Agromet 36 (1): 42-50, 2022

Agromet

journal.ipb.ac.id/index.php/agromet

ISSN : 0126 - 3633

PERHIMPI

Bogor Water Adequacy Status for 2009-2019

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ARTICLE INFO

Received
29 July 2021

Revised
28 December 2021

Accepted for Publication
7 April 2022

Published
20 May 2022

doi: 10.29244/j.agromet.36.1.42-50

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ABSTRACT

Water adequacy becomes one of the global concerns as the trend of population growth continues to arise. The condition of water adequacy can be worse in some regions since it also relates to rainfall, which is greatly influenced by global climate change. Here we explore water adequacy at local scale especially in Bogor, Indonesia based on sectoral water demands. The study aims to analysis water adequacy for 2009-2019 based on a climatic water balance. Water supply-demand analysis was performed using water usage index (WUI) in which high WUI corresponds to high critical water balance. Our results showed there was a deceased trend for water supply in Bogor approximately 0.6% per year, whereas an increased trend was observed for water demand (1.7% per year). The main contributor for the increased demand was from domestic water demand by 48%. Generally, water adequacy in Bogor for the period analysis (2009 -2019) is still adequate, but a proper management of water resource will ensure water adequacy in the long run in response to population explosion and climate change.

KEYWORDS
climatic water balance, rainfall, water demand, water scarcity, water supply

INTRODUCTION

Global warming becomes human concern as an increased temperature will influence human activities (e.g. Mahmudah et al., 2021; Suciantini et al., 2020; Sugiarto et al., 2017). Since the last centuries, global temperature has increased by approximately 0.6°C, and it still show a positive trend (Haustein et al., 2017). The increased temperature has indirectly influenced climate patterns in local and global scales (Bathiany et al., 2018; Julianto et al., 2021), including rainfall pattern (Moda et al., 2019). The change in rainfall pattern will possibly affect water adequacy, especially in the high populated region.

There are two factors, which affect water adequacy in the future, namely climate and non-climate. Climatic factor means the influence from climate variables, such as rainfall, temperature, and evaporation. For non-climate factors, water adequacy can be affected by land use changes (Esse et al., 2021), or water usages in response to the population (Falkenmark, 2020), lifestyle (Ragusa, 2021), and technology (Qiao et al., 2020). Water adequacy varies based on its supply and demand. The supply is limited and depends on the rainfall, as the primary input. Meanwhile, water demand tends to continuously increase along with the population rise and various developments (Boretti and Rosa, 2019). This condition results in an insufficiency of water supply to fulfill water demand which leads to water scarcity in various regions (He et al., 2021; Yin et al., 2020).

Previous studies had discussed water scarcity related to climate change impact across the globe, including Indonesia (Putri and Perdinan, 2019; Romsan et al., 2017; Santikayasa et al., 2017). The World Water Forum II had projected that Indonesia will experience water crisis in 2025. This problem has worsened by poor water management, such as inefficiency of water usage (Nastiti et al., 2017). In addition, climate change will increase the intensity of both dry and wet seasons which strongly leads to higher drought and flood risks (Christidis and Stott, 2021; Lestari and Dasanto, 2019; Liu et al., 2022).

Based on this description, analysis on water availability related to climate change is important for further research. The knowledge of historical water adequacy can be carried out by considering the climate variables, which directly affect water availability. This research will specifically assess water adequacy and its relation to climate variables in Bogor from 2009 to 2019 based on water balance approach. The results are expected to be used as scientific based to establish policies or activities related to water resources preservation, and climate change mitigation.

RESEARCH METHODS

Data Sources

This research used secondary data from various sources. We used two climate variables, namely rainfall and air temperature at daily basis, obtained from Dramaga Meteorological, Climatological, and Geophysical Agency (BMKG) (http://dataonline.bmkg.go.id/). For rainfall data, we also used monthly rainfall at 0.25° resolution from CHIRPS, Climate Hazards Group InfraRed Precipitation with Station dataset (http://iridl.ldeo.columbia.edu/), as a comparison to the station data. The meteo-rological data was primarily used for calculating water supply and evapotranspiration in water balance analysis. To calculate other water demand parameters (domestic, industry, and agriculture), we used data from Bogor Statistical Agency, which includes: (1) population data, (2) average daily water usage for individual purpose, (3) the number of industrial site and its daily water usage, and (4) agricultural area data. All data covered Bogor from 2009 to 2019.

