Abstract. Java is the most populous island with the largest percentage of rice fields in Indonesia. However, rice fields in Java Island often experience water shortages, so an analysis of the potential water availability for irrigation in Java is required. This research aims to analyze water’s potential to meet irrigation water needs in each catchment area in Java. In this research, the potential for irrigation water in Java is calculated based on the balance of water availability between water availability and DMI and Irrigation water needs. This research is divided into two parts: (1) analysis of water availability using the WFLOW hydrological simulation; and (2) water demand analysis based on population statistical data. Based on this research, it can be concluded that the water balance between water resources and irrigation water needs in Java is still in the surplus category, even though there are deficits in several catchment areas (WS): in the Kepulauan Seribu, Wiso Gelis, and Welang Rejoso WS. WS with the most water availability is generally located in wide (WS) areas, while several WS with abundant water needs is generally located in WS with the densest population. According to The Central Bureau of Statistics (BPS), the agricultural area in Java has decreased by an average of 20 thousand hectares per year, so that the demand for irrigation water on the island of Java will also decrease. Consequently, the excess water potential in Java Island needs to be allocated to meet the needs of DMI, which are increasing every year. In addition, the results also show that the development of irrigation areas in the future should be focused on large (WS) areas that have the potential for significant amounts of irrigation water.

1. Introduction

Use has increased beyond the natural replenishing rate, resulting in water scarcity in many parts of the world (York et al., 2009). Irrigated agriculture is the dominant water user, accounted for about 80% of global water use (Molden, 2007).

The cost of the irregular distribution of worldwide water resources is evident. Even in parts of the planet where water resources are abundant, the problems of availability or scarcity are common due to water mismanagement practices and anthropic activities (Aparicio, 2018). Water resources assessment is the key to the analysis of catchment management (Wurbs, 2005). In this regard, a hydrological model is a tool that could be used to support better water resources management.

The water supply is calculated using a hydrological method, whereas the water demands are calculated based on each sector’s water demand and environmental water demand. There are several standard hydrological models: Soil and Water Assessment Tool (SWAT), National Rural Electric Cooperative Association (NRECA), (FJ. Mock, 1973), and WFLOW. The SWAT model uses parameters such as land-use change, global change, and land conservation techniques (Neitsch et al., 2011). The NRECA uses an index of the soil moisture storage capacity, discharge rate from groundwater storage to a stream, daily rainfall data, and potential evapotranspiration data (Komariah et al., 2019). The Mock model uses daily rainfall data, evapotranspiration, and hydrologic watershed characteristics. WFLOW is Deltares solution to model hydrological processes, allowing users to modify precipitation, interception, snow accumulation and melt, evapotranspiration, soil water, surface water and groundwater recharge in a fully distributed environment (Schellekens, 2019). However, this research does not include water availability from deep groundwater due to the tools’ limitation. Radhika et al. (2017) already used a similar method to calculate water availability in Indonesia. However, that research did not specifically analyze the water balance with the scale of river basins (with this after referred to as Wilayah Sungai (WS)) even though Indonesia’s water management is divided based on its WS. The irrigation water potential research in Java was limited to only the scale of irrigation areas (Faishal et al., 2013; Tampubolon et al., 2017) or watershed areas (Rahmawan, et al., 2016; Taufik, et al., 2019). The water balance calculation for Java has been published by Hidayat et al. (2018), but not in the scale of a river basin.

This study aims to analyze water potential in Java for irrigation water needs in every river basin WS). The analysis of water availability was performed using WFLOW, and the
calculation of water needs used the population data from the Central Bureau of Statistics of Indonesia for every WS in Indonesia to determine the available water for irrigation in each WS.

