Preliminary assessment of water balance at Mayang watershed, East Java

A M C Sihombing¹, I Indarto¹ and S Wahyuningsih²

¹Departement of Natural Resources and Environmental Management, Postgraduate Faculty, University of Jember, Indonesia
²Department of Agricultural Engineering, Faculty of Agricultural Technology, University of Jember
E-mail : sihombing92@gmail.com

Abstract. Mayang watershed is prone to hydrological disasters. The watershed is subject to flooding events during the rainy season, and potentially prone to drought risk during the dry season. This study aims to assess the sustainability of water balance on the watershed using the Water Evaluation and Planning (WEAP) model. Supply water comes from rainfall. Demand is calculated based on the need for irrigation, domestic, urban, industrial, and livestock uses. The unit of time to calculate the water balance is ten days. In one month it is divided into three periods. WEAP modeling is based on current water requirements. The results showed that from 2002 to 2019, the available water resources were not able to meet all water demand throughout the year. Unmet demand occurs from May 2nd to December 2nd. From December 3rd to May 1st, the Mayang river and its tributaries were able to supply the water for all demand sites up to 100%.

1. Introduction
Water resources on the watershed use to supply and to meet the water demand for irrigation, domestic, urban, industrial, livestock and fisheries, and other needs. Water becomes a very valuable resource, both in terms of quality and quantity [1]. Regional development will cause water demand to continue to increase in line with population growth rates. Fulfilling food needs and population activities is always closely related to the need for water. Especially during the pandemic due to Covid-19, as it is now, all elements of society are required to live clean and healthy lives [2]. Thus, this leads to the implementation of adequate water resources management, which becomes very important to determine how much water is available for human use and economic activities that water should be shared among users.

Water resource policymakers need tools to achieve a balance in water supply and demand, to protect the environment, ensure fair use of water resources, promote efficient use of water and develop priorities in shared water resources. WEAP is used to assist decision-makers in managing water demand, water availability, waste costs, and water costs and evaluating water development and management options [3]. WEAP is an integrated water resource planning software. It also provides a user-friendly, flexible, and, comprehensive framework for water balance development, scenario creation, planning, and policy analysis. WEAP operates on the basic principle of water balance and can be applied to the agricultural system in a single watershed or watershed across regions [4]. This model uses standard linear programming to solve the water resource allocation problem every time.
An integrated water resource planning step analysis can also build and analyze various future scenarios using alternative assumptions about the impact of water requirements and supply policies [5]–[7].

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 [8]. Understanding the water balance in an area 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 people are living in the Mayang watershed [9]. People depend on the Mayang river and its main tributaries. They use the water for agriculture, domestic, urban, industrial, and livestock. Although the catchment receives an average annual rainfall of 1733 mm, and it can be counted as an abundance of water resources. However, the watershed is still prone to hydro-meteorological disasters. The watershed has the potential of flooding during the rainy season, and subject to drought during the dry season. From 2007 to 2015, there were several hydro-meteorological disasters such as floods, landslides, and drought have occurred. Floods occurred in Tempurejo, Ambulu, and Mayang districts. Then landslides reported occurred in Tempurejo and Kalisat Districts. Furthermore, the lack of water supply during the prolonged dry period has frequently occurred in the Silo District [10]. This phenomenon, in turn, affects the livelihoods and socio-economic activities in and around the community [11].

Planning, development, and proper management of water resources is essential to meet current and future water demand and to avoid potential water scarcity, crises, and conflicts [12]. Effective management of water resources depends on a thorough understanding of the quantity and quality of water available [13]. The purpose of this study was to determine the potential of water resources as well as the characteristics of the hydrological components which will then be used to determine the water balance, in particular the Mayang watershed.

2. Material and Methods

2.1. Study Site and Input Data
The Mayang watershed (Figure. 1) has an area of 1135 km². The altitude on the watershed varies from 95 to 3175 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.

![Study site - Mayang Watershed](image_url)

Both hydrological data series and geo-spatial and are used as input for modeling in the WEAP. The hydrological data series consists of rainfall and water demands data. Rainfall 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) rainfall stations on the watershed. Then, the data series related to irrigation water demand was obtained from the local agency of public works and water resources management. Furthermore, water demands from other sectors, namely domestic, urban, industrial, and livestock are calculated from existing statistical data.

