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RESEARCH ARTICLE

Water Balance Supporting the Irrigation Water Demand in Java Island, Indonesia

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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 balance 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.

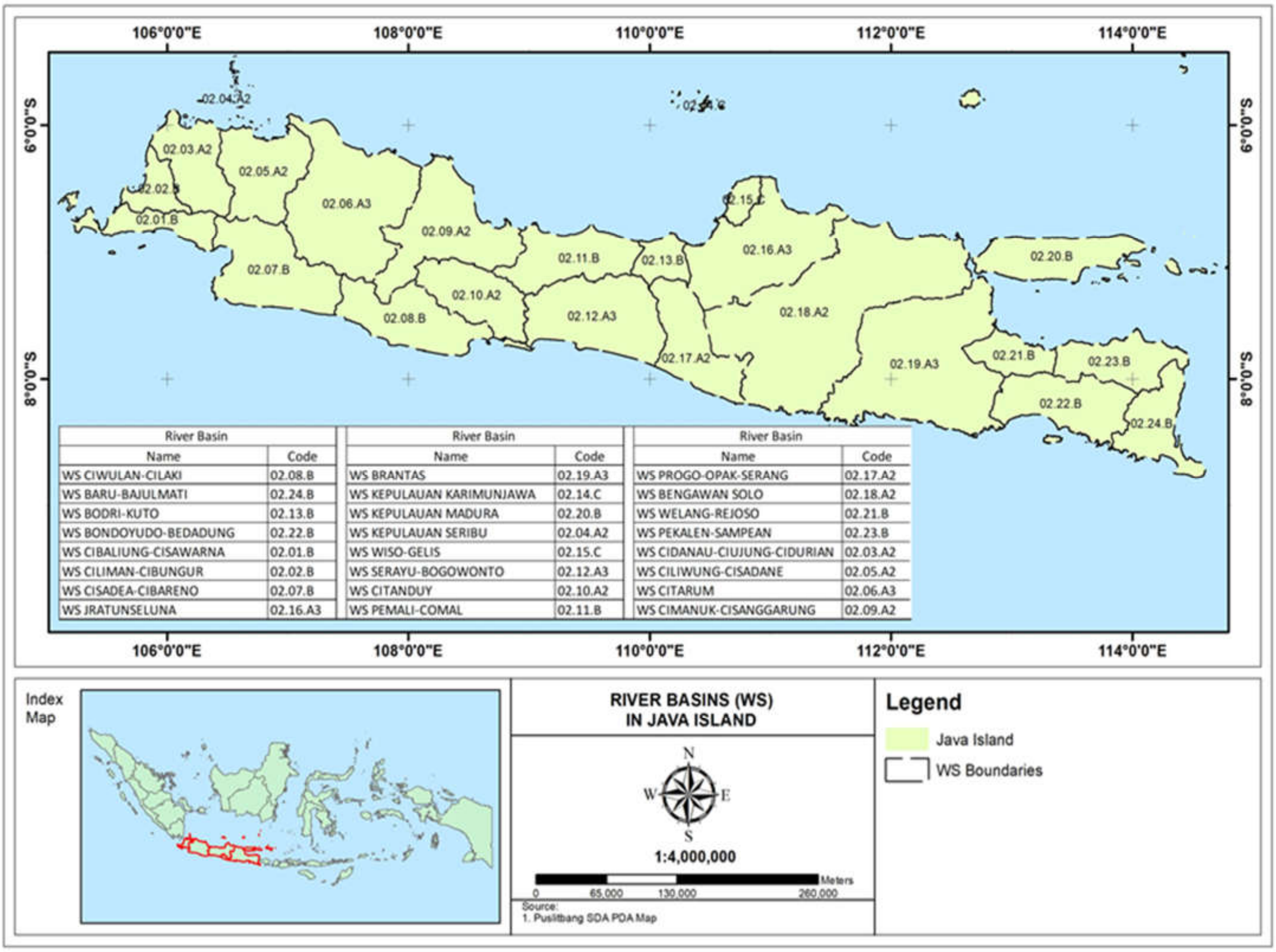
Indonesia is the largest archipelago in the world, with more than 17.000 islands. Five main islands in Indonesia, from the largest to the smallest, are Kalimantan, Sumatera, Papua, Sulawesi, and Java. Even though Java is the smallest island among the five, Java is the most densely-populated island in 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 strategic nationally: WS Citarum, WS Jratunseluna, 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*,