Indonesia is the largest archipelago in the world, with more than 17,000 islands. Five main islands in Indonesia, from the largest to the smallest, are Kalimantan, Sumatera, Papua, Sulawesi, and Java. Even though Java is the smallest island among the five, Java is the most densely-populated island in Indonesia, with more than 50% of the Indonesian population. Indonesia's water management is divided by their respective River Basins (Wilayah Sungai, with this after referred by WS). Based on the Ministry of Public Works and Housing (2015), Indonesia is divided into 131 river basin territories (WS). Java itself is divided into 24 river basins (WS). Out of 24, 4 are regarded as very strategically nationally: WS Citarum, WS Iratunseluna, WS Serayu Bogowonto, and WS Brantas. In addition, 6 of the 24 are included in the Cross Provincial WS and 11 WS Cross District / City WS (Fig. 1). Due to its population, Java Island has the largest paddy field area with the highest irrigation water demand (Central Bureau of Statistics, 2019). Approximately 84% of the Java paddy fields use irrigation water, with the rest use rainwater (Asian Development Bank, 2016). While Java acts as the center of Indonesian food production, it only has 4% of Indonesian water resources. Due to that, water availability analysis is very important for irrigation planning.

The TRMM satellite rain data covering all Indonesia regions was used because the accuracy is satisfactory to be used for meteorological analysis (Vernimmen et al., 2012). The data were collected from Jan 1, 2003, to Dec 31, 2018. Evapotranspiration data was obtained from the CGIAR satellite. This potential evapotranspiration value results from the average climate from the last 50 years in the region. The map used is based on NASA SRTM data with a resolution of 90m. By using QGIS software, other data, including river flow maps, watershed / sub-watershed, and outlet points, could be extracted. The land use map used is based on data from Bakosurtanal (2007). It could be classified into six general land-use classes: forest, irrigation agriculture, rainfed agriculture, grassland/bush, paved area / built area, and water body. The map of soil types used is based on FAO (2007) data with a resolution of 1: 5,000,000. The map of soil types shown is classified into clay, loam, clayey loam, sandy loam, loamy sand, and sandy loam. The discharge data was calibrated using data from 7 river gauging stations (hereby after referred as PDA). The criteria for the chosen PDAs were:

1. Good data quality;
2. Data Availability (2003-2018);
3. The variation of soil types and land uses

List and Map of PDA used are presented in the following Table 1 and Figure 2.

The data’s primary source to analyze the urban and household water demand was from The Central Bureau of Statistics (Badan Pusat Statistik) in 2018. The domestic, urban, and industrial water demand was calculated by using Indonesian National Standard (Standar Nasional Indonesia, 2018).
with this after referred to as SNI) SNI 6728.1-2015 (Badan Standardisasi Nasional, 2015). The population and average water use per capita data were used to calculate the household and urban water demand. Additionally, to calculate the industrial water demand, the data regarding the number of regency/industries, the number of regencies / industrial workers, and the average industrial water demand divided by industry type were used.

The main source of the spatial data for irrigation water demand analysis was obtained from PUSDATIN (2014). However, the quality of the data was not adequate due to the overlapping irrigations in several WSs. Hence, the data was updated with the river basin (catchment) plan reports' data to obtain the most up-to-date data.

Table 1. List of PDAs used for calibration

| No | PDA                      |
|----|--------------------------|
| 1  | Cimanuk-Wado             |
| 2  | Cisadane-Batubeulah      |
| 3  | Citanduy-Cirahong        |
| 4  | Citarum-Nanjung          |
| 5  | B.Solo-Jurug             |
| 6  | Ciujung-Rangkasbitung    |
| 7  | Cimanuk-Leuw Daun        |

2.Method 
Water Availability Analysis

The surface water availability is calculated using the WFLOW model calibrated with river flow discharge data from the river gauging station. The water availability of each river basin in Indonesia was expressed as the average monthly flow height, the dependable flow of Q80%, and the dependable flow of Q90%. The steps for the calculation of surface water availability in this research are:
1) Water discharge data collection
   • Collection of daily river flow data;
   • Choosing the appropriate PDA for water discharge data to be used for model calibration
2) Rain and evapotranspiration data collection
   • TRMM satellite rainfall data was collected from 2002 – 2018;
   • The collection of evapotranspiration data from CGIAR satellites (2009)
3) Soil types and land use data collection
   • The soil type map was obtained from FAO Digital Soil Map of the World (2007);
   • The land use map was collected from BAKOSURTANAL (2007)
4) WFLOW Modeling, Calibration, and Verification Steps
   • Build a WFLOW model for Java Island;
   • Perform model calibration using data from selected PDA’s discharge data;
Industrial Water Demand

Water in industrial fields was mainly used for production activities, which include the use to process raw materials and other industrial support demands (Gunawan, 2008). According to Standar Nasional Indonesia (SNI) 6728.1-2015, to get a precise calculation of industrial water demand, data regarding total worker, industrial area, and industrial type are needed. However, if the data are limited, the estimation could be made by using water usage predictions.

