Assessing freshwater water balance in Cimanuk River Basin

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Abstract. Indramayu Estuary plays a vital role in the sufficiency of food crop production in Indonesia. Managing freshwater inflows is essential due to the complex interaction between river flow and water extraction for multiple users. This study aimed to evaluate the freshwater water balance in the lower Cimanuk River Basin, West Java, Indonesia. The hydrological, meteorological, and statistical data were analyzed to evaluate water availability and demand. The Water Evaluation and Planning System model was used to evaluate water demand and supply, taking into account changes in river flow. The model was calibrated using the streamflow and water requirement for irrigation, fishery, domestic, and industries. The study showed that the Lower Cimanuk River Basin’s current water shortages were relatively high, indicated by flow discharge of only 2.7 to 48.04 CMS from August to December 2020. This shortage would become a critical constraint in which coverage of water demand does not satisfy water users for irrigating food crop cultivation in the areas and it is threatening the sustainability of food need nationally. Therefore, it is necessary to store freshwater inflow in the study area for the relevant decision-makers by rubber dam restoration at the lower Cimanuk River Basin.

1. Introduction
Freshwater is a vital natural resource for life-sustaining. It plays an essential role in supporting productive human activities such as agriculture, industry, sanitation, fishing, ecology, and energy. Human activities affect these vital resources, especially in the river basin and estuaries. Changes in water balance between water abstraction and water inflow into the river basin will seriously affect natural life sustainability. The increasing pressure on water demand and water competition potentially causes conflict among water users. According to UN Report in 2010, the agricultural sector’s 70% water consumption is the predominant water user, who consumes most of the available fresh water, resulting in the unbalance of water supply for the other sectors [1].

Cimanuk is one of the largest rivers in West Java Province and covers several regencies, such as Indramayu, Sumedang, Kuningan, Majalengka, and Garut. There is a significant gap in water volumes between the dry season and wet season. The water flow in the Cimanuk River is only 20 m\(^3\) s\(^{-1}\) during the dry season, compared to 600 m\(^3\) s\(^{-1}\) during the rainy season [2]. The water volume in the river basin could not be sufficient for supplying water demand in the downstream area. Moreover, the seawater intrusion problem during the dry season because the less freshwater could not push the intrusion [3].

Water scarcity has occurred in the Cimanuk River Basin. Water allocation and distribution among water users downstream appear inhumane and unfair. This condition is caused by the ability to diminish water supplies with a high degree of uncertainty among different water users. The problem will be compounded by the diversity of water availability inter-temporal and inter-area; thus, the water supply’s
ability for agricultural purposes, domestic and household decreased. Various water uses are likely to exceed the water availability, putting pressures on water resources. The proportion of water use for each sector is very dynamic and challenging to establish precisely and accurately. Solving conflicts in water demand and supply is essential at high demand, which requires freshwater management regarding water availability, water demand, water supply, and allocation in the river basin system. The WEAP model is commonly used to analyze both municipal and agricultural systems and deal with comprehensive issues, including sectoral water conservation, water demand estimates, water rights and allocation priorities, streamflow model, ecosystem requirements, operation of reservoir, and project cost-benefit analyses [4]. WEAP uses the mass balance concept in a river system, concerning allowance for water abstractions and inflows. This study aimed to evaluate the freshwater balance in the lower Cimanuk River Basin.

2. Materials and methods

2.1. Location description
The study was carried out in the lower Cimanuk River Basin in Indramayu Regency, West Java Province. Geographically, the Cimanuk River Basin is located between 107° 42' 51.02" - 108° 54' 31.38" East longitude and 6° 14' 43.96 - 7° 23' 56.03" South latitude. It covers a total area of 3,600 km², and the length of the main river is 230 km (figure 1).

![Figure 1. Location of lower Cimanuk River Basin.](image)

The lower Cimanuk River Basin is the coastal plain about 50 m above sea level. The lower river basin is relatively featureless, comprising mainly alluvial plains and terraces with, in the south, some very low hills.

2.2. Climate
The Cimanuk River Basin is categorized into the tropical zone. Meanwhile, the temperature and humidity are relatively constant for a year. The monsoons influenced the local climate conditions, mainly winds that blow over Indonesia from the northwest and southwest for about six months of the
year. The wet season starts from November until May and the dry season starts from May until November [2].

