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Research article

Assessing the water criticality index of the Welaran Watershed in Kebumen Geopark, Central Java: Towards good water resource management

Nandian Mareta[1], Rizka Maria[1], Rachmat Fajar Lubis[2], Boy Yoseph C.S.S. Syah Alam[3], & M. Sapari D. Hadian[3]

[1] Research Centre for Geological Resources, National Research and Innovation Agency (BRIN), Indonesia
[2]Research Centre for Limnology and Water Resources, National Research and Innovation Agency (BRIN), Indonesia
[3]Faculty of Geological Engineering, Padjadjaran University

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Corresponding author:
Nandian Mareta
Email address: nand009@brin.go.id

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ABSTRACT

The water criticality index (WCI) is the ratio between water use and availability. The higher the WCI value, the more concerned the water conditions in the area will be. The water crisis can be handled if various parties manage water resources following good management. The Welaran area is a watershed that is part of the Lukulo Watershed, where the population often experiences water shortages. Therefore, by knowing the value of WCI, it is hoped that various parties can know the water conditions in this watershed. Based on research and calculation of the water balance in the Welaran Watershed, it is known that with total water needs in 2019-2020 of 746,937 m^3 and total water availability of 1,555,318 m^3, the WCI value of the Welaran Watershed is 48.02%. In 2020, Karangsambung was designated as a part of Kebumen Global Geopark, which will certainly increase the number of tourists visiting here. The increase in tourist visits will also increase the need for water, including in the Welaran Watershed. To overcome these conditions, the Kebumen regency's government and stakeholders are expected to be able to formulate a water management step by effective management.

INTRODUCTION

Water is the most unique natural resource when compared to other natural resources, because of its renewable and dynamic nature (Kodoatie & Sjarief, 2010). The main source of water is the form of rain that always comes in the season corresponding to the time. In certain conditions, water can be non-existent renewable, e.g., in geological conditions, certain places of groundwater travel takes thousands of years, so when groundwater intake is carried out excessively, the water will run out (Amalia, et al., 2014; Kodoatie & Sjarief, 2010). Water demand in the world has increased by approximately 1% per year due to population growth, economic improvement, and changes in community consumption patterns

(Wilopo et al., 2021). One of the primary water sources on the Earth is groundwater, which accounts for approximately 30.1% of freshwater (Shiklomanov, 1993 in Wilopo et al., 2021). The advantages of groundwater compared to surface water are that it is of better quality and has a more stable quantity (Winter et al., 1998). Water is a natural resource that is needed by living things for the sustainability of daily life. For humans, water is used for various needs, such as domestic needs, irrigation, agriculture, and livestock (Allen, et al., 1998). The study of the water criticality index (WCI), also called the water scarcity index (WSI), is used to evaluate the condition of water resources in an area.

The Welaran Watershed in Karangsambung, Kebumen regency, often experiences water drought (Mareta et al., 2021). In this study, we use the term water criticality index instead of water scarcity index because it better describes the actual state of water resources in the Welaran Watershed. WCI is the ratio between water use and availability (Judeh, T., 2022; Santikayasa, et al, 2022; Liu et al, 2022). The higher the WCI value, the more concerned the availability of water in an area.