Climatic Annual Water Balance

Water balance approach was used to identify water supply and water demand balance in certain areas. The method may result in two conditions, surplus or deficit. If water supply exceeded the demand, the condition was defined as surplus condition. On the contrary, if water demand exceeded the supply, the condition was defined as deficit condition, which may further lead to water crisis in the area. Generally, water balance (WB) calculation was based on annual water supply (WS) and demand (WD) difference in cubic meter (Equation 1).

$$WB = WS - WD \quad (1)$$

The water supply was derived from rainfall data. We assumed that 70% of the rainfall amount generates runoff and the remaining 30% was stored as groundwater. The water supply was then calculated using Equation 2.

$$WS = \frac{P}{1000} \times 0.3 \times A \quad (2)$$

where P is annual rainfall (mm), and A is the total area of water catchment (m^2).

The water demand summarized the water usage in 3 categories, namely domestic use, industry, and agriculture (Equation 3). Domestic water demand was calculated from individual water usage multiplied by the total population (Equation 4). We assumed that each individual uses the same amount of water.

$$WD = Dom + Ind + Agr \quad (3)$$

$$Dom = k \times pop \times n \quad (4)$$

where k is individual water usage (0.15 m^3/day), pop is total population, and n is number of days in a year.

Aside from domestic use, the number of industrial sites in a region also influences water demand of those area (Carrard et al., 2019). In Bogor, industrial sites are divided into three categories, i.e., home industry, small industry, and medium-large industry. Home industry is a small-scale industry in which activities are usually carried out at home by family members and located in villages or small towns. A small industry is an industry in which production is catered to fulfill a small-scale demand in semi-urban and urban areas. A medium-large industry is an industry that involves more than 20 workers and less than 250 workers (Al-Haddad et al., 2019). The industrial water demand (Ind) was calculated using Equation 5.

$$Ind = i \times ki \times n \quad (5)$$

where i is the number of industrial sites, and ki is water usage coefficient, which varies for each type of industry, stands for water used for consumption.

Agricultural water demand was calculated from crop water requirement. Here we assumed that Bogor is dominated by paddy field and crops as the major agricultural commodity. The rice was produced twice a year in which need 4 months for each planting period. The crops commodity was planted once a year, which consisted of a 9-month planting period. After-wards, the crop water requirement can be obtained by multiplying the plant coefficient with the potential evapotranspiration (Suryadi et al., 2019), which was influenced by temperature and duration of sunlight (Luo et al., 2021). The potential evapotranspiration was calculated according to Thornthwaite's empirical equation (Equation 6 and 7).

$$PET = (j \ x \ E \ x \ 10)/dm \quad (6)$$

$$E = 1.6(10T/I)^a \quad (7)$$

where PET is the potential evapotranspiration, j is the ajustment factor, T is monthly air temperature, I is heat index, and a is $(6.75 \times 10^{-7})I^3 - (7.71 \times 10^{-5})I^2 + (1.792 \times 10^{-2})I + 0.49239$. The total water requirement for agriculture was summed from water loss for evapotranspiration of each commodity, which calculated based on Equation 8.

$$WR_c = (A_c \; x \; KTA_c x \; PR_c)/1000 \qquad (8)$$

where WR_c is water requirement for plant c, rice or crops (m^3), A_c is total planting area in m^2, KTA_c is water demand (m^3) and PR is planting period in month.