River Basin		River Basin		River Basin	
Name	Code	Name	Code	Name	Code
WS CIWULAN-CILAKI	02.08.B	WS BRANTAS	02.19.A3	WS PROGO-OPAK-SERANG	02.17.A2
WS BARU-BAJULMATI	02.24.B	WS KEPULAUAN KARIMUNJAWA	02.14.C	WS BENGAWAN SOLO	02.18.A2
WS BODRI-KUTO	02.13.B	WS KEPULAUAN MADURA	02.20.B	WS WELANG-REJOSO	02.21.B
WS BONDOYUDO-BEDADUNG	02.22.B	WS KEPULAUAN SERIBU	02.04.A2	WS PEKALEN-SAMPEAN	02.23.B
WS CIBALIUNG-CISAWARNA	02.01.B	WS WISO-GELIS	02.15.C	WS CIDANAU-CIUJUNG-CIDURIAN	02.03.A2
WS CILIMAN-CIBUNGUR	02.02.B	WS SERAYU-BOGOWONTO	02.12.A3	WS CILIWUNG-CISADANE	02.05.A2
WS CISADEA-CIBARENO	02.07.B	WS CITANDUY	02.10.A2	WS CITARUM	02.06.A3
WS JRATUNSELUNA	02.16.A3	WS PEMALI-COMAL	02.11.B	WS CIMANUK-CISANGGARUNG	02.09.A2

Figure 1. River basins in Java Island Indonesian Government, (2012)