The industrial water demand was assumed to be 30% - 70% of the total household and urban water demand. Due to the limited data of industries in Indonesia, the industrial area classification was adapted from the national spatial planning approach (Indonesian Government decree no. 26/2008). Based on the decree, as mentioned above, three types of activity center in Indonesia depend on their scale. The largest activity center is called National Activity Center (Pusat Kegiatan Nasional, PKN). PKN is an urban area that is intended to provide international, national, and provincial scale demand. In a smaller scale, Regional Activity Center (Pusat Kegiatan Wilayah-PKW) is an urban area that has a function to serve provincial or several district/city scale activities. Lastly, the smallest area is named Local Activity Center (Pusat Kegiatan Lokal, PKL), which has an activity in the district/subdistrict scale.

Based on the classification, it is assumed that the amount of industrial water demand for the regions in the PKN group is higher than both the PKW and PKL areas. Areas that are included in the PKN category are assumed to have an industry water demand value of 50% of the total water household demand, while areas that are in the PKW category are assumed to have an industry water demand value of 40% of the total water demand of that a household. If an area is in the PKL category, then the region is assumed to have an industrial water demand value of 30% of the total household water demand.

Irrigation Water Demand

Irrigation water demands are calculated based on KP01 Irrigation Planning Guidelines Ministry of Public Work and Housing (2013). The Demand is affected by planting area, planting schedules, reference evapotranspiration, effective rain, soil type, and irrigation channel efficiency. The calculation of irrigation water needs is then compared with data on water withdrawal for irrigation from dams.

Irrigation water is used for agriculture, livestock, and fisheries. However, in this research, the calculation is limited only to agricultural use. Irrigation water demands are influenced by several factors, namely the Demand for land preparation (IR), the Demand for plant water consumption (Etc), percolation (P), the water demand to replace the water layer (RW), effective rainfall (ER), water efficiency irrigation (IE) and irrigated land area (A). The amount of irrigation water demand is calculated based on the following equation:

\[
IG = \frac{(Etc + IR + RW + P − ER)}{IE} \times A
\]

Where:
IG = Irrigation water demand, (m³)
Etc = Consumptive water requirements, (mm/day)
IR = Water requirements for land preparation, (mm/day)
Water balance illustrates the difference between water availability and water demand. The amount of available water was obtained from calculating the dependable flow of Q80%, while the value of water demand is obtained from a total of various water uses, including household, urban, industrial use, and irrigation. The difference between water availability and water demand can be classified into two classes: deficit and surplus. If the water availability is less than the water demand, it is classified as a deficit. On the other hand, if the value of water availability is greater than the value of water demand, then it is classified as surplus.

### 3. Results and Discussion

#### Water Availability

**WFLOW Modelling and Calibration**

The WFLOW discharge model was compared to the observed discharge at the river gauging station (PDA). If the discharge value generated by WFLOW greatly differs from the observation data, the WFLOW parameters were adjusted. The flexible variables include first zone capacity and first zone minimum capacity, canopy gap fraction, first zone ksatVer, Infill capsoil, N & N_River, ThetaS and ThetaR, and Max Canopy Storage. The parameter was then modified to see the extent of its effect on the WFLOW results. After the discharge result obtained from WFLOW is similar to the observed discharge, the calibrated WFLOW result is obtained.

Calibration on Java Island was carried out using 6 (six) River gauging stations in which the data had been statistically tested (Fig. 3). The alleged water posts are Solo-Jurug PDA, Citarum-Nanjung PDA, Cimanuk - Leuwidaun PDA, Cimanuk - Wado PDA, Ciujung - Rangkasbitung PDA, and Serayu-Banjarnegara PDA. The calibration result is presented in Table 3-Table 7.

