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Research Article

Water Balance Assessment, Land Use Land Cover Change and Increasing Water Demand in Three Major Watersheds in Jember, East Java, Indonesia

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ABSTRACT

Jember Regency is the third largest agricultural area in East Java Province. Expansion of built-up and agricultural areas occurred and significantly changed the landscape. Moreover, increasing both types of land cover will increase water consumption. Therefore, there may be changes in the condition of the water balance in the Jember Regency area. This area has three major watersheds: Bedadung, Mayang, and Tanggul. This study evaluated the water balance condition at the three major watersheds in Jember, East Java, Indonesia. The WEAP (Water Evaluation and Planning) model calculated the water balance. Research procedures include (1) inventory of spatial and non-spatial data; (2) setup of the WEAP scheme; (3) Calibration; (4) Validation; and (5) Simulation of water balance model in scenario increasing water demand and land-use change). From 1997 to 2020, the water balance was evaluated using a 10-day interval. The results show that from the November 1st to August 2nd periods, the watershed can supply all demand sites with 100% coverage. However, from August 2nd t to October 3rd periods, the watershed's ability to supply the water needs decreased. This deficit is due mainly to the uneven rainfall distribution between rainy and dry seasons. Variation in annual rainfall received from 1997 to 2020 also affects the water balance's surplus and deficit. The fluctuation of land-use change contributed to the surplus and shortage of water balance.

Keywords : Supply; Demand; Water Balance; WEAP; Jember; East Java

INTRODUCTION

Water is a basic need of living things that must be met. If viewed from the aspect of quantity, the water on earth is still able to meet the needs of all living things. However, the spatial and temporal distribution of water is often unbalanced. Therefore, floods and droughts can occur in different places and times (Setiawan & Hariyanto, 2017; Setiawan et al., 2019). Discussing water indeed cannot be separated from the concept of a Watershed. Rainwater is a source of surface water. It falls to the earth and then flows from a high to a lower place, overflows into a stream that goes to the mouth of a river and ends in the sea (Setiawan et al., 2019; Sihombing et al., 2021).

Over the past two decades (from 2000 to 2018), land use land cover (LULC) has changed significantly in the region. A more detailed view using five subsets of areas shows the main driving forces of LULC change: transport infrastructure development; sub-urbanization; development and change of agricultural practices; industrial site development; and tourism activities. Such changes manifest as urban sprawl, usually distributed irregularly, perhaps due to development planning. Over the past two decades, regional development and population growth have significantly changed LULC (Indarto & Hakim, 2021; Slaymane & Soliman, 2022)

The impact of land-use change on the water balance shows an increase in surface runoff and water yields and a decrease in actual evapotranspiration. Changes in the curve number's value cause land use's impact on water yields. The numerical value of the curve was found to be higher with increasing settlements, vacant agricultural land, and decreasing forest area (Kundu et al., 2017; Dinka & Chaka, 2019). Changes in LULC have implications for the water balance component and will continue to impact ecosystems and water resource development in the Pre-River Basin. The expected increase in surface runoff during the rainy season could cause flooding, while its reduction during the dry season could affect agricultural activities. Intensification of soil erosion and sedimentation of water resource structures is also possible due to increased surface runoff (Awotwi et al., 2018; Astuti et al., 2019). Changes in land use play an important role in water balance, as indicated by the increase in surface flow and River discharge due to the lower area and rate of vegetation cover (Nugroho et al., 2013; Losiri et al., 2016).

Jember region is the third-highest harvested area in East Java (BPS, 2021). The extension of agricultural fields causes the increase of agricultural water needed. Furthermore, the development of urban and built areas during the last two decades increased water demand. Contrary, the source of water is limited and fluctuates depending on the seasons. Therefore, assessment of the adequacy of water resources in meeting water needs for irrigation, domestic, non-domestic, industry, and Livestock is very important in mitigating water disasters (droughts and floods) (McNamara et al., 2020).

This study aims to evaluate the condition of the water balance in the Bedadung, Mayang, and Tanggul watersheds from 1997 to 2020. WEAP was used to assess the condition of the water balance in each watershed by considering the supply-demand component in conditions of increasing water demand and changes in land use (USCS). WEAP is a powerful tool that can assess and manage the water situation at the basin level (Mourad & Alshihabi., 2015). This study uses WEAP to calculate the water balance. The novelty of this study is pointed out by including land use land cover (LULC) change from 1997 - 2021. Landsat data from 1997 to 2000 were used to classify and interpret the LULC change in the region.

METHODS

Study Area

This study uses three major watersheds of the Jember Regency consisting Bedadung, Mayang, and Tanggul. Bedadung watershed has an area of 1042.48 km2, the Mayang watershed has an area of 1205.63 km2, and the Tanggul watershed has an area of 501.70 km2. The research location is shown in Figure 1.

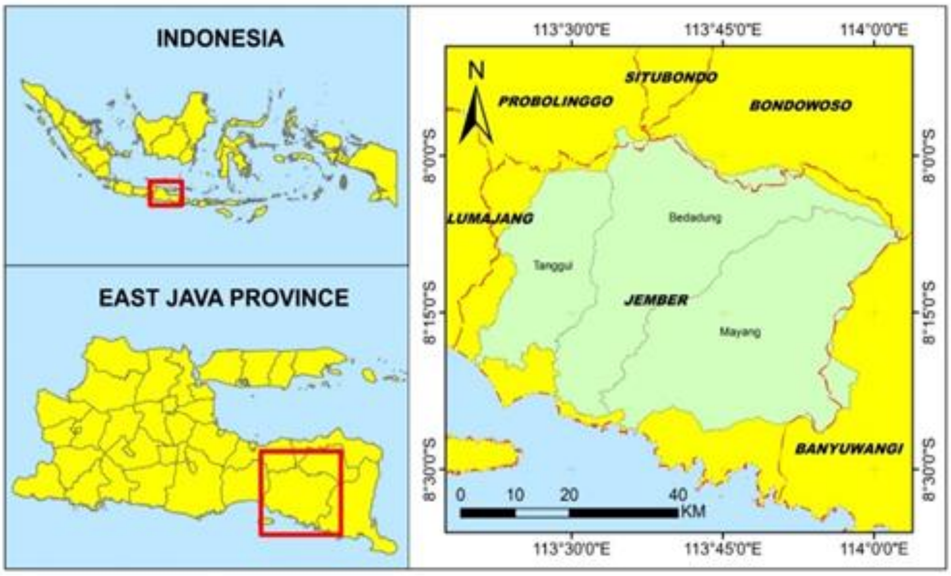


Figure 1. Study area

Tool and Input Data

Table 1 shows the input data (both spatial and non-spatial) used for this study.

Table 1. Input data and sources

Data Type	Tool Analysis	Data Source
Spatial Data		
Landsat Imagery (1997, 2002, 2014, and 2020)	Classification of land cover with analysis Geostatistics using QGIS 3.0	Google Earth Engine (https://explorer.earthengine.google.com/#workspace)
Digital Elevation Model (DEM)	Making watershed and flow boundaries River with analysis Geostatistics using QGIS 3.0	the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003) (https://search.earthdata.nasa.gov/search/)
Soil Type Map	Palawija Relative Factor (PRF) Palawija Relative Area (PRA) using Ms. Excel	Watershed Management Center and Protected Forest (BPDAS-HL) Brantas-Sampean in Sidoarjo
Non-Spatial Data		
Quantity Data Population	Calculation of domestic water needs using Ms. Excel	Regency Central Statistics Agency (BPS) Jember Regency, Bondowoso Regency, and Regency Probolinggo.
Quantity Data Cattle	Calculate farm water needs using Excel.	
Industrial Water Demand Data	Calculation of industrial water needs using Excel	District Drinking Water Company (PDAM) Jember Regency
Agricultural Water Demand Data	PRF-PRA using Ms. Excel	Service Profession General Affairs (PU) of Highways and Water Resources Jember Regency
Rainfall Data	Thiessen polygons using QGIS 3.0 and Ms. Excel	
Air Temperature Data	Evapotranspiration by using WEAP	DAM Umbul climate station in Lumajang Managed by Implementing Unit Technical Management Source River Basin Water Power (UPT PSDA-WS) Bondoyudo in Lumajang

This study used 41 year recording period from 1979 to 2020 (both for rainfall and climate data). Meanwhile, recorded debit data is available from 2009 to 2015. The primary tool used is QGIS, and WEAP (USCS, 2015).

