductivity and sodium content in water. It expresses the suitability of water for irrigation in several grades, namely excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable, and unsuitable [13].

#### 3.4 USSL diagram analysis

The USSL diagram was used to determine the relationship between salinity hazard and sodium hazard (sodium grades), which reflects the suitability of a water source for irrigation. For this purpose, the classification of the USSL diagrams is explained in Table 3.

**Table 3.** The USSL Diagram Classification

C/S	S1	S2	S3	S4
C1	Good	Moderate to good	Moderate	Moderate to poor
C2	Moderate to good	Moderate	Moderate to poor	Poor
C3	Moderate	Moderate to poor	Poor	Very poor
C4	Moderate to poor	Poor	Very poor	Unusable

Source: USSL (1954)[22]

## 4 Results and discussion

### 4.1 Na% and SAR

The laboratory tests of the major elements of water samples from February 2019 until January 2020 proved that Beton Spring met the water quality standards for irrigation (Table 4). There was no significant difference between the values of  $Ca^{2+}$  (2-5.59 meq/l),  $Mg^{2+}$  (0.16-2.6 meq/l), and  $K^+$  (0.03-0.2 meq/l). In contrast,  $Na^+$  was found to fluctuate somewhat widely: up to 9.35 meq/l in the sample collected on 9/20/2019, but below 0.1 meq/l on other days. This was attributable to the drop in the spring water discharge from 1,500 to 1,000 liters/second, decreasing the dilution of the solution concentration in water [14]. Similarly, the electrical conductivity (EC) differed insignificantly between 319 and 522  $\mu S$  averagely. These figures indicate relatively low EC or freshwater, which meets the water quality standards for irrigation.

Based on the laboratory test results, the sodium concentrations (Na%) of the water samples varied (Table 5). One sample on 9/20/2019 contained 60.69 % sodium. With this high sodium concentration, the irrigation water is categorically bad for crop growth. This level of sodium was caused by a decrease in water discharge, intensifying the presence of one of the dominant major ions, particularly hardness parameters [14]. Rising hardness values in irrigation water adversely affect plants and living organisms in the receiving area. However, samples collected on different dates contained 3.78 to 14.46 % sodium or were categorized as Excellent. The same water quality grade

with Excellent sodium levels can also be found in karst springs in Pindul Cave, Gunungkidul, which are located close to Beton Spring [23]. Meanwhile, significantly different sodium concentrations have been detected at several springs in Rembang Regency [24].

Based on the SAR analysis results, all water samples were classified as Excellent (Table 5). The SAR of the spring water varied between 0.17 and 5.32. Low SAR leads to low adsorption of sodium by the soil, resulting in less optimal crop growth. Similarly, karst springs around Pindul Cave (Gunungkidul Regency) also have categorically excellent SAR [23]. Figure 3 shows an increasing pattern of SAR and Na% during the dry season and a decreasing trend during the rainy season.

### 4.2. Irrigation water classification based on the USSL and Wilcox methods

The USSL analysis of water suitability for irrigation showed that, overall, the water samples fell into the C2-S1 category, or moderate to good (Figure 4). This category indicates that Beton Spring has low sodium hazard and moderate salinity hazard, making it suitable for irrigation. Similarly, the springs around Pindul Cave, which are also influenced by allogenic recharge, also belong to the C2-S1 category [23].

Meanwhile, the Wilcox diagram analysis of water suitability for irrigation categorized the water sample series into excellent to good (Figure 5). In other words, Beton Spring water is suitable for irrigation. This result is believed to be the product of low EC, which was below 1000  $\mu S$ . The same Wilcox-based water quality grade (excellent to good) applies at springs in Pindul Cave that have the same recharge characteristics [23]. On the contrary, the springs in Rembang Regency, which emerge from undeveloped karst aquifers and have no allogenic recharge, are permissible to doubtful [24].

Analysis of water suitability for irrigation must be carried out in series to obtain a complete year-round picture during dry and rainy seasons. This is in contrast to the one-season analysis performed in Pindul Cave (Gunungkidul) and Karst Rembang. Although the limited analysis could not reflect the water suitability for irrigation in different seasons, it provides adequate information as consideration for irrigation systems in both sites.

