METEOROLOGICAL WATER SCARCITY PROJECTION FOR 2021-2035 BASED ON CMIP6 (*COUPLED MODEL INTERCOMPARISON PROJECT PHASE 6*) SCENARIO IN DAERAH ISTIMEWA YOGYAKARTA

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ABSTRACT

Climate change can lead to an imbalance between water demand and supply, resulting in problems such as water scarcity. To avoid this, a projection of the level of water scarcity is needed. Water scarcity is calculated as the percentage of water demand to water supply. This research aims to determine the level of need, availability, and scarcity of meteorological water. This research uses meteorological water supply obtained through Thornthwaite-Mather water balance calculation from CMIP6 rainfall and temperature projection modeling data in SSP2 and SSP5 scenarios. CMIP6 data was corrected using distribution mapping and average ratios methods to improve the distribution and data values. Water demand indicators are reviewed from three sectors, namely domestic water demands, agricultural water demands, and livestock water demands. The water supply calculation results in Daerah Istimewa Yogyakarta (DIY) show a pattern that fluctuates from year to year during the 2021-2035. Meanwhile, water demand continues to increase along with population growth. The level of water scarcity shows that, overall, DIY is classified as not critical to slightly critical in the SSP2 scenario and not critical to critical in the SSP5 scenario. The difference in the level of scarcity is influenced by socio-economic development and climate change mitigation efforts assumed in each scenario. By knowing the projected level of water scarcity, policymakers are expected to pursue appropriate climate change mitigation measures to actualize the best SSP scenario.

Keywords: meteorological water balance, water demand, climate projection, climate change impacts

1. Introduction

Water is the main natural resource needed by living creatures. Water supply in an area is generally used to meet domestic, livestock, agricultural, and industrial water demands [1]. Population growth, environmental exploitation, and climate change that happen nowadays have made sustainable water management a major concern. These factors have led to a significant gap in the water balance and caused water supply resources to be under increasing pressure [2]. Daerah Istimewa Yogyakarta (DIY) is one of the provinces in Indonesia that has the potential to experience climate change. One of the most obvious impacts of climate change is related to the water demand and water scarcity [3]. It is important to carry out studies regarding water scarcity to see the condition of existing water resources in an area, including DIY. This study focuses on assessing future changes in water scarcity levels by considering two different scenarios, *Shared Socioeconomic Pathway* (SSP) 2 and 5. Projections of water supply and demand will have an impact on water scarcity in the future. This can be measured through the level of water scarcity. This parameter shows the comparison between water supply and water demand. The greater the amount of water available, the smaller the water scarcity level, and vice versa.

DIY is an area that has chances to experience meteorological drought, especially when the climate in this region is influenced by global circulation phenomena such as El Nino-Southern Oscillation and Indian Ocean Dipole [4]. Meteorological drought occurs when the rainfall received is below normal, resulting in an imbalance between water supply and demand. The water scarcity level indicator describes how the water supply in an area can meet its water demands. In this research, the level of water scarcity is evaluated based on meteorological water supply obtained from water balance calculations and water demands, including domestic water demands, agricultural water demands, and livestock water demands.

Water supply is the volume of water within the hydrological cycle in an area, which is a combination of rainwater, surface water, and groundwater [5]. A meteorological water supply comes from rainwater. The uneven distribution of rainfall as a result of variations in physiographic conditions causes water supply to differ in each region [6]. Calculations regarding water supply are important to determine the potential of water resources in an area [7]. Water supply can be determined through water balance analysis. Water balance is the relationship between inflow and outflow in an area within a certain period. Rainwater that falls to the earth's surface will undergo a process of evapotranspiration, infiltration, or flow across the earth's surface as the surface flows towards lower locations [8]. The amount of water entering and leaving a system through precipitation and evapotranspiration can be determined using the Thornthwaite-Mather method by considering rainfall and temperature parameters.

Water demands cover various sectors, including water demands for household (domestic) activities and agricultural water demands, which include the wetland agriculture and livestock sectors. Domestic water demand is the water used for household and community needs [9]. Domestic water demands are largely determined by population and consumption. This can be proven by the fact that a larger population has greater domestic water demand [10]. The increasing need for water could cause water scarcity if it is not balanced by an increase in water supply [11]. Coupled with a stagnant or declining water supply, this might lead to an imbalance that triggers water scarcity.

Water scarcity occurs when water demand exceeds 75% of the available supply [12]. This condition highlights the critical imbalance between water demand and supply, which can be quantified as a mitigation strategy. The percentage of water scarcity level can be obtained by comparing water demands with water supply [13]. A high water scarcity percentage indicates that water demand is relatively high compared to its supply. If this percentage exceeds 100%, it means that the amount of water demand is greater than the supply of water. This could have an impact on the water crisis if there are no mitigation measures.

The level of water scarcity can be influenced by many factors, one of which is climate change. Climate change is projected based on a specific set of assumptions that characterize uncertainty in complex systems of human and environmental interactions. This series of assumptions is contained in a scenario prepared by the IPCC and regularly updated to adapt to current developments. SSP is structured as an underlying condition modeling climate projection by considering how socio-economic factors develop in the future and influence climate mitigation and adaptation policies [14]. SSP is divided into five main scenarios, namely SSP1: *Taking the Green Road*, SSP2: *Middle of The Road*, SSP3: *A Rocky Road*, SSP4: *A Road Divided*, and SSP5: *Taking The Highway*.