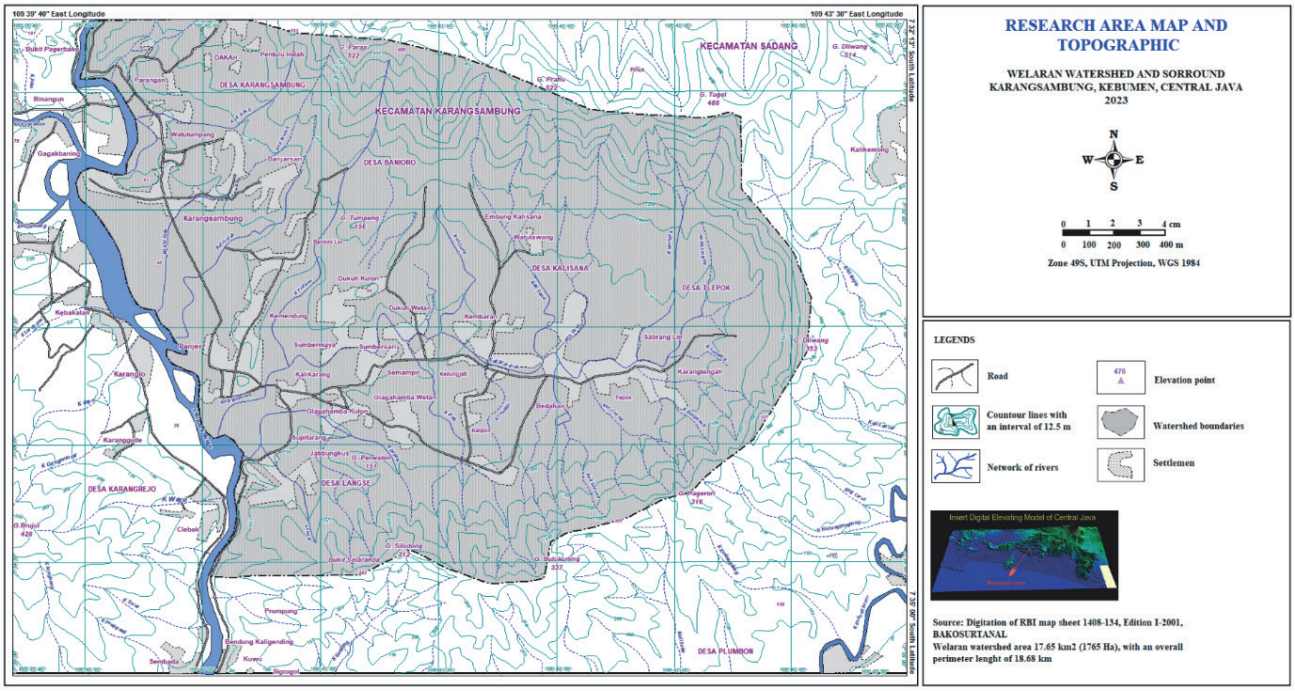


Figure 1. Research area map and Topographic of Welaran Watershed (Mareta et al, 2021)

Previous studies showed that some of the most significant water resource problems have occurred in recent decades (Rejekiningrum, 2014a; Rejekiningrum, 2014b). These problems are the symptoms of reduced water resources, the shrinking of irrigated agricultural land due to conversion, the lack of clarity in determining water tenure rights, weak coordination between agencies in handling water resources, and weaknesses in water resources policy.

Climate change is a global phenomenon that has undeniable impact recently. Characteristics of the climate change that occurs globally, among which are the average water vapor and rainfall are projected to increase (Mizyed, 2008 in Amalia, et al., 2014). Climate change and water availability have a strong correlation that will also affect water scarcity in an area. In 2000, it was estimated that Java, Madura, and Bali, were already in the very critical category. Java and Madura were suspected to have a WCI of 189%, and the WCI of Bali was 113%. West Nusa Tenggara is classified as a critical state with a WCI value of 92%. In other areas, except East Nusa Tenggara (WCI 73%), the condition is still relatively good with WCI below 50% (Sayekti, 2017 in Rejekiningrum, 2020).

The water crisis can be handled if various parties manage water resources. Water resources management is the activity of planning, developing, distributing, and managing the optimal use of water resources. Water resources management in an area will be effective and efficient if the community and the government know the hydrological conditions of the area. This study aims to determine the value of WCI in the Welaran watershed and what the future scenario will be.

STUDY AREA

The Welaran Watershed is administratively part of Karangsambung subdistrict, Kebumen Regency, Central Java. The coordinates are 7˚32'13"-7˚34'32" South Latitude and 109˚40'00"-109˚43'10" East Longitude (Figure 1). This watershed has an area of 17.65 km^2 (Figure 2). The hills around the Welaran Watershed are the boundary, namely, Paras Hills in the North, Dliwang Hills in the East, and Waturanda Hills in the South. In the western part, it is bounded by the Lukulo River (Mareta, et al., 2021) (Figure 2). The Welaran Watershed covers seven villages, namely, Karangsambung, Plumbon, Kaligending, Langse, Kalisana, Banioro, and Tlepok with a population of 20,464 (BPS, 2019).

Based on the geomorphological map of the Welaran Watershed (Mareta et al. 2021) (Figure 2), the Welaran Watershed is divided into two geomorphological units. The first unit is the weak-strong Undulating Plains Unit (Green Color), with an area of 1260 Ha (71.39%), and the morphometry unit is 0-12% with a slope of 1-15˚. The second unit is the steep Hills Unit (Red Color), with an area of 505 Ha (28.61%) The morphometric is 21-55% with a slope of 16-35˚. The geology of the Welaran Watershed is composed of five rock formations, namely; Karangsambung Formation with its olistholites, Totogan Formation, Diabase intrusion, Waturanda Formation, and Alluvial (Figure 3).