**Table 4.** The measured parameter values of water suitability for irrigation in beton spring

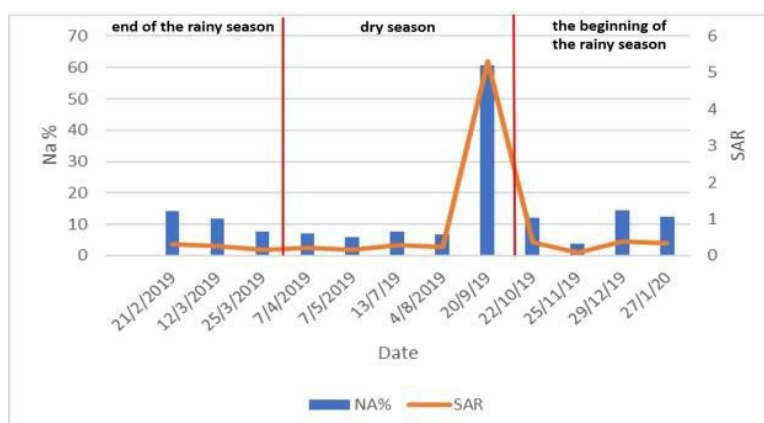
Dates	Hours	Major Ions (meq/L)				EC (μS)
		Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	
21/2/2019	13:30	2.00	0.40	0.35	0.05	319
12/3/2019	12:45	2.30	0.40	0.30	0.05	333
25/3/2019	15:50	2.74	0.44	0.22	0.05	366
7/4/2019	15:30	4.59	0.72	0.35	0.05	423
7/5/2019	14:00	4.04	0.96	0.26	0.05	434
13/7/2019	14:15	4.14	2.60	0.52	0.03	468
4/8/2019	13:15	5.59	0.64	0.43	0.03	510
20/9/2019	14:30	4.99	1.20	9.35	0.20	490
22/10/2019	13:00	3.11	0.56	0.48	0.03	511
25/11/2019	12:45	3.41	2.49	0.16	0.08	522
29/12/2019	14:00	2.91	0.48	0.52	0.05	315
27/1/2020	14:15	3.06	0.16	0.43	0.03	365

Sources: Laboratory Analysis and Field Survey (2020)

**Table 5.** The Na% and SAR of beton spring

Dates	NA%	NA% Classification for Irrigation Water	SAR	SAR Classification for Irrigation Water
21/2/2019	14.28	Excellent	0.32	Excellent
12/3/2019	11.67	Excellent	0.26	Excellent
25/3/2019	7.78	Excellent	0.17	Excellent
7/4/2019	6.99	Excellent	0.21	Excellent
7/5/2019	5.88	Excellent	0.17	Excellent
13/7/19	7.51	Excellent	0.28	Excellent
4/8/2019	6.88	Excellent	0.25	Excellent
20/9/19	60.69	Doubtful	5.32	Excellent
22/10/19	12.07	Excellent	0.35	Excellent
25/11/19	3.78	Excellent	0.09	Excellent
29/12/19	14.46	Excellent	0.40	Excellent
27/1/20	12.52	Excellent	0.34	Excellent

Source: Data Analysis (2020)



**Fig. 3.** Temporal Variation of Na% and SAR at Beton Spring, Gunungsewu Karst Area



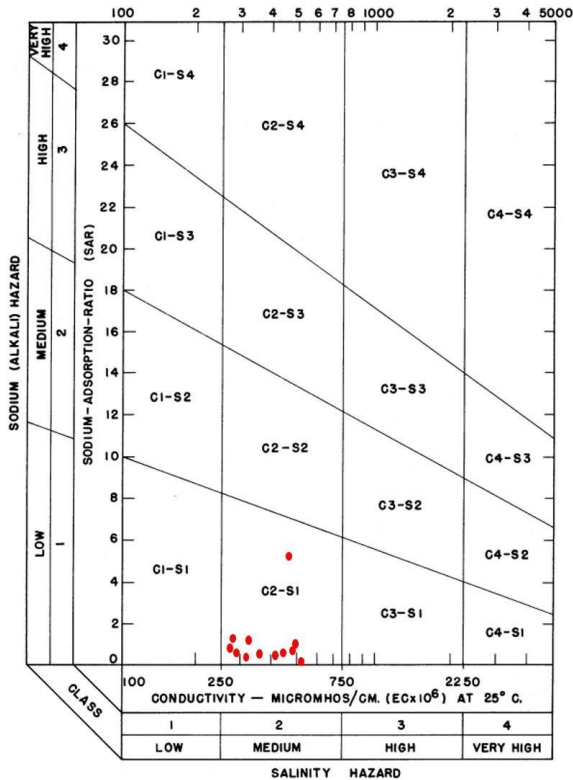


Fig. 4. USSL diagram for water suitability classification of beton spring

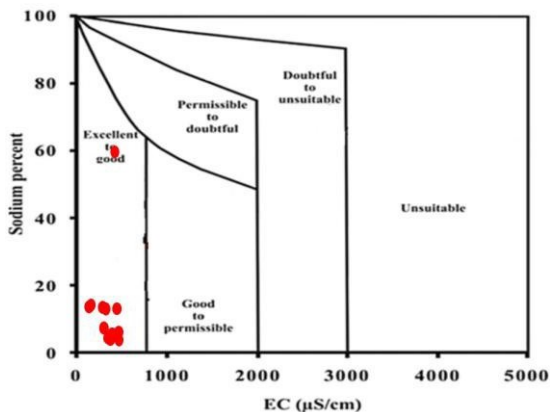


Fig. 5. Wilcox diagram for water suitability classification of beton spring

## 5 Conclusion

Temporal analyses, namely Sodium, SAR, USSL diagram, and Wilcox diagram, prove that Beton Spring water is suitable for irrigation. The time series method creates a good benchmark in assessing the suitability of water for irrigation in detail during the rainy and dry seasons. Beton Spring has suitable water for irrigation during both seasons.

