RESEARCH ARTICLE

Assessment of Water Balance at Mayang Watershed, East Java

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Abstract

Mayang Watersheds frequently hit by floods during the rainy season and drought during the dry season. This study aims to assess the water balance by calculating water resource availability and water demand in the Mayang watershed. The Water Evaluation and Planning (WEAP) model was used as the primary tool for the analysis. The supply of water comes only from precipitation. Demand was calculated based on the water demand for irrigation, domestic, urban, industrial, and livestock uses. The unit of time to calculate the water balance is ten days. It means that each month is divided into three-time steps. Analysis of the WEAP is based on the water demand from 2002 to 2019. The results showed that from 3rd December to 1st May, the Mayang river and its tributaries could supply all demand sites up to 100%. However, unmet demand occurs from 2nd May to 2nd December. The highest first unmet demand occurred in October, with 0.67 million m^3. The management of water resources, especially in terms of distribution during the rainy season and dry season, must be considered.

Keywords: Water balance; Water supply; Water demand; Mayang; Watershed; WEAP

1. Introduction

Water is an essential requirement for human survival; without water, there would be no life on earth. Water demand is water that is used to fulfill daily activities. Water sources for daily needs, in general, must meet the quantity and quality standards (Kencanawati & Mustakim, 2017). Water resources on the watershed use to supply water demand for irrigation, domestic, urban, industrial, livestock, and other needs. Water becomes a valuable resource, both in terms of quality and quantity (Misra, 2014). A Watershed is an ecosystem that has elements including natural and human resources. Natural resources act as objects consisting of land, vegetation, and water, while the human element is the subject or actor of the utilization of the elements of natural resources (Zuriyani, 2017). Regional development will cause water demand to increase in line with population growth. Fulfilling food needs and population activities is always closely related to water demand. Thus, water resources

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management becomes critical to determine how much water is available for supporting human use and economic activities.

Water resource policymakers use such a tool to calculate the balance between water supply and demand. The policymakers are also responsible for the protection of the environment. They should ensure the fair use of water resources, promote efficient water use, and determine shared water resource priorities. A tool, for example, Water Evaluation and Planning (WEAP). WEAP operates on the water balance principle and can be applied to the agricultural system in a single watershed or watershed across regions (Sieber & Purkey, 2015). This model uses standard linear programming to solve the water resource allocation problem for every time step. An integrated water resource planning analysis can also be developed for various future scenarios using alternative assumptions about the impact of water requirements and supply policies (Duque, 2017; George et al., 2018).

Water balance modeling using WEAP requires data on water availability, data collection on climate, hydrology, and water demand to map existing water resources and their use in river areas (Dimova et al., 2013). Understanding the water balance is very important to determine how much water is available in the area for consumptive needs over a certain period and how that water should be shared among users in the planning process.

Around 799,352 peoples are living in the Mayang watershed (Badan Pusat Statistik Kabupaten Jember, 2020). People depend on the Mayang river and its main tributaries. They use the water for irrigation, domestic, urban, industrial, and livestock. Precipitation is the amount of water that falls on a flat land surface during a certain period which is measured in units of a millimeter (mm) height above the horizontal surface (Purba & Ulama, 2016). Precipitation is assumed to be the sole input in the watershed hydrological system, while river, spring, and groundwater are other forms of rainwater (Munajad & Suprayogi, 2015). Although the catchment receives an average annual precipitation of 1,733 mm, it can be counted as an abundance of water resources. However, the watershed is still prone to hydro-meteorological disasters. This watershed is subject to flood during the rainy season and risk of drought during the prolonged dry season. Several hydro-meteorological disasters (such as floods, landslides, and drought) have occurred from 2007 to 2015. This will affect livelihoods and socio-economic activities in the future. WEAP can analyze the water balance of a watershed. WEAP can analyze the surplus and deficit of water resources in the watershed. The analysis results can be used as a basis for decision-making in watershed management for the future.

Planning, development, and proper water resources management are essential to meet current and future water demand (Sivakumar, 2011). This study focuses on a water balance

that is modeled using the WEAP. Several researchers have focused on the WEAP application. For example, WEAP calculates the water balance of the Rawatamtu Sub-watershed (Setiawan et al., 2019). This research is limited to agricultural water balance. Our study intends to calculate the overall water balance in the whole area of the Mayang Watershed. In this study, the water balance component consists of water demand from various fields, such as irrigation, domestic, urban, industrial, and livestock. Therefore, this study calculates the water balance in more detail. This study aims to calculate the availability of water resources and water demand in the Mayang watershed.

2. Methods

2.1 Study Site and Input Data

The Mayang watershed (Figure 1) has an area of 1,135 km². The altitude on the watershed varies from 95 to 3,175 masl (meter above sea level). More than 95% of the watershed area is located at Jember Regency, while only a few areas are located at Banyuwangi Regency.
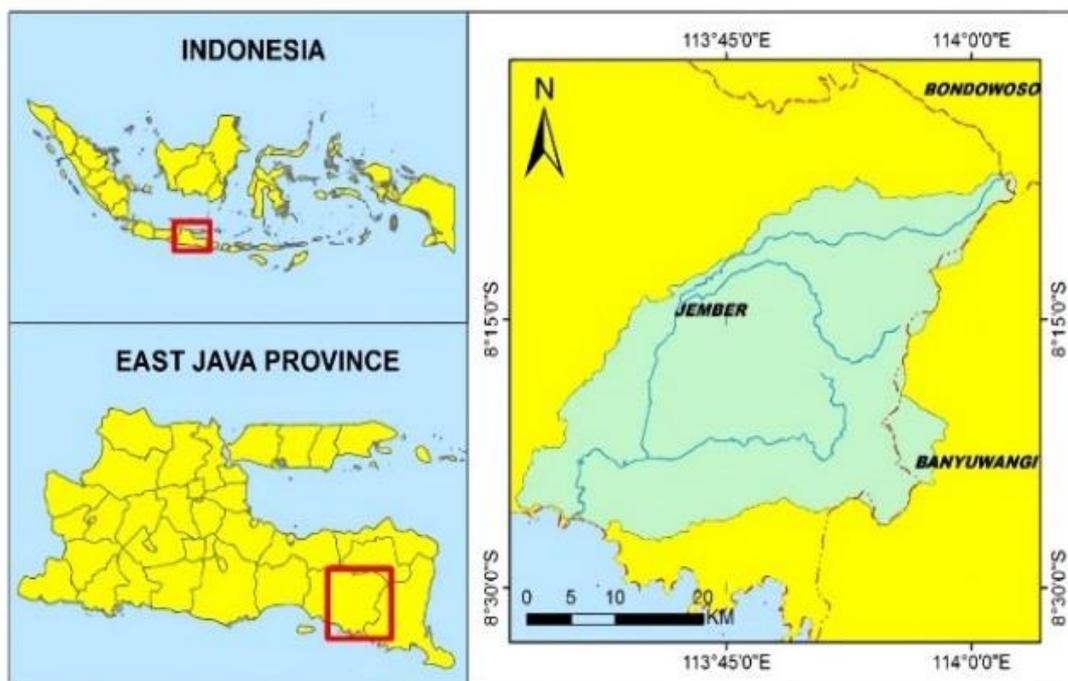

Figure 1. Study site - Mayang Watershed

Both hydrological data series and geo-spatial are used as input for modeling in the WEAP. The hydrological data series consists of precipitation and water demands data. Precipitation data were selected from seven (7) measurement sites having the most extended recording periods (i.e., 2002-2019). Figure 2 presents the location of the seven (7) precipitation stations on the watershed. Data series related to irrigation water demand is

obtained from the local water agency. Furthermore, water demands from other sectors, i.e., domestic, urban, industrial, and livestock, are calculated from existing statistical data.