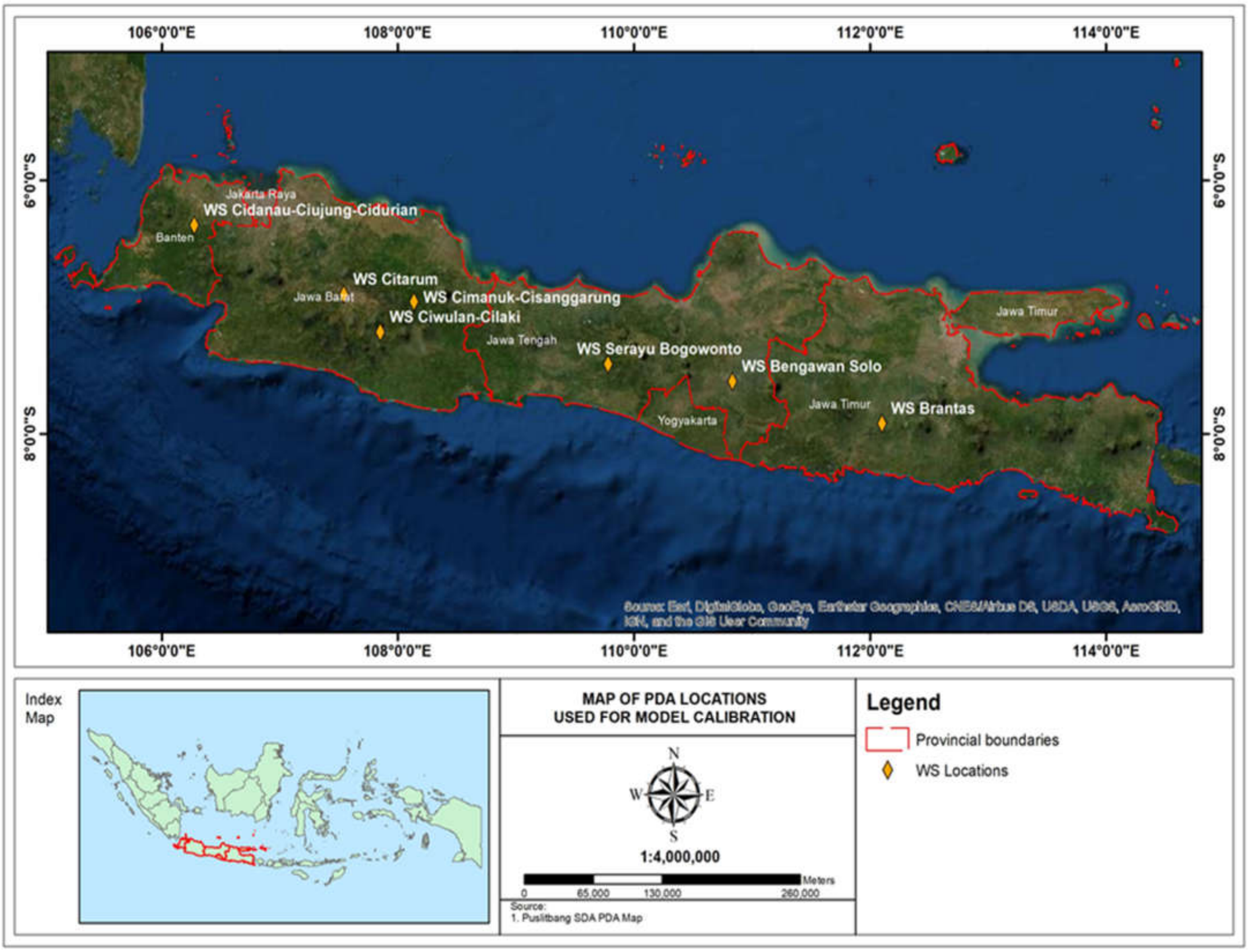


Figure 2. Map of PDA locations used for model calibration (Google Earth, 2020)

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-Leuwi Daun

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.

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;

- Model verification with Indonesian Meteorological and Geophysical Agency (BMKG) rain data;
- Generating a discharge flow per watershed and/or sub -watershed in the river basin

Model calibration is conducted by comparing the observation discharges at the river gauging station (PDA) with the same outlet's modeling discharge. The model was calibrated by:

1. Graphics comparison
   The flow pattern of the discharge simulation was compared to the observed discharge.
2. Statistical comparisons

Statistical measures are used to see the similarities between the results of simulation and observation. Some statistical measures used are Correlation, Size of Prediction Accuracy, Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE).

Water Demand Analysis

Household, urban, and industrial water demand were calculated using population statistics. The calculation of raw water demands is compared with raw water distribution data by the Regional Raw Water Companies (Perusahaan Daerah Air Minum-PDAM).

Household Water Demand

The average population data in Java was used to calculate the water demand, which was obtained from The Central Bureau of Statistics (2019). The amount of household raw water demand depends on the city category based on the population in Liter/Person/Day (L/ P/D) unit (Table 2). The water losses were also taken into consideration to calculate the total household raw water demand. The losses could come from:

1. The loss in the process of 6%;
2. Uncountable water loss (25%)

Urban Water Demand

The water demand for daily life includes water use for commercial and social aspects such as, but not limited to: shops, warehouses, workshops, schools, hospitals, and hotels, which are assumed to demand between 15% to 30% of total household water use. In this study, the upper limit value of 30% was used.

Table 2. Household Raw Water Demand per Person Per Day by City Category

City Category	Total Population (Life)	Raw Water Demand (L/P/D)
Semi Urban (Capital District / Village)	3.000 – 20.000	60 - 90
Small City	20.000 – 100.000	90 – 110
Medium City	100.000 – 500.000	100- 125
Big City	500.000-1.000.000	120 – 150
Metropolis	> 1.000.000	150 – 200

Source: Badan Standardisasi Nasional (2015)

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, (m^3)

Etc = Consumptive water requirements, (mm/day)

IR = Water requirements for land preparation, (mm/day)

RW = Demand for water to replace the water layer, (mm/day)
P = percolation, (mm/day)
ER = Effective rain, (mm/day)
IE = irrigation efficiency
A = Area of irrigation area, (m^2)

Irrigation water demand is the amount of water demanded to cultivate paddy rice and water loss in the irrigation network. To calculate irrigation water demand according to the planned cropping pattern, several factors need to be considered, including the planned cropping pattern, area of irrigation, percolation, effective rainfall, and irrigation efficiency.

1. Planting Pattern

Based on the planting plan data, the planned crop pattern in the area is paddy-secondary crops. The first planting season (*Masa Tanam*-MT) group I started in October, MT-II group one started in March. Secondary crops were planted during the dry season. The paddy rice type used for MT-I and MT-II is different. In MT I, *rendeng* paddy was used, whereas *gadu* paddy was used in MT-II. Regarding the duration, MT-I lasted for five months, and MT-II lasted slightly shorter at 4.5 months. The land preparation period is carried out for one month for MT-I and MT-II.

2. Irrigated land area

The total irrigated area was obtained from PUSDATIN (2014).

3. Percolation

The percolation rate depends on the nature of the soil in the research area, which is influenced by its geomorphological characteristics and land use patterns. In heavy clay soils with good characteristics, the percolation rate can reach 1-3 mm/day. In lighter soil types, the percolation rate can be higher.

4. Irrigation water efficiency

Irrigation water efficiency is the percentage of water reaching the rice fields compared to the total water entering the irrigation. The efficiency value used is 0.65.