SSP2 scenario or scenario *Middle of the Road* represents ongoing historical patterns throughout the 21st century as a basis for projections. Based on this scenario, the human population is projected to reach 9.2 billion people in 2050 and fall to 9 billion in 2100. Coal, oil, and gas are still the main energy sources in this scenario, but renewable energy sources are also being developed and are becoming widely used. Together with other factors, this condition results in emissions that continue to increase, reaching 65-85 Gt CO_2 in 2100, resulting in warming of 3.8-4.2°C [14].

SSP5 scenario or scenario *Taking the Highway* represents the most severe condition overall, with total emissions reaching 104-106 Gt CO_2, which resulted in a warming of 4.7-5.1°C. SSP5, together with SSP1, is the scenario that describes the lowest human population growth. In the SSP5 scenario, the human population peaks in 2050-2060 at 8.5 billion people and declines to around 7 billion people in 2100. Even though the population has decreased, this scenario predicts the highest energy use among the four other scenarios. This results in very high emissions because the main energy source is still dominated by fossil fuels [14].

Based on the background and problems related to the water scarcity in DIY which has been mentioned, this study aims to 1) Know the projected meteorological water supply and demands in DIY from 2021 to 2035; 2) Compare meteorological water scarcity levels of DIY from 2021 to 2035 according to the CMIP6 model in the SSP2 scenario and SSP5 scenario; and 3) Comparing the average level of meteorological water scarcity in 2010–2014 with 2031–2035 according to the SSP2 and SSP5 scenarios in each district/city in DIY.

2. Methods

Study Area. DIY is a province located in the south-central part of Java Island. Geographically, this province is located at 8º 30'–7º 20' S and 109º 40'–111º 0' E. DIY has an area of 3,186 km² with a population of 3.689 million people in 2020. DIY is divided into four districts and one city, namely Sleman, Bantul, Kulon Progo, Gunungkidul, and Yogyakarta City. Each district in DIY has a relatively diverse topography, such as mountains, hills, and plains. The position of DIY is at low latitudes close to the equator, so it has a tropical type of climate with balanced rainy and dry seasons in one year [15]. DIY rainfall ranges from 100-500 mm every month during the rainy season [16].

Table 1. Data about BMKG Observation Stations

Station Name	Latitude	Longitude	Elevation
BPP Kokap	07° 50' 09.6" S	110° 05' 48.2" E	107 m
BPP Samigaluh	07° 40' 00.0" S	110° 10' 00.0" E	475 m
BPP. Panjatan	07° 54' 39.5" S	110° 09' 21.6" E	18 m
Dadapan Gununganyar	07° 38' 40.0" S	110° 21' 48.5" E	414 m
Stageof Yogyakarta	07° 49' 05.9" S	110° 17' 49.1" E	153 m
Maguwoharjo/Santan	07° 47' 03.5" S	110° 25' 45.2" E	139 m
BPP. Nglipar	07° 53' 10.0" S	110° 36' 11.0" E	178 m
BPP. Panggang	08° 00' 51.8" S	110° 26' 45.6" E	305 m
BPP. Tepus	08° 04' 58.8" S	110° 37' 40.8" E	249 m
SDA Gandok	07° 51' 32.0" S	110° 22' 31.0" E	73 m
BPP Sanden	07° 59' 14.1" S	110° 16' 27.8" E	19 m
SDA Piyungan	07° 50' 27.0" S	110° 25' 33.0" E	101 m

Source: BMKG DIY

Table 2. Data used in research

No.	Data	Unit	Source
1.	Monthly Temperature Observation Data	°C	BMKG DIY
2.	Monthly Rainfall Observation Data	millimeters	BMKG DIY
3.	CMIP6 Model Rainfall Data BCC, CMCC, MRI Models	kg/m^2s	Beijing Climate Center, China; Euro-Mediterranean Center on Climate Change, Italy; Meteorological Research Institute, Japan
4.	CMIP6 Modeling Temperature Data Model GFDL, CMCC, MRI	Kelvin	National Oceanic and Atmospheric Administration, USA; Euro-Mediterranean Center on Climate Change, Italy; Meteorological Research Institute, Japan
5.	DIY Population Projection Data for 2021-2035 Per Regency	thousand people	Central Agency of Statistics, DIY
6.	Data on the area of irrigated rice fields for 2010 and 2017	hectares	Central Agency of Statistics, DIY
7.	Data on Rainfed Rice Field Area for 2010 and 2017	hectares	Central Agency of Statistics, DIY
8.	Number of Livestock Per Regency	-	DIY in Figures, Central Agency of Statistics DIY

Data. The data used in this research consists of observation data and climate projection data, both in meteorological water supply and water demand aspects. Observation data includes monthly rainfall and temperature data in the period of 2010-2014 taken from 12 Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) observation stations. The observation stations used can be seen in **Table 1**.

The model data obtained from CMIP6 covers the period from 2010 to 2014 as the historical baseline and 2021 to 2035 as the projection period. SSP2 is chosen as it represents the ongoing socio-economic pattern, while SSP5 is selected as it represents the most severe conditions of greenhouse gas emissions that alter the atmosphere. The models used in CMIP6 data include the BCC-CSM2-MR, CMCC-ESM2, GFDL-ESM4, and MRI-ESM2-0 models with an approximate horizontal resolution of 100 km and a temporal resolution of monthly averages. Data on population, agricultural land area, and number of livestock are used to calculate water demands. The details of the data in this research are shown in **Table 2**.