Water Usage Index (WUI)

Water Usage Index (WUI) is the ratio of the water demand to water supply in a certain area (Equation 9). A lower WUI score indicates an adequate water resource as the total water supply could met the demand. Hence, a higher WUI score may also indicated a more critical water balance in those areas (Hatmoko et al., 2018; Mediawan et al., 2021). Table 1 shows the classification of water condition in an area according to their WUI score (KLHK, 2009).

$$WUI = \frac{WD}{WS} \qquad (9)$$

Table 1. Water Usage Index (WUI) criteria

No	WUI Score	Qualifications
1	≤0.25	Very Low
2	0.25 – 0.50	Low
3	0.50 – 0.75	Moderate
4	0.75 – 1.00	High
5	≥ 1.00	Very High

Water Availability per Capita Index

Water availability per capita index or water stress index (WSI) defines the amount of climatic water consumable by individual in a year. This index is essentially a ratio of the climatic water supply to the total population in an area, which mostly used by the government to estimate the condition of water supplies (Kurniasari et al., 2021). Similar to WUI, there is also a classification of water condition in an area according to their WSI score (Table 2).

$$WSI = \frac{WS}{pop} \qquad (10)$$

where WSI is water availability per capita index (m^3/year/capita), WS is annual water supply (m^3), and pop is population of Bogor.

Table 2. Criteria of the water availability per capita index (Falkenmark, 2020)

No	WSI Score	Conditions
1	> 1,700	No Stress
2	1,000 – 1,700	Stress
3	500 – 1,000	Scarcity
4	< 500	Absolute Scarcity

RESULTS AND DISCUSSION

Rainfall

Rainfall is the main meteorological variable affecting water supply. Figure 1 shows that Bogor has a monsoonal rainfall pattern, with peak rain normally occurred in December-February (DJF).

According to Figure 1, the highest annual rainfall (almost 6,000 mm) occurred in 2010 and 2016. This was due to the La Nina phenomenon, which may increase rainfall and also trigger floods in most regions of Indonesia. On the contrary, the lowest annual rainfall (3,000 mm) occurred in 2011 and 2015. This was due to the El Nino phenomenon, which lead to decreasing rainfall far from its normal condition. Figure 2 also shows that annual rainfall in Bogor from 2009-2019 has a downward trend. This indicates that the rainfall in Bogor has a decreasing tendency in the following years. Similarly, Runtunuwu and Syahbuddin (2007) reported that there has been a decreasing trend

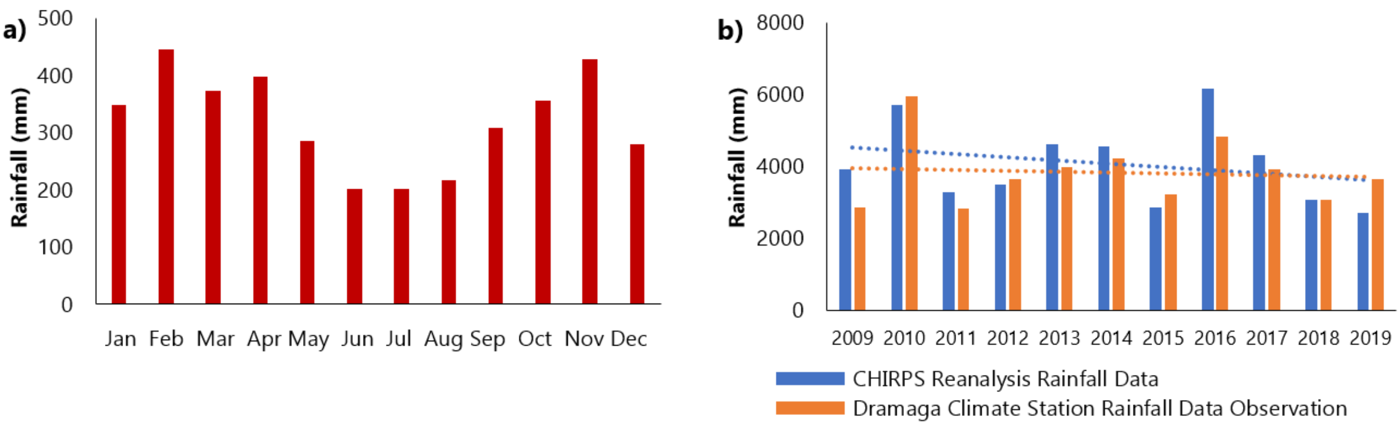

Figure 1. Rainfall variability at Bogor for 2009-2019: a) average monthly rainfall, b) annual rainfall.