Procedure

The first step is collecting land use, climate, and water demand data (Figure 2). Then, set up the WEAP Schema and enter the data into the model. Furthermore, conduct the calibration and validation of the water balance model. The last step is simulating the model. The model results in unmet water balance, coverage, and watershed demand. The water balance in the watershed is calculated by considering the main supply of rainfall and water needs for irrigation, domestic, Livestock, and industrial needs.

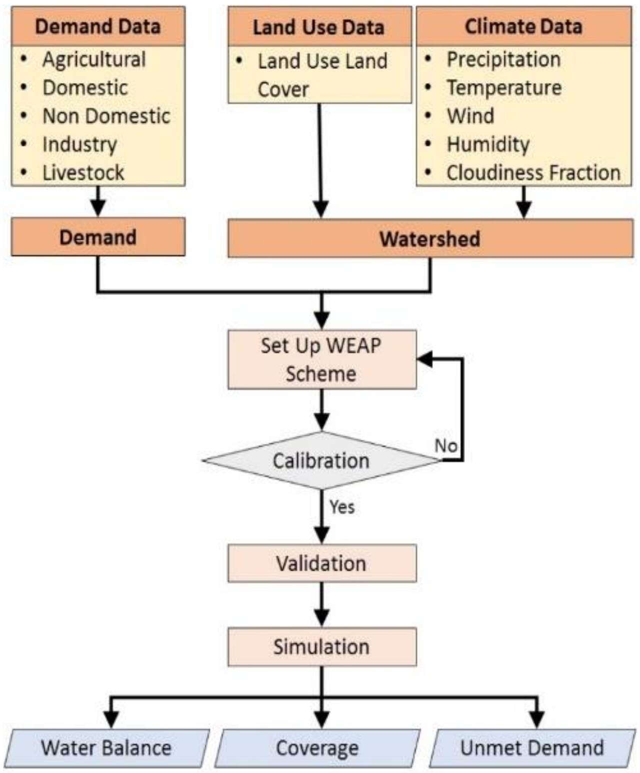


Figure 2. Research procedure

Land Use Land Cover Data

Processing of Landsat images is done using a semi-automatic classification plugin in QGIS. The Landsat image was composed using six bands (2, 3, 4, 5, 6, and 7). Classification of Landsat images to produce LULC maps was done using the Maximum Likelihood algorithm. The Kappa index was used to evaluate the classification results with a threshold >80%. The subset is used to clarify the accuracy analysis (Indarto & Hakim, 2021).

Watershed Boundaries

In the first stage, the river basin area is delineated based on the DEM of the watershed area. The ASTER GDEM V2 (30 x 30 meters in pixel size) is used to derive DEM for the watershed area. We observed at several area based on the natural topographic boundary of the watershed. The size of the threshold value is used to determine the number of river networks (Sujarwo et al., 2019)

Regional Rainfall Data Processing

The Thiessen polygon method is used to interpolate points data to arear rainfall data. The result of the Thiessen Polygon calculation by Suwarno (2015) showed the average rainfall data for the three watershed areas (Figure 3). Then, each watershed's average regional rainfall data are entered into the WEAP in the Catchment node.

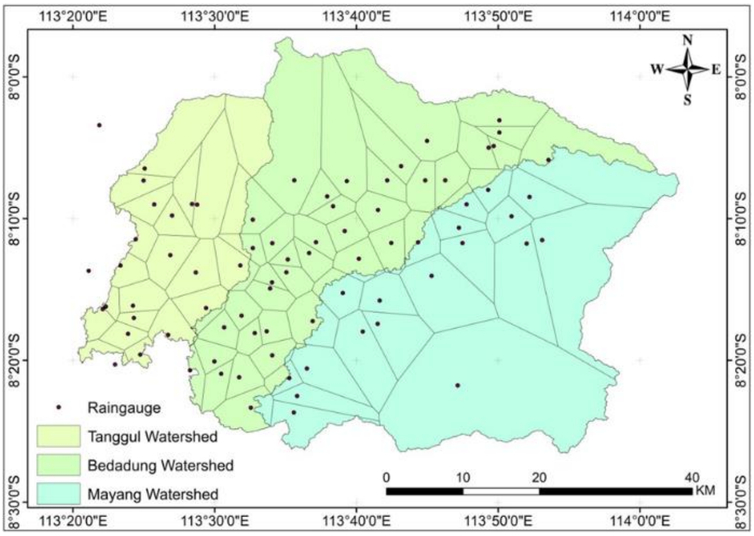


Figure 3. Thiessen Polygon Method of Study Area

Water Demand Analysis

Irrigation water demand

Irrigation water requirement is the amount of water needed to irrigate the plant. The types of crops grown in the watershed during the annual (crop data calendar) determine the Palawija Relative Area (PRA). "Palawija" categorizes all non-rice crops, such as corn, soybeans, and green beans. Palawija is the second plant and most widely grown agricultural crop in the dry season. The water requirement for this type of plant is significantly different from that of rice fields but is relatively the same as each other. In Indonesia, rice usually requires more water than other crops. The rice fields usually occupy more space. Mainly, Irrigation infrastructure is developed to support rice fields. Therefore, PRA calculates plants' practical water requirements by comparing each plant type's area (Sihombing et al., 2021). The Bedadung watershed has 180 irrigation areas ("Daerah Irigasi/DI") with a total area of 29,944 ha of rice fields. The Mayang watershed has 85 irrigation areas (DI) with a total rice field of about 20,027 ha. The Tanggul watershed has 70 irrigation areas with a total rice field of 13,903 ha.

Domestic, Urban, and Industrial Water Demand

Firstly, domestic water needs (DWD) is how much households use to meet their everyday life. Households usually draw water from the unsaturated soil layer through sinks or boreholes. Otherwise, households obtain water from municipal water supply system services (BSN, 2015). We calculated DWD according to population at each area. Population growth is a main factor that related to domestic water demand. Jember Regency is classified as a medium city, so the standard water requirement is estimated at 100-125 l/person (BSN, 2015)

Secondly, urban water needs (UWD) is a term that is defined to meet public needs in urban areas with an assumption of 15% -30%. Then Industrial Demand Data (IWD) is obtained from the city or district regional water management agency.

Livestock

The water requirement for Livestock is calculated based on the number and type of Livestock in each watershed.

Table 2. 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

Soil Moisture

We used Soil moisture method to ensure both surface and sub surface run off, and percolation for catchment area. Identification of land use characters is calculated by considering the type of soil. Then, percolation at each watershed considers surface run off and groundwater (USCS, 2016).

Setup of the WEAP Scheme

Several data are needed, including land use maps, satellite images, DEM, watershed boundary maps, soil types maps, administrative boundary maps, river maps, rain-gauges locations, and water use locations to produce a scheme model of the water balance of the watershed (Figure 4, 5 and 6).