Methods. Data modeling CMIP6 was corrected using the distribution mapping method and average ratio method. The data used for the correction process covers only a 5-year period, from 2010 to 2014, due to limitations in the available and usable data. The distribution mapping method, as described by Piani et al. [17], involves three steps: first, calculating the probability density of the gamma distribution using equation (1); second, calculating the cumulative distribution using equation (2); and third, creating a cumulative distribution transfer function using the general formula in equation (3). A third-order polynomial regression equation between the observational data and model data was chosen, as it has been tested by Jatmiko et al. [18].

$$pdf(x) = \frac{It\ is^{\left(-\frac{x}{\theta}\right)} x^{(k-1)}}{\Gamma(k)\theta^k} \quad (1)$$

$$cdf(x) = \frac{It\ is^{\left(-\frac{x}{\theta}\right)} x^{(k-1)}}{\Gamma(k)\theta^k} dx' + cdf(0) \quad (2)$$

$$y = ax^3 + bx^2 + cx + d \quad (3)$$

where x is the data model, θ is the shape parameters, and k is the parameter scale. The results of the distribution mapping method were corrected again using the average ratio method proposed by Lenderink et al. [19] with the formula:

$$P'_{mdl} = P_{mdl} \times \left(\frac{\mu_m\, P_{obs}}{\mu_m\, P_{mdl}}\right) \quad (4)$$

where P'_{mdl} is corrected model data, P_{mdl} is model data, $\mu_m P_{obs}$ is the average of observation data, and $\mu_m P_{mdl}$ is the average of model data.

Water supply is known through a water balance approach using the calculation method proposed by Thornthwaite and Mather [20]. This method is used to determine the amount of water surplus and deficit based on rainfall and temperature data. The amount of water surplus and deficit in one year is accumulated and then multiplied by the areas to get the value of water supply as written in equation (5).

$$Water\ supply = (\Sigma\, S - D) \times A \quad (5)$$

where S is surplus (mm); D is deficit (mm); and A is area (km^2).

Based on the Indonesian National Standard (SNI) (2002) on water resources, city residents need 120L/day/capita of water, while rural residents need 60L/day/capita. Based on these assumptions, the water demands of rural and urban residents can be formulated using equations (6) and (7).

$$KAD = Pd \times 365 \times 60\, L \quad (6)$$

$$KAK = Pd \times 365 \times 120\, L \quad (7)$$

where *KAD* is rural residents' water demands (L/year), *KAK* is urban residents' water demands (L/year), and Pd is the total population.

Calculations of agricultural water requirements for historical and projected periods are assumed to be constant. The land area considered includes irrigated agricultural land and rainfed agricultural land in each district of DIY. The reference year is 2010 for the historical period and 2017 for the projection period. The calculation of agricultural water requirements is based on the assumption of a cropping pattern, which is divided into three planting periods: MT I (November-February), MT II (March-June), and MT III (July-October). Irrigated fields in planting periods I and II have a rice planting pattern, while planting period III has a secondary crop planting pattern. Rain-fed fields had a rice planting pattern in the first planting period, secondary crops in the second planting period, and *bero* (not planted) in the third planting period. Rice plants are assumed to have a water requirement of 1 L/sec/ha, while secondary crops require 0.25 L/sec/ha of water [21]. According to the SNI (2002), the agricultural water calculation formula is written in equation (8).

$$A = L \times Lt \times a \quad (8)$$

where A is irrigation water use, L is area of irrigation area (ha), Lt is plant intensity (sec), and a is standard water use (1 L/sec/ha) or 0.001 m/sec/ha × 3600 × 24 × 120 days/season.

Water requirements for livestock are determined by the size of the livestock scale. The type of livestock also influences water requirements. Cows and buffalo consume 40 L/day of water, horses consume 37.85 L/day, sheep and goats consume 5 L/day, pigs consume 6 L/day, and birds consume 0.6 L/day [22]. Livestock water requirements are the number of livestock multiplied by the standard livestock water requirements.

$$Q(L) = 365 \times \{q_{(\frac{c}{b})} \times P_{(\frac{c}{b})} + q_{(\frac{s}{g})} \times P_{(\frac{s}{g})} + q_{(pi)} \times P_{(pi)} + q_{(po)} \times P_{(po)}\} \quad (9)$$

where Q(L) is water requirements for livestock (m^3/year), $q_{(c/b)}$ is water requirements for cows/buffaloes (L/day), $q_{(s/g)}$ is water requirements for sheep/goats (L/day), $q_{(pi)}$ is water requirements for pigs (L/day), $q_{(po)}$ is water requirements for poultry (L/day), $P_{(c/b)}$ is number of cows/buffalo, $P_{(s/g)}$ is number of sheep/goats, $P_{(pi)}$ is number of pigs, and $P_{(po)}$ is number of birds.

The level of water scarcity is expressed as a percentage comparison between water demand and water supply. The calculation formula is as follows:

$$Water\ scarcity\ level = \frac{water\ demands}{water\ supply} \times 100\%$$

Water scarcity levels are divided into the following four classes (**Table 3**).

Table 3. Classification of Water Scarcity Levels

No.	scarcity Class	Information
1	<50%	Not critical
2	50-75%	A bit critical
3	76-100%	Critical
4	>100%	Very Critical

Source: Martopo, 1991

3. Result and Discussion

Correlation. The projected water scarcity level is calculated using CMIP6 data, which has been corrected with historical observation data from 2010–2014 due to limitations in the available data. The individual RMSE values of the models used, namely BCC, CMCC, and MRI before the correction process, are 152.84 mm, 103.17 mm, and 118.25 mm, with a correlation coefficient of 0.43, 0.75, and 0.67, respectively. Meanwhile, the RMSE value of the ensemble is 98.37 mm, with a correlation coefficient of 0.72. After the correction process, the RMSE value of the ensemble model decreased to 68.07 mm, while the correlation coefficient value increased to 0.87. The results of the climate data correction are then used to determine the water supply by calculating the water balance. The comparison between CMIP6 monthly precipitation data and the observation data can be seen in **Figure 1**.