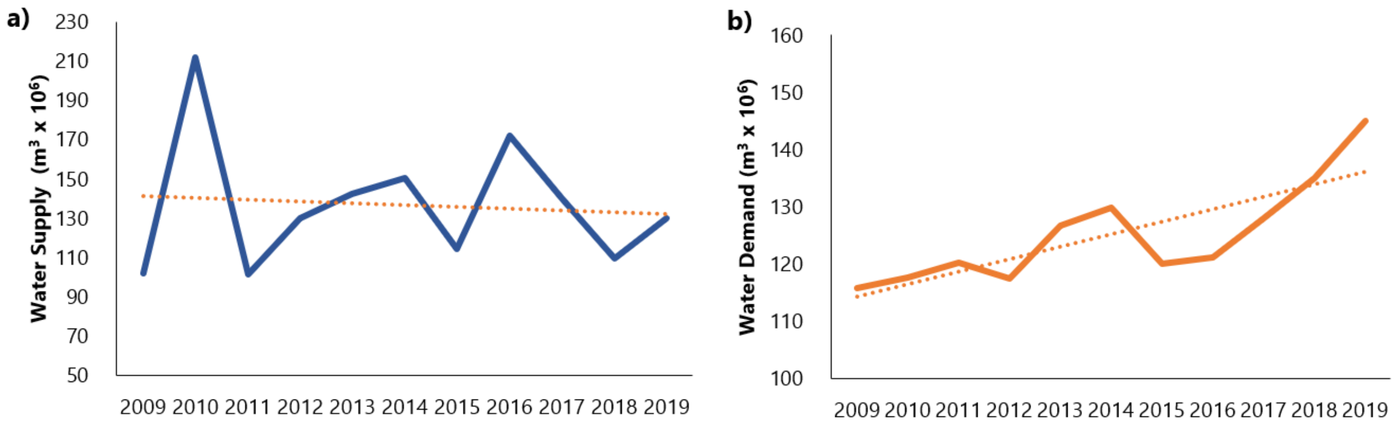

Figure 2. Bogor annual a) water supply and b) water demand for 2009-2019.

from 1879 – 2006 in rainfall, accompanied by rainfall pattern changes in various locations in West Java. This resulted in a seasonal shift, which would in turn decreasing the water supply.

Climatic Water Supply

Figure 3 showed that the annual water supply from 2009-2019 was ranging from 100 million m^3 to 200 million m^3. The highest water supply condition occurred in 2010, while the lowest in 2011 and 2015. Since climatic water supply is mainly influenced by rainfall, high water supply in 2010 was also due to La Nina phenomenon and a negative IOD (Indian Ocean Dipole) (-), which created a low-pressure center in Indonesia, thereby increasing rainfall. The opposite phenomenon occurred in 2011 and 2015, where El Nino phenomena and positive IOD (+) resulted in a high-pressure center (Bramawanto and Abida, 2017). Figure 3 also showed the decreasing trend in water supply. This indicated that Bogor water supply tends to decrease by 0.6% or 840,000 m^3 annually in the following years. This is similar to the rainfall trend, which has the same tendency due to climate change (Nahib et al., 2021; Runtunuwu and Syahbuddin, 2007).

Water Demand

Water demand summarized three components, namely domestic, industrial, and agricultural water demand. Agricultural water demand is defined by D'Odorico et al., (2020) as the irrigation water requirement, which is mostly met from surface water. This number is calculated by various factors such as climate factors, crop coefficient, etc.

According to Figure 4, Bogor annual water demand ranged from 115 million m^3 to 145 million m^3. The water demand has an increasing trend for about 1.7 % or 2 million m^3 annually.

Based on Figure 5, annual domestic water demand had the highest value, which ranged from 51 million m^3 to 60 million m^3. This was followed by industrial water demand, which ranged from 30 million m^3 to 46 million m^3. Figure 5 also shows that industrial water demand tends to increase by 4% or about 1.5 million m^3 annually, while domestic water demand was about 1.4% or around 800,000 m^3.