![Figure 2. Polygon Thiessen Mayang Watershed.](image)

The Geo-spatial data includes the Digital elevation model (DEM), land cover map, and soil type map. The DEM was extracted from the DEMNAS. 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 web site [14]. The DEMNAS use to delineate the watershed boundary, determine river network, and to describe the schematic of water balance (supply vs demand) on the WEAP platform.

Two types of land cover maps were used in this study. The first map was clipped from the RBI Rupa Bumi Indonesia (RBI) digital maps and downloaded from the BIG website [15]. 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 [16]. 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 [17] and use to represent the soil layer condition of the watershed.

2.2. Procedure
2.2.1. Analysis of rainfall data
The consistency test [18] was calculated for each rainfall station. Table 1 present the test results for the seven stations. It can be concluded that the seven stations are consistent, which means that the measured and calculated data are accurate and correct according to the phenomenon when the rain occurs.

| No | Station Name       | Y           | R²     | Explanation |
|----|--------------------|-------------|--------|-------------|
| 1  | Dam Talang         | 0.9382x - 264.38 | 0.9898 | Consistent  |
| 2  | Jatisari           | 1.1276x + 120.89 | 0.9928 | Consistent  |
| 3  | Jenggawah          | 1.1181x + 76.954 | 0.9903 | Consistent  |
| 4  | Karang Kedawung    | 1.039x + 44.115 | 0.9953 | Consistent  |
Then, point rainfall measurement is then interpolated to areal rainfall by using the Thiessen polygon interpolation method. The interpolation was prepared using the existing tutorial [19].

2.2.2. Analysis of Land Cover Change
The land cover data on WEAP use to simulate the hydrological and to calculate evapotranspiration. Table 2 shows the distribution of significant land cover (LC) and percentage of change (in % of the total watershed area) between 2001 and 2015.

**Table 2. Mayang Watershed Land Cover**

| Land Cover                  | Area (Km²) | Percentage 2001 | Percentage 2015 | Percentage 2015 |
|-----------------------------|------------|-----------------|-----------------|-----------------|
| Built-Up Area (1)           | 91.19      | 7.84%           | 121.32          | 10.43%          |
| Irrigated Paddy (2)         | 198.89     | 17.10%          | 321.12          | 27.60%          |
| Non-Irrigated Land (3)      | 1.98       | 0.17%           | 38.46           | 3.31%           |
| Marginal Land (4)           | 133.49     | 11.47%          | 302.58          | 26.01%          |
| 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    | 100.00%         | 1163.41         | 100.00%         |

Source: Analysis, 2020

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 land cover have turned into agricultural land and developed land.

**Figure 3. Land Cover Map in 2001 and 2015**
2.2.3. Water Demand Analysis

2.2.3.1 Demand for Irrigation

Irrigation water demand is the amount of water required for irrigation. The calculation of irrigation needs begins with processing the plant data used to determine the Palawija Relative Area (LPR). LPR is the ratio of water requirements between one type of plant and another [20]. The coefficient of plant species can be seen in Table 3.

| Plant type       | Plant coefficient |
|------------------|-------------------|
| Palawija         | 1                 |
| Rainy paddy      |                   |
| a. Nursery       | 20                |
| b. Land cultivation | 6              |
| c. Growth        | 4                 |
| Legal paddy      |                   |
| a. Nursery       | 20                |
| b. Land cultivation | 6              |
| c. Growth        | 4                 |
| Illegal paddy    | 1                 |
| Sugarcane        |                   |
| a. Planting      | 1,5               |
| b. Growth        | 1,5               |
| c. Harvest       | 0                 |
| Tobacco or rosella | 1              |

Source: [20]

The LPR value is determined based on equation 2 as follows:

\[
LPR = A_{crop} \times C_{crop} \\
LPR_{a,b} = \left(4 \times A_{palawija} + 1 \times A_{pluvd} + 1,5 \times A_{tebu} + 1 \times A_{tebk}\right)
\]  

Remarks: LPR = Relative Palawija Area (ha.pol), A crop = Planting area (ha), C crop = Coefesion of plant types. Then proceed with determining the value of the Relative Palawija Factor (FPR) using a soil type map. A soil type map is presented in Figure 4. The FPR value is determined by the type of soil in the study area. FPR values for each type of land are presented in Table 4.

![Figure 4. Map of Soil Types of the Mayang Watershed](image)
Table 4. FPR value based on soil type

| Soil type  | 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: DPU Level II East Java Unit Pengelolaan SDA Wilayah Sungai Bango-Gedangan, 2009.