Water Balance. The water balance describes the amount of rainfall and evapotranspiration in an area. **Figure 2** shows a graph of the projected meteorological water balance in each district/city in DIY from 2021–2035 according to the SSP2 and SSP5 scenarios. The results of SSP2 water balance data processing depict almost the same pattern for each district/city, even though the values are different. The lowest values occurred in 2021, 2026, and 2033, while the highest values occurred in 2023, 2030, and 2034. The highest water surplus was in Sleman Regency, with a range of 1034.26-1688.01 mm. The lowest water surplus is in Kulon Progo Regency, with a range of 158.21-717.23 mm. Water balance trends in Sleman Regency, Bantul, Kulon Progo, Gunungkidul, and Yogyakarta City, are 8.66, 0.64, 0.76, 1.19, and 0.82, respectively. The SSP5 scenario shows relatively extreme fluctuations, with the highest water balance values for each district in 2021, 2029, and 2034, while the lowest values occurred in 2023, 2027, and 2031. The highest water surplus was received by Sleman Regency with a range of 941.37-1780.54 mm, followed by Gunungkidul Regency with a range of 474.18-1104.05 mm. The lowest water balance is in Bantul Regency, with a range of 113.49-664.28 mm. Water balance trends in Sleman Regency, Bantul, Kulon Progo, Gunungkidul, and Yogyakarta City, are 1.56, 0.66, 1.20, 0.83, and 1.45, respectively.

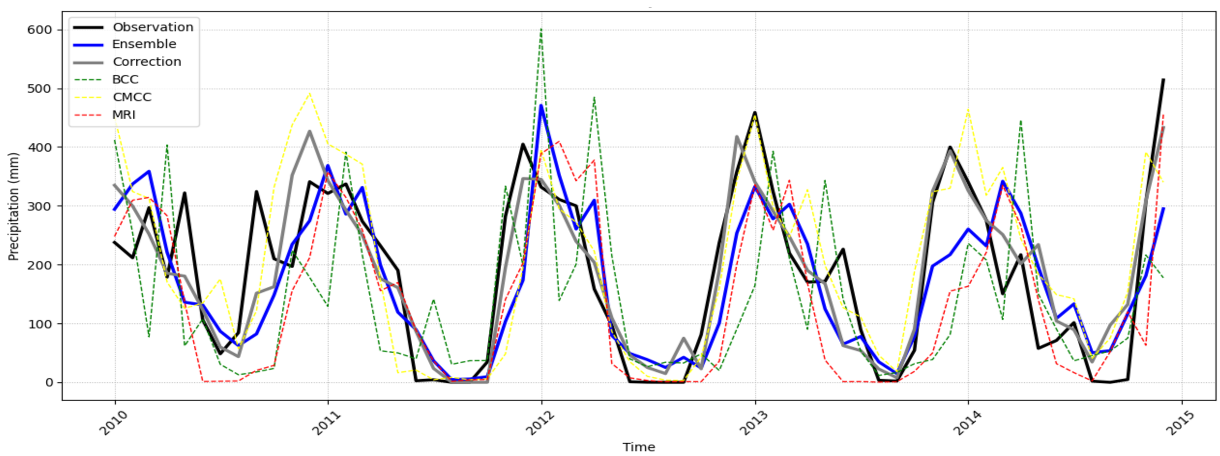

Figure 1 Comparison Graph of Historical Rainfall Data (source: data processing, 2023)

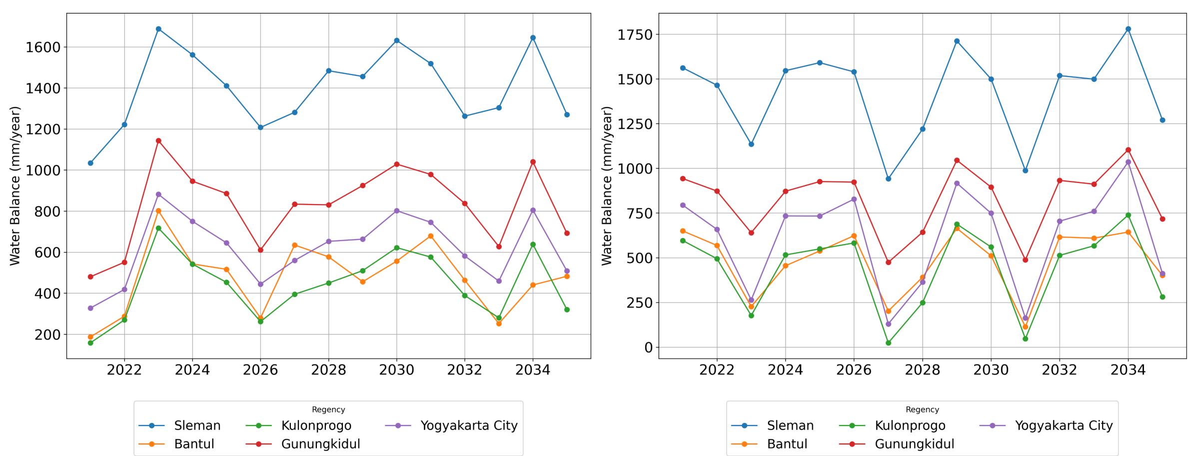

Figure 2 Meteorological Water Balance Projection Graph with SSP2 scenario (left) and SSP5 scenario (right) (source: data processing, 2023)