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## References

1. M. Valipour, et al., Sustainability, **12**,416:1–30 (2019). <http://doi:10.3390/su12010416>
2. N. Hatcho, S. Ochi, Y. Matsuno, Irrig and Drain, **59**:4–16 (2010). <http://DOI:10.1002/ird.542>
3. S. Siebert, et al., Hydrol Earth Syst Sci, **19**: 1521–1545 (2015). <http://doi:10.5194/hess-19-1521-2015>
4. F.L.F.D. Jesus, et al., Revista Brasileira de Agricultura Irrigada, **11**,5:1677–1684(2017). <http://DOI:10.7127/rbai.v11n500747>
5. A. Garrido, P. Martínez-Santos, M.R. Llamas., Hydrogeology Journal **14**,3:340–349(2005). <http://DOI10.1007/s10040-005-0006-z>
6. S.K. Mandal, S.K. Dutta, R.K. Kole, International Journal of Environmental Science and Technology, **16**,1:451–462(2019). <https://doi.org/10.1007/s13762-018-1657-3>
7. E.M. El-Hadidi, M.M. Saied, F.M. Ghaly, R.M. Khalifa, J Soil Sci and Gric Eng, **7**,6:397–407(2016).
8. G. Megersa, J. Abdulahi, Int J Water Res Environ Eng, **7**,3: 29–37 (2015). <http://doi:10.5897/IJWREE2014.0556>
9. K. Roy, et al., Journal of Water Resource and Hydraulic Engineering, **4**,4:303–317(2015). <http://DOI:10.5963/JWRHE0404001>
10. B. Latos, A. Szczucińska, R. Kozłowski, QUAESTIONES GEOGRAPHICAE **38**,3:67–79(2019). <http://doi:10.2478/quageo-2019-0030>
11. R.M. Khalifa, W.H. Hassan, IJCE, **2**,3:21–34 (2013).
12. L.V. Wilcox, *Classification and Use of Irrigation Use*, US. Dept. Agric. Circ.969. Washington, D.C., 40 pp (1955).
13. C. Sadashivaiah, R. Ramakrishnaiah, G. Ranganna, International Journal Res. Public Health, **5**,3: 158–164 (2008).
14. A. Cahyadi, et al., Analisis Konektivitas dan Karakteristik Lorong pada Sistem Hidrogeologi Mataair Beton, Kawasa Karst Gunungsewu, Kabupaten Gunungkidul dengan Uji Peruntutan. Research Report. Yogyakarta: Faculty of Geography, Universitas Gadjah Mada (2019).
15. Cahyadi, A., et al., *Allogenic River in the Hydrogeological System of Gremeng Cave, Gunungsewu Karst Area, Java Island*,

- Indonesia*. IOP Conference Series Earth and Environmental Science (2020).  
<http://doi:10.1088/1755-1315/488/1/012018>
16. T.N. Adji, E. Haryono, A. Mujib, H. Fatchurohman, I.Y. Bahtiar, Carbonates Evaporites, **34**,1: 53–66 (2017). <http://org.doi/10.1007/s13146-017-0403-0>
  17. A. Brunsch, T.N. Adji, D. Stoffe, M. Ikhwan, P. Oberle, F. Nestmann, *Hydrological Assessment of a Karst Area in Southern Java with Respect to Climate Phenomena*. Asian Trans-Disciplinary Karst Conference 2011, Yogyakarta, Indonesia (2011).
  18. I. Wredaningrum, Sudibyakto, Jurnal Bumi Indonesia, **3**, 4, (2014).
  19. W. Rahardjo, Sukandarrumidi, H.M.D. Rosidi, *Peta Geologi Lembar Yogyakarta, Jawa skala 1: 100.000*. Bandung: Geological Research and Development Centre (1995).
  20. E. Haryono, M. Day, *Journal of Cave and Karst Studies*, **66**(2): 62–69 (2004).
  21. E. Haryono, D.H. Barianto, A. Cahyadi, *Hidrogeologi Kawasan Karst Gunungsewu: Panduan Lapangan Fieldtrip PIT PAAI ke-2*. Yogyakarta: Perhimpunan Ahli Airtanah Indonesia (PAAI), (2017).
  22. USSL. Diagnosis and Improvement of Saline and Alkali Soils: US Department of Agriculture (USDA), *Handbook No. 60*, pp:160 (1954).
  23. A. Hidayat, S. Suprayogi, A. Cahyadi, Analisis Kesesuaian Kualitas Air untuk Irigasi pada beberapa Mataair di Kawasan Karst Sistem Goa Pindul. In: S. Suprayogi, S. Purnama, A. Cahyadi, H. Fatchurohman, *Hidrologi dan Kepariwisata Kawasan Karst Goa Pindul, Kabupaten Gunungkidul*. Yogyakarta: BPFK (2016).
  24. S.N. Suhana, A. Cahyadi, Penaksiran Kesesuaian Kualitas Airtanah untuk Irigasi di sebagian Mataair Kabupaten Rembang. *Proceeding of National Seminar on Environmental Management*. Semarang: Universitas Diponegoro (2015).