2.3. Irrigation water demands
Crop water requirements were calculated considering water demand with hydrological processes. The following equation is as shown below [5].

\[
ET_0 = 0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)
\]  

Where ET₀ is evapotranspiration, Rn-G is the net balance of energy available at the surface [MJ m⁻² d⁻¹], (eₛ − eₐ) represents the vapor pressure deficit of air at the reference (weather measurement) height [kPa], T represents air Temperature, \( \gamma \) is the psychometric constant [kPa °C⁻¹]. We also calculated Effective rainfall using rainfall data monthly and the USDA Soil Conservation Service method as the following criteria below [6].

\[
ER = \frac{\text{Total R*(125-0.2 TR)}}{125} \quad \text{(For Total Rainfall <250mm)}
\]

\[
ER = 125 +0.1 * \text{Total Rainfall} \quad \text{(For Total Rainfall >250mm)}
\]

\[
\text{CWR} = ETo* Kc
\]

\[
IWR = (ETo* Kc) - ER
\]

Where ER is Effective rainfall, TR is total rainfall, CWR is Crop Water Requirement, Kc is the crop coefficient. The climate data were obtained from the surrounding weather stations. The soil characteristics of the Cimanuk River Basin were mainly clay loam [2]. There were two types of crops cultivated by farmers surrounding the river. The cropping patterns for irrigated agriculture were paddy and grain. The mean rainfall irrigation requirement was generated by Thiessen polygon. Climate data from nine-stations were used to create the polygon in this study using the Geographic Information System (GIS) tool.

2.4. Non-irrigation water demand estimation
Water demand computation for agriculture, domestic, and industry entities relied on a disaggregated accounting for social and economic activities such as population served [7].

2.4.1. Domestic. Domestic and livestock water requirements are the volume of water required for drinking, washing, and goods production. Generally, the proportional water use with concerning the number of people and households affected the amount of water consumption. Small household families tended to use less water rather than a more prominent family. In contrast, the municipal water demand needed water for municipal facilities, such as commercial facilities, tourism facilities, religious facilities, and health facilities. The number of urban facilities determined the amount of municipal water demand. The development of the city dramatically influenced this need following the standards of water use of Ministry of public work, which was calculated based on water use rate (litre person⁻¹ day⁻¹ or L head⁻¹ day⁻¹) [2].

2.4.2. Fisheries water demand. The water requirement for fishing was the volume of water required for filling pools and changing water loss due to evaporation and percolation. Water demand was divided into four stages: land preparation, filling, flushing, and cleaning. Under the standards of water use for fishery as a Geospatial Information Agency (BIG) recommended, the average water needs for fisheries was 3.91 to 5.91 litre head⁻¹ day⁻¹ [8].
2.4.3. *Industry water demand.* The water requirement for industrial demand was water used for the daily industrial operation, which was determined by estimating the water use coefficient. Mostly, water use was proportional to the number of industrial units and the size of the industry. The Water Standard of water use from the Ministry of Public Works was presented in L unit ‘year’\(^{-1}\) [9].

2.4.4. *Livestock.* Water need for drinking, cleaning sites, and ecological purposes and water required for livestock were computed based on water use rate in L head ‘day’\(^{-1}\) [9].

2.5. *Water balance modeling*

The water balance of the land details the input, output, and the change in water storage contains in an environment for a particular period [10]. The relationship among the components of the water balance was analyzed in the form of a general water balance equation 3.2 [11].

\[
P = Q + E \pm \Delta S \tag{2}
\]

Where:

- \(P\) = precipitation;
- \(E\) = evapotranspiration;
- \(\Delta S\) = the storage in the soil, aquifers or reservoirs;
- \(Q\) = runoff.

WEAP modeled a total water balance for a complex water system. The WEAP built a network consisting of water resources and demand sites connected by links that deliver water from the resource node to the demand site. The WEAP included sub-basin in the river basin area, main river, and tributaries.