The Lukulo River, which is west of the Welaran Watershed, is a river that flows all year round. Lukulo surface water potential 935.7 million m^3 - 1,318.67 million m^3 (BBWSSO, 2003 in Mareta, et al., 2016). We do not include the surface water potential of the Lukulo River in the calculation of the water balance as the availability of water in the Welaran Watershed because we only want to know and calculate the water potential in the Welaran Watershed.

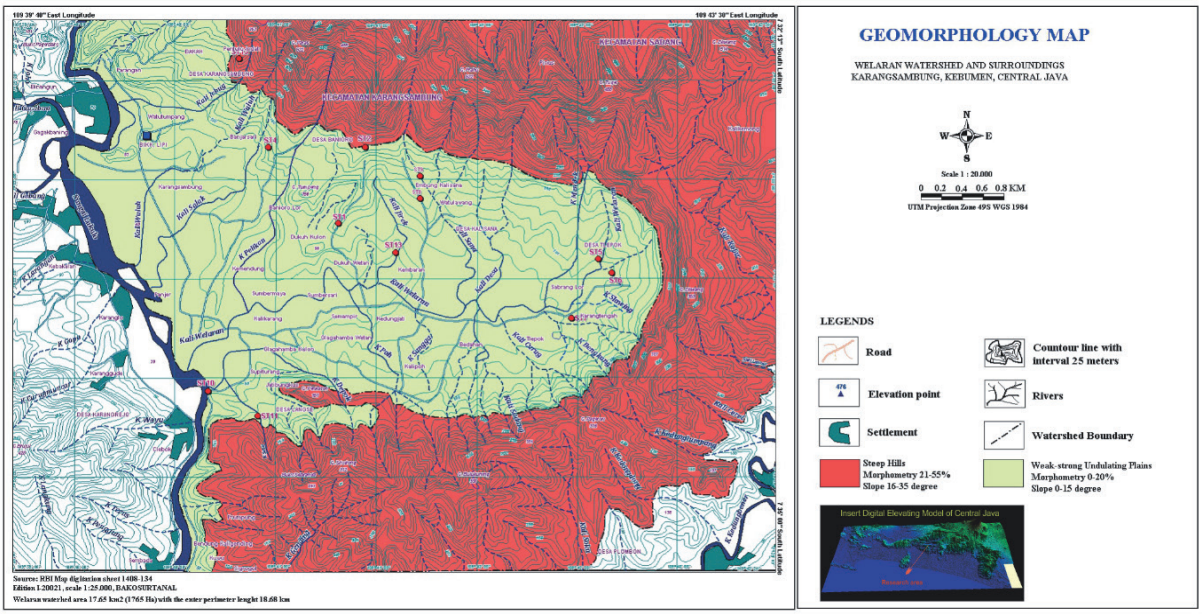


Figure 2. Geomorphologic map of Welaran Watershed (Mareta et al., 2021)