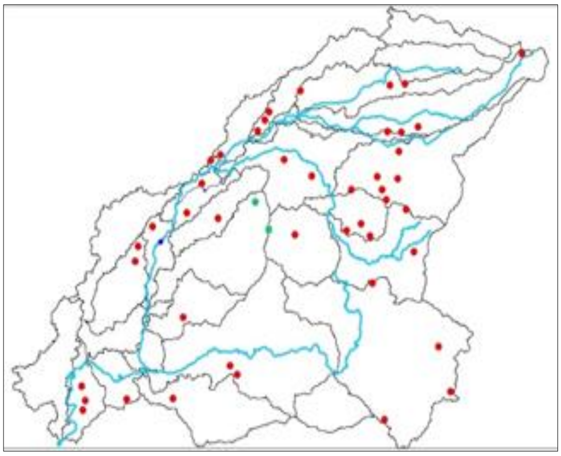


Figure 4. The WEAP Scheme model Mayang Watershed

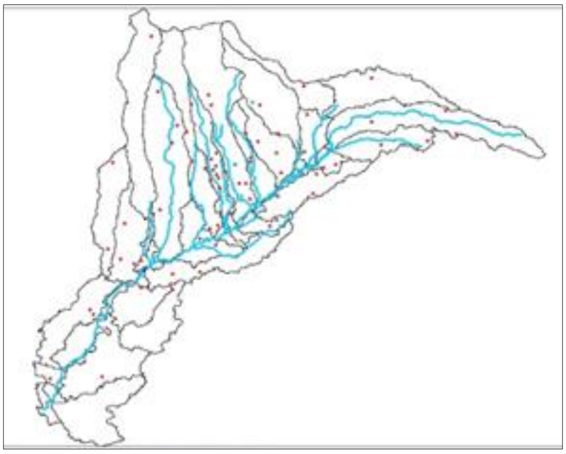


Figure 5. The WEAP Scheme model Bedadung Watershed

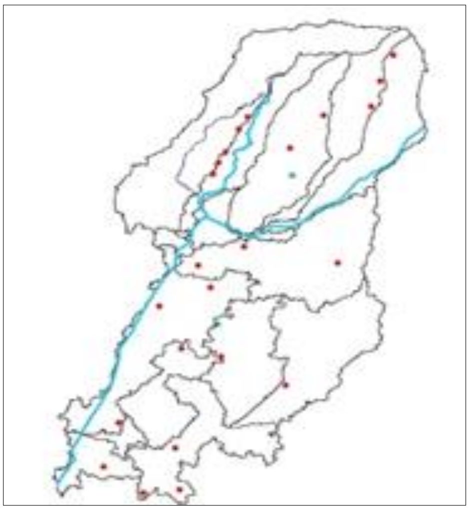


Figure 6. The WEAP Scheme model Tanggul Watershed

Calibration and Validation

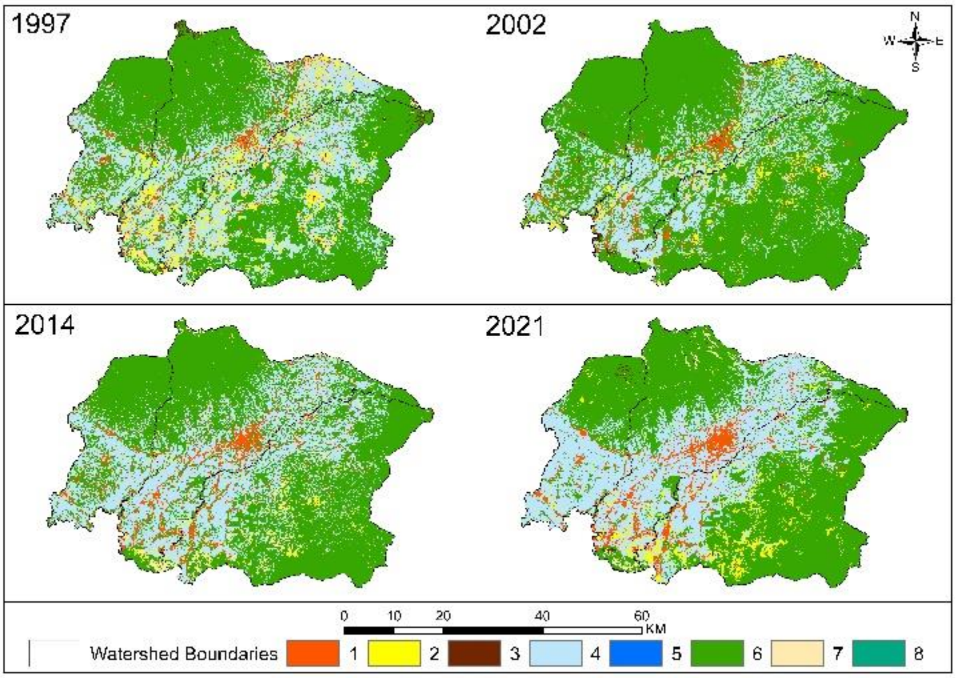
The river discharge or flow data is used for calibration and validation steps (Agarwal et al., 2019). The calibration uses flow data from 2009 to 2012, while the validation uses flow data from 2013 to 2015. The Parameter Estimation Tool (PEST tool) optimizes the calibration process. Statistical methods, i.e., coefficient of determination (R2), Nash-Sutcliffe Efficiency (NSE), and Root Mean Squared Error (RMSE), were used to evaluate the performance of the calibration and validation processes. If the process is still not done, rebuild the mapping schema, re-enter the data, and look for missing factors in the model design. Then, the model can be re-simulated. The process is stopped until the water balance results are sufficiently modeled.

RESULTS

Land Use Land Cover

The LULC for each watershed is determined from the Landsat Imagery (1997, 2002, 2014, and 2021), presented in Table 3 and Figure 7. The results showed that all watersheds have significant LULC changes. The most significant LULC change occurred in the built-up area (+ 2.29%), followed by the paddy field (+1.52%) and open water (+0.07%). The most significant increase in the built-up area occurred in the Bedadung watershed. The increase in population number automatically increases the water demand. Water from rain will fall to the ground surface, and due to land cover changes from vegetation to pavement, the water will flow as surface runoff.

The demographic characteristics of women in the study region are dominated by their productive age, high school / vocational education, housewifery, and agricultural labor. They still have adequate agricultural land to cultivate food, therefore food sufficiency is rather good. In the studied region, household control of agricultural land is somewhat constrained, and as a result, agricultural outputs tend to meet household needs. This condition is reflected in the research area's adequate food availability, despite the region's extreme poverty. The difficulties posed by the COVID-19 pandemic have compelled women to keep the household economy in order to assist their husbands in sustaining themselves. Due to the little arable land in the research area, land ownership is not typically associated with poverty. Women use social contacts, family ties, and government assistance to escape the poverty trap. The condition of the area that has easier accessibility is favorable for women to do petty trading. Although, women are faced with the difficulty of completing odd jobs in the area. The research area is in the Merapi volcano disaster-prone area, so further research on the study of women's strategies in an effort to escape the poverty trap in a multi-disaster area needs to be carried out, in addition to the focus of respondents on female household heads to find out more details about women's ability to escape.