The demand for irrigation (Q) are obtained from the results of the LPR and FPR multiplication and are expressed by the following equation based on the DPU Level II East Java (1997) in (Dewi et al., 2014):

\[ Q = LPR \times FPRQ = LPR \times FPR \]

(2)

Remarks: Q = demand for irrigation (l/s)
LPR = relative palawija area (ha.pol), FPR = relative palawija factor (l/s/ha)

2.2.3.2 Domestic, Urban, and Industrial Water Demand

2.2.3.2.1 Domestic Water Demand

Domestic water demand is needed by households that are obtained individually from water sources or obtained from the PDAM drinking water supply system service [22]. Domestic water demand is calculated based on the number of residents in the area [23]. The main factor determining domestic water demand is knowing the number and population growth [24]. Domestic water demand depends on the city category based on the population in liters/person/day [22]. These categories are presented in Table 5.

Table 5. Domestic Water Demand by City Category

| Urban Category        | Total Population (Person) | Water Demand (l/p/d) |
|-----------------------|----------------------------|----------------------|
| Semi urban (capital of the district/village) | 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              |

Source: [22]

The equation for calculating domestic water demand is as follows:

\[ \text{Domestic water demand} = \sum \text{population} \times 10\% \times 120i \]

(3)

2.2.3.2.2 Urban

Urban water demand, namely for social and commercial purposes such as hospitals, hotels, schools, shops, and warehouses, is assumed to be 15% -30% of the total domestic water demand [22]. The equation for calculating urban water demand is as follows:

\[ \text{Urban water demand} = \text{Domestic water demand} \times 15\% \]

(4)
2.2.3.2.3 Industry
Industrial water demand tends to be constant with time. The more the industry increases, the water demand increases. Industrial water demand tends to be constant with time. The more the industry increases, the water demand increases [22]. Industrial water demand is obtained from the Dinas PU Pengairan, Jember Regency.

2.2.3.3 Livestock
The demand for livestock water is calculated based on the number and types of livestock in the area with the level of water demand for each type of livestock [25]. The main factor in determining the livestock water demand is knowing the number and growth rate of livestock [26]. For this reason, an analysis is needed to estimate the number of livestock in the next few years. The amount of water demand for livestock is presented in Table 6.

| Types of Livestock | Water Demand l/d |
|--------------------|------------------|
| Cow / buffalo / horse | 40               |
| Goat/sheep         | 5                |
| Pig                | 6                |
| Poultry            | 0,6              |

Source: [22].

The equation for calculating livestock water demand is as follows:

$$Q_l = (q_1 \times P_1 + q_2 \times P_2 + q_3 \times P_3)$$

Remarks: $QE$ = 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 (l/day) $P_1 = number of types of livestock$.

2.2.4. Soil Moisture
The 2 compartment soil moisture calculation scheme is based on empirical functions describing evapotranspiration, surface runoff, subsurface runoff (i.e., interflow), and deep percolation for a catchment unit. This method allows the characterization of land use and the impact of soil types on these processes. Deep percolation within the watershed unit can be channeled to surface water bodies as a baseline or directly to groundwater storage if appropriate connections are made between the watershed unit nodes and groundwater nodes [27].

2.2.5. Preparing WEAP scheme
The boundary map of the Mayang watershed was obtained from the DEMNAS map extract using the GIS application. The river flow network is represented by a blue line and the location of the output points is represented by around point in red. A demand site is best defined as a set of water users that share a physical distribution system, that is all within a defined region, or that share an important withdrawal supply point [4]. The WEAP scheme model of the Mayang watershed hydrological model can be seen in Figure 5.
2.2.6. Calibration and validation
The WEAP model calibration is done by comparing the simulation results with discharge data from the 2003-2009 measurements. The two discharge data analyzed the coefficient of determination (R²). Validation is a process of evaluating a model to get an idea of the level of uncertainty a model has in predicting the hydrological process. To test the validity of the model in this study, it was carried out by using the resulting discharge from the calibration and by using different data series in the calibration process. The validation of the WEAP model is done by comparing the simulation results for the 2010-2019 discharge data and the observed discharge data. The two discharge data analyzed the coefficient of determination (R²).

3. Results and Discussion

3.1 Calibration and Validation
The WEAP model calibration is presented in Figure 6. R² results of 0.78 which have a high influence. This value indicates a close relationship between the simulation discharge and the observation discharge of the Mayang river. The WEAP model Validation is presented in Figure 7. The R² result is 0.88 which is considered a high influence. This means that the model can produce reliable results.