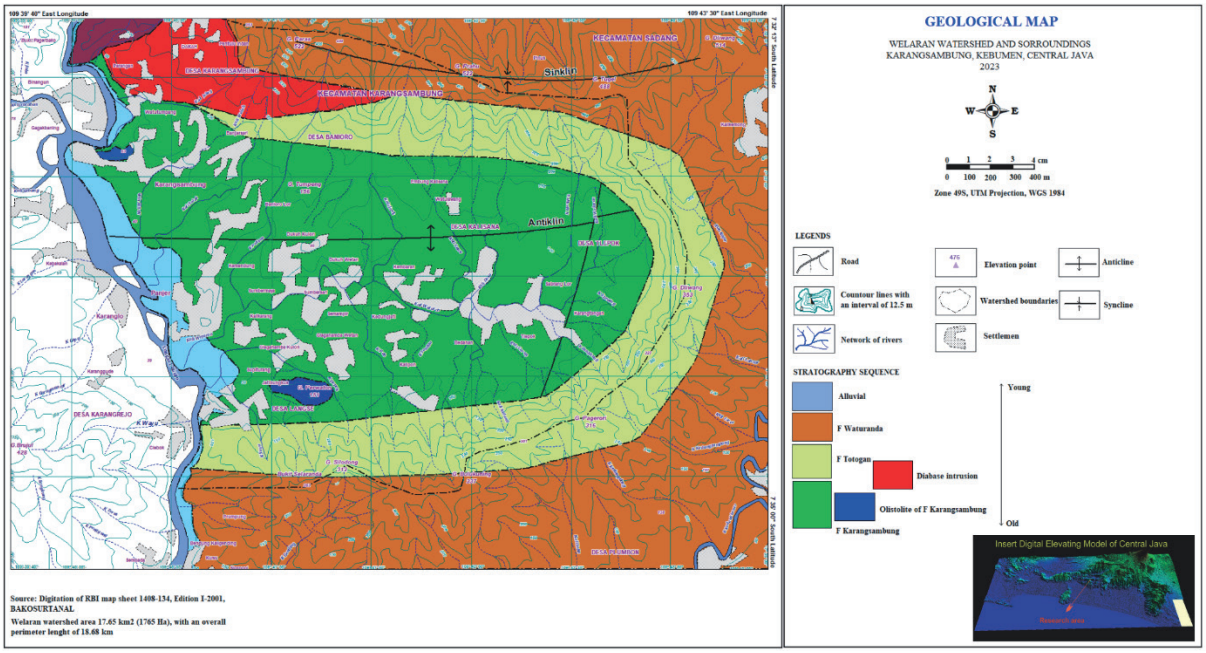


Figure 3. Geological map of Welaran Watershed (Mareta et al., 2021)

The stratigraphic sequence of the Welaran watershed and surroundings from old to young (Mareta et al., 2021; Asikin, et al., 1992), namely, 1). Karangsambung Formation with its olistholites, 2). Totogan Formation, 3). Diabase and Basalt Intrusion, 4). Waturanda Formation, 5). Alluvial. According to Mareta, et al. (2021), the age of the rock formations exposed in the Welaran watershed from the oldest, namely the Eocene (F Karangsambung) - Holocene (Alluvial). According to Asikin, et al. (1992), the Lukulo is a river that erodes all rock formations in the Karangsambung and surrounding from the oldest, namely the Upper Cretaceous (Melange Complex) - Holocene (Alluvial). Other rock formations in the Welaran watershed are not exposed on the surface. These formations are part of the Karangsambung area as a whole. Details of the stratigraphic sequence in Karangsambung can be seen in Figure 4.

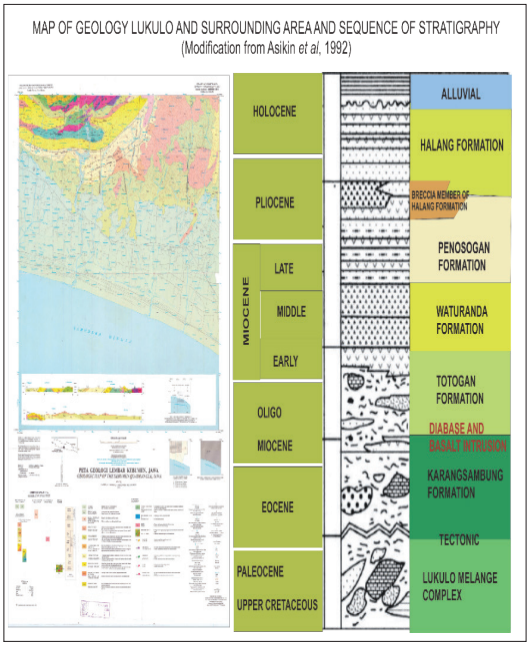


Figure 4. Stratigraphic sequence of Karangsambung and surround (Asikin, et al., 1992)

METHODS

The study compares the quantity of water resources in Welaran Watershed with the total needs of the population. The result is the knowledge of WCI in the watershed. The calculation of groundwater and water balance in the Welaran Watershed uses an algebraic method with the rainfall equation equal to the surface flow plus evapotranspiration plus water reserves. Rainfall is the amount and intensity of rain that falls in a particular region.

The criticality index of water is calculated using the following equation:

$$WCI = \frac{Wn}{Ws} \; x \; 100\% \quad (1)$$

Where WCI = water critical index (%), Wn = amount of water needed (m^3), and Ws = amount of water supply (m^3).

The critical index of water can be obtained from the water balance in an area based on the comparison of the value of water availability and the value of water demand. Water availability is the amount of water that enters the hydrological cycle in an area (Sosrodarsono & Takeda., 2002 in Esterlita et al., 2019).

Water needs are greatly influenced by the number of inhabitants in the area. If the population growth rate in Kebumen district is 1.17 in 2022 (BPS., 2022), then the projected water demand will also increase geometrically. The total population in the Welaran watershed in 2019 (BPS, 2019) was 20,464. The formula for calculating the population projection with the rate of population increase is:

$$Pn = Po\ (1+r)^n \quad (2)$$

Where, Pn = number of inhabitants in year n, Po = number of inhabitants in year known, r = rate of population increasing, and n = number of calculated years.