2.6. *Model calibration and validation*

The calibration methods have described the outcomes of the calibration parameter value, including performance statistics. The calibration period was chosen for 7-year periods where complete daily data are available for inflow upstream and downstream. After that, to complete the second phase, model validation is examined in the 2 years. A statistical approach designed, especially for evaluating the fit's performance in river flow was the Nash-Sutcliffe Efficiency Index [12]. This index relied on the square of error summation between model and measurement. The other used in hydrology are Percent bias (PBIAS), the coefficient of correlation, the coefficient of determination, and Index of Agreement [13]. All measures stress on different types of model performance. The Nash-Sutcliffe index and other have relied on squared discrepancy focusing on the best fit during peak flows and poorly represent improvements in baseflows. Performing the Nash-Sutcliffe Efficiency examination on the natural log converted stream data and model predictions advance the assessment of base flows while detecting systematic over or under forecast [14].

3. *Results and discussion*

3.1. *Irrigation water requirement*

Irrigation water demand for paddy rice was calculated in one hectare of an irrigation area in mm. The crop calendar is determined at the beginning of the rainy season. This computation considered wet season in October to March and dry season in April to September with the irrigation efficiency assumption of 65\%. The irrigation system at the Rentang Station, flooding system, applies as called the "golongan" systems, which divide the specific area into smaller areas to decrease the number of laborer/area and simplify water supply. The sowing date in each subdivided area is staggered successively by 15 days. The study area is divided into three "golongan" and sowing started on 17\(^{th}\) October. This study was converted planting date in 15 days into a monthly basis, as shown in table 1.
Table 1. Agriculture water demand unit (cubic meter ha\(^{-1}\)) in Rentang Irrigation System.

|       | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|-------|-----|-----|-----|-----|-----|------|------|-----|------|-----|-----|-----|-------|
| Wet   | 111 | 111 | 125 |     |     |      |      |     |      | 14  | 88  | 111 | 559   |
| Dry   | 78  | 51  | 51  | 51  | 37  | 11   |      |     |      |     |     |     | 277   |

Irrigation water demand was needed when started rice planting season I, namely, in mid-October, when the farmers began to prepare rice fields. In contrast, the second planting season started around March. Water availability declines towards the end of the planting season in the dry season. The monthly water use rate for paddy within the wet season was higher than that in the dry season due to the strategic management practices by decreasing irrigated area up to 31% of the total area during the dry season. The crop pattern applied in the farm was paddy-paddy-cash crops within the wet season to the dry season.

3.2. Water demands for all users

Besides agriculture water demand, other sectors were calculated, such as domestic, livestock, industries, and fisheries. Monthly water demand estimated from 2003 to 2009 was shown in figure 2.

Figure 2. Monthly and annual water demands in the Cimanuk River Basin (a) Monthly water demand. (b) Annual water demand.

The study showed that the highest water demand takes place in March, in which the irrigation sector highly consumes 86 million m\(^3\) (figure 2a). This is because the farmers still irrigate the paddy field area for the harvesting stage at the end of the wet season. Fisheries water demand tends to stable during all seasons, approximately about 11 million m\(^3\). Meanwhile, annual water demand for the irrigation sector
during 2003 to 2009 is the highest demand by 580 million m$^3$; the second most water user is fisheries, which gradually rise as concomitants.

![Image of water demand consumption in Cimanuk River Basin]

**Figure 3.** Annual water demand consumption in Cimanuk River Basin.

The annual sectoral water demand in the lower Cimanuk River Basin was 736 million m$^3$. The irrigation sector occupies approximately 79% of total water demand, as shown in figure 3. The fisheries sector was the second water user by 16%, and the third one was a downstream domestic sector by 3%. Industries and livestock have insignificant water demand in the Cimanuk River Basin, approximately 1%.

3.3. Surface water availability in 2003-2009
The water availability in the lower Cimanuk River basin was varied depending on the time. Streamflow was greatly affected by high rainfall that occurred in the river basin. From October to April, the river discharge was very high compared to the release in other months. The study area's lack of data from 2003 to 2009 was taken to observe the river flow at the Rentang Weir and Kertasemaya Station as upstream and downstream stations, respectively. The highest flow at the Rentang Station due to the high rainfall occurred in a year (figure 4). The most increased flow in the Rentang occurred in 2004 by 3.6 billion m$^3$. At the same time, the lowest flow was in 2009 by 612.3 million m$^3$. One of the installed stations below Rentang weir is Kertasemaya station, which was supplied from one of the most significant tributaries Jatiwangi. The highest flow at that station occurred in 2003 by 4.8 billion m$^3$, while the lowest flow was 894 million m$^3$ in 2009.