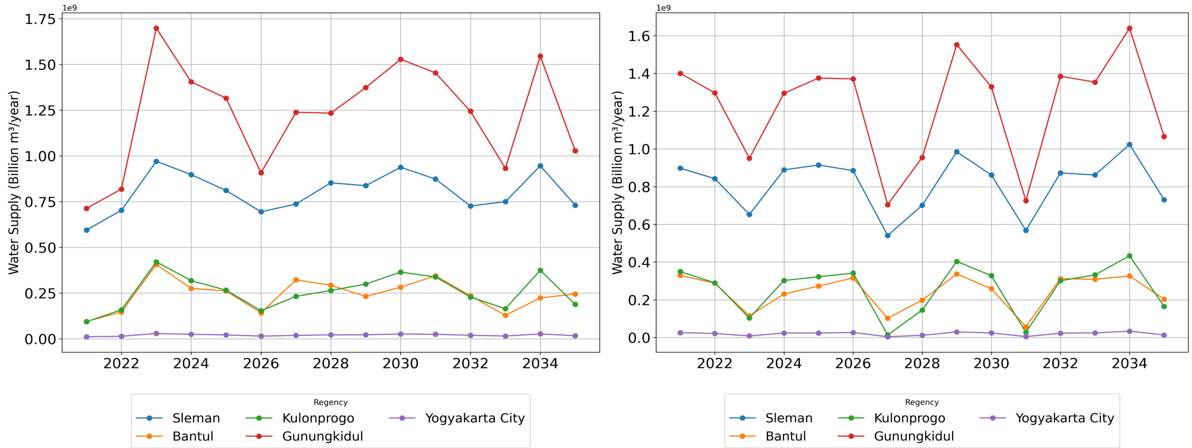

Figure 3 Meteorological Water supply Graph for SSP2 Scenario (left) and SSP5 Scenario (right) in DIY 2021-2035 (source: data processing, 2023)

Table 4 water demands in every regency from 2021 to 2035

Year	Water Demand (m^3)				
	Sleman	Bantul	Kulonprogo	Gunungkidul	Yogyakarta City
2021	490,592,452	375,668,560	250,380,675	160,612,073	163,024,228
2022	491,104,912	376,059,256	250,489,299	160,675,145	164,110,468
2023	491,605,984	376,437,250	250,593,105	160,732,085	165,158,164
2024	492,095,668	376,801,666	250,692,531	160,783,769	166,166,002
2025	492,573,526	377,152,066	250,786,263	160,827,569	167,131,792
2026	493,039,996	377,490,202	250,875,615	160,865,675	168,059,038
2027	493,497,268	377,816,074	250,961,463	160,896,773	168,948,616
2028	493,944,904	378,130,558	251,042,055	160,921,301	169,800,964
2029	494,382,028	378,433,654	251,118,705	160,939,697	170,614,330
2030	494,809,078	378,725,362	251,190,099	160,950,647	171,388,714
2031	495,227,806	379,008,748	251,259,741	160,958,093	172,134,628
2032	495,642,154	379,287,754	251,327,631	160,963,349	172,864,336
2033	496,051,246	379,562,818	251,395,083	160,967,729	173,576,524
2034	496,453,768	379,833,064	251,462,097	160,970,357	176,459,878
2035	496,850,158	380,098,492	251,527,797	160,971,233	174,944,398

Source: data processing, 2023

Water Supply. Figure 3 is a graph of water supply in each district/city in DIY from 2021 to 2035 according to the SSP2 and SSP5 scenarios. According to SSP2 and SSP5, Gunungkidul Regency is the district with the highest amount of meteorological water supply out of the five districts in DIY, with an average amount of water supply of 1,228,894,954 m^3 (SSP2) and 1,226,674,473 m^3 (SSP5). Meanwhile, Yogyakarta City is the city that has the least meteorological water supply with an average amount of water supply of 20,031,002 m^3 (SSP2) and 20,031,461 m^3 (SSP5). According to these projections, the water supply in the SSP5 scenario fluctuates much more than the water supply in the SSP2 scenario.

Water Demands. Table 4 shows projected water demands from 2021–2035. The data shows that Sleman is the area with the highest needs, followed by Bantul and Kulon Progo. Meanwhile, Gunungkidul and Yogyakarta City show water demands in the same range. However, the increase in water demand in Yogyakarta City tends to be faster than the other four regions, indicated by the trend of increasing water demand by 891,987 m^3 every year. Meanwhile, Gunungkidul showed the slowest increase in water demand, with a trend of 24,237 m^3 every year. Projections for district/city water demand in DIY in 2021–2035 indicate that there is increasing water demand, as evidenced by a positive trend during that period. The main factor influencing this water demand is population growth. As the population increases, the need for water will increase.