The Geo-spatial data includes the Digital elevation model (DEM), land cover map, and soil type map. The DEM is extracted from the DEMNAS (Badan Informasi Geospasial, 2019). The DEMNAS is the digital elevation model data at the national level that can be freely downloaded from the National Geospatial Information Agency (Badan Informasi Geospatial or BIG) through their official website (Badan Informasi Geospasial, 2019). The DEMNAS is used to delineate the watershed boundary, determine the river network, and describe the water balance schematic (supply vs. demand) on the WEAP platform.
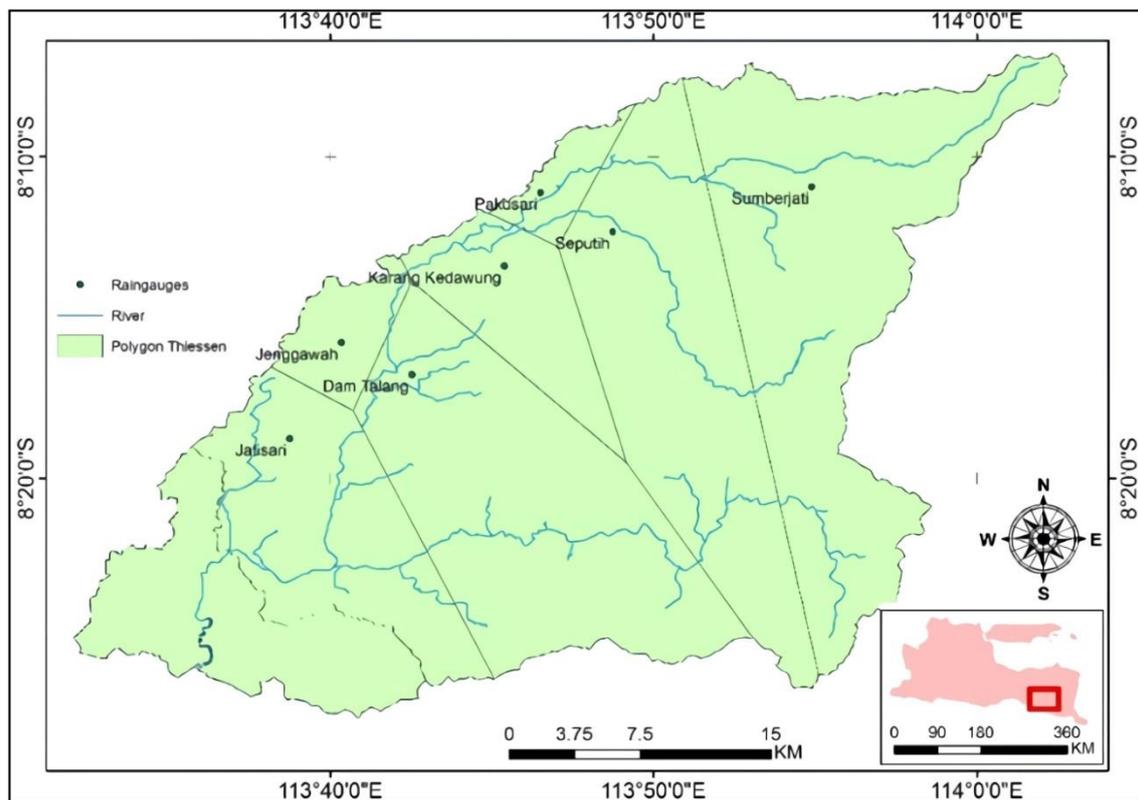

Figure 2. Thiessen polygone of Mayang Watershed

This map uses to describe the condition of the watershed for the periods from 2011 to 2020. Finally, the soil type layer was obtained from the existing database (Soil Research Institute, 1998) and represented the soil layer condition.

2.2 WEAP

The WEAP model is integrated modeling software that simulates and calculates water supply, water demand, and environmental requirements and considers the impact of water quantity, water quality, and ecosystem policies. WEAP considers supply preferences and demand priorities to solve water allocation problems using a combination of linear and

heuristic programming (Sieber & Purkey, 2015). WEAP can be used as a tool to support decisions in water resource management (Le Page et al., 2012)

2.3 Procedure

2.3.1 Analysis of Precipitation Data

The consistency test was calculated for each precipitation station (Ilham et al., 2018). This process needs to be done because the rainfall required to prepare a water use design is the average rainfall in all areas concerned, not rainfall at a certain point (Mangende et al., 2016). Table 1 present the test result for the seven stations. It can be concluded that the seven stations are consistent, which means that the measured and calculated data are correlated. Then, point precipitation measurement is then interpolated to areal precipitation by using the Thiessen polygon interpolation method. The interpolation was prepared using the existing tutorial.

Table 1. Consistency test of precipitation stations

Station Name	R^2	Explanation
Dam Talang	0.9898	Consistent
Jatisari	0.9928	Consistent
Jenggawah	0.9903	Consistent
Karang Kedawung	0.9953	Consistent
Pakusari	0.9981	Consistent
Seputih	0.9981	Consistent
Sumberjati	0.9892	Consistent

2.3.2 Analysis of Land Cover Change

Two types of land cover maps were used in this study. The first map was a clip from the "Rupa Bumi Indonesia" (RBI) digital maps and downloaded from the BIG website (Badan Informasi Geospasial, 2019). This map uses to represent the land cover of the watershed for the periods of 2000 to 2010. The second landcover maps were obtained from the classified Landsat-8 image (Hakim, 2019).

The land cover data is used to simulate the hydrological and to calculate evapotranspiration. Table 2 shows the land cover class distribution (in km^2) and the change (in % of the total watershed area) from 2001 to 2015.

Table 2. Land cover (LC) at Mayang Watershed

Class	2001		2015	
	(km^2)	(%)	(km^2)	(%)
Built-Up Area (1)	91.19	7.84	121.32	10.43
Irrigated Paddy (2)	198.89	17.10	321.12	27.6
Non-Irrigated Land (3)	1.98	0.17	38.46	3.3
Marginal Land (4)	133.49	11.47	302.58	26.0
Forest / Plantation (5)	735.29	63.20	378.57	32.54
Water Body (6)	2.56	0.22	1.36	0.12
Total	1163.41	100	1163.41	100