Note : 1. Bulit-up/Urban; 2. Heterogeneous Agricultural Land, 3. Bare Soil, 4. Paddy Field, 5. Open Water Bodies, 6 . Vegetation, 7. Shrubland, 8. Wetland

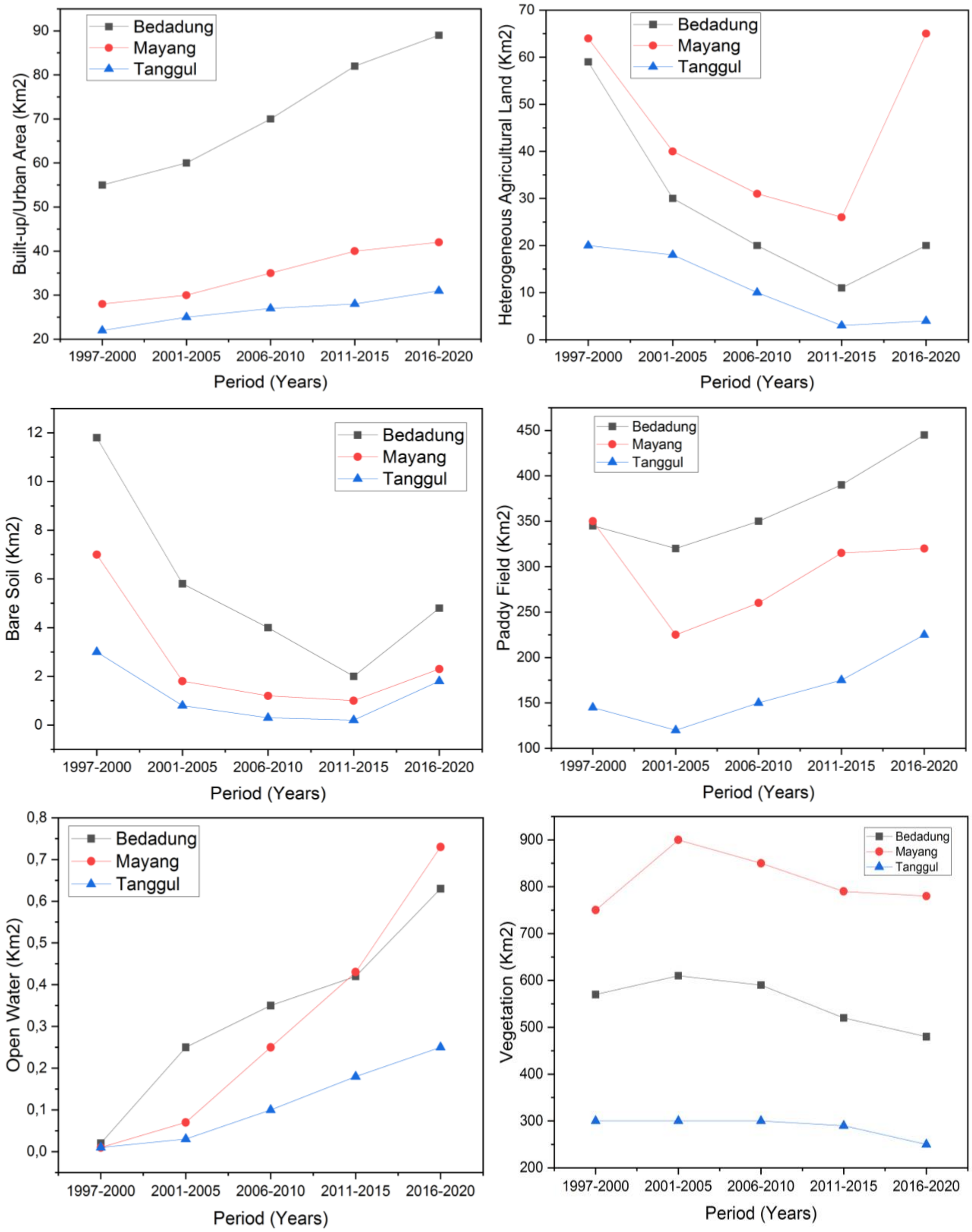
Figure 7. Land use and land cover (LULC) Changes in Three Watersheds

Table 3. Land Use Land Cover (Km^2) Study at Study Area

Classes	Landsat 1997		Landsat 2002		Landsat 2014		Landsat 2021	
	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)
Built-up/Urban (BU)	87.89	3.74	88.53	3.77	131.39	5.60	141.56	6.03
Heterogeneous Agricultural Land (HAL)	148.88	6.34	75.36	3.21	30.45	1.30	111.22	4.74
Bare Soil (BS)	24.63	1.05	7.54	0.32	2.38	0.10	9.94	0.42
Paddy Field (PF)	785.12	33.44	538.82	22.95	759.71	32.35	820.79	34.96
Open Water (OW)	0.00	0.00	0.26	0.01	0.90	0.04	1.68	0.07
Vegetation (VG)	1264.63	53.86	1626.34	69.26	1346.43	57.34	1243.58	52.96
Shrubland (SH)	36.05	1.54	11.25	0.48	76.79	3.27	18.79	0.80
Wetland (WL)	0.91	0.04	0.02	0.00	0.07	0.00	0.56	0.02
Total	2348.11	100.00	2348.11	100.00	2348.11	100.00	2348.11	100.00
OVA		95.18		90.82		84.82		90.27
KAPPA		93.65		89.07		81.14		87.31

Note :

Built-up	Represents all artificial surface features mainly occupied by dwellings and buildings.
Heterogeneous Agricultural Land	Represents annual or seasonal crops associated with all types of 'non-rice field' agricultural areas (Palawija)
Bare Soil	Represents the surface covered by sand and rock. The sand is most commonly found in coastal areas. Rock mainly on the mining and mountain/hill areas.
Paddy Field	The Paddy field consists of all areas dominated by paddy: technical irrigated and non-irrigated land.
Open Water	Represents the surface features covered by deep water bodies such as lakes, weirs, reservoirs, and rivers
Vegetation	Represents all non-agricultural plants, including woody perennial plants, primary tropical forest, secondary forest, and mixed plantation
Shrubland	Covering all surface features such as grass, mixed-grass, dry area with less vegetation, abandoned agricultural land
Wetland	Represents the surface features covered by shallow water bodies such as fishponds, streams, canals, and flooded paddy fields


Built-up/Urban Area (Km2)
Heterogeneous Agricultural Land (Km2)
Bare Soil (Km2)
Paddy Field (Km2)
Open Water (Km2)
Vegetation (Km2)
Period (Years)
1997-2000
2001-2005
2006-2010
2011-2015
2016-2020
Bedadung
Mayang
Tanggul