The total surface water available in a year at upstream Rentang station was 2.4 Billion m$^3$. Such variation inflow was observed in a year due to high rainfall in the river upstream (figure 5). It indicated that there was increasing streamflow during the rainy season from October to March, which has 348.8 million m$^3$ of the monthly average streamflow. However, the streamflow decreases in the dry season from March to September has 105.5 million m$^3$ of the monthly average streamflow. Furthermore, it can be stated that water availability during the rainy season is double value rather than that during the dry season. The other fact, this study confirms that the increased rainfall upstream has a significant increase in river flow over the lower Cimanuk River Basin during that time.
Figure 4. Annual streamflow at the Rentang and Kertasemaya observation stations.

Figure 5. Monthly streamflow during 2003 to 2009 in Cimanuk River.

3.4. Unmet water demand

The annual unmet demand during seven years was 63.8 million m$^3$ in the lower Cimanuk River Basin. Accordingly, there is a water deficit of about 4% of the total water availability. The highest water shortage took place in 2008 by 238.9 million m$^3$ (table 2). The annual unmet demand smoothly fluctuated during that time.
Table 2. Yearly unmet demand during 2003-2009 in Cimanuk River Basin.

| Sectors | 2003  | 2004  | 2005  | 2006  | 2007  | 2008  | 2009  |
|---------|-------|-------|-------|-------|-------|-------|-------|
| Irrigation | 13.59 | 1.16  | -     | 59.54 | 2.90  | 187.99| 177.08|
| Fisheries  | 16.97 | 19.41 | 14.68 | 39.40 | 16.43 | 48.69 | 52.18 |
| Industries | -     | 0.01  | -     | -     | 0.11  | 0.44  | 0.10  |
| Domestic  | -     | 0.16  | -     | -     | 0.20  | 0.86  | 0.20  |
| Livestock  | 0.29  | 0.45  | 0.46  | 0.83  | 0.53  | 0.93  | 1.17  |
| **Total** | 30.85 | 21.19 | 15.14 | 99.77 | 20.17 | 238.92| 230.73|

The table showed that the fisheries sector had the highest water shortage, approximately an average of 96% of total water shortage. However, the industry sector was the lowest water shortage by 0.3% of the total.

![Figure 6](image-url)  
**Figure 6.** Monthly unmet demand during 2003-2009 in Cimanuk River Basin.

The study showed that the monthly water shortage from 2003 to 2009 generally occurred ten months during all season (figure 6). Whereas there is no water shortage either in the rainy season or the dry season for only two months (March and April). The irrigation sector was the most affected because of this water shortage. The peak of water shortage took place in November and July by approximately 17 million m³. The heights of water shortage occurred in the dry season’s peak months, where the irrigation sector and fisheries were almost the same as the deficit. Meanwhile, during the rainy season, the irrigation sector is the highest impact of discharge. It indicated that irrigation sectors were the most useful streamflow in the lower Cimanuk River Basin.

3.5. Model calibration

The accuracy of the calibration was used to evaluate model performance by comparing simulated and observed value. Calibration respected anthropogenic activities along the Cimanuk river as water demand abstraction and return flow. The monthly simulated and the observed stream flows for the calibration period of 2003 to 2007 were done at the control station Kertasemaya. The period of 2008 to 2009 was
for validation purposes. The calibrated model was manually done by altering the water consumption and losses to the system. This is to obtain the fit between the simulated and observed flow.