Figure 3 shows the two land cover maps of the watershed. The forest-plantation area decreased significantly from 2001 to 2015 by 30.66%. Changes in forest-plantation land cover have turned into agricultural land and build-up area.
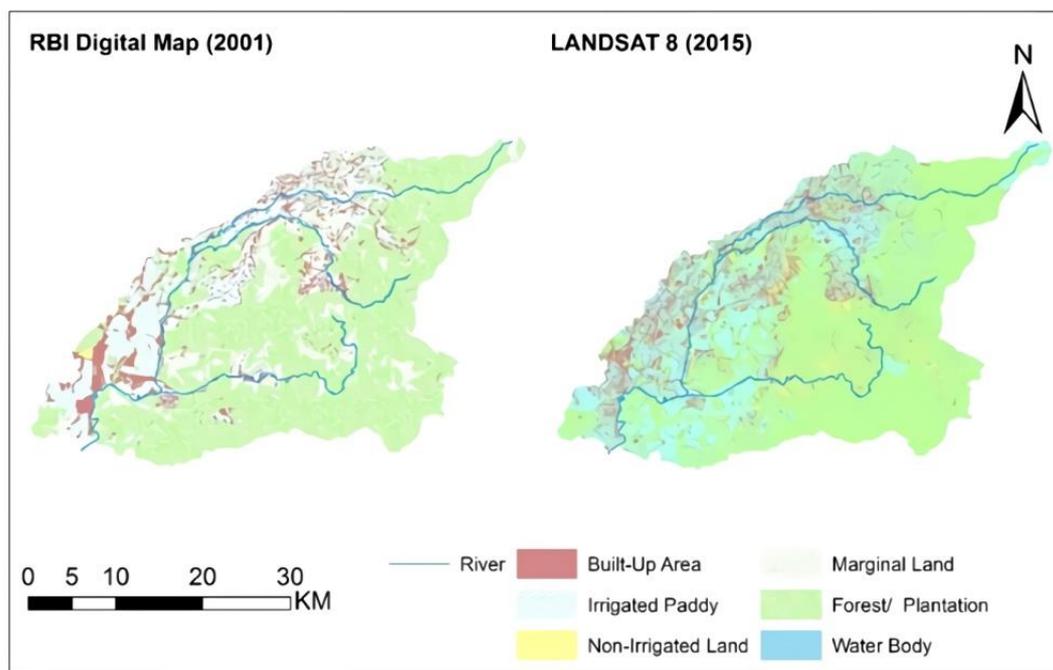

Figure 3. Land cover map in 2001 and 2015

2.3.3 Water Demand Analysis

a. Irrigation water demand

The crop data used to determine the Palawija Relative Area (PRA). PRA is the ratio of water requirements between one crop type to another (Haliem et al., 2013). Then, the PRA is used to calculate the irrigation water demand. Furthermore, the coefficient for each crop type is determined by using Table 3.

Table 3.Crop type coefficients (Haliem et al., 2013)

Crop type	Crop coefficient
Palawija	1
Irrigated-paddy	
a. Nursery	20
b. Land cultivation	6
c. Growth	4
Non-irrigated paddy	
a. Nursery	20
b. Land cultivation	6
c. Growth	4
Sugarcane	
a. Planting	1.5
b. Growth	1.5
c. Harvest	0
Tobacco or rosella	1

The PRA value is determined based on eq. 1:

$$PRA = A_{crop} \; x \; C_{crop} \tag{1}$$

Where, *PRA*: Palawija relative area (ha.pol); A_{crop}: Crop type area (ha); C_{crop}: Coefficient of crop types. The Palawija Relative Factor (PRF) value is determined by considering each soil type map's value, as shown in Figure 4. The soil type map clip from the soil layer database as published by (Soil Research Institute, 1998). Furthermore, the PRF values for each type of soil class are presented in Table 4.
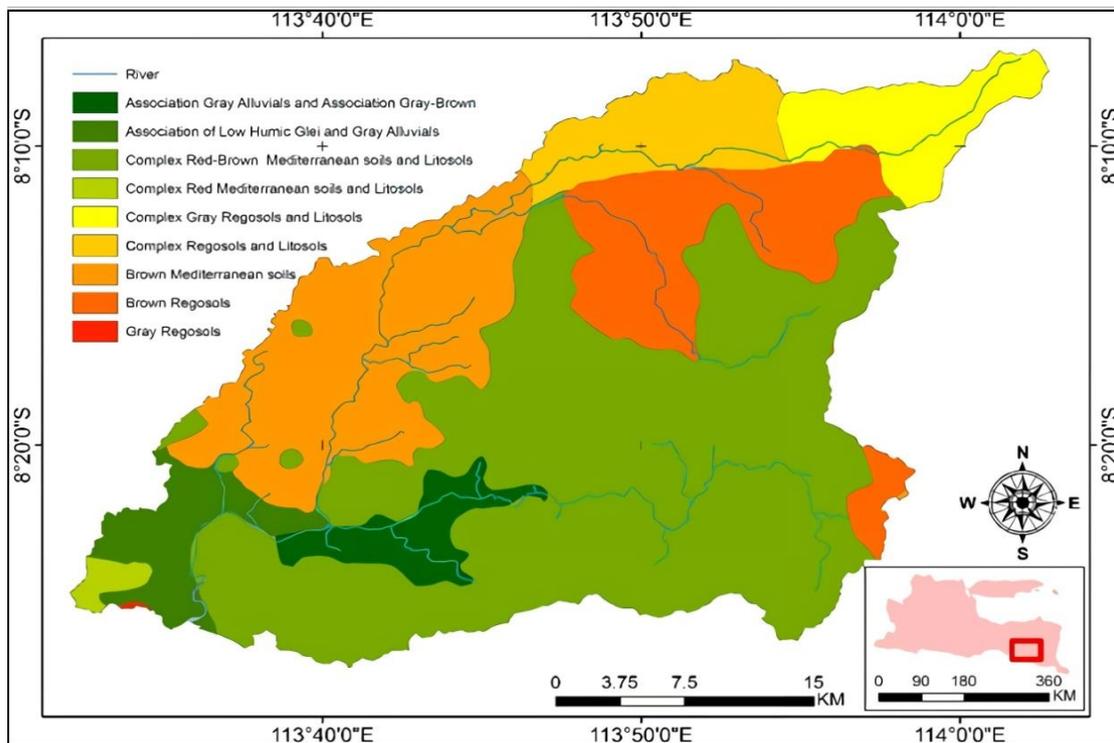

Figure 4. Soil type map of the watershed

Table 4. FPR value based on soil type (Haliem et al., 2013)

Soil type	FPR (l/s/ha.pol)		
	Less water	Enough water	More water
Alluvial	0.18	0.18-0.36	0.36
Latosol	0.12	0.12-0.23	0.23
Grumusol	0.06	0.06-0.12	0.12

Source:

Finally, the demand for irrigation (Q_{ir}) is obtained from the multiplication of the PRA and PRF which can be written on eq. 2 (Dewi et al., 2014):

$$Q_{ir} = PRA \; x \; PRF \tag{2}$$

where, Q_{ir}: irrigation water demand (l/s); PRA: palawija relative area (ha.pol); PRF: palawija relative factor (l/s/ha).

b. Domestic, Urban, and Industrial Water Demand

First, the domestic water demand (DWD) is needed by households. The households usually withdrawal water directly by a sink or borehole from the unsaturated zone. Otherwise, households obtained water from the Municipal water supply system service (BSN, 2015). In this case, the DWD is calculated based on the number of residents in the area (Mashuri et al., 2015). The main factor determining domestic water demand is population growth (Afrianto et al., 2015). DWD depends on the city category based on the population in liters/person/day, as presented in Table 5 (BSN, 2015).

Table 5. Domestic water demand per city category

Urban Category	Total population (person)	Water Demand (l/person)
Semi-urban	3,000-20,000	60-90
Small Town	20,000-100,000	90-110
Medium City	100,000-500,000	100-125
Big city	500,000-1,000,000	120-150
Metropolitan	>1,000,000	150-200

The equation for calculating domestic water demand can be written in eq. (3):

$$DWD = \sum Pop \; x \; 120l \tag{3}$$

Second, the urban water demand (UWD) is defined as the water needed to support the social and commercial facilities, such as hospitals, hotels, schools, shops, and warehouses are assumed to be 15% -30% of the total DWD (BSN, 2015). The equation for calculating urban water demand can be written in eq. (4) :

$$UWD = DWD \; x \; 15\% \tag{4}$$

Thirdly, Industrial water demand (IWD) assumed tends to be constant with time. The more the industry increases, the more water demand increases (BSN, 2015). Data of industrial water demand (IWD) is obtained from the local public water service at the regency level during the field survey.

c. Livestock

The livestock water demand (LWD) is calculated based on the number and types of livestock in the watershed area (Zulkipli et al., 2012). The LWD is determined by the number and growth rate of livestock (Putri et al., 2016). For this reason, an analysis is needed to estimate the number of livestock in the next fews years. The amount of LWD is presented in Table 6.