The calibration results show that the discharge model is good and represents the low flow rates, and can be used to calculate water availability.

In general, the average water availability in Java is 5.6 thousand m$^3$/s or equivalent to 175.7 billion m$^3$/y. 80% dependable water availability is 3.8 thousand m$^3$/s or equivalent to 118.7 billion m$^3$/y. The highest potential is the Bengawan Solo WS with 21.9 thousand m$^3$/s water available, while the lowest potential is the WS Kepulauan Seribu with 0.26 m$^3$/s. The following table presents the water availability in Java. The value obtained in this research is comparable to the research from Radhika et al. (2017). Curk et al. (2016) stated that the most important factor affecting water

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**Table 3. Comparison of WFLOW Simulation Results with Observation Data in Citarum – Nanjung PDA**

|                  | Throughout the year | Dry Season (April-September) | Rainy Season (October-March) | 3 Dry Months (July-September) |
|------------------|---------------------|-------------------------------|-------------------------------|-------------------------------|
| R2               | 91%                 | 94%                           | 87%                           | 98%                           |
| MAE              | 23.04               | 14.13                         | 31.76                         | 8.21                          |
| MSE              | 1002.23             | 409.04                        | 1583.31                       | 165.78                        |
| MAPE             | 0.31                | 0.33                          | 0.28                          | 0.41                          |
| RMSE             | 31.66               | 20.22                         | 39.79                         | 12.88                         |

Source: Result of Analysis (2019)
availability is climate. Because of the tropical climate, Java has a relatively high rainfall. This makes Java into an area with a high potential for irrigation water. Besides that, the area of the respective WS is also affecting the irrigation potential. The larger the area, the more water could be contained in the WS.

**Water Demand**

**Domestic, Municipal and Industry (DMI) Water Demand**

The water demand is constrained by administrative boundaries, which were then overlaid into river basin boundaries. The water needs for DMI is calculated based on the population in areas. The calculation results show that Java's water demand for the household is 260 m³/s while urban water demand is 77.9 m³/s. Additionally, the industrial water demand is 135 m³/s, making the total water demand for Java island 472.5 m³/s. The province with the highest water demand is West Java with 153.7 m³/s, followed by East Java with 124.7 m³/s. The water demand in DKI Jakarta, the capital city of Indonesia, is 33.05 m³/s. The water demand of Java's urban and industrial households are presented in Table 9.

The value for industrial water demand is similar to that of minimal industrial water use per year in Java based on the Asian Development Bank (2016) research, which is 137.86...
Table 6. Comparison of WFLOW Simulation Results with Observation Data in Serayu-Banjarnegara PDA

|               | Throughout the year | Dry Season (April-September) | Rainy Season (October-March) | 3 Dry Months (July-September) |
|---------------|---------------------|------------------------------|------------------------------|-------------------------------|
| R2           | 73%                 | 78%                          | 58%                          | 36%                           |
| Bias         | 4.76                | 3.32                         | 6.15                         | 1.36                          |
| MAE          | 14.74               | 9.67                         | 19.63                        | 6.91                          |
| MSE          | 418.96              | 269.58                       | 563.00                       | 215.22                        |
| MAPE         | 0.40                | 0.37                         | 0.43                         | 0.41                          |
| RMSE         | 20.46               | 16.41                        | 23.72                        | 14.67                         |
| (mean sim - mean obs)/mean obs | 0.09 | 0.11 | 0.11 | 0.089 |

Source: Results of Analysis (2019)

Table 7. Comparison of WFLOW Simulation Results with Observation Data in Solo – Jurug PDA

|               | Throughout the year | Dry Season (April-September) | Rainy Season (October-March) | 3 Dry Months (July-September) |
|---------------|---------------------|------------------------------|------------------------------|-------------------------------|
| R2           | 84%                 | 91%                          | 78%                          | 84%                           |
| Bias         | 35.60               | 22.84                        | 48.16                        | 9.90                          |
| MAE          | 50.49               | 30.90                        | 69.78                        | 16.49                         |
| MSE          | 5061.56             | 2080.25                      | 7998.37                      | 607.51                        |
| MAPE         | 0.78                | 0.73                         | 0.84                         | 0.77                          |
| RMSE         | 71.14               | 45.60                        | 89.43                        | 24.64                         |
| (mean sim - mean obs)/mean obs | 0.32 | 0.31 | 0.31 | 0.31 |