![Figure 7. Result of Monthly calibration and validation during 2003-2009 in Cimanuk River Basin.](image)

The graph showed that the simulated value is fitting well in the observed and simulated data. The model performance is perfect and provides a reasonable estimate (figure 7). In most months, the simulated and the observed flows are close. Additionally, several model indicators were applied, as summarized in table 3. There is a good fit between the simulated and the observed flow values. The PBIAS negative value implied that there is overestimation during the simulation.

| Period   | Year     | Qobs(CMS) | Qsim(CMS) | R²   | NSE   | PBIAS |
|----------|----------|-----------|-----------|------|-------|-------|
| Calibration | 2003-2007 | 62.2      | 62.4      | 0.75 | 0.75  | -0.40 |
| Validation | 2008-2009 | 32.5      | 33.0      | 0.76 | 0.73  | -1.48 |

The model evaluation criteria for PBIAS and NSE was shown in table 4.

| Performance       | PBIAS (%)       | NSE            |
|-------------------|-----------------|----------------|
| Very Good         | PBIAS < ± 10    | 0.75 < NSE < 1.00 |
| Good              | ± 10 < PBIAS < ± 15 | 0.65 < NSE < 0.75 |
| Satisfactory      | ± 15 < PBIAS < ± 25 | 0.50 < NSE < 0.65 |
| Unsatisfactory    | PBIAS > ± 25    | NSE > 0.5      |
Although the validation result was unsatisfactory with concerning PBIAS, it is still accepted. Firstly, the calibrated model during the river flow period was strongly influenced by irrigation. Surface water has been randomly abstracted, which was challenging to adjust the withdrawals systematically. Secondly, the study's purpose must be taken into account when evaluating the model performance as well. Water balance is the primary purpose of the research and is not the simulation of flood events. Small shifting of the simulated flood event has a significant impact on the PBIAS indicator. Therefore, the importance of the PBIAS indicator is less emphasized. Visual evaluation of the hydrographs has a good agreement between the observed and simulated data. Consequently, it can be stated the calibration procedure is suitable and sufficient for its purpose.

The calibrated model is used to project water supply and demand in the future with time step 2003 to 2030. The water surface on the river basin was repeatedly assumed for future conditions. Streamflow coming years was selected by analyzing projected discharge at the Rentang Station, as shown in figure 8.

![Flow time series and Average Flow](image)

**Figure 8.** Surface water flow projection in 2003-2030 in Cimanuk River Basin.

Surface water availability in 2009 and 2021 decreases approximately, indicated by the flow discharge, only 2.7 to 48.04 CMS, as shown on the brown circle. Furthermore, we evaluated the unmet demand in both years. Water demand for all sectors was projected to slightly increase; about 1% of domestic and industries, 5% of livestock, and 5% of fisheries. However, water demand for the irrigation sector was expected to be steady without reducing the irrigated area. The result of the model projection represented the faced problem of the extreme year, which scenario illustrates the volume of unmet demand in 2009 and 2021 in a monthly basis as shown in figure 9., which was realized that the rise of water shortage occurs in 2009 and 2021 for all water sectors. The peak of the water deficit is during July and November, respectively.

Commonly, the total unmet demand in 2021 is more extensive than 2009 because of the rise of water demand and steady water supply. The study showed that water allocation priorities were given the highest for domestic. Therefore, there was a minor water deficit for domestic water users. However, water deficit occurs in the irrigation sector, fisheries, and livestock due to the impact of lower water supply for those water users.
The Lower Cimanuk River Basin study highlighted the importance of considering water abstraction of several water users. The water balance model has been operated concerning water abstraction by water users, head flow from the Rentang Station, and water loss from the system during water flow downstream. WEAP was used to evaluate water balance at surface streamflow. WEAP model correctly simulated water balance in current and future conditions. Model performance could be improved by using long time series data, water losing data, and significant water consumption for each water user. Water shortages in the Lower Cimanuk River Basin are relatively high. It becomes a big problem in which coverage of water demand is not satisfied with water users. The irrigation sector is the dominant water user that has the most significant impact on water shortage.

4. Conclusions
A freshwater balance tool in the Cimanuk River Basin was developed successfully through a water evaluation and planning model. WEAP model projected that more water deficit occurs in 2021 rather than in 2009. The irrigation and fisheries water sector will affect more to the shortage of water. Water management needs to improve to reduce water deficit in 2021 by storing freshwater inflow through rubber dam restoration at the lower Cimanuk River Basin.

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