The calculation of the population projection in the Welaran watershed in 2023 is in accordance with equation (2). Then, in 2023, it will be 21,421.7152, which is rounded to 21,422. The classification of the water criticality index is presented in Table 1 below, which refers to the Guidelines for the Implementation of Watershed Management in Rejekiningrum, 2014b.

Table 1. Classification of Water Critical Index

Water Criticality Index	Class
< 50%	Not yet Critical
50% - 75%	Near Critical
75% - 100%	Critical
>100%	Very Critical

The proportion of water crisis areas nationally is projected to increase from 6% in 2000 to 9.6% in 2045 (BAPPENAS, 2019). This is due to the imbalance of the water balance due to the critical condition of the upstream catchment area as well as excessive groundwater exploration, especially in urban areas. Water quality is also expected to decline significantly.

RESULT AND DISCUSSION

Rainfall Potential

Rainfall data was collected over 13 months to determine the average rainfall conditions at the study site. In one year, from September 2019 to September 2020, rainfall in Karangsambung, Kebumen, was 3,593 mm, with a total of 144 rainy days (Table 2). The number of wet months is November 2019,

December 2019, January 2020, February 2020, March 2020, April 2020, and May 2020. The number of humid months was two months, namely October 2019 and June 2020, and the number of dry months was four, namely September 2019, July 2020, August 2020, and September 2020.

The average daily rainfall is 276.38 mm, with an average rainy day of 11.08. The rainfall potential in the Welaran Watershed, with a watershed area of 17.65 km^2, is 63,416,450 m^3. Based on the classification of climate types from Oldeman. (1982) in Wahid et al. (2017), the division by the number of wet, humid, and dry months, then in the Welaran Watershed, the climate type is C2, which means 6-7 months of wet length and 2-3 months of dry length. Areas with this type of climate are areas with fairly high rainfall and gentle topography, where orographic factors greatly influence the process.

Table 2. Rainfall Data from September 2019 to September 2020

No	Month	Rainfall (mm)	Rainy Days	Types of months (Oldeman, 1982)
1	September 2019	47	2	Dry
2	October 2019	160	8	Humid
3	November 2019	370	13	Wet
4	December 2019	380	14	Wet
5	January 2020	310	11	Wet
6	February 2020	378	14	Wet
7	March 2020	355	19	Wet
8	April 2020	573	19	Wet
9	May 2020	540	20	Wet
10	June 2020	200	9	Humid
11	July 2020	90	3	Dry
12	August 2020	92	5	Dry
13	September 2020	98	7	Dry
Summary		3593	144	
Average		276.38	11.08	

Groundwater Potential and Water Balance

Rainfall covers the needs of evapotranspiration, while part of the rainfall is stored in water reserves. When the water reserves reach their maximum, they become surplus water. Water reserves in soils/rocks are affected by lithological conditions and land cover.

Table 3. Water Balance Calculation for Semester I (October 2019 – March 2020) in the Welaran Watershed

MonthType		Humid	Wet	Wet	Wet	Wet	Wet	Semester I
Component	Unit	Oct	Nop	Des	Jan	Feb	Mar	Amount I
		2019	2019	2019	2020	2020	2020	
P	mm	160	370	380	310	378	355	1953
Daily Ep	mm	3.27	3.41	3.28	3.55	3.23	3.67	
Monthly Ep	mm	101.37	102.3	101.68	110.05	93.67	113.77	622.84
P-EP	mm	58.63	267.7	278.32	199.95	284.33	241.23	1330.16
RO	mm	99.2	229.4	235.6	192.2	234.36	220.1	1210.86
APWL	mm	-40.57	0	0	0	0	0	

MonthType		Humid	Wet	Wet	Wet	Wet	Wet	Semester I
Component	Unit	Oct	Nop	Des	Jan	Feb	Mar	Amount I
		2019	2019	2019	2020	2020	2020	
Storage	mm	-40.57	38.3	42.72	7.75	49.97	21.13	119.3
Region Storage	m^3	-716,061	675,995	754,008	136,788	881,971	372,945	**2,105,645**
Region RO	m^3	1,750,880	4,048,910	4,158,340	3,392,330	4,136,454	3,884,765	21,371,679
Region P	m^3	2,824,000	6,530,500	6,707,000	5,471,500	6,671,700	6,265,750	34,470,450

*Information: P = Precipitation, EP = Evapotranspiration, RO = Run Off

Figure 5. Graph of Regional Storage Line in Semester I

Table 4. Water Balance Calculation for the Semester II (April 2020 – September 2020) in the Welaran Watershed