Source: Results of Analysis (2019)

Table 8. Java Island Water Availability.

| River Basin (WS)       | WS Area (km²) | Average Discharge | Dependable flow 80% |
|------------------------|---------------|-------------------|---------------------|
| WS CIBALIUNG-CISAWARNA | 2,594.32      | 146.32            | 4,614               |
| WS CILIMAN-CIBUNGUR    | 1,738.27      | 75.99             | 2,396               |
| WS CIDANAU-CIJUNG-CIDURIAN | 4,147.53 | 202.60            | 6,389               |
| WS KEPULAUAN SERIBU    | 8.75          | 0.26              | 8                   |
| WS CILIWUNG-CISADANE   | 5,267.84      | 201.63            | 6,359               |
| WS CITARUM             | 11,321.79     | 454.37            | 14,329              |
| WS CISADEA-CIBARENO    | 6,806.24      | 402.55            | 12,695              |
| WS CIWULAN CILAKI      | 5,372.33      | 256.61            | 8,092               |
| WS CUMANUK-CISANGGARUNG| 7,703.75      | 542.71            | 17,115              |
| WS CITANDUY            | 4,506.99      | 250.64            | 7,904               |
| WS PEMALI-COMAL        | 4,831.24      | 230.59            | 7,272               |
| WS PEMALI-COMAL        | 7,370.57      | 417.22            | 13,157              |
| WS BODRI-KUTO          | 1,646.78      | 68.01             | 2,145               |
| WS KEPULAUAN KARIMUNJAWA | 42.22       | 1.33              | 42                  |
| WS WISO-GENIS          | 665.29        | 18.44             | 582                 |
| WS JRATUNSELUNA        | 9,073.57      | 243.05            | 7,665               |
| WS PROGO-OPAK-SERANG   | 4,878.05      | 211.51            | 6,670               |
| WS BENGAWAN SOLO       | 19,697.18     | 693.93            | 21,884              |
| WS BRANTAS             | 14,251.46     | 579.77            | 18,284              |
| WS MADURA-BAWEAN       | 5,615.27      | 91.27             | 2,878               |
| WS WELANG-REJOSO       | 2,189.72      | 72.87             | 2,298               |
| WS BONDOYUDO-BEDADUNG  | 5,343.37      | 200.79            | 6,332               |
| WS PEKALEN-SAMPEAN     | 3,933.43      | 106.95            | 3,373               |
| WS BARU-BAJULMATI      | 3,692.17      | 102.53            | 3,233               |
| JAVA ISLAND            | 132,698.13    | 5,571.94          | 175,717             |

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### Table 9. Household, Urban, and Industrial Water Demand of all Provinces in Java Island

| Province       | Population 2018 (Life) | Household | Urban | Industrial | Total |
|----------------|------------------------|-----------|-------|------------|-------|
| DKI Jakarta    | 10,458,200             | 18.16     | 5.45  | 9.44       | 33.05 |
| Jawa Barat     | 48,645,600             | 84.45     | 25.34 | 43.92      | 153.71|
| Jawa Tengah    | 34,473,600             | 59.85     | 17.96 | 31.12      | 108.93|
| DIYogyakarta   | 3,800,800              | 6.60      | 1.98  | 3.43       | 12.01 |
| Jawa Timur     | 39,470,800             | 68.53     | 20.56 | 35.63      | 124.72|
| Banten         | 12,678,600             | 22.01     | 6.60  | 11.45      | 40.06 |
| Java Island    | 149,527,600            | 259.60    | 77.88 | 134.99     | 472.47|