5. Effective Rainfall

Based on KP01 Irrigation Planning Guidelines Ministry of Public Work and Housing (2013), effective rainfall value is 70% of R80 for rice plant and 70% of R50 value for secondary corps. Calculation of effective rainfall is as follows:

$$Re\ rice = (0.7 \times R80)/15$$

$$Re\ secondary\ crops = (0.7 \times R50)/15$$

with the formula for the effective rainfall R80 and R50 calculation is as follows:

$$R80\ and\ R50 \quad Probability = m/(n + 1)$$

with
n = number of years of rainfall data
m = sequence number from large to small

At the study area, rainfall data used for effective rainfall calculation was obtained from TRMM satellite data (2003-2018).

Water balance

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, Infilt 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

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)

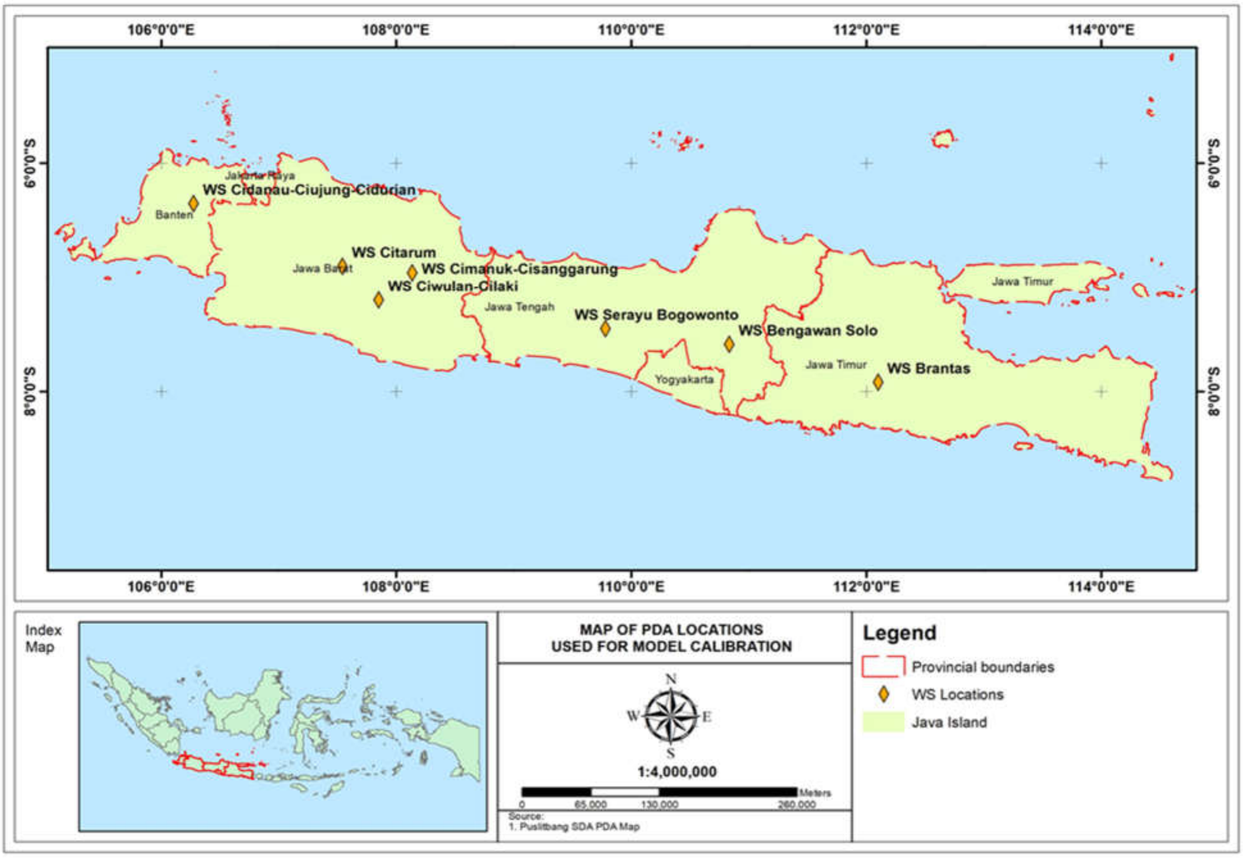


Figure 3. Locations of Calibration Points in Java

Table 4. Comparison of WFLOW Simulation Results with Observation Data in Ciujung - Rangkas Bitung PDA