Table 6. Water demand for livestock (BSN, 2015)

Types of Livestock	Water Demand (l/d)
Cow / buffalo / horse	40
Goat/sheep	5
Pig	6
Poultry	0.6

The eq. (5) is used for calculating LWD :

$$LWD = ((q_1 \ x \ P_1) + (q_2 \ x \ P_2) + (q_3 \ x \ P_3) \tag{5}$$

where, LWD = livestock water demand (l /day), q_1 = water requirements for types of livestock and horses (l/day), q_2 = water requirements for goats and sheep (l/day), q_3 = water requirements for poultry (/day) P_1 , P_2, P_3, = number of types of livestock.

2.3.4 Preparing the WEAP scheme

The boundary of the watershed was derived from the DEMNAS using a hydrological function and WEAP tool. A blue line represents the river flow network. A point in red represents the location of the output points. A demand site relates to a set of water users in an area (Sieber & Purkey, 2015). The WEAP scheme model of the Mayang watershed is shown in Figure 5.
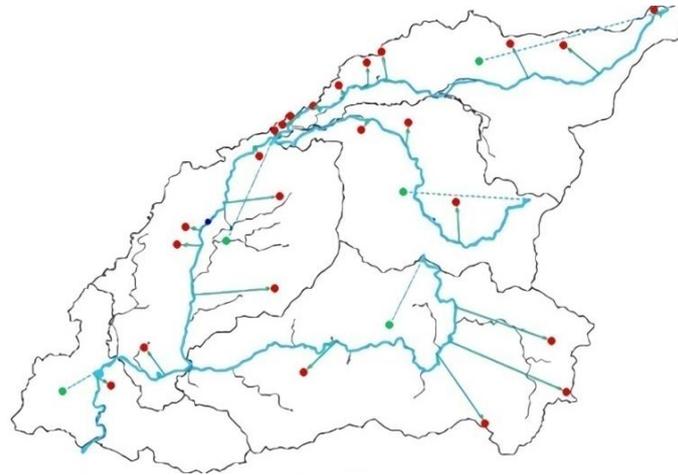
Figure 5. WEAP scheme map

2.3.5 Calibration and Validation

The data used in the calibration and validation process are 10-day period discharge data. The discharge from the 2003-2009 period was used as a calibration. In comparison, the discharge from the 2010 to 2019 period was used as validation. Calibration and validation were performed by comparing the simulated vs. observed flows for the two recording periods. A simple statistical measure (i.e., the coefficient of determination or R^2) is used to evaluate the calibration and validation performances.

3. Results and Discussion

3.1 Calibration and Validation

The calibration processes produce a coefficient of determination (R^2)= 0.78 (Figure 6), while for validation result of $R^2 = 0.88$ (Figure 7). Both R^2 values relatively acceptable to measure the correlation between simulated and observed discharge.
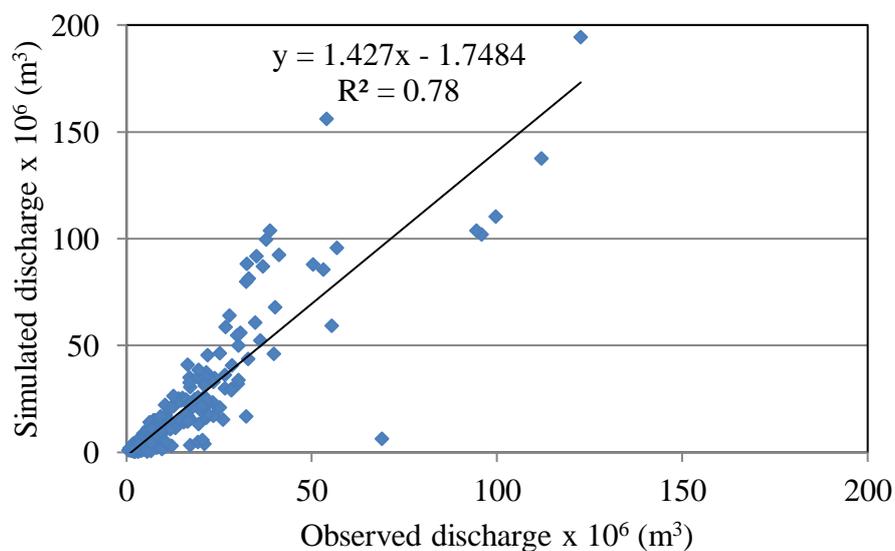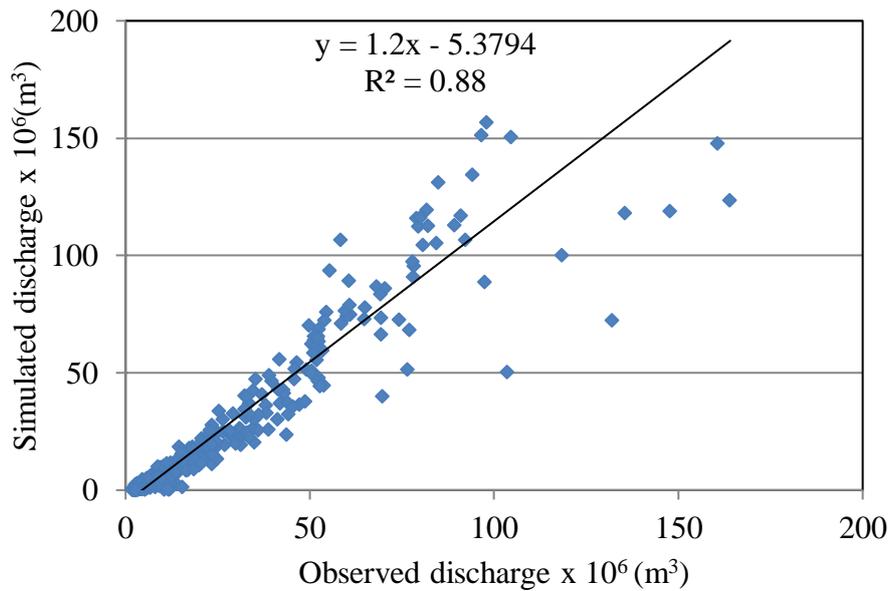

Figure 6. The WEAP model calibration

Figure 7. The WEAP model validation

3.2 Inflow and Outflow of Watershed

The average volume of inflow and outflow per 10-day period from 2002 to 2019 is presented in Figure 8. The average volume of precipitation per period is 56.02 million m^3. The average volume of evapotranspiration per 10-days period is 20.43 million m^3. Evapotranspiration is 36.5% of the total precipitation. The value of evapotranspiration is quite significant. The same result was also found by Setiawan et al. (2019), where the amount of evapotranspiration of precipitation was 41.2%. The amount of water that comes out as a result of evapotranspiration is a combination of evaporation and transpiration of plants that live on the earth's surface. Water evaporated by plants is released into the atmosphere.