Month Type		Wet	Wet	Humid	Dry	Dry	Dry	Semester II
Component	Unit	Apr	May	Jun	Jul	Aug	Sep	Jumlah II
		2020	2020	2020	2020	2020	2020	
P	mm	573	540	200	90	92	98	1593
Daily Ep	mm	3.54	3.07	3.24	3.75	3.60	3.67	
Monthly Ep	mm	106.2	95.17	97.2	116.25	111.6	110.1	636.52
P-EP	mm	466.8	444.83	102.8	-26.25	-19.6	-12.1	956.48
RO	mm	355.26	334.8	124	55.8	57.04	60.76	987.66
APWL	mm	0	0	-21.2	-103.25	-124.45	-248.9	-248.9
Storage	mm	111.54	110.03	-21.2	-82.05	-76,64	-72.86	-31.18
Region Storage	m^3	1,968,681	1,942,030	-374,180	-1,448,183	-1,352,696	-1,285,979	**-550,327**
Region RO	m^3	6,270,339	5,909,220	2,188,600	984,870	1,006,756	1,072,414	17,432,199
Region P	m^3	10,113,450	9,531,000	3,530,000	1,588,500	1,623,800	1,729,700	28,116,450

Figure 6. Graph of Regional Storaging Line in Semester II

September 2019 was not included in the calculation of the water balance in a year because the calculation of the water balance was limited to 12 months. The groundwater potential during semester I (October 2019-March 2020) is 2,105,645 m^3 (Table 3). Figure 5 shows that the graph line in the semester I tends to go up.

Semester II (April 2020-September 2020), based on regional storage, has a deficit of 550,327 m^3. The storage deficit occurred in October 2019, June 2020, July 2020, August 2020, and September 2020. The deficit occurs in 2 humid months and 4 dry months. The calculation for one year shows that there is still groundwater storage of 1,555,318 m^3 (Table 4). Figure 6, it can be seen that the graph line in semester II tends to fall.

The largest daily evapotranspiration in July 2020 was 3.75 mm/h (Table 4), while the lowest daily evapotranspiration in February 2020 was 3.23 mm/h (Table 3). The average daily evapotranspiration in the Welaran Watershed was 3.44 mm/h (Table 4).

Water Requirements and Water Criticality Index

The results of calculating the water balance in the Welaran Watershed for one year (October 2019-September 2020), as in Tables 3 and 4, show the amount of regional storage in one year of

1,555,318 m^3. The total population for the 7 (seven) villages in the Welaran Watershed in 2019 was 20,464, with a breakdown of 10,223 males and 10,241 females (Table 5). The villages with the highest population in a row are: 1. Plumbon; 2. Karangsambung; 3. Kaligending; 4. Langse; 5. Kalisana; 6. Banioro; 7. Tlepok (Figure 9).

Table 5. Details of Raw Water Needs for Each Village in the Welaran Watershed

No	Village	Inhabitant		Amount	Water requirements per person/m^3/day/ of the year
		Male	Female		
1	Plumbon	2357	2469	4826	176.149
2	Karangsambung	1978	1908	3886	141.839
3	Kaligending	1853	1808	3661	133.626.5
4	Langse	1333	1336	2669	97.418.5
5	Kalisana	1191	1131	2322	84.753
6	Banioro	898	884	1782	65.043
7	Tlepok	613	705	1318	48.107
Summary		10,223	10,241	20,464	746,936

Source: BPS Kabupaten Kebumen, 2019

The need for raw water per person/day refers to the PU Construction and Building Guidelines, in the Directorate of Irrigation & Irrigation, Bappenas, (2006) of 100 liters/person/day for areas with a population of more than 20 thousand people. In one year (365 days), the water requirement was 746,936 m^3 (Table 5), with an average per month of 62,244.67 m^3 (rounded 62,245 m^3). The availability of groundwater in a year amounted to 1,555,318 m^3.