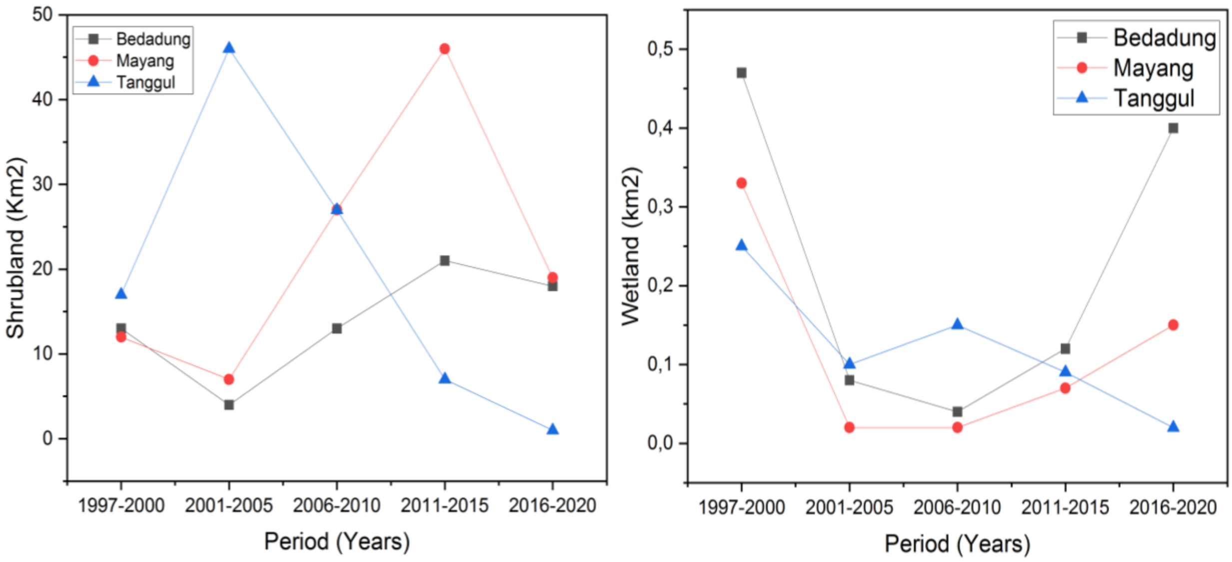
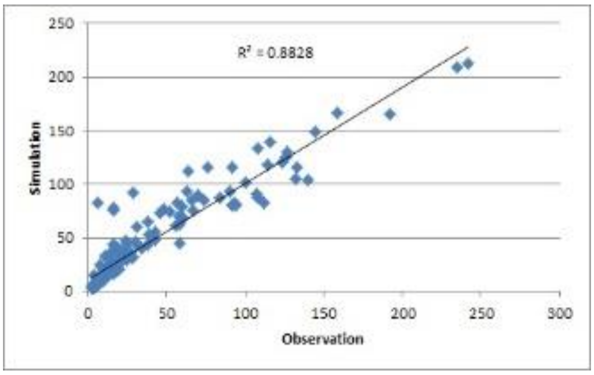
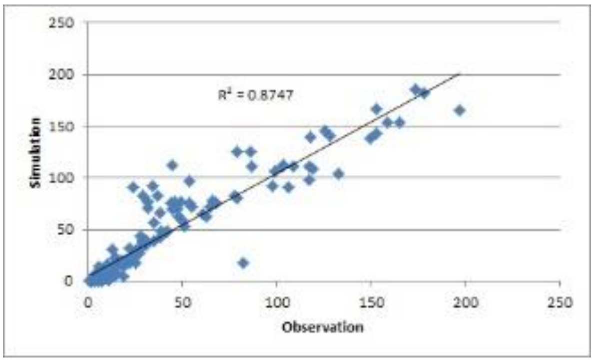


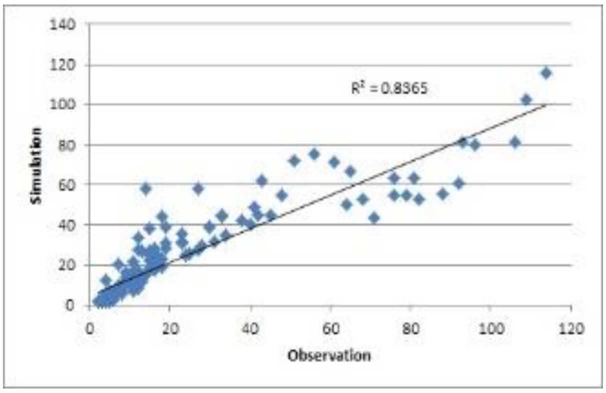
Figure 8. Graph of LULC change for each period in the Mayang, Bedadung, and Tanggul watersheds



Mayang Watershed ($R^2 = 0.88$; Nash = 0.86; RMSE = 17.71)

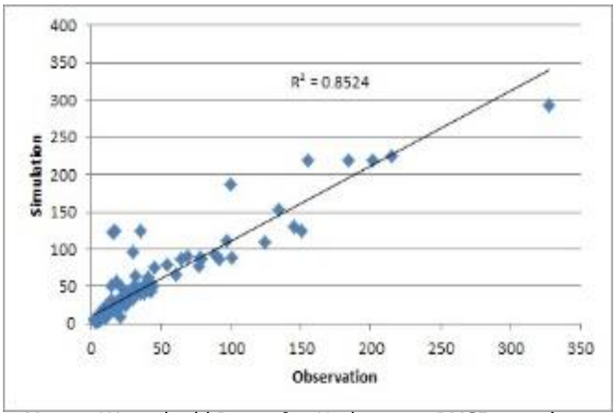


Bedadung Watershed ($R^2 = 0.87$; Nash = 0.85; RMSE = 17.59)

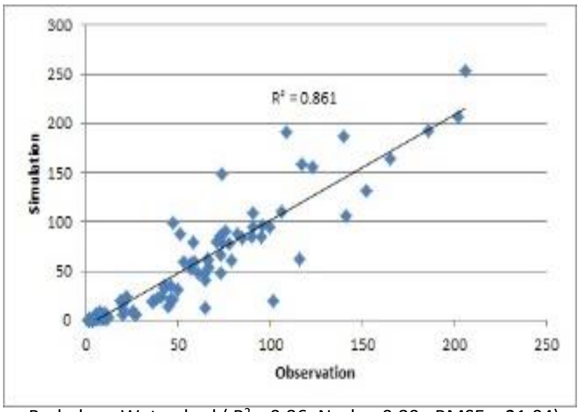


Tanggul Watershed ($R^2 = 0.83$; Nash= 0.83; RMSE = 10.52)

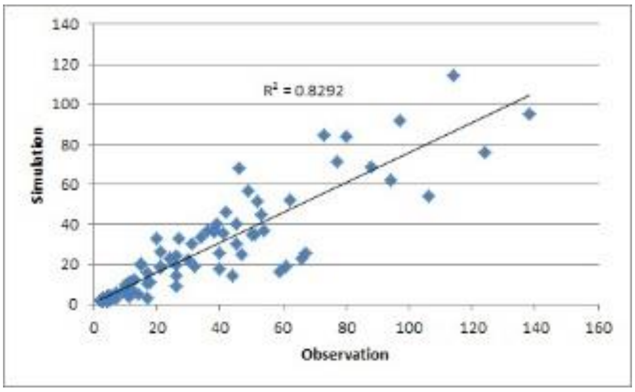
Figure 9. Scatter-plot of water balance calibration results for Mayang, Bedadung, and Tanggul Watersheds



Mayang Watershed (R2 = 0.85 ; Nash = 0.79 ; RMSE = 24.11)



Bedadung Watershed (R^2 = 0.86; Nash = 0.80 ; RMSE = 21.04)



Tanggul Watershed (R2= 0.83; Nash = 0.78 ; RMSE = 13.92)