3.2. Inflow dan Outflow Mayang Watershed
Inflow and outflow per period and annually in the Mayang watershed are presented in Figure 8 and Figure 9. Rainfall as input, respectively. The average volume of rainfall per period is 56.02 million m³ and the annual rainfall of 1733 mm. The average evapotranspiration volume per period is 20.43
million m$^3$ and the annual average evapotranspiration of 632.23mm. The average volume of surface runoff per period was 29.75 million m$^3$ and the annual average surface runoff is 920.61 million mm.

**Figure 8.** Mayang watershed inflow and outflow per period

**Figure 9.** Mayang watershed annual inflow and outflow
3.3. Water Demand

3.3.1. Irrigation Water Demand

The volume of irrigation demand per period and annually is presented in Figure 10 and Figure 11. Irrigation water demand for the Mayang watershed per period is 1.48 million m$^3$, and the annual irrigation water demand is 53.43 million m$^3$. The demand for irrigation in the Mayang watershed tends to be constant every year.

![Figure 10. Irrigation water demand per period](image1)

![Figure 11. Annual irrigation water demand](image2)

3.3.2. Domestic, Urban, and Industry Water Demand

The volume of domestic, urban, and industrial water demand and annual, respectively, is presented in Figure 12 and Figure 13. The average domestic, urban, and industrial water demand per period is 0.94 million m$^3$. The volume of domestic, urban, and industrial water demand in a year is 33.97 million m$^3$.

![Figure 12. Domestic, Urban, and industrial water demand per period](image3)

![Figure 13. Annual domestic, urban, and industrial water demand](image4)

3.3.3 Livestock

The volume of water demand for livestock per period and annually in the Mayang watershed is shown in Figure 14 and Figure 15. The average livestock water demand per period in the Mayang watershed is 0.11 million m$^3$. The volume of livestock water demand in a year is 4.07 million m$^3$. 

![Figure 14. Livestock water demand per period](image5)

![Figure 15. Annual livestock water demand](image6)
3.4 Coverage
The results of WEAP modeling show that water demand cannot be met throughout the year. This is presented in Figure 16. The graph shows that water demand from May 2nd to December 2nd was insufficient. The peak was on October 1st, the water demand of all demand sites was only able to be met by 74.92%. Meanwhile, from December 3rd to May 1st, the Mayang watershed was able to meet the water demand at all demand sites up to 100%.

3.5 Unmet Demand
The volume of unmet demand per period and annually in the Mayang watershed is shown in Figure 17 and Figure 18. Unmet demand is the amount of water needed but not supplied from its source. It is important to know the magnitude of the water shortage [4]. The highest unmet demand occurred on October 1st with 0.67 million m$^3$. The average unmet demand per period in a year is 0.15 million m$^3$. The smallest unmet demand occurred in 2010 at 0 million m$^3$. The biggest unmet demand occurred in 2019 with 15.95 million m$^3$. The annual average unmet demand is 5.33 million m$^3$. 
3.6 Discussion

The water balance was observed for 18 years. The main component of inflow in the WEAP model is rainfall. The annual rainfall that enters the Mayang watershed is 1733.56 mm. The rainfall in the Mayang watershed tends to be constant every year. Meanwhile, the demand for water for each site in demand tends to increase every year. Especially domestic, urban, and industrial water demand sites. Domestic, urban, and industrial water demand sites are based on the population in an area. The increase in the population of the Mayang watershed is expected to be quite large considering that each year there is an increase of 0.55% [9]. The increase in population will certainly increase domestic water demand in the Mayang watershed. 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 largest components of the outflow, where the value depends on the percentage of land cover. The greater the land cover, the smaller the runoff and the greater the evapotranspiration because this is a natural system in the hydrological cycle.

The coverage percentage is the percentage of each site demand that is met, from 0% (no water) to 100% (sufficient water requirement). The percentage of coverage provides an assessment of how well demand is met [27]. The modeling results show that the condition of the water resources in the Mayang watershed can meet the demand for water from December 3rd to May 1st. The coverage value reaches 100%. Meanwhile, from May 2nd to December 2nd, the demand for water from all demand sites was insufficient. The highest unmet demand occurred on October 1st, with 0.67 million m³. Unmet demand occurs due to the amount of water used by other sectors and the amount allocated to EFR (environmental flow requirements) [28].

The simple things that can be done to increase coverage in meeting 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 [29]. However, to apply this method, a more in-depth study of the demand for irrigation water is needed.