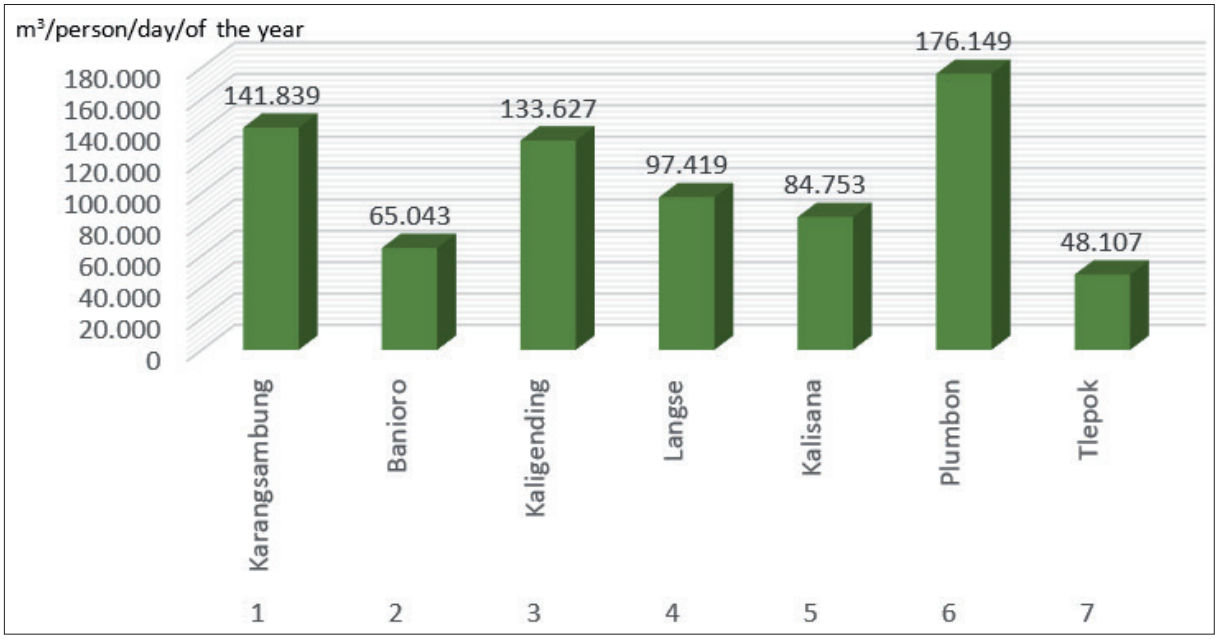
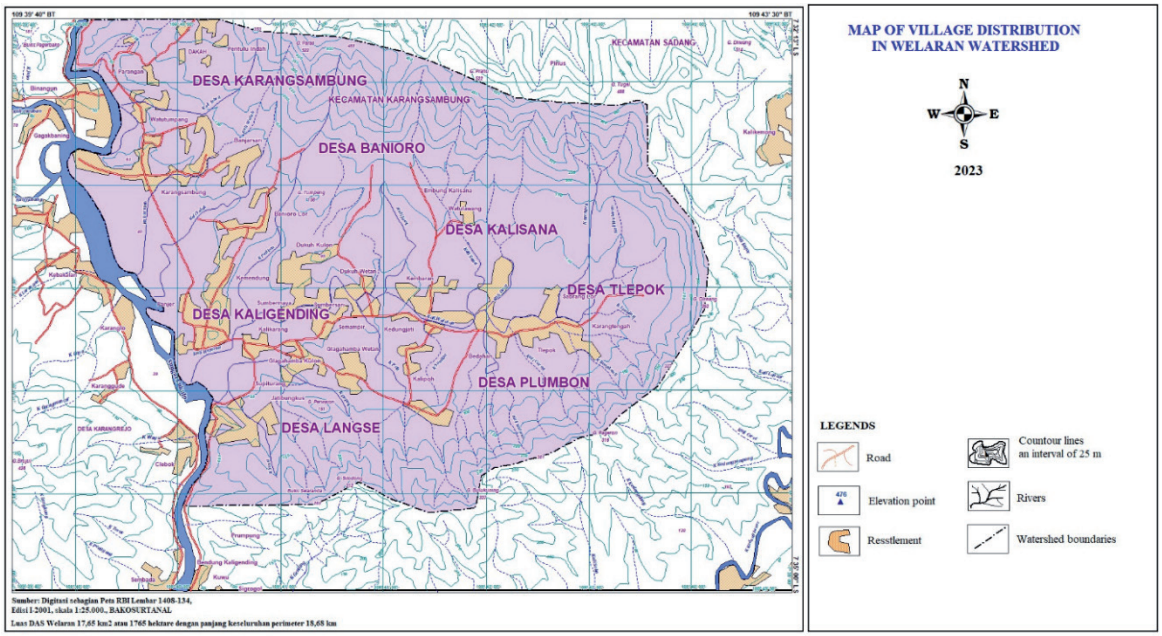


Figure 7. Bar graph of each village's water needs in one year

Looking at Figures 7 and 8, Plumbon is the village that has the most water needs, followed by Karangsambung, Kaligending, Langse, Kalisana, Banioro, and Tlepok. The total raw water needs of the population in one year amounted to 746,936 m^3.