The average volume of surface runoff per period is 29.75 million m^3. Figure 8 shows that the dry season can start from 1st May to 1st November, followed by the rainy season (monsoon), starting from November to 2nd April. Figure 9 also illustrates the typical properties of tropical climate regions, where the strong contrast condition exists between rainy and dry seasons.
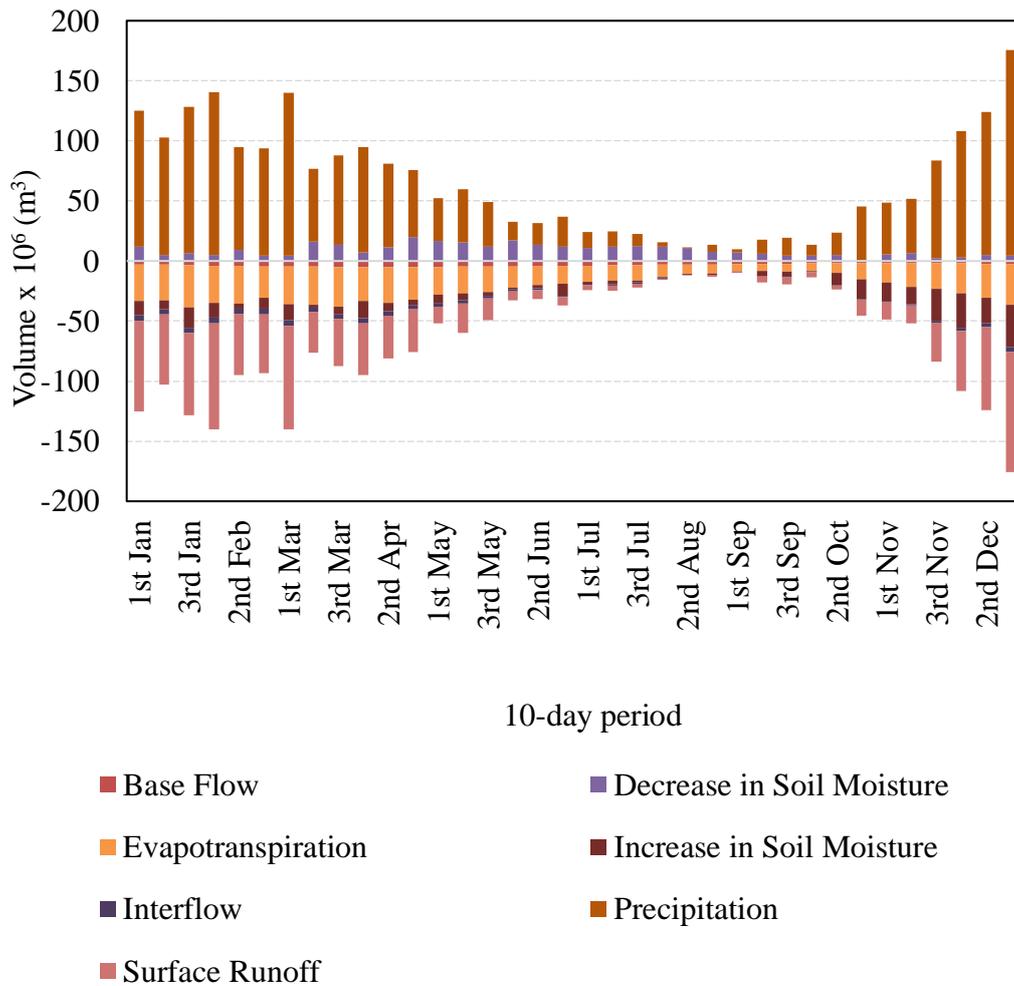
Figure 8. Inflow and outflow per 10-day period

Surface runoff as the outflow is influenced by land cover. Forest and plantation land cover are transformed into agricultural land and housing. Forest and plantation land cover in 2015 decreased by 30.66% (Table 2). This causes water that falls as precipitation less infiltrate to the soil layer. The storage in the soil layer (groundwater) decreases, and therefore more precipitation is converted directly to runoff.

The amount of annual precipitation from 2002 to 2019 is illustrated in Figure 12. The average annual precipitation is 1,733 mm. However, the maximum annual precipitation can reach 4,000 mm per year, while the minimum can go down to 632.23 mm. The average annual precipitation is 1,733 mm. The average annual evapotranspiration is 632.23 mm and for runoff is 920.61 million mm. The precipitation trend in the Mayang watershed area from 2002-2019 has increased, although slightly. This increase was also found by Setiawan & Hariyanto (2017) in several regions in East Java.
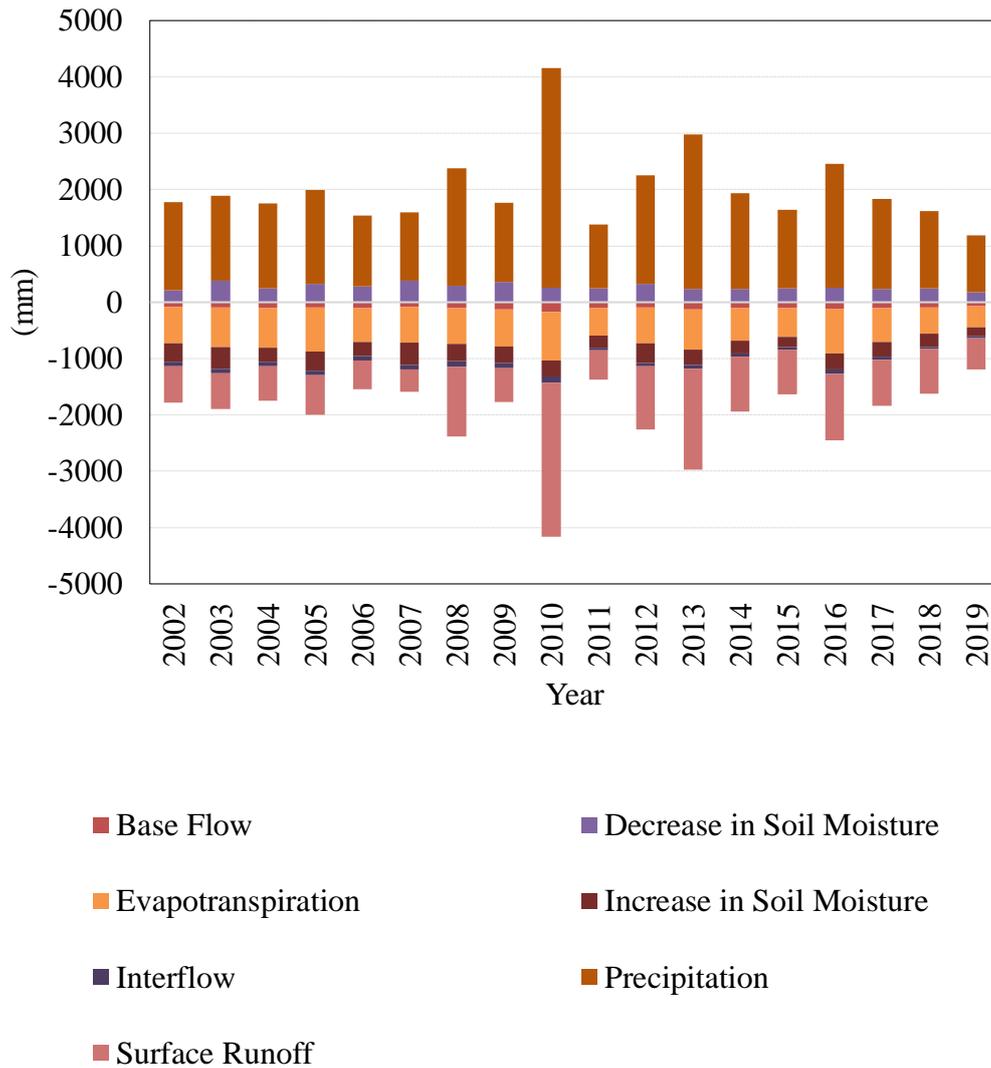
Figure 9. Mayang watershed annual inflow and outflow

It means that the amount of precipitation received is sufficiently available. However, the distribution of precipitation between rainy and dry seasons is significant. Therefore, the leading water resources management problem is how to deal with the inequality of water distribution between dry and rainy seasons. In other words, the problem of water resources management is more accentuated by water balance.