### Table 10. Household, Urban, and Industrial Water Demand of the Java Island based on River Basins

| WS Name                  | DMI Water Demand (m³/s) |
|--------------------------|-------------------------|
| WS CIBALIUNG-CISAWARNA   | 10.97                   |
| WS CILIMAN-CIBUNGUR      | 7.42                    |
| WS CIDANAU-CIJUJUNG-CIDURIAN | 18.39                |
| WS KEPULAUAN SERIBU      | 0.51                    |
| WS CILIWUNG-CISADANE     | 51.51                   |
| WS CITARUM               | 46.81                   |
| WS CISADEA-CIBARENO      | 28.14                   |
| WS CIWULAN CILAKI        | 22.24                   |
| WS CIMANUK-CISANGGARUNG  | 31.10                   |
| WS CITANDUY              | 16.91                   |
| WS PEMALI-COMAL          | 15.31                   |
| WS SERAYU BOWONGWONTO    | 23.38                   |
| WS BODRI-KUTO            | 5.21                    |
| WS KEPULAUAN KARIMUNJAWA | 0.15                    |
| WS WISO-GELIS            | 2.88                    |
| WS J RATUNSELUNA         | 28.05                   |
| WS PROGO-OPAK-SERANG     | 17.23                   |
| WS BENGAWAN SOLO         | 55.27                   |
| WS BRANTAS               | 37.06                   |
| WS MADURA-BAWEAN         | 14.61                   |
| WS WELANG-REJOSO         | 5.69                    |
| WS BONDOYUDO-BEDADUNG   | 13.88                   |
| WS PEKALEN-SAMPEAN       | 10.21                   |
| WS BARU-BAJULMATI        | 9.59                    |
| JAVA ISLAND              | 472.50                  |

### Table 11. Average yearly irrigation water needs

| WS Name                  | Irrigation Area (Ha) | Irrigation Water Demand (m³/s) |
|--------------------------|----------------------|--------------------------------|
| WS CIBALIUNG-CISAWARNA   | 22,240               | 14.27                          |
| WS CILIMAN-CIBUNGUR      | 17,459               | 13.07                          |
| WS CIDANAU-CIJUJUNG-CIDURIAN | 54,910             | 41.69                          |
| WS KEPULAUAN SERIBU      | -                    | -                             |
| WS CILIWUNG-CISADANE     | 81,478               | 58.53                          |
| WS CITARUM               | 295,503              | 232.71                         |
| WS CISADEA-CIBARENO      | 79,353               | 60.57                          |
| WS CIWULAN CILAKI        | 73,882               | 54.67                          |
| WS CIMANUK-CISANGGARUNG  | 213,322              | 164.80                         |
| WS CITANDUY              | 129,283              | 97.61                          |
| WS PEMALI-COMAL          | 75,423               | 57.31                          |
| WS SERAYU BOWONGWONTO    | 128,272              | 95.47                          |
| WS KEPULAUAN KARIMUNJAWA | 153,866              | 116.70                         |
| WS WISO-GELIS            | 66,690               | 48.02                          |
| WS J RATUNSELUNA         | 13,004               | 8.93                           |
| WS PROGO-OPAK-SERANG     | 153,866              | 116.70                         |
| WS BENGAWAN SOLO         | 387,982              | 290.04                         |
| WS BRANTAS               | 307,253              | 211.14                         |
| WS MADURA-BAWEAN         | 25,202               | 17.01                          |
| WS WELANG-REJOSO         | 66,690               | 48.02                          |
| WS BONDOYUDO-BEDADUNG   | 98,323               | 76.36                          |
| WS PEKALEN-SAMPEAN       | 55,247               | 40.61                          |
| WS BARU-BAJULMATI        | 58,568               | 45.00                          |
| JAVA ISLAND              | 2,468,515            | 1,838.35                       |
Overall, the water used for household, urban, and industry in Java is 472.47 m³/y (approximately 14,900 m³/year). This value itself is higher than Italy, Germany, Spain, Poland, Netherlands, Sweden, and many, if not all, countries in Europe. Italy itself has the highest water consumption, with approximately 5,200 m³/y (EurEau, 2017).