The Water Criticality Index (WCI) in the Welaran watershed and its surroundings are:
WCI = (746,936/1,555,318) x 100%



= 48.02% (not yet critical)

Figure 8. Map of Village Distribution in the Welaran Watershed

The WCI value is less than 50%, hence, the status is not yet critical (Table 1). The details of the water criticality index calculated per month are recorded in Table 6. This table details the comparison between water needs per month and water availability (storage) per month. Table 6 shows that there are five months with a critical status, namely; October 2019, June 2020, July 2020, August 2020, and September 2020. These critical five months occurred because the availability of water (storage) in those months was negative (deficit). This means there is no water availability while the water demand during those months.

January 2020, with a WCI value of 46.48%, is nearly critical. The WCI value in January 2020 is almost the same as the WCI value per year in the Welaran Watershed of 48.02%. Meanwhile, in the other months, November 2019, December 2019, February 2020, March 2020, April 2020, and May 2020, the WCI values are very small (less than 10%, except March at 17.01%) and categorized as not yet critical. These months with WCI are not yet critical because water availability increases significantly while the monthly water requirement is relatively fixed.

Projections are made to calculate the WCI value in 2023 assuming a population growth rate of 1.17 (BPS, 2022). The projection calculation results refer to equation 2 in the methodology, which is 21,422. With a total population in 2023 of 21,422, the need for water in one year (365 days) is 781,903 m^3/day/year. If water availability is assumed to remain following Table 4, then the WCI in 2023 will be 50.27% (near critical).

From the calculation of WCI for 2019-2020 and WCI projections for 2023, it turns out that the value of WCI will continue to increase if the rate of population growth continues to increase while the availability of water is assumed to be fixed. WCI projections are not only influenced by population growth but also by climate change.

Table 6. Comparison of Water Needs with Water Availability per Month (Water Criticality Index/ month)

No	Month	Rainfall (mm)	Water needs of resident/month	Water availability in one month	WCI (%)
1	October 2019	160	63,438.4	-716,061	Negative (critical)
2	November 2019	370	61,392.0	675,995	9,08 (not yet)
3	December 2019	380	63,438.4	754,008	8,41 (not yet)
4	January 2020	310	63,438.4	136,788	46,48 (near)
5	February 2020	378	57,299.2	881,971	6,49 (not yet)
6	March 2020	355	63,438.4	372,945	17,01 (not yet)
7	April 2020	573	61,392.0	1,968,681	3,12 (not yet)
8	May 2020	540	63,438.4	1,942,030	3,26 (not yet)
9	June 2020	200	61,392.0	-374,180	Negative (critical)
10	July 2020	90	63,438.4	-1,448,183	Negative (critical)
11	August 2020	92	63,438.4	-1,352,696	Negative (critical)
12	September 2020	98	61,392.0	-1,285,979	Negative (critical)

**The calculation of the amount of water requirement refers to the number of days in the month.*

The Welaran Watershed in particular, and Kebumen district, in general, have been designated as a Global Geopark in 2022. The number of tourists visiting this area will increase the need for water, this will certainly further add to the status of the WCI value in the Welaran watershed. This needs to be a concern from various parties, especially the government of Kebumen Regency and the surrounding community to be better able to manage water resources in the Welaran Watershed.

CONCLUSION

Based on the results of research and data discussion, several things can be concluded:

1. The total amount of rainfall in the Welaran watershed, Karangsambung for a year (Oct 2019-Sept 2020) is 3546 mm with 142 rainy days. This C2 climate type describes moderate rainfall with several dry months of more than 2 in a year, so it is worth noting during dry months, which is only 100 mm per month.
2. There are 5 months with a critical status water criticality index (WCI), namely October 2019, June 2020, July 2020, August 2020, and September 2020. This critical five months occurred because the availability of water (storage) in that month was negative (deficit). This means there is no water availability while the water demand in these months is relatively fixed.
3. WCI value in 2019-2020 was 48.02% (not yet critical). WCI projection value in 2023, with a population growth rate of 1.17, the WCI value is 50.02%.

SUGGESTION

1. Rainfall in the Welaran Watershed can be utilized by making rain harvests reservoirs.
2. WCI needs to be better known and understood by various parties to develop a more appropriate management of water resources.

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CONTRIBUTOR STATEMENT

Nandian Mareta is the main contributor of this paper, with support from Rizka Maria, Rachmat Fajar Lubis, Boy Yoseph CSSSA and M. Sapari Dwi Hadian.

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