	Through out the year	Dry Season (April-September)	Rainy Season (October-March)	3 Dry Months (July - September)
R2	38%	45%	21%	51%
MAE	26.00	20.51	31.32	16.80
MSE	1240.95	843.62	1625.47	608.89
MAPE	1.20	1.31	1.10	1.33
RMSE	35.23	29.05	40.32	24.68

Source: Results of Analysis (2019)

Table 5. Comparison of WFLOW Simulation Results with Observation Data in the Cimanuk - Leuwidaun PDA

	Throughout the year	Dry Season (April-September)	Rainy Season (October -March)	3 Dry Months (July - September)
R2	68%	79%	55%	67%
Bias	1.45	2.46	0.45	-2.83
MAE	10.17	7.90	12.39	5.45
MSE	191.43	119.87	261.69	62.49
MAPE	0.53	0.55	0.51	0.39
RMSE	13.84	10.95	16.17	7.90
(mean sim - mean obs)/ mean obs	0.044	0.13	0.12	-0.21

Source: Results 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 m^3/s while urban water demand is 77.9 m^3/s. Additionally, the industrial water demand is 135 m^3/s, making the total water demand for Java island 472.5 m^3/s. The province with the highest water demand is West Java with 153.7 m^3/s, followed by East Java with 124.7 m^3/s. The water demand in DKI Jakarta, the capital city of Indonesia, is 33.05 m^3/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 (km^2)	Average Discharge		Dependable flow 80%	
		m^3/s	Million m^3/year	m^3/s	Million m^3/year
WS CIBALIUNG-CISAWARNA	2,594.32	146.32	4,614	101.49	3,201
WS CILIMAN-CIBUNGUR	1,738.27	75.99	2,396	52.53	1,657
WS CIDANAU-CIUJUNG-CIDURIAN	4,147.53	202.60	6,389	149.48	4,714
WS KEPULAUAN SERIBU	8.75	0.26	8	0.07	2
WS CILIWUNG-CISADANE	5,267.84	201.63	6,359	131.55	4,149
WS CITARUM	11,321.79	454.37	14,329	304.44	9,601
WS CISADEA-CIBARENO	6,806.24	402.55	12,695	291.03	9,178
WS CIWULAN CILAKI	5,372.33	256.61	8,092	177.26	5,590
WS CIMANUK-CISANGGARUNG	7,703.75	542.71	17,115	380.32	11,994
WS CITANDUY	4,506.99	250.64	7,904	179.29	5,654
WS PEMALI-COMAL	4,831.24	230.59	7,272	167.50	5,282
WS PEMALI-COMAL	7,370.57	417.22	13,157	290.04	9,147
WS BODRI-KUTO	1,646.78	68.01	2,145	44.90	1,416
WS KEPULAUAN KARIMUNJAWA	42.22	1.33	42	0.83	26
WS WISO-GELIS	665.29	18.44	582	11.24	354
WS JRATUNSELUNA	9,073.57	243.05	7,665	152.64	4,814
WS PROGO-OPAK-SERANG	4,878.05	211.51	6,670	143.01	4,510
WS BENGAWAN SOLO	19,697.18	693.93	21,884	455.71	14,371
WS BRANTAS	14,251.46	579.77	18,284	375.19	11,832
WS MADURA-BAWEAN	5,615.27	91.27	2,878	52.21	1,646
WS WELANG-REJOSO	2,189.72	72.87	2,298	47.42	1,495
WS BONDOYUDO-BEDADUNG	5,343.37	200.79	6,332	126.35	3,985
WS PEKALEN-SAMPEAN	3,933.43	106.95	3,373	65.96	2,080
WS BARU-BAJULMATI	3,692.17	102.53	3,233	64.43	2,032
JAVA ISLAND	132,698.13	5,571.94	175,717	3,764.89	118,730

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

Population 2018 (Life)		Water Demand (m3/s)			
		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
DI Yogyakarta	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 (m^3/s)
WS CIBALIUNG-CISAWARNA	10.97
WS CILIMAN-CIBUNGUR	7.42
WS CIDANAU-CIUJUNG-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 BOGOWONTO	23.38
WS BODRI-KUTO	5.21
WS KEPULAUAN KARIMUNJAWA	0.15
WS WISO-GELIS	2.88
WS JRATUNSELUNA	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