Table 5 historical & projection data of population in every regency

Year	Sleman	Bantul	Kulonprogo	Gunungkidul	Yogyakarta City	DIY
Historical Data						
2010	1093110	911503	388869	675382	388627	3457491
2011	1113297	927846	393796	682670	392388	3509997
2012	1130140	941414	397639	688135	395134	3552462
2013	1147037	955015	401450	693523	397828	3594853
2014	1163970	968632	405222	698825	400467	3637116
Projection Data						
2021	1134150	991880	438200	748270	375270	3687770
2022	1145850	1000800	440680	749710	375520	3712560
2023	1157290	1009430	443050	751010	375700	3736480
2024	1168470	1017750	445320	752190	375780	3759510
2025	1179380	1025750	447460	753190	375770	3781550
2026	1190030	1033470	449500	754060	375660	3802720
2027	1200470	1040910	451460	754770	375420	3823030
2028	1210690	1048090	453300	755330	375070	3842480
2029	1220670	1055010	455050	755750	375070	3861550
2030	1230420	1061670	456680	756000	373970	3878740
2031	1239980	1068140	458270	756170	373220	3895780
2032	1249440	1074510	459820	756290	372360	3912420
2033	1258780	1080790	461360	756390	371370	3928690
2034	1267970	1086960	462890	756450	370250	3944520
2035	1277020	1093020	464390	756470	369020	3959920

source: DIY in numbers, 2015 & DIY population projections from population census results, 2020

Table 6 domestic, agriculture, and farm water demands in 2035

Regency	Domestic	Agriculture	Farm	Total
Sleman	55,933,476	438,719,328	2,197,354	496,850,158
Bantul	47,874,276	330,422,976	1,801,241	380,098,493
Kulon Progo	20,340,282	229,376,448	1,811,067	251,527,797
Gunungkidul	33,133,386	124,600,032	3,237,815	160,971,233
Yogyakarta City	173,444,496	1,492,992	6,910	174,944,398
DIY	330,725,916	1,124,611,776	9,054,388	1,133,666,165

Source: data processing, 2023

Table 5 shows population data in DIY using historical data and projected data. Population data is used to process domestic water demands. Population can affect domestic water demands. The high population also can cause high domestic water demands. **Table 5** shows that the highest population is in Sleman Regency with a range of 1,000,000 - 1,200,000. In other areas, it does not reach 1,000,000 population. This could be due to the regency's wide area (574.8 km^2). Although Gunungkidul has the largest area (1485.36 km^2), this area has a sparse population. The city of Yogyakarta has the smallest population. However, it is the most densely populated area compared to others because it has the narrowest size (32.5 km^2).

Water demands are obtained from the sum of domestic, agricultural, and livestock water demands. **Table 6** shows the amount of water demand for each sector in every regency for the final year. The agricultural sector has the largest water demand in four out of five regencies. This indicates that agriculture has a dominant role in water use in the region. Water is used in various agricultural processes such as watering, washing, irrigation, and processing agricultural products. Therefore, efficient and sustainable water management is very important in the agricultural context to ensure the availability of sufficient water to meet agricultural needs. Different conditions can be observed in Yogyakarta City, where domestic water demand is much higher than agricultural water demand. This can happen because high domestic demand causes high urban water demand.

Water Scarcity. Table 7 and **Table 8** show the projection of water scarcity levels according to the SSP2 and SSP5 scenarios. Based on these tables, Yogyakarta City has the highest percentage of water scarcity levels compared to other districts. In the SSP2, the peak of meteorological water scarcity occurs in 2021 in each district, while the lowest level of water scarcity occurs in 2023. The highest average water scarcity is in Yogyakarta City with a percentage of 910.42%, while the lowest average scarcity is in Gunungkidul Regency with a percentage of 13.91%. Meanwhile, the SSP5 table shows the highest peak of water scarcity in 2027. The region with the lowest percentage level is Gunungkidul Regency which has an average percentage of scarcity level of 13.96%, while the region with the highest percentage level is Yogyakarta City which has an average of 1240.84%.

Table 7 Projection of meteorological water scarcity level in SSP2 Scenario

Year	Meteorological Water Scarcity with SSP2 Scenario (%)				
	Sleman	Bantul	Kulonprogo	Gunungkidul	Yogyakarta City
2021	82.52	396.33	269.92	22.52	1531.362
2022	69.92	257.98	158.39	19.64	1207.623
2023	50.67	92.65	59.59	9.47	576.261
2024	54.83	137.01	78.94	11.45	681.371
2025	60.75	144.09	94.38	12.22	796.922
2026	71.03	266.51	163.45	17.72	1163.526
2027	67.01	117.42	108.35	12.99	928.710
2028	57.92	129.28	95.20	13.04	800.409
2029	59.07	163.78	84.00	11.72	791.562
2030	52.76	134.33	68.90	10.53	657.535
2031	56.73	110.08	74.39	11.07	710.524
2032	68.28	161.53	110.23	12.94	914.586
2033	66.18	296.94	153.07	17.27	1163.143
2034	52.49	170.28	67.20	10.42	674.558
2035	68.04	155.40	133.86	15.66	1058.267

Source: data processing, 2023

Table 8 Projection of meteorological water scarcity level in SSP5 Scenario

Year	Meteorological Water Scarcity with SSP5 Scenario (%)				
	Sleman	Bantul	Kulonprogo	Gunungkidul	Yogyakarta City
2021	54.63	114.05	71.64	11.47	631.49
2022	58.32	130.44	86.41	12.39	766.69
2023	75.33	327.94	241.68	16.91	1923.84
2024	55.36	163.37	82.91	12.42	696.88
2025	53.86	138.36	77.87	11.69	701.54
2026	55.72	119.48	73.45	11.73	624.66
2027	91.20	369.37	1801.68	22.84	4004.75
2028	70.47	190.80	172.26	16.86	1438.15
2029	50.22	112.40	62.24	10.37	572.40
2030	57.41	146.26	76.55	12.11	704.16
2031	87.22	658.90	908.41	22.19	3257.97
2032	56.78	121.48	83.55	11.62	754.99
2033	57.57	122.90	75.65	11.89	702.65