3.3 Water Demand

3.3.1 Irrigation Water Demand

The average volume of irrigation demand per 10-day period from 2002 to 2019 is presented in figure 10. It is noted that per the 10-days, the irrigation water demand is about 1.48 million m^3.
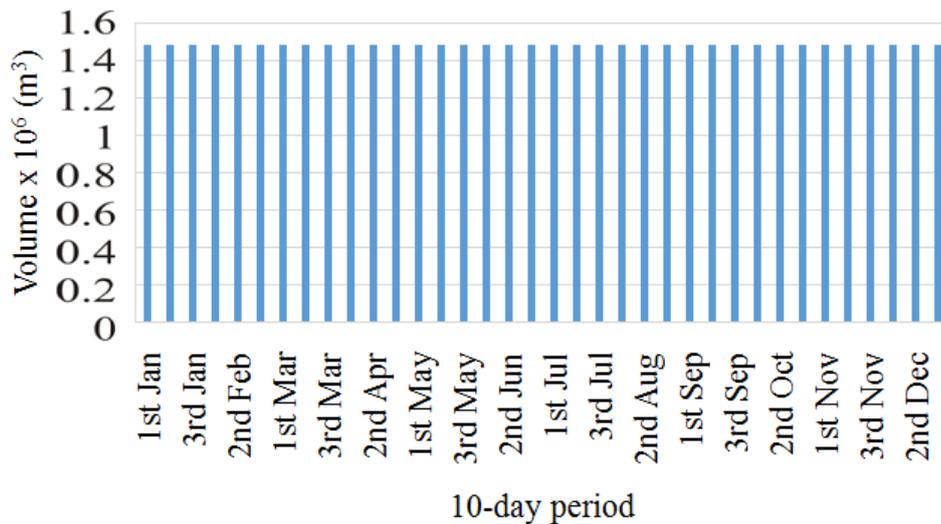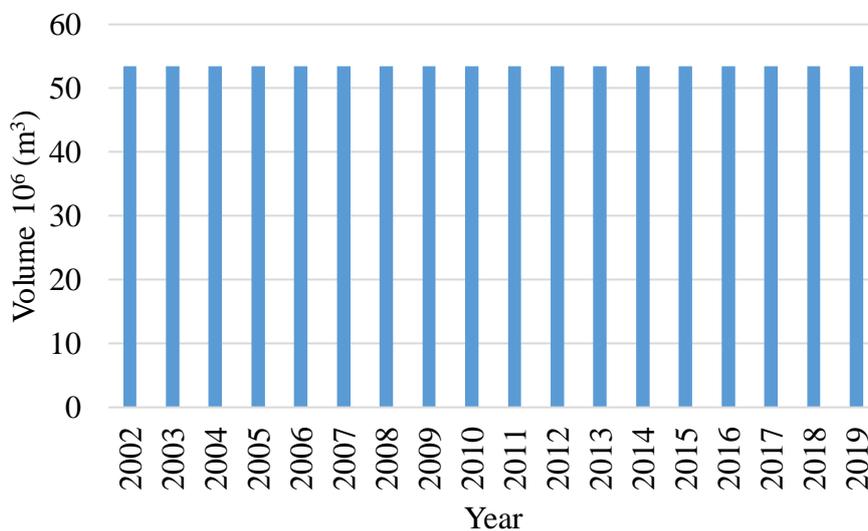
Figure 10. Irrigation water demand per 10-day period

Figure 11. Annual irrigation water demand

Furthermore, figure 11 presents the volume of annual irrigation water demands. Figure 11 shows that the annual water demand for irrigation is 53.43 million m^3. The demand for irrigation in the Mayang watershed tends to be constant every year. However, the annual irrigation water demand in the Mayang watershed is relatively high. Moreover, Agarwal et al. (2018) also found a high water demand for irrigation. This is due to the wide agricultural area and cropping patterns in the study area that are not in accordance with climatic conditions. The cropping pattern applied in the Mayang watershed is rice three times a year. This is incompatible with the climate of the Mayang watershed. Where according to Schmidt Ferguson, the climate classification of the watershed is type C. The climate with a Q value of 50%. Climate type C is not suitable for planting paddy three times a year. This

statement was supported by Putri et al. (2016), who stated that another aspect that affects the irrigation water demand is climate.

3.3.2 Domestic, Urban, and Industry Water Demand

The average water demand volume (per 10-day interval) for domestic, urban, and industrial from 2002 to 2019 is about 0.94 million m^3 (Figure 12). The average annual volume of domestic, urban, and industrial water demand is 33.97 million m^3 (Figure 13).
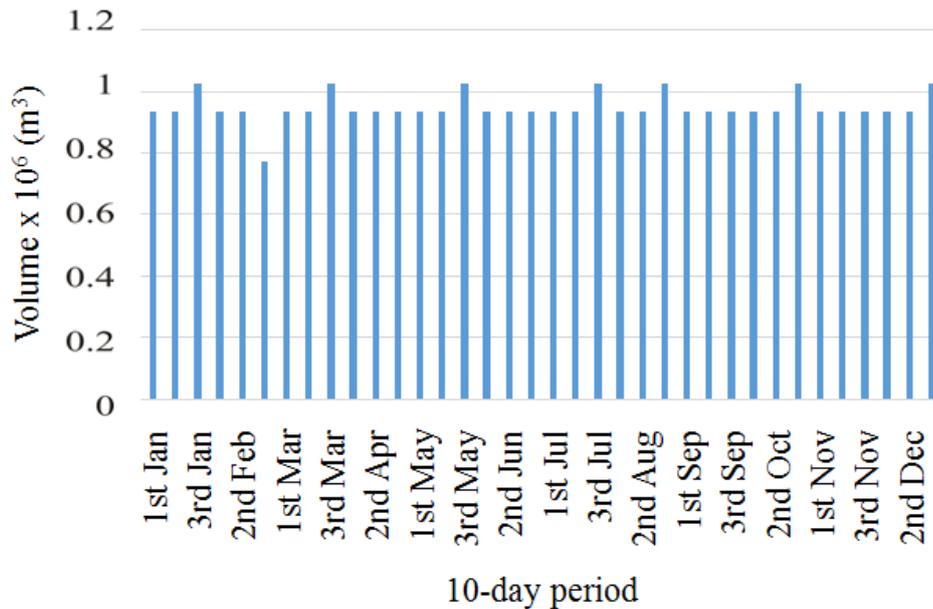
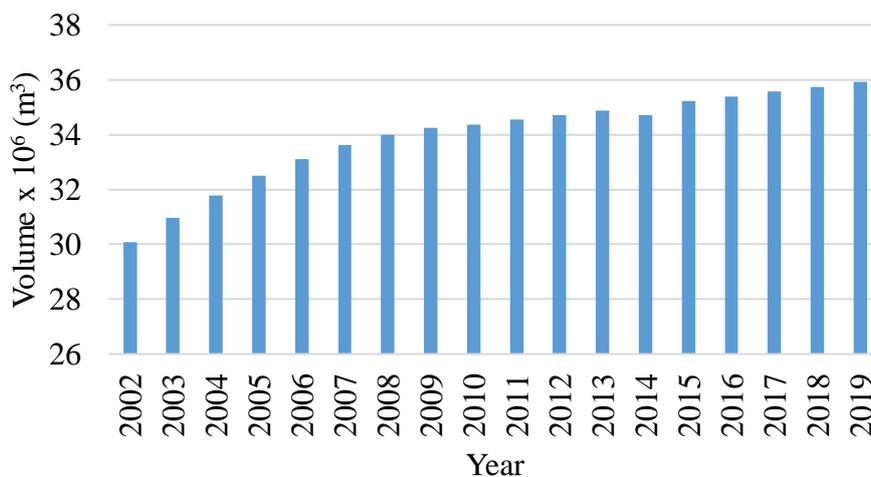Figure 12. Domestic, Urban, and industrial water demand per 10-day period