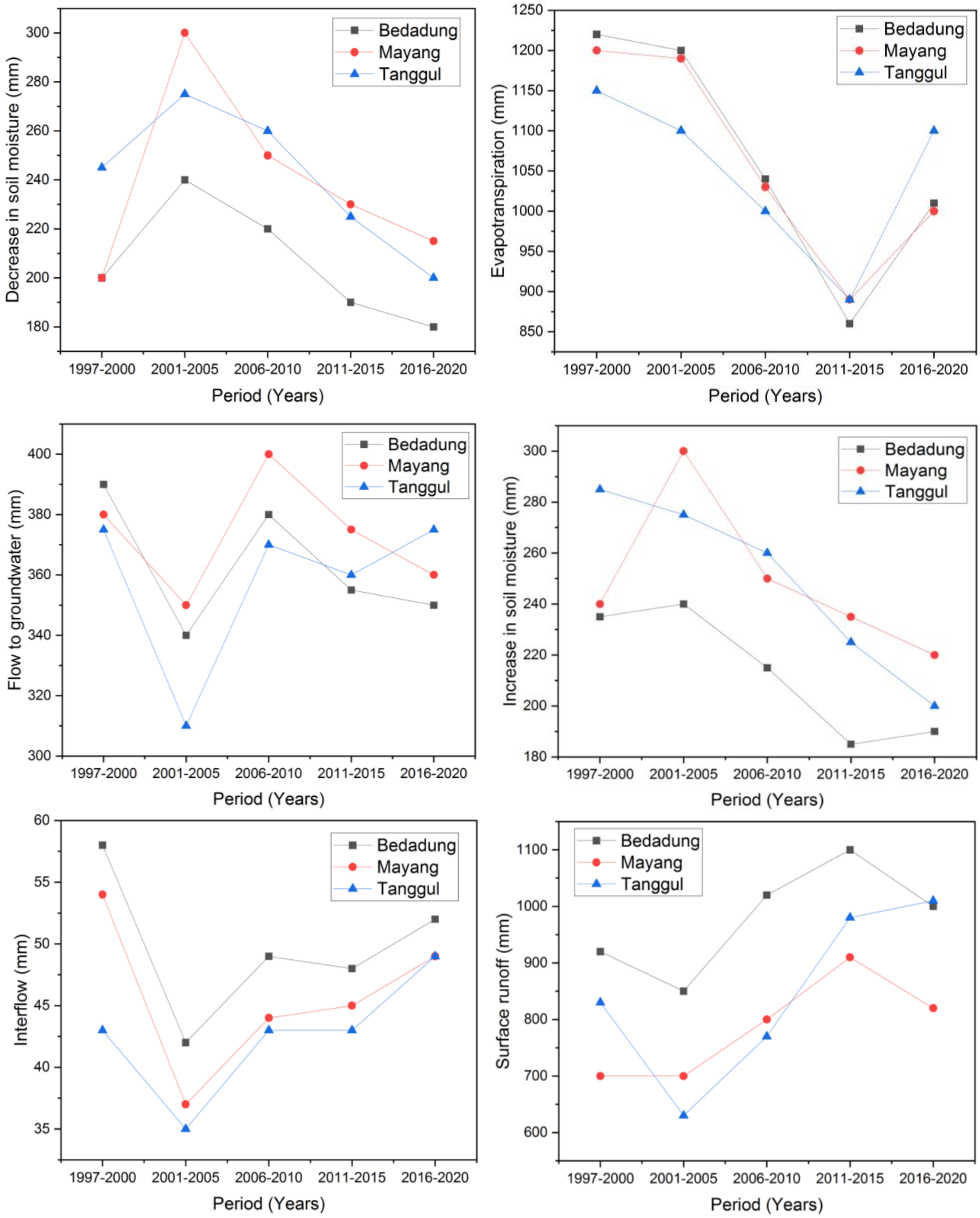
Figure 10. Scatter-plot of water balance calibration for Mayang, Bedadung, and Tanggul watersheds

Calibration and Validation

This study calibrated and validated the WEAP model to ensure the discharge simulation matched the observations. This study uses the Parameter Estimation (PEST) module available in the WEAP. PEST is used as a tool for model calibration. The model calibration uses recorded discharge data for each measurement station (Bedadung watershed on Rowotamtu, Mayang watershed on Talang, and Tanggul watershed on Pondokwaluh). The data used for calibration span from 2009 to 2012 (Figure 9). In comparison, the model validation uses the flow data on the exact location for the recording period from 2013 to 2015 (Figure 10).

Inflow and Outflow Component

Based on the model results, it is known that the annual water balance of each watershed has a varying value. The water balance input components used are Precipitation (P) and Decrease in Soil Moisture (DSM), and the resulting output is Increase in Soil Moisture (ISM), Surface Runoff (SR), Evapotranspiration (ET), Flow to Ground Water (FGW), and Interflow (IF). Figure 11 shows the water balance calculation result The results of the calculation of the water balance for each period of the year in each watershed are is presented in Figure 11 below.


Decrease in soil moisture (mm)
Evapotranspiration (mm)
Flow to groundwater (mm)
Increase in soil moisture (mm)
Interflow (mm)
Surface runoff (mm)
Period (Years)
1997-2000
2001-2005
2006-2010
2011-2015
2016-2020
Bedadung
Mayang
Tanggul

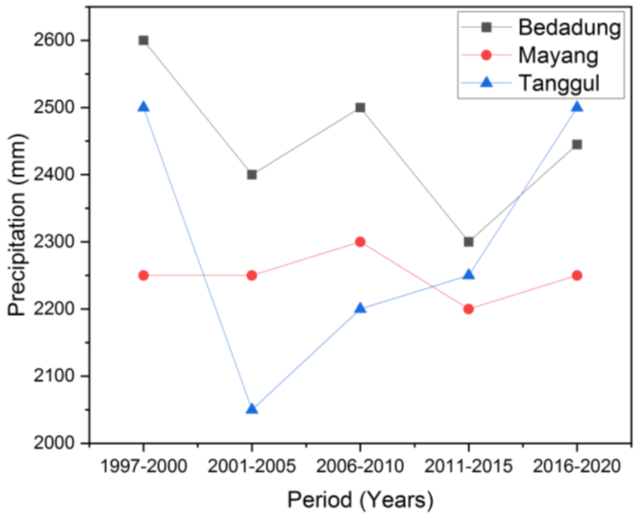
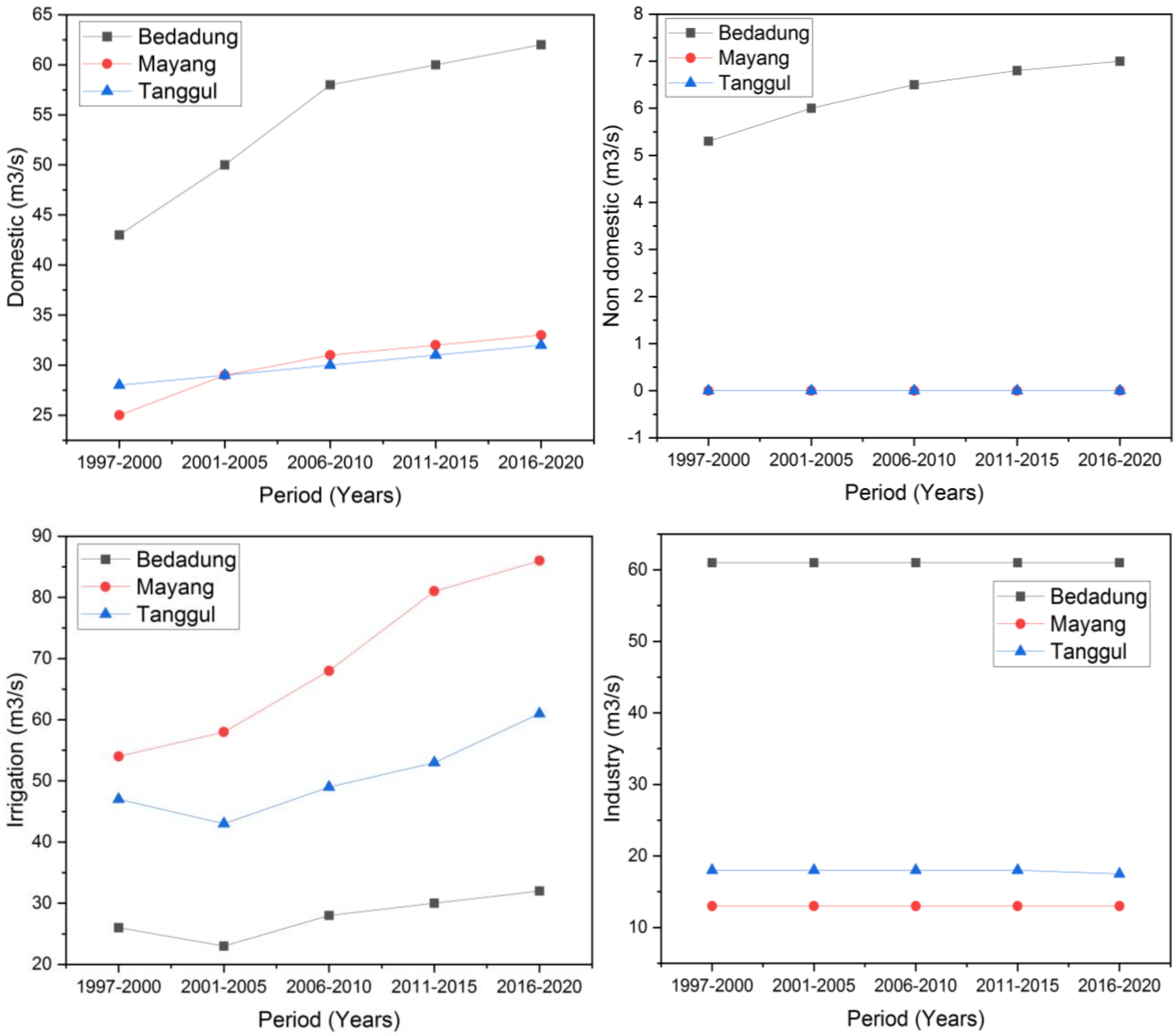