2034	48.51	116.44	58.05	9.82	524.12
2035	68.05	187.10	152.99	15.10	1308.37

source: data processing, 2023

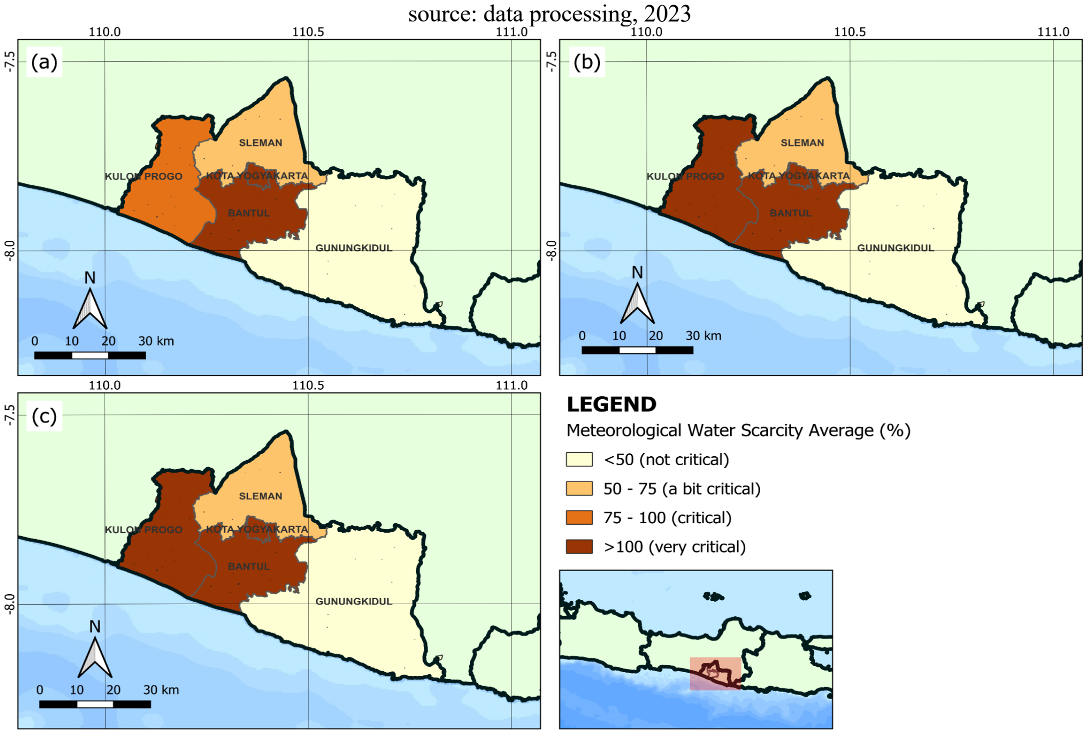

Figure 4. Map of Average Meteorological Water Scarcity Level for DIY, (a) Historical, (b) SSP2, (c) SSP5 (source: analysis results, 2023)

The scarcity level is projected according to the SSP2 and SSP5 scenario. Projection results of SSP5 show a scarcity percentage with similar values but higher than SSP2. Differences in water supply, demand, and scarcity between SSP2 and SSP5 can be caused by differences in the implementation of environmental and water management policies [23]. Calculations for these two scenarios involve the influence of rainfall, evapotranspiration, water balance, and area. In addition, both scenarios take into account future changes in land and water use, including the area of land used for domestic, agricultural, and livestock purposes. According to O'Neill, et al. [14], the SSP5 scenario includes rapid technological change but still relies on fossil fuels as the main energy source. This causes climate change, which triggers an increase in extreme rainfall.

Results of the comparison of water scarcity levels according to SSP2 and SSP5 at DIY show that the SSP2 projection results are closer to the scarcity level in the historical period. Projection results of the SSP5 scenario show a higher scarcity percentage than SSP2. The value of the scarcity level of water in DIY, according to SSP2, is in the range of 28.08%-51.24%, while according to SSP5 is in the range of 43.60%-90.87%. This shows that the SSP2 scenario produces a better level of water scarcity. This condition can occur because SSP2 describes medium challenges to mitigation and adaptation, whereas SSP5 describes the most severe conditions with high mitigation challenges and low adaptation challenges. In other words, the SSP5 scenario is a condition that is best avoided in the future.

Global circulation phenomena such as ENSO and IOD can influence the level of water scarcity. Based on a previous study, the influence of El Nino causes a decrease in rainfall and drought in Indonesia, which can have an impact on reducing water supply, especially the supply of meteorological water [3]. On the other hand, the positive IOD phase tends to reduce rainfall in Indonesia and vice versa when the IOD phase is negative. Therefore, phase rotation in these two phenomena is reflected in the years when the scarcity value reaches its highest and lowest points. Years when scarcity values tend to be low, such as 2021, 2026, and 2033 in SSP2 and 2023, 2027, and 2021 in SSP5, might indicate conditions resembling La Niña and negative IOD phases, which are generally associated with increased rainfall in certain regions [24]. Meanwhile, periods of highest scarcity, such as 2023, 2030, and 2034 in SSP2 and 2021, 2029, and 2034 in SSP5, might correspond to climate conditions similar to positive El Niño and IOD phases, which are typically linked to drier conditions [24].