Based on the DMI water needs calculation, the highest water consumption occurred in WS, which has metropolitan areas (e.g., WS Ciliwung, WS Citarum, and WS Bengawan Solo). The same conclusion was stated by Curk et al. (2016), which said that water consumption tends to be the highest in metropolitan areas.

Due to the population’s projection, the water demand for domestic and urban use will also increase. The rise is expected to be 40% for domestic water use and more than 100% for Indonesia’s industrial water use in 2030 (Asian Development Bank, 2016).

| River Basin                        | Water Availability (m³/s) | Water Demand (m³/s) | Water Balance (m³/s) |
|------------------------------------|---------------------------|---------------------|----------------------|
|                                    |                           | DUI                 | Irrigation           | Total                |                      |
| WS CIBALIUNG-CISAWARNA             | 101.49                    | 10.97               | 14.27                | 25.24                | 76.25                |
| WS CILIMAN-CIBUNGUR                | 52.53                     | 7.42                | 13.07                | 20.48                | 32.05                |
| WS CIDANAU-CIUJUNG-CIDURIAN         | 149.48                    | 18.39               | 41.69                | 60.07                | 89.41                |
| WS KEPULAUAN SERIBU                | 0.07                      | 0.51                |                      | 0.51                 | -0.44                |
| WS CILIWUNG-CISADANE               | 131.55                    | 51.51               | 58.53                | 110.04               | 21.51                |
| WS CITARUM                         | 304.44                    | 46.81               | 232.71               | 279.53               | 24.91                |
| WS CISADEA-CIBARENO                | 291.03                    | 28.14               | 60.57                | 88.71                | 202.32               |
| WS CIWULAN CILAKI                  | 177.26                    | 22.24               | 54.67                | 76.91                | 100.35               |
| WS CIMANUK-CISANGGARUNG            | 380.32                    | 31.10               | 164.80               | 195.90               | 184.42               |
| WS CITANDUY                        | 179.29                    | 16.91               | 57.31                | 74.22                | 105.07               |
| WS PEMALI-COMAL                    | 167.50                    | 15.31               | 97.61                | 112.91               | 54.59                |
| WS PEMALI-COMAL                    | 290.04                    | 15.31               | 97.61                | 112.91               | 177.13               |
| WS BODRI-KUTO                      | 44.90                     | 5.21                | 27.40                | 32.61                | 12.29                |
| WS KEPULAUAN KARIMUNJAWA           | 0.83                      | 0.15                |                      | 0.15                 | 0.68                 |
| WS WISO-GERIS                      | 11.24                     | 2.88                | 8.93                 | 11.81                | -0.57                |
| WS JRATUNSELUNA                    | 152.64                    | 28.05               | 116.70               | 144.75               | 7.89                 |
| WS PROGO-OPAK-SERANG               | 143.01                    | 17.23               | 66.45                | 83.68                | 59.33                |
| WS BENGAWAN SOLO                   | 455.71                    | 55.27               | 290.04               | 345.31               | 110.40               |
| WS BRANTAS                         | 375.19                    | 37.06               | 211.14               | 248.20               | 126.99               |
| WS MADURA-BAWEEN                   | 52.21                     | 14.61               | 17.01                | 31.62                | 20.59                |
| WS WELANG-REJOSO                   | 47.42                     | 5.69                | 48.02                | 53.71                | -6.29                |
| WS BONDOYUDO-BEDADUNG             | 126.35                    | 13.88               | 76.36                | 90.24                | 36.11                |
| WS PEKALEN-SAMPEAN                 | 65.96                     | 10.21               | 40.61                | 50.82                | 15.14                |
| WS BARU-BAJULMATI                  | 64.43                     | 9.59                | 45.00                | 54.59                | 9.84                 |
| JAVA ISLAND                        | 3,764.89                  | 464.43              | 1,840.49             | 2,304.92             | 1,459.97             |
Irrigation Water Demand Analysis

Java Island has an irrigation area of 2,047 million hectares with an irrigation water demand of 1.52 thousand m³/s (Table 11). The water demand in WS Brantas, with an irrigation area of 325 thousand hectares, is the highest, with an average water demand of 223 m³/s. The second and the third largest irrigation area is in WS Jatunseluana with an irrigation area of 257 thousand ha and an average water demand of 195 m³/s and Cimanuk-Cisanggarung WS with an irrigation area of 176 thousand ha and an average water requirement of 136 m³/s.