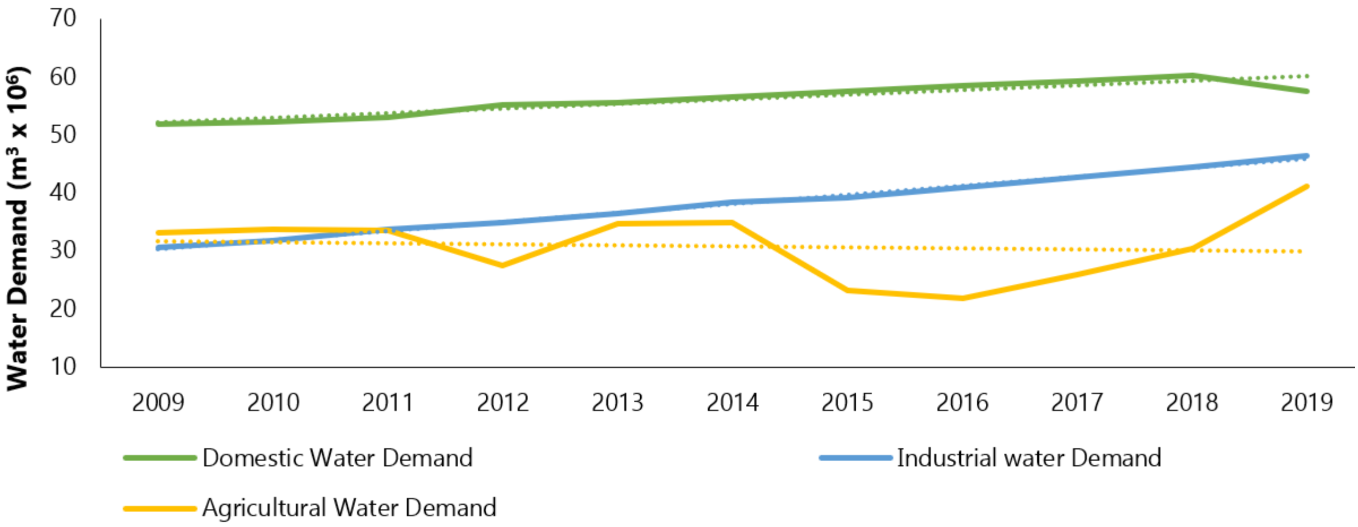

Figure 3. Component of total annual water demand in Bogor for 2009-2019.

Table 3. Annual proportion of water demand for each category (in %).

Year	Domestic Water Demand (%)	Industrial Water Demand (%)	Agricultural Water Demand (%)
2009	44.8	26.5	28.7
2010	45.0	27.5	29.1
2011	45.8	29.1	28.9
2012	47.6	30.0	23.8
2013	48.0	31.5	29.9
2014	48.8	33.2	30.0
2015	49.7	33.9	20.0
2016	50.5	35.3	18.8
2017	51.2	36.8	22.4
2018	52.0	38.4	26.2
2019	49.7	40.0	35.5

Agricultural water demand had the lowest value, ranged from 21 million m^3 to 41 million m^3, with a decreasing trend for about 0.5% or 200,000 m^3 annually. The decreasing trend may occur because of land use change and agricultural land conversion due to population growth and increasing industrial site (Rondhi et al., 2018). Agricultural water demand also highly varied compared to domestic and industrial water demand. One of the reason is because agricultural water demand mainly depends on climatic factors, such as rainfall and temperature (Salman et al., 2020). Contribution percentage of each water demand component to total water demand is presented in Table 3.

Calculating the contribution of each component is important to estimate Bogor water demand trend for the following years. With proper estimation, the government will be able to provide the adequate amount of clean water supply. Table 3 showed that the annual domestic water demand had the highest contribution to the total demand, ranging from 40% to 50%. Industrial and agricultural water demand followed with percentage ranging from 20% to 30%. Domestic water demand normally had a higher value compared to non-domestic water demand. It is estimated that the amount of non-domestic water demand is 10% to 15% of domestic water demand (Ministry of Public Works, 2007).

Climatic Water Balance

According to Figure 5, water supply during rainy season was higher than the water demand, except in 2011, 2017, and 2018. During those years, water supply was influenced by decreasing rainfall due to El Nino phenomenon. Water supply during dry season was always lower than the water demand, except in 2010, 2013, 2016, and 2017. On the contrary, this occurred due to increasing rainfall during La Nina phenomenon.