Figure 13. Annual domestic, urban, and industrial water demand

Furthermore, Figure 13 visualize the increase of water demand as the increase of slope of Figure 13. From 2002 to 2019, more water is needed to support industry

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development, population density, and the increase of public facilities. This was also found by Afrianto et al. (2015), where the increase in population impacted increasing water demand. The phenomena may continue for the next years as the population always grows.

3.3.3 Livestock

The average water demand volume (per 10-day period) to support livestock production from 2002 to 2019 is 0.11 million m^3 (Figure 14). The annual water demand for livestock production from 2002 to 2019 varies from 3.7 to 4.8 million m^3, while the average annual demand is 4.07 million m^3 (Figure 15).
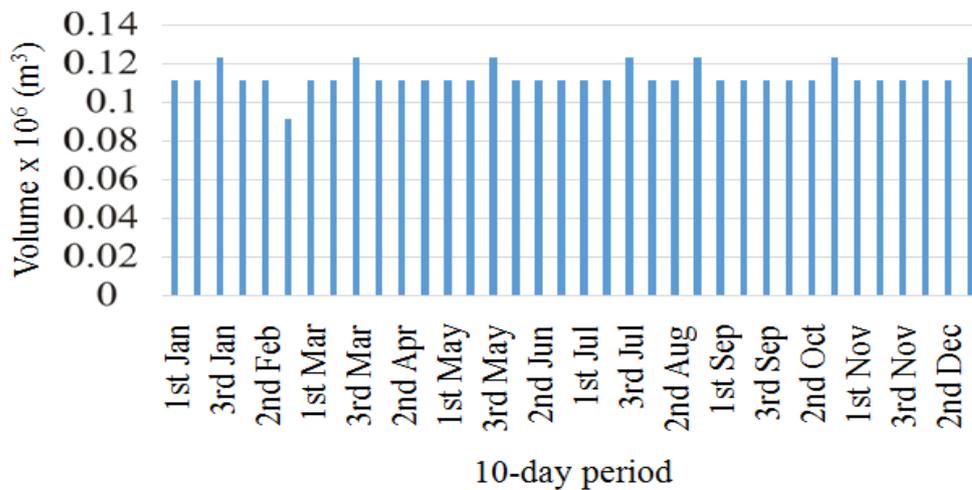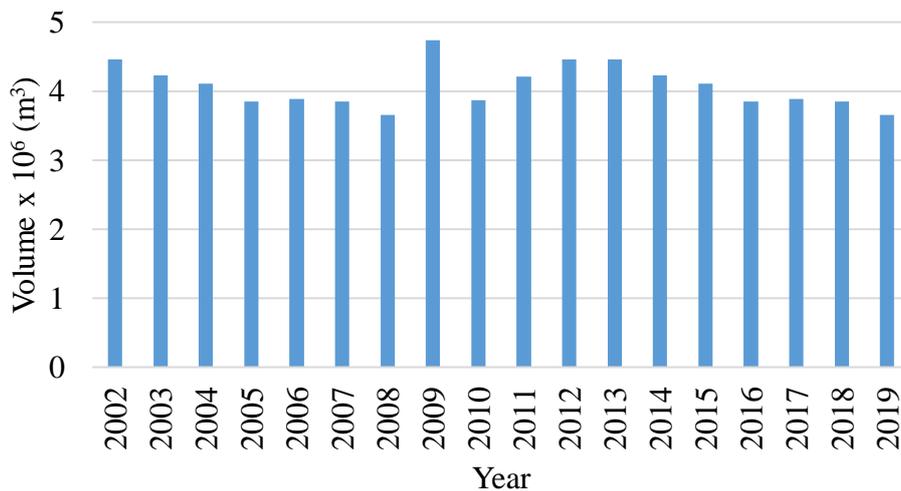
Figure 14. Livestock water demand per 10-day

Figure 15. Annual livestock water demand

The changes in the number of livestock are not the same every year, and each type of livestock has different water demand. Therefore, the total annual water demand for livestock more fluctuates each year. The type of cows/horses/buffalo is the type of livestock with the

most significant water demand. Water demand for cows/buffaloes is 40l / day. So the number of cows in the study site will determine the high demand for livestock water. This also happens in the Krueng Khe watershed, where the number of cows greatly affects the amount of water demand for livestock (Putri et al., 2016).

3.3.4 Coverage and Unmet Demand

Figure 16 illustrates the average coverage from 2002 to 2019 analyzed by SWAT. The coverage is the percentage of each site demand met, from 0% (no water) to 100% (sufficient water supply). Coverage 100% means that the supply can cover all water demand.
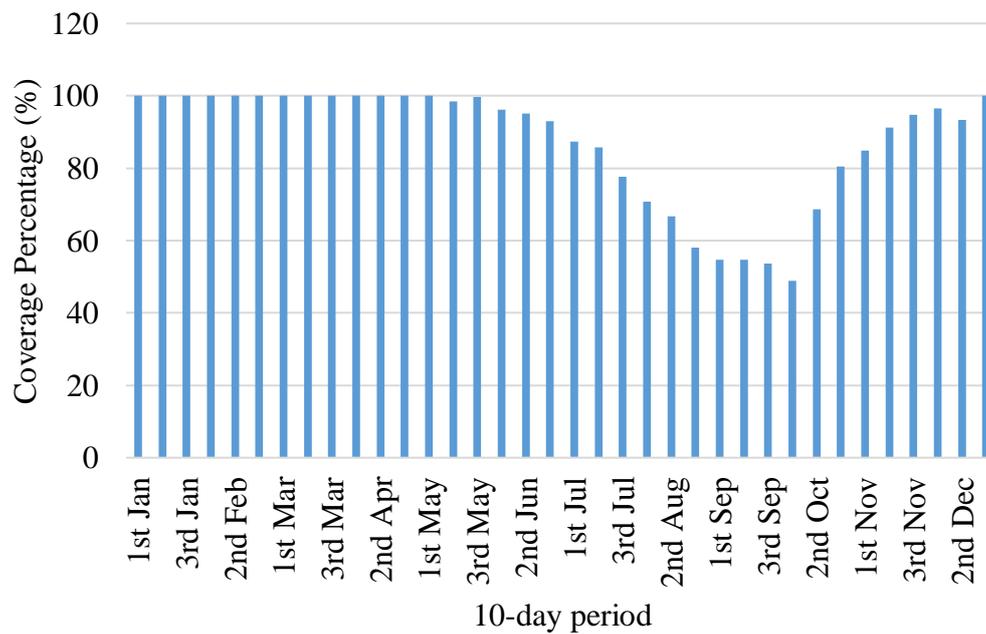