The average distribution of water scarcity levels in DIY based on historical data (2010–2014), SSP2 scenario (2031–2035), and SSP5 scenario (2031–2035) can be seen in **Figure 4**. The limitations of historical data are due to policy restrictions imposed by the BMKG. We have selected a 5-year correction period (2031-2035) to align the correction database with its projections. Based on this image, there were not many differences found in the results of the data processing carried out, both from historical data, the SSP2 scenario, and the SSP5 scenario. The average level of water scarcity from highest to lowest classification according to historical data (**Figure 4a)**, namely Bantul Regency (196.25%), Yogyakarta City (108.30%), Kulon Progo Regency (77.17%), Sleman Regency (68.53%), and Gunungkidul Regency (21.45%). Meanwhile, no differences were found between the average water scarcity level maps based on the SSP2 and SSP5 scenarios. Average water scarcity level from highest to lowest classification according to SSP2 scenario **(Figure 4b)**, namely Yogyakarta City (904.22%), Bantul Regency (178.84%), Kulon Progo Regency (107.75%), Sleman Regency (62.34%), and Gunungkidul Regency (13.91%). Meanwhile, the average level of water scarcity is from the highest to the lowest classification according to the SSP5 scenario **(Figure 4c)**, namely Yogyakarta City (1240.84%), Kulon Progo Regency (268.35%), Bantul Regency (201.28%), Sleman Regency (62.71%), and Gunungkidul Regency (13.96%). In general, the highest average level of water scarcity is Yogyakarta City, while the lowest average level of water scarcity is Gunungkidul Regency.

The average water scarcity shows different values in each district. **Figure 4** shows a change in the level of scarcity that occurred between the historical and projected periods, namely in Kulon Progo Regency. The average in the SSP2 scenario **(Figure 4b)** and SSP5 scenario **(Figure 4c)** shows that Kulon Progo, Bantul, and Yogyakarta City have a water scarcity level with a very critical classification (>100%), which is higher than the other two regions. Differences in average scarcity between regions can be influenced by several factors, such as differences in population growth rates and the effects of climate change in each region [25]. The influence of population growth on water scarcity can be seen in Yogyakarta City, which has the highest amount of water demand and scarcity. This is associated with the population growth of Yogyakarta City, which is faster than other districts, in line with the characteristics of this region as an urban area [26].

Differences in regional altitude and topography are the climate control factors that can cause differences in evapotranspiration and precipitation, thereby impacting water supply and scarcity [27]. This influence is proven by the relatively high average scarcity in Bantul, especially compared to the Sleman area. Bantul receives a much lower amount of precipitation than Sleman because of its low elevation. Meanwhile, Sleman's higher elevation makes the temperature relatively lower, which contributes to higher precipitation in the area. Apart from that, the topography of Mount Merapi in Sleman also plays a role in creating orographic rain.

The average level of water scarcity in each district in DIY is divided based on the four classes in **Table 3,** with the lowest class (<50%) being in Gunungkidul Regency. **Figure 3** shows that the level of water supply in Gunungkidul is always higher compared to other districts. The Gunungkidul region is the largest compared to other regions, so it has the highest level of meteorological water supply. As confirmed by Santosa [28], Gunungkidul is an area that has high annual average rainfall and excessive amounts of rain, but it only happens in certain months with high intensity. This can cause environmental damage because it triggers landslides and erosion.

The low level of scarcity of meteorological water is inversely proportional to the phenomenon of frequent droughts. Some literature even states that Gunungkidul is a barren area and always lacks water, so it is one of the districts in DIY with the worst threat of drought [29]. The characteristics of the Gunungkidul region are composed of carbonate rock (karst), which have many cavities and are easily dissolved in water so that the surface drainage system tends not to develop compared to subsurface drainage [30]. This is what causes the water to be deep underground and difficult to reach.

Based on the results of research that has been carried out, it can be seen that projections of future water supply and demand are very important for identifying the critical level of water. The SSP2 scenario projection results show a better level of meteorological water scarcity than the scenario projection results of SSP5. Spatially, every district/city in the DIY has different levels of water scarcity due to different regional characteristics. The impact of climate change causes the rainy season and dry season to be unpredictable, so the level of water scarcity is also uncertain. Therefore, the scarcity level of water demands must be taken into account to optimize the use of water resources. This water scarcity level projection can be used as a reference in preparing climate change mitigation efforts.

4. Conclusion and Recommendation

Projections of meteorological water supply of DIY in 2021–2035 show a fluctuating pattern. Meteorological water supply in the SSP2 scenario is relatively more stable than in the SSP5 scenario. Meanwhile, each district's water demands continue to increase, but at different ranges. Meteorological water scarcity level in DIY in 2021-2035, according to SSP5, is around 15-30% higher compared to SSP2. The level of water scarcity in DIY is classified as not critical to somewhat critical (28.08%-51.24%) for the

SSP2 scenario and not critical to critical (44.72%-90.87%) for the SSP5 scenario.

The average meteorological water scarcity levels in DIY show a significant increase from the period 2010–2014 to 2031–2035 under both the SSP2 and SSP5 scenarios. Sleman showed an increase from about 54% to 71% (SSP2) and 80% (SSP5), while Bantul experienced a sharp rise from 115% to 145% (SSP2) and 162% (SSP5). Kulonprogo also showed an increase from 47% to 68% (SSP2) and 73% (SSP5), while Gunungkidul rose from 20–22% to 31% (SSP2) and 39% (SSP5). The city of Yogyakarta showed a surge from about 45% to 57% (SSP2) and 66% (SSP5). Overall, the SSP5 scenario indicates higher levels of water scarcity compared to SSP2 in all regions, with Bantul being the most critical area, followed by Sleman, while Gunungkidul continues to have the lowest level of water scarcity.

This research is still limited to the supply of meteorological water and has not considered other factors, such as regional geomorphological conditions or other hydrological factors. Apart from that, water demands have only been reviewed from certain sectors and do not yet include other sectors, such as the industrial, fisheries, and tourism sectors. Therefore, this research can be developed further by considering these things so that it is more comprehensive and representative.

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