Water balance in rainy season indicated a water surplus condition in Bogor. The opposite condition, or deficit condition, occurred in the dry season. Surplus condition is if the annual rainfall was higher the water loss amount in an area. On the contrary, deficit condition is if the annual rainfall was lower. Surplus or deficit condition was mainly influenced by the water supply and climatic condition in the area. Since one of the driving factors is rainfall, water management during rainy season must be prioritized to preserve water resource in the future especially in dry season.

Based on table 4, highest annual water surplus in Bogor was in 2010 and 2016. However, the climatic water supply in Bogor from 2009 to 2019 tends to decrease along with rainfall. This was related to the im-

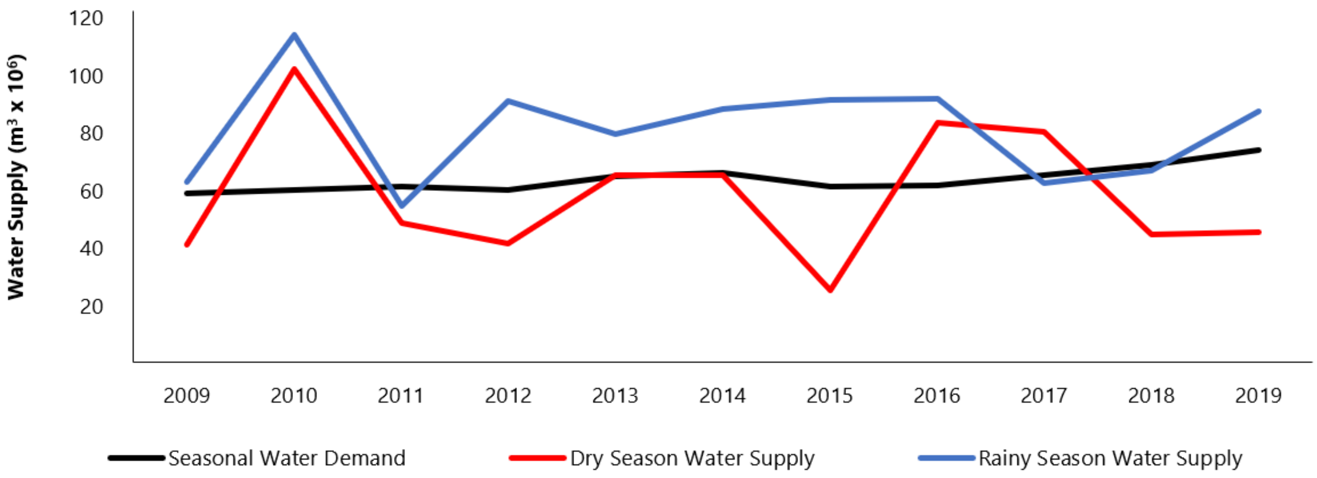

Figure 4. Comparison of water supply in rainy and dry season with water demand in Bogor for 2009-2019.

Table 4. Bogor climatic water adequacy status for 2009-2019.

Year	Total Water Demand (m^3)	Total Climatic Water Supply (m^3)	Climatic Water Balance (m^3)	Water Balance Percentage (%)	Status
2009	115,841,314	101,992,950	- 13,848,364	-14	Deficit
2010	117,726,992	211,824,675	94,097,683	44	Surplus
2011	120,273,616	101,104,200	- 19,169,416	-19	Deficit
2012	117,510,902	129,899,700	12,388,798	10	Surplus
2013	126,778,194	142,057,800	15,279,606	11	Surplus
2014	129,799,773	150,394,275	20,594,502	14	Surplus
2015	119,963,442	114,279,030	- 5,684,412	-5	Deficit
2016	121,152,043	171,777,600	50,625,557	29	Surplus
2017	127,963,048	139,924,800	11,961,752	9	Surplus
2018	135,078,954	109,387,350	- 25,691,604	-23	Deficit
2019	145,043,309	130,041,900	- 15,001,409	-12	Deficit

pact of climate change (Tabari, 2020). On the other hand, annual water demand continued to increase due to population growth. This is in accordance with (Armadi et al., 2019), who projected an increasing demand for clean water in Bogor in 2020.