Tabel 11. Average yearly irrigation water needs

WS Name	Irrigation Area	Irrigation Water Demand
	Ha	m^3/s
WS CIBALIUNG-CISAWARNA	22,240	14.27
WS CILIMAN-CIBUNGUR	17,459	13.07
WS CIDANAU-CIUJUNG-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	75,423	57.31
WS PEMALI-COMAL	129,283	97.61
WS SERAYU BOGOWONTO	128,272	95.47
WS BODRI-KUTO	38,327	27.40
WS KEPULAUAN KARIMUNJAWA	-	-
WS WISO-GELIS	13,004	8.93
WS JRATUNSELUNA	153,866	116.70
WS PROGO-OPAK-SERANG	92,948	66.45
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

Table 11. Java Island Water Balance

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-GELIS	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-BAWEAN	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

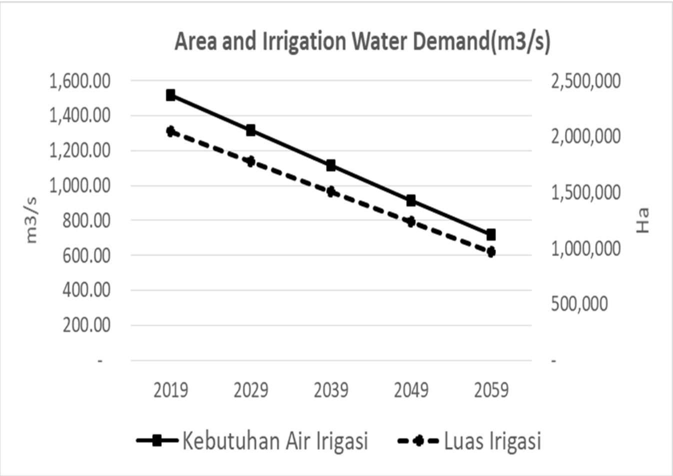


Figure 4. Area and Irrigation Water Demand in Java Island

m³/y. Overall, the water used for household, urban, and industry in Java is 472.47 m3/s (approximately 14.900 m³/y). This value itself is higher than Italy, Germany, Spain, Poland, Netherland, Sweden, and many, if not all, countries in Europe. Italy itself has the highest water consumption, with approximately 5200 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).

Irrigation Water Demand Analysis

Java Island has an irrigation area of 2,047 million hectares with an irrigation water demand of 1.52 thousand m^3/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 m^3/s. The second and the third largest irrigation area is in WS Jratunseluna with an irrigation area of 257 thousand ha and average water demand of 195 m^3/s and Cimanuk-Cisanggarung WS with an irrigation area of 176 thousand ha and an average water requirement of 136 m^3/s.

In total, the water requirement for irrigation in Java is 1.518 m3/s or 47.872 million m^3/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 m^3/s to 678.72 m^3/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 in line 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 m^3/s compared to 1,459.97 m^3/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 m^3/s or equivalent to 175.7 billion m^3/y. Q80% dependable flow is 3.8 thousand m^3/s or equivalent to 118.7 billion $m^3/year$. Java Island household demand is 260 m^3/s while urban water demand is 77.9 m^3/s, and industrial water demand is 135 m^3/s. Java Island has an irrigation area of 2,468,515 ha with an irrigation water requirement of 1838.4 m^3/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 m^3/s. Overall, there is a surplus of water in Java even though several river basins have a water deficit, *namely in the WS Kepulauan Seribu, WS Wiso Gelis, 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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References

Asian Development Bank (2016). *Indonesia: Country Water Assessment*. Philippines: Asian Development Bank, 38-39.

Badan Pusat Statistik (2018). *Statistik Indonesia dalam Infografis 2018. Http://bps.go.id.* Accessed 6th September 2020, 02.05 PM.

Badan Pusat Statistik (2019). *Statistik Indonesia 2019. Http://bps.go.id.* Accessed 6th September 2020, 02.45 PM.

Badan Standardisasi Nasional (2015): *Standar Nasional Indonesia (SNI) 6728.1-2015: Penyusunan neraca spasial sumber daya alam-Bagian 1: Sumber Daya Air* (in Indonesian). Jakarta: Badan Standardisasi Nasional.

Bakosurtanal (2007). *Peta Tata Guna Lahan Indonesia. https://bnpb.go.id/.* Accessed 7th August 2020, 10.45 AM.

Curk, Barbara & Rožič, Petra & Silvoni, R. & Franco, Cucchi & Calligaris, Chiara & Nistor, Mărgărit & Vrhovnik, Petra & Verbovšek, Timotej & Kostelic, B. & Babic, D. & Karleuša, Barbara & Radman, I. & Matic, Branislava B. & Dimkić, Dejan & Lukic, V. & Ibrahimllari, A. & Aliaj, A. & Lukovac, N. & Džajic-Valjevac, M. & Tsitsifli, Stavroula (2016). Regional water resources availability and vulnerability. Ljubljanan.

Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, NL. & Linsey, K.S. (2018). Estimated use of water in the United States in 2015: US Geological Survey Circular 1441, 65 p.. https://doi.org/10.3133/cir1441.

EurEau (2017). Europe's water in figures: An overview of the

European drinking water and waste water sectores.The European Federation of National Associations of Water Services, 2017 edition.

Faishal, A., Suyono, M.S., (2013). Evaluasi Ketersediaan Dan Kebutuhan Air Untuk Pertanian

Daerah Irigasi Boro Kabupaten Purworejo Provinsi Jawa Tengah, Jurnal Bumi Indonesia 2 (4) 2013.

FAO (2007). *Digital Soil Map of the World*. http://www.fao.org/. Accessed Aug 15 2020, 10.00 AM.

FAO. (2011). *The State of the World's Land and Water Resources for Food and Agriculture: Managing Systems at risk*. New York: The Food and Agriculture Organization of the United Nations and Earthscan. http://www.fao.org/. Accessed Aug 15 2020, 10.15 AM.

Gleick, P. (2003). Global freshwater resources: soft-path solutions for the 21st century. *Science 302 (5650):* 1524-1528.

Google Earth. (2020). Accessed Aug 8 2020, 09.00 AM.

Gunawan, B. (2008). Kenaikan muka air laut dan adaptasi masyarakat (in Indonesian). *Walhi*.

Hanjra, M.A. & Qureshi, M.E. (2010). Global water crisis and future food security in an era of climate change,. *Food Policy 35 (5):* 365-377.

Hidayat, N.M., Mulyo, A.P., Azani, A.A., Aofany, D.R., Nadiansyah, R., Rejeki, H.A., 2018, Evaluasi Ketersediaan Sumber Daya Air Berbasis Metode Neraca Air Thornthwaite Mather Untuk Pendugaan Surplus dan Defisit Air Di Pulau Jawa. DOI: 10.20961/prosidingsnfa.v3i0.28506.

Huang, LiGuo & Yin, Li. (2017). Supply and Demand Analysis of Water Resources based on System Dynamics Model. Journal of Engineering and Technological Sciences. 49 (6) 2017, 705-720. DOI: 10.5614/j.eng.technol.sci.2017.49.6.1.

Indonesian Government. (2008). Indonesian Government Decree no. 26/2008 about National Urban Planning. https://peraturan.bpk.go.id/. Accessed Sept 8 2020, 09.00 AM.

Indonesian Government. (2012). Indonesian Presidential Decree no. 12/2012 regarding River Basins determination. https://peraturan.bpk.go.id/. Accessed Sept 8 2020, 09.30 AM.

KLHK. (2019). WEBGIS Kementerian Lingkungan Hidup dan Kehutanan. URL: http://webgis.menlhk.go.id:8080/kemenhut/index.php/id/peta/peta-interaktif. Accessed Aug 6 2020, 10.05 AM.

Komariah, I. & Matsumoto T. (2019). Application of Hydrological Method for Sustainable Water Management in the Upper-Middle Ciliwung (UMC) River Basin, Indonesia. *Journal of Water and Environment Technology 17 (4)*: 2013-217.

Li Y, Wang H, Chen Y, Deng M, Li Q, Wufu A, Wang D, Ma L. Estimation of regional irrigation water requirements and water balance in Xinjiang, China during 1995-2017. PeerJ. 2020 Jan 3;8:e8243. doi: 10.7717/peerj.8243. PMID: 31915574; PMCID: PMC6944122.

Ministry of Publik Work and Housing (2013). *Irrigation Planning Guidelines: Planning Criteria, Part Irrigation System Planning KP-01* (in Indonesian). http://sibima.pu.go.id/. Accessed Aug 25 2020, 03.05 PM.

Ministry of Publik Work and Housing (2015). *Ministry of Public Work and Housing Regulation no. 4/PRT/M/2015 regarding River Basin Criteria and Determination* (in Indonesian). http://sibima.pu.go.id/. Accessed Aug 25 2020, 03.05 PM.