Figure 11. Graph of the inflow-outflow water balance of the Mayang watershed, Bedadung Watershed, and Tanggul watershed



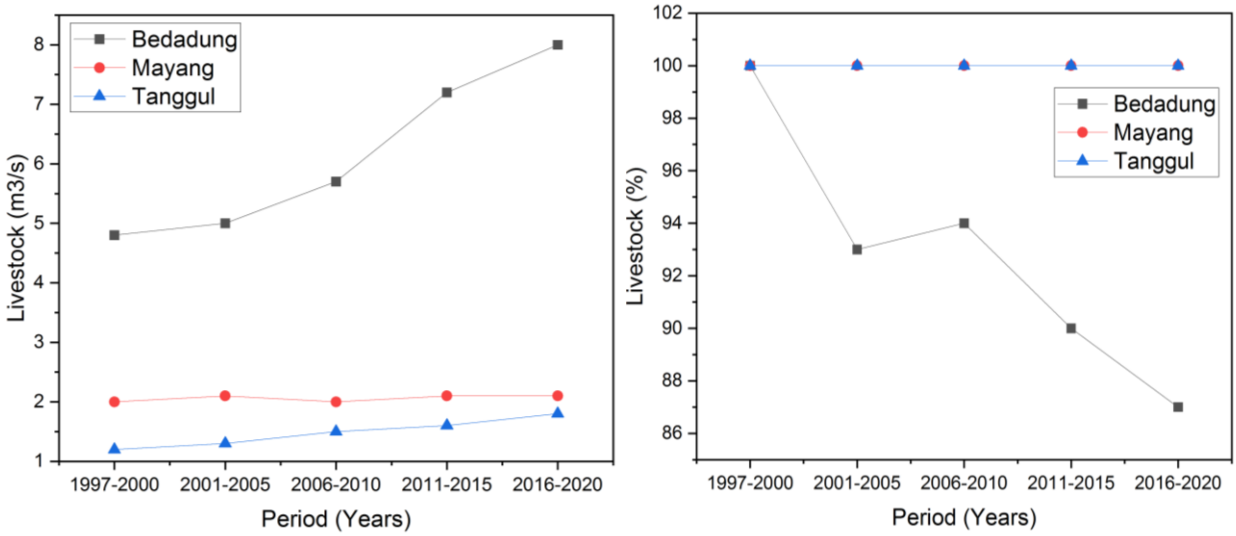
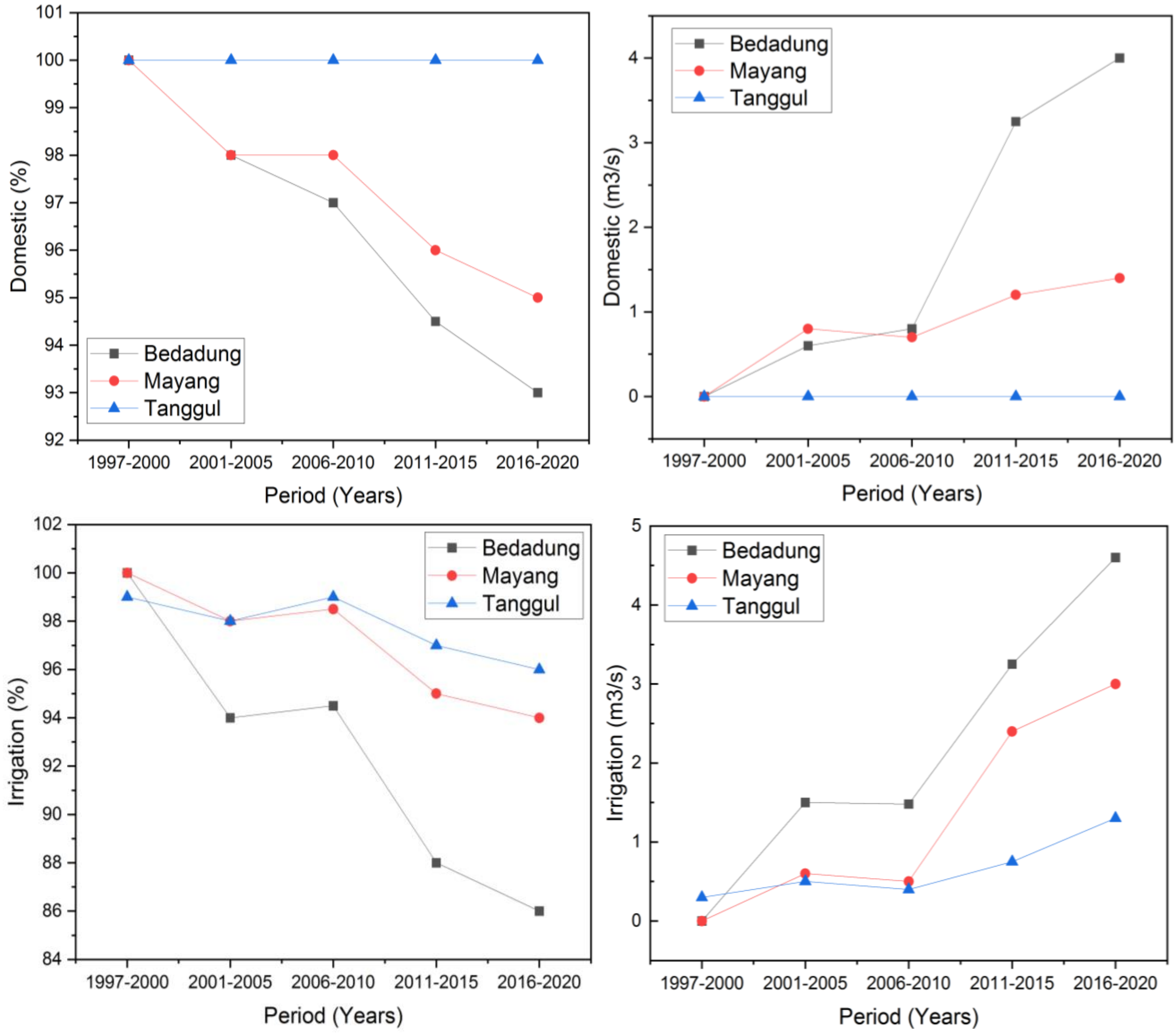


Figure 12. Graph of Water Demand for Mayang Watershed, Bedadung Watershed, and Tanggul Watershed