Figure 16. Coverage

Figure 16 shows that from 2nd May to 2nd December, the supply is insufficient to meet the demand. It is supposed that 1st May is the start of the dry season, and therefore the lack of water supply starts on 2nd May. This happens because of the low precipitation due to the dry season. Apart from low precipitation, the need for water in 10 days is also high due to the three times rice planting pattern in a year in the study location. As a result, there is a severe shortage of water. On 1st October, the peak was only 74.92% of water demand can be covered by water supply. Meanwhile, from 3rd December to 1st May, the watershed can supply all the water demand up to 100%. The volume of unmet demand per 10-day period and annually in the Mayang watershed is shown in figure 17 and figure 18.
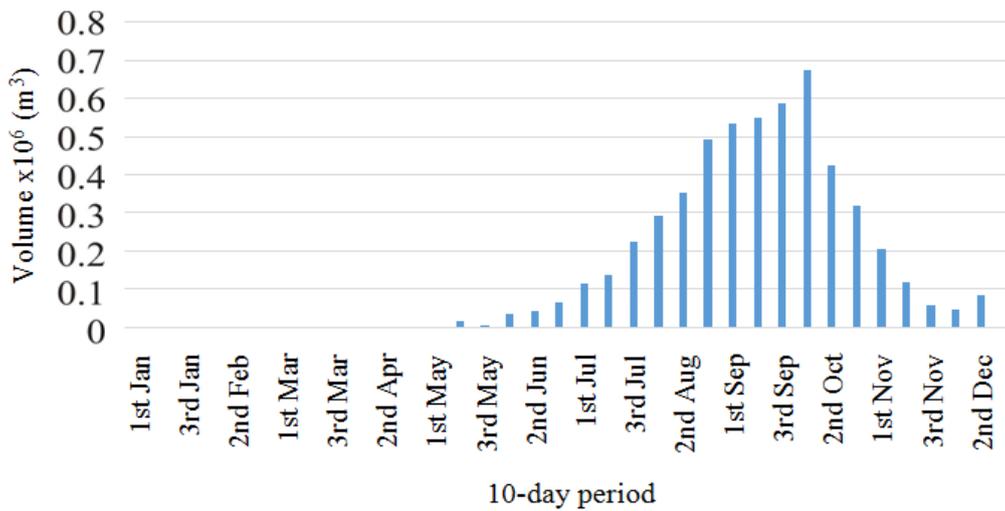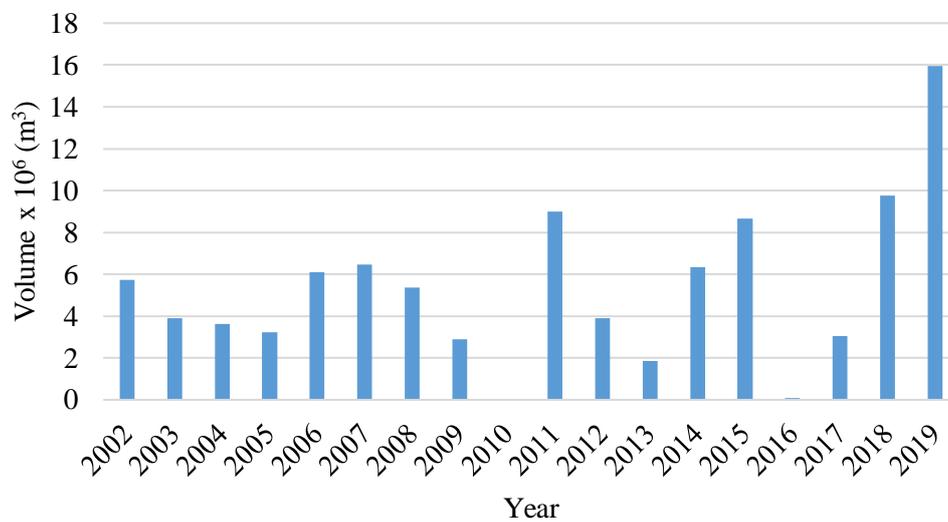
Figure 17. Unmet demand per 10-day period

Figure 18. Annual unmet demand

Unmet demand is the amount of water needed but can not be supplied from the available water resources. It is essential to know the magnitude of the water shortage (Sieber & Purkey, 2015). The highest unmet demand occurred on October 1st period, where about 0.67 million m^3 of demand can not be covered. The average volume of unmet demand is 0.15 million m^3. Figure 18 shows a lack of water occurrence for the dry season. For example, in 2019, the unmet demand is 15.95 million m^3. If the unmet demand occurs continuously, it will propagate an impact on various aspects of life. It does not rule out hydrological disasters such as drought and floods. The management of water resources, especially in terms of distribution during the rainy season and dry season, must be considered. The average annual unmet demand is 5.33 million m^3.

The water demand for each site tends to increase every year (i.e., domestic, urban, and industrial water demand sites). The increase of population on the watershed is expected to be quite large, considering an increase of 0.55% (Badan Pusat Statistik Kabupaten Jember, 2020). The increase in population will undoubtedly increase domestic water demand. In addition to water demand for various sites, the demand for outflow components in this model is surface runoff and evapotranspiration. Surface runoff and evapotranspiration are the most significant components of the outflow. The value depends on the percentage of vegetation land cover—the more the vegetation cover, the smaller the runoff. The simple things that can be done to increase water demand for domestic, urban, industrial, and livestock are savings or efficiency measures. The application of saving demand for irrigation water can be made by applying the SRI method. The SRI method can reduce irrigation water demand by 25% with the SRI method (Subari et al., 2012).

However, to apply this method, a more in-depth study of the water demand for irrigation. The application of savings for irrigation water demand can also be made by changing cropping patterns. This is because the demand for irrigation water is the most significant demand than water demand in other sectors. This is supported by Kumalajati et al.(2017) research which states that agriculture is the largest user of water. Changes in paddy cropping three times a year can be replaced with palawija during the dry season. This can help reduce the water demand for irrigation, given that the water demand for palawija is much smaller than for rice. For groundwater preservation during the rainy season, a simple thing that can be done is to make infiltration wells in the house's yard. The same result was conveyed by Kahirun & Hasani (2017) regarding technical efforts in forest and land rehabilitation by applying soil and water conservation principles. This can help reduce surface runoff and prevent water from being discharged into water bodies.

4. Conclusion

The water balance of Mayang Watershed was observed for 18 years (2002 to 2019) using the WEAP model. The average annual precipitation that supplies the watershed is 1733.56 mm. The demand for water for each site tends to increase every year. The modeling results show that from 2002 to 2019, the water resources condition in the watershed can meet the demand from 3rd December to 1st May. The coverage value reaches 100%. However, from 2nd May to 2nd December, the demand for water from all demand sites was insufficient. The highest [first] unmet demand occurred in October, with 0.67 million m^3. The management of water resources, especially in terms of distribution during the rainy season and dry season,

must be considered. It is also noted that the WEAP can simulate the main component of water balance in the watershed.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

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