Minzhong Zou, Shaozhong Kang, Jun Niu, Hongna Lu, (2018), A new technique to estimate regional irrigation water demand and driving factor effects using an improved SWAT model with LMDI factor decomposition in an arid basin, Journal of Cleaner Production, Volume 185, 2018, Pages 814-828,

Mock, F.J. (1973). *Land Capability Appraisal Indonesia: Water Availability Appraisal, Basic study prepared for the FAO/UNDP Land*. Bogor: FAO.

Molden, D. (2007). Water for food water for life: A comprehensive assessment of water in agriculture. *Proc. R. Soc. Lond. Ser. A. 193*

Mulyani, A., Kuncoro, D., Nursyamsi, D., Agus, F. (2015). Analisis Konversi Lahan Sawah: Penggunaan Data Spasial Resolusi Tinggi Memperlihatkan Laju Konversi yang Mengkhawatirkan, Jurnal Tanah dan Iklim Vol. 40, No.2, Hal 121 - 133.

Neitsch, S.L., Arnold, J.G., Kiniry, JR & Williams, J.R. (2011).. *Soil and water assessment tool theoretical documentation version 2009.* Texas Water Resources Institute Technical Report no. 406

Ricky Nadiansyah, Hasti Amrih Rejeki, 2018, Evaluasi Ketersediaan Sumber Daya Air Berbasis Metode Neraca Air Thornthwaite Mather Untuk Pendugaan Surplus Dan Defisit Air Di Pulau Jawa, Prosiding SNFA (Seminar Nasional Fisika dan Aplikasinya) 2018. DOI: 10.20961/prosidingsnfa.v3i0.28506

Radhika, Fauzi, M., Rahmawati, Firmansyah, R., Fathoni, A. & Hatmoko, W. (2013). *Neraca Ketersediaan Air Permukaan dan Kebutuhan Air pada Wilayah Sungai di Indonesia (in Indonesian)*. Conference paper.

Radhika, Firmansyah, R. & Hatmoko, W. (2017) Perhitungan Ketersediaan Air Permukaan di Indonesia berdasarkan Data Satelit (in Indonesian). *Jurnal Sumber Daya Air 13 (2)*: 115-130.

Rahmawan, K., Makrup, L., 2016, Evaluasi Ketersediaan dan Kebutuhan Air Untuk Daerah Irigasi Soropan Di DAS Hulu Sungai Elo, Prosiding Kolokium Program Studi Teknik Sipil (KPSTS) FTSP UII 2016,

Schellekens, J. (2019). *WFLOW Documentation*. https://WFLOW.readthedocs.io/. Accesed Aug 20 2020, 03.40 PM.

Seckler, D.; Amarasinghe, U.; Molden, D.; de Silva, R.; Barker, R. 1998. World water demand and supply, 1990 to 2025: scenarios and issues. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI). vi, 40p. (IWMI Research Report 019 / IIMI Research Report 019) doi: http://dx.doi.org/10.3910/2009.019

Senent-Aparicio, J., Liu, S., Pérez-Sánchez, J., López-Ballesteros, A. & Jimeno-Saéz, P. (2018). Assessing impacts of climate variability and reforestation activities on water resources in the headwaters of the Segura River Basin (SE Spain). *Sustainability 10(9):* 3277.

Tampubolon, S.B., Suprayogi, S., 2017, Analisis Kebutuhan Air Untuk Pertanian Di Daerah Irigasi Karangloso Kabupaten Bantul, Jurnal Bumi Indonesia. 6 (4) Tahun 2017.

Taufik, I., Yanuar J. M., Purwanto, Pramudya, B., Saptomo, S., 2019, Analisis Neraca Air Permukaan DAS Ciliman, Jurnal Ilmu Lingkungan, Volume 17 Issue 3(2019) :452-464

Vernimmen, R., Hooijer, A. & Mamenun, N.K. (2012). Evaluation and bias correction of satellite rainfall data for drought monitoring in Indonesia. *Hydrology and Earth System Sciences Discussions 8(8):* 5969-5997.

Wang, Fei & Yaning, Chen & Li, Zhi & Fang, Gonghuan & Peng, Li & Xia, Zhenhua. (2019). Assessment of the Irrigation Water Requirement and Water Supply Risk in the Tarim River Basin, Northwest China. Sustainability. 11. 4941. 10.3390/su11184941.

Wurbs, R.A. (2005). Modeling river/reservoir system management, water allocation, and supply reliability. *Journal of Hydrology 300 (1-4):* 100-113.

York, R. & Longo, S.B. (2009). Structural influences on water withdrawals: an exploratory macro-comparative analysis,. *Human Ecology Review 16 (1):* 75-83.