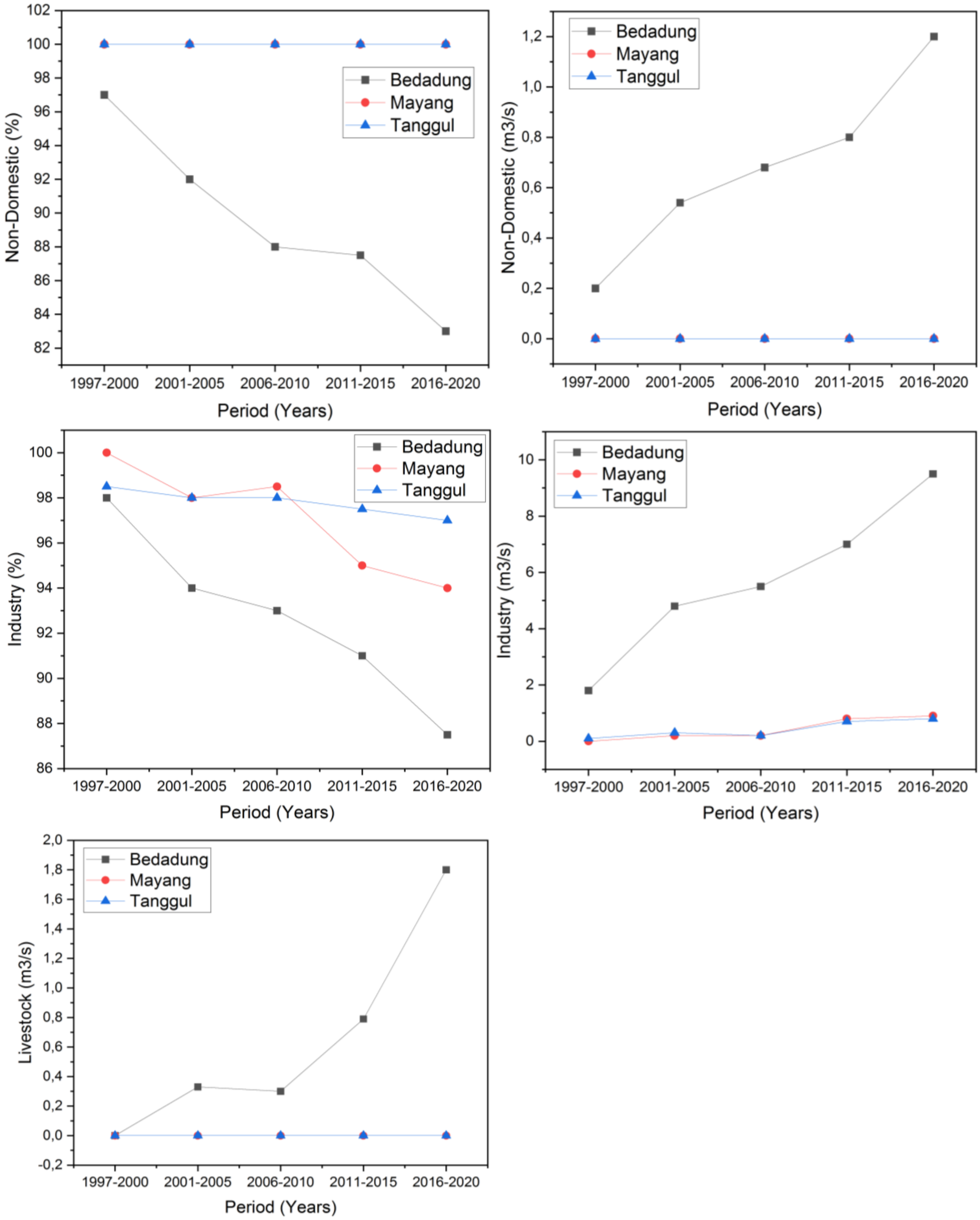


Figure 13. Graph of unmet demand for Mayang, Bedadung, and Tanggul watersheds

Water Needs

Figure 12 shows that the Bedadung watershed requires more water to supply domestic, non-domestic, industrial, and livestock needs. Meanwhile, the highest demand for water for agricultural activities is shown in the Mayang watershed. Moreover, Figure 7 shows that LULC changes are proportional to increased water demand in the Bedadung watershed. The increased changes in built-up are followed by an increase in the need for water for domestic, non-domestic, industrial, and livestock needs.

Coverage

Based on the results, as shown in Figure 12, it can be seen that there is a downward trend in the level of coverage of the three watersheds for each period of the year. This aligns with the LULC change in vegetation land cover, which is experiencing a downward trend, especially for the Bedadung watershed. In addition, the recapitulation results show that all watersheds experienced a deficit based on July III because usually, the dry season starts in July.

Unmet Demand

The description of the deficit in each watershed is presented in Figure 13. The most significant deficit in each component of water demand occurs in the Bedadung watershed because the most significant built-up area of land use is in the Bedadung watershed. Bedadung River crosses the city center of Jember, so many people use its water. Meanwhile, the deficit condition in the Mayang watershed occurred in the domestic, industrial, and irrigation sectors. The Tanggul watershed has a water demand deficit in the irrigation and industrial sectors. The highest deficit for each watershed occurred in the 2016-2020 period.

DISCUSSION

The water deficit in each watershed varies. In the Mayang watershed, domestic, irrigation, and industrial deficits occur. Previous study by Carpenter & Choudhary (2022) by found similar results in another case of a watershed that the rise of population growth directly influences the rise of water demand in the Veda River Basin, Madhya Pradesh. Yao et al. (2021) was also found that the high demand for irrigation and domestic water. The research describes the higher demand for rice irrigation and drinking water supply to urban centers in Lobo Watershed.

The most significant deficit in water demand occurs in domestic water needs, with the highest value, which requires water at 0.09 m3/s in the third decade of October. In the Bedadung watershed, the water demand experienced a deficit in domestic, non-domestic, irrigation, industrial, and livestock water needs. The highest water deficit value for industrial demand occurs in the third decade of September in the third decade. There is also a water deficit in the Tanggul watershed, with a deficit in water demand for industrial and irrigation water needs. The highest water deficit occurs in the need for water used for domestic purposes with the most considerable value reaching 0.30 m3/s in the third decade of September. Similarly, it is also found in other studies by Abdi & Ayenew (2011) in the Central Rift Valley basin of Ethiopia. In recent years, water requirement for irrigation remarkably increased in the dry periods due to little precipitation in these months.

Watershed management must be holistic and cannot be done only by optimizing one component, where limited efforts to address the water crisis throughout the country (Mourad & Alshihabi, 2016). Finally, this study recommended strengthening the regulations related to surface water used for industry and agriculture in the Mayang, Bedadung, and Tanggul watersheds, which is urgently required as a practical solution.

CONCLUSION

The water balance of the Mayang, Bedadung, and Tanggul watersheds varies yearly depending on the fluctuation of annual rainfall. It is supposed that the annual rainfall events are sufficient to supply water demand in the watershed; however, the unequal distribution between wet and dry seasons propagates the unmet demand or deficit of water supply during the dry seasons. The most significant deficit in the three watersheds occurred in 2019. The Mayang watershed had a deficit of 16.00 m3/s, the Bedadung watershed reached 49.25 m3/s, and the Tanggul watershed 8.41 m3/s. This is because 2019 was the driest year. The annual water balance deficit of more than -5 m3/s in the Mayang watershed occurred in 2015, 2018, and 2019; The Bedadung watershed experienced a deficit in 1999, 2001, 2002, 2004, 2006, 2007, 2008, 2009, 2011, 2014, 2015, 2017, 2018, 2019, and 2020; the deficit in the Tanggul watershed occurred in 2019.

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DECLARATIONS

Conflict of Interest

The authors declared that they had no known competing interests.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

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