In total, the water requirement for irrigation in Java is 1.518 m³/s or 47.872 million m³/y. Americans used only one-third of 163.666 million m³/y water for their irrigation in 2015 (Dieter et al., 2018). Agricultural land in Java will be challenging to maintain due to the continuous physical development that continues to grow. Based on the Asian Development Bank (2016) data, the area of paddy fields continues to decline with a reduction rate of more than 20 thousand hectares per year. Hence, the demand for irrigation water on Java Island will also decrease even more (Figure 4).

In contrast, the paddy field is expected to grow in Sumatera and Sulawesi (Asian Development Bank, 2016). Meanwhile, according to the Central Bureau of Statistics (2015), the yearly population growth in Java is 0.953%. Consequently, the projected irrigation water needs in 40 years are only 717.28 m³/s while DMI water needs increase by approximately 50% (from 472.47 m³/s to 678.72 m³/s). The decrease in irrigation water needs contradicts the global trend, which tends to increase caused by the needs to increase food production (Zou et al., 2018; Huang and Yin, 2017; Li et al., 2020).

Water Balance in Java

The water balance in Java island is still a surplus. The conclusion is inline with the previous result from Radhika et al. (2013). Based on that research, there was no WS with a deficit status in Java in 2010. However, in this research, there were deficits in several river basins, namely in WS Kepulauan Seribu, WS Wiso-Gelis, and WS Welang-Rejoso (Table 11). Compared to water scarcity status globally, approximately 40% of rural people live in water-scarcity river basins, including regions like the Middle East, Indian sub-continent, and northeastern China (FAO, 2011), Java is still in the safe water balance status. Likely, Sub-Saharan Africa and the Americas are also still in a low water stress status.

In 40 years from now, the water surplus in Java is projected to be 2,368.69 m³/s compared to 1,459.97 m³/s. This is mainly due to the decrease in the paddy field area (Asian Development Bank, 2016). Based on this scenario, the water surplus needs to be focused on the water use for DMI in the future.

On the other side, according to the global trend, the water needs for irrigation will increase due to the need for increased food production. The irrigation in Java can be expanded further because the water is still in a surplus. The irrigation area should be expanded in the WS with the most abundant water resources, namely WS, that have large areas.

The result above is quite different from arid regions, which have low rainfall (Li et al., 2020). Countries in arid regions focus on water use efficiency for irrigation, either by using technology or planting pattern optimization (Seckler et al., 1998; Wang et al., 2019) and water resource optimization by recycling the water (Huang & Yin, 2017). In Java, however, the water resource problems are solved by focusing on water resource optimization by improving the planning to expand the irrigation field area. (Li et al., 2020) suggest inter-basins water subsidy as a solution to solve uneven water distribution.

5. Conclusion

The average water availability in Java is 5.6 thousand m³/s or equivalent to 175.7 billion m³/y. Q80% dependable flow is 3.8 thousand m³/s or equivalent to 118.7 billion m³/year. Java Island household demand is 260 m³/s while urban water demand is 77.9 m³/s, and industrial water demand is 135 m³/s. Java Island has an irrigation area of 2,468,515 ha with an irrigation water requirement of 1838.4 m³/ s. The highest water demand is in WS Brantas, with an area of 325 thousand hectares of irrigation and an average water requirement of 223 m³/s. Overall, there is a surplus of water in Java even though several river basins have a water deficit, namely in WS Kepulauan Seribu, WS Wiso Gelsi, and WS Welang Rejoso. The WSs with the most abundant water resources are WSs with large areas, whereas WSs with the most considerable amount of water use are WSs with high population density. The water in Java is projected to have an enormous surplus in the future due to the land change from the paddy field into buildings Asian Development Bank (2016). The water surplus needs to be focused on the water use for DMI, increasing population growth. Besides that, if the irrigation area were to be developed, the development should take place in WSs with a large area to ensure that it has sufficient water resources.

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