4. Conclusion

The results showed that from 2002 to 2019, the available water resources were not able to meet all water demand sites throughout the year. Unmet demand occurs from May 2nd to December 2nd. Meanwhile, from December 3rd to May 1st, the Mayang watershed was able to meet the water demand at all demand sites up to 100%. What can be done to increase coverage in meeting domestic, urban, industrial and livestock water demand is savings or efficiency.
5. References

[1] Misra A K 2014 *Int. J. Sustain. Built Environ.*, 3(1) 153–165
[2] Barneveld K, Quinlan M, Kriesler P, Junor A, Baum Fran, Clibbon S, Flanagan F and Friel S 2020 *ELRR 3* 133-157
[3] Van Loon A and Droogers P 2016 *Water Evaluation and Planning System Kitui – Kenya* (Netherlands : WatManSup research report no. 2)
[4] Sieber J and Purkey D 2015 *WEAP User Guide* (Stockholm : Stockholm Environment Institute)
[5] Duque LF 2017 *Maskana 8* 125–146
[6] George O, Metobwa M, Mourad K A and Ribbe L 2018 *Int. J. Nat. Resour. Ecol. Manag.* 3(1)9–18
[7] Yates D, Sieber J, Purkey D and Huber-Lee A 2005 *Water Int.* 1487–500
[8] Dimova I, Tzanov E, Ninov P, Ribarova I and Kossida M 2013 *Procedia Eng.* 70 563–572
[9] BPS Jember Regency 2020 *Jember Dalam Angka Tahun 2020* (Jember: BPS Kabupaten Jember)
[10] BPBD 2015 *Rekapitulasi Badan Penanggulangan Bencana Daerah 2007-2015* (Jember: BPBD)
[11] Nick A 2015 *The Chongwe Catchment: A Hydrological, Hydrogeological and Hydrochemical Characterisation for the Establishment of a Catchment Management Plan*(Lusaka : Minist. Energy Water Development)
[12] Sivakumar B 2011 *Hydrol. Sci. J.* 56 (4)531–552
[13] Lorenz D and Ziegeweid J 2016 *Methods to Estimate Historical Daily Streamflow for Engaged Stream Locations in Minnesota* (Virginia: U.S Geoloycal Survey)
[14] BIG Badan Informasi Geospasial (BIG) 2019 [Online] Available: http://tides.big.go.id/demnas/.
[15] BIG Badan Informasi Geospasial (BIG) *Website Ina-Geoportal* 2019 [Online]. Available: http://tanahair.indonesia.go.id/portal-web.
[16] Hakim F L 2019 *Interpretasi Citra Satelit Landsat 8 untuk Pemetaan Tutupan Lahan Provinsi Jawa Timur* (Jember : Universitas Jember)
[17] Soil Research Institute 1998 *East Java Soil Type Map* (Bogor : Directorate General of Forestry)
[18] Ilham R K, Limantara L M and Marsudi S 2018 *J. Mhs. Jur. Tek. Pengair* 1 2
[19] Indarto 2013 *Analisis Geostatistik* (Yogyakarta: Graha Ilmu)
[20] Haliem W, Juwono P T and Priyantoro D 2012 *J. Pengair* 3(2)230–239
[21] Unit Pengelolaan SDA Wilayah Sungai Bango-Gedangan 2009*Laporan Kegiatan Alokasi Air DAS Amprong, Malang*
[22] BSN 2015 *Penyusunan neraca spasial sumber daya alam – Bagian 1 : Sumber daya air Jakarta*, BSN
[23] Mashuri, Fauzi M and Sandhyavivitr A 2015 *Jom FTEKNIK* 2(1)1–12
[24] Afrianto L, Rohmat D and Jupri 2015 *Antol. Geogr* 3(3)1–12
[25] Zulkipi, Soetopo W and Prasetijo H 2012 *J. Tek. Pengair* 3(2)87–96
[26] Putri A, Chairani S and Ichwana 2016 *J. Ilm. Mhs. Pertan. Unsyiah* 1(1)1002–1008
[27] SEI 2008*User Guide for WEAP21* Available: www.seib.org/weap. [Accessed: 10-Jan-2019],
[28] Ayele S A 2016 *Application of Water Evaluation and Allocation Planning (WEAP) Model to Assess Future Water Demands and Water Balance of The Caledon River Basin*(South Africa : Central University of Technology)
[29] Subari S, Joubert M D, Sofiyuddin H A and Triyono J 2012 *J. Irig.* 7(1)28