Water Usage Index (WUI)

Water Use Index (WUI) is important in drought mitigation. The WUI score mainly depends on water supply and water demand of an area. A low WUI score shows that there was still an abundant amount of potential available water to meet the total water demand, and vice versa. The WUI score of Bogor from 2009-2019 is presented in Table 5.

Table 5 showed that WUI score from 2009 to 2019 was varied but tends to increase in the following years. This condition might be caused by the decreased climatic water supply due to the impact of climate change. The WUI score was mostly classified as high and very high, except in 2010 and 2016 (moderate). This might occur due to the abundant climatic water supply during La Nina phenomenon.

Water Availability per Capita Index

The water availability per capita index was designed by Falkenmark (1989) as an approach in determining the criticality of water adequacy in an area. The water availability index per capita of Bogor from 2009 to 2019 showed an exceptionally low score with absolute scarcity conditions. This indicated that the available water was not sufficient to meet the water demand per capita equally (Table 6). This might occure since Bogor is an administrative area with dense population within a relatively narrow area. The score of water availability index per capita also tends to decrease in the following years.

The decrease in the index might be driven by population growth and pattern changes in domestic water usage. This may trigger a problem in providing water for the community. Preserving water resources

Table 5. Bogor Water Usage Index (WUI) for 2009-2019.

Year	Total Water Demand (m^3)	Total Climatic Water Supply (m^3)	Water Usage Index (WUI)	Status
2009	115,841,314	101,992,950	1.14	Very High
2010	117,726,992	211,824,675	0.56	Moderate
2011	120,273,616	101,104,200	1.19	Very High
2012	117,510,902	129,899,700	0.90	High
2013	126,778,194	142,057,800	0.89	High
2014	129,799,773	150,394,275	0.86	High
2015	119,963,442	114,279,030	1.05	Very High
2016	121,152,043	171,777,600	0.71	Moderate
2017	127,963,048	139,924,800	0.91	High
2018	135,078,954	109,387,350	1.23	Very High
2019	145,043,309	130,041,900	1.12	Very High

Table 6. Annual index of water availability per capita in Bogor from 2009-2019.

Year	Population (People)	Total Climatic Water Supply (m^3)	Domestic Water Demand (m^3)	Index of water availability per capita (m^3/capita/year)	Status
2009	946,204	101,992,950	51,946,600	108	Absolute Scarcity
2010	950,334	211,824,675	52,173,337	223	Absolute Scarcity
2011	987,315	101,104,200	53,110,150	102	Absolute Scarcity
2012	1,004,831	129,899,700	55,165,222	129	Absolute Scarcity
2013	1,013,019	142,057,800	55,614,743	140	Absolute Scarcity
2014	1,030,720	150,394,275	56,586,528	146	Absolute Scarcity
2015	1,047,822	114,279,030	57,530,918	109	Absolute Scarcity
2016	1,064,687	171,777,600	58,451,316	161	Absolute Scarcity
2017	1,081,009	139,924,800	59,347,394	129	Absolute Scarcity
2018	1,096,828	109,387,350	60,215,857	100	Absolute Scarcity
2019	1,048,610	130,041,900	57,568,689	117	Absolute Scarcity

must be a priority for the government and related parties in maintaining water availability and water balance in Bogor. The availability mostly depends on water catchment condition and hydrological function. Apart from providing water, conserving the water catchment area is also a form of minimizing climate change impact.

CONCLUSIONS

Climatic water supply in Bogor had a decreased trend of 0.6% annually. This corresponded to a decreased rainfall on climatic water supply. On the contrary, the water demand tend to increase by 1.7% annually, with the largest contribution from domestic water demand (48%). The climatic water adequacy in Bogor showed that the highest percentage of water balance is 44% and the lowest is -23%. This indicated that in the last decade, the climatic water supply in Bogor had not always been able to met its water demand. According to Bogor Water Use Index (WUI), there was absolute scarcity conditions with exceptionally low WUI score. Furthermore, the water availability index per capita tends to decrease in the following years. The decline was mainly driven by population growth and pattern changes in domestic water usage. Therefore, preserving water resource and proper water management should be prioritized to avoid problem in providing water for the community.

ACKNOWLEDGEMENT

The authors thank to two anonymous reviewers for their comments and suggestion that improve the manuscript.

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