Analysis of water balance conditions as the impact of climate and land-use changes in Kapuas Watershed, Indonesia

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Abstract. The Kapuas River is located in the West Kalimantan province and is the longest river in Indonesia. Climate change has an impact on the frequency and intensity of hydro-meteorological disasters. This study aims to analyze the spatial and temporal distribution of the water balance in the Kapuas watershed using the water balance equation. The data used is the monthly rainfall and evapotranspiration data for the years 1901–2019 from the CHIRPS and CRU data as well as the Kapuas watershed land cover data. Based on the study conducted, the Kapuas watershed experienced a significant increase in the dry month, but the trend of the magnitude of the dry month decreased but not significantly. The lowest average potential evapotranspiration occurred in DJF, which ranged from 2.8 to 3.2 mm / day, while the highest average potential evapotranspiration occurred in March–April–May (MAM), which ranged from 3.2 to 3.6 mm / day. The Kapuas watershed always experiences a water surplus, with the lowest water surplus occurring in July. Swamp forest in the southwestern and northeastern part of the Kapuas watershed has decreased in area, this is because the swamp forest has turned into agricultural land and plantations, so this condition has an effect on a significant increase in the incidence of dry months in the Kapuas watershed.

1. Introduction
The Kapuas River is located in the West Kalimantan province and is the longest river in Indonesia [1]. The people of West Kalimantan make the Kapuas river their main source of life [2]. According to [3], the Kapuas river has two hydrological issues, there are decreasing amount of river flow and increase river sedimentation. Climate change has an impact on the frequency and intensity of hydro-meteorological disasters [4]. Understanding watersheds is very important for water resource planning [5]. Watershed management is a human effort in regulating the reciprocal relationship between natural resources and humans in the watershed and all their activities to realize the sustainability and harmony of the ecosystem and increase the benefits of natural resources for humans sustainably. The spatial and temporal distribution of water availability and describing trends in water availability in the Kapuas watershed were studied to provide basic information in the management of water resources around the Kapuas watershed given the important role of the Kapuas watershed for the people of West Kalimantan.

Several studies related to the Kapuas watershed have been carried out but these studies did not cover the entire area of the Kapuas watershed, such as [6] assessing the Ensabal sub-watershed, [7] examining the Upper section of the Kapuas Watershed, and [8] assessing the Landak sub-watershed. In this case,
we conducted a study related to the distribution of spatial and temporal data on water availability in the Kapuas watershed. Spatial data describes the condition of an area that is represented by an image (raster) that has a certain value. Temporal data provide information on rainfall trends, water availability, and the effect of land cover on the Kapuas watershed. The purpose of this study was to study and analyze the spatial and temporal distribution of water availability in the Kapuas watershed using the water balance equation. This research also discusses how land cover affects water availability.

2. Data and methods

2.1 Study Area

The study area used in this research is the Kapuas River Basin. Administratively, this watershed is located in West Kalimantan province, extending from the Kapuas upstream area to Pontianak City, and across five other districts, namely: Sintang District, Melawi Regency, Sekadu Regency, Sanggu Regency, Landak Regency, and Pontianak Regency, the length of the watershed is 1,143 Km. The study area is located at latitude 1.975° N - 1.375° S, and longitude 108.3° - 114.3° E.

2.2 Data

This study used a series of monthly rainfall and evapotranspiration data for the years 1901 – 2019 in the Kapuas watershed. Kapuas watershed rainfall data is obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) [10] with a spatial resolution of 0.05° x 0.05° and a monthly temporal resolution from 1989 - 2019. While the Precipitation and Evapotranspiration data were obtained from the Climatic Research Unit (CRU) data with a resolution with a spatial resolution of 0.05° x 0.05° and monthly temporal resolution from 1901-2019. In addition to the CHIRPS and CRU data, this study also uses shapefile data (.shp) for the Kapuas watershed study area and Kapuas watershed land cover data obtained from http://geoportal.menhk.go.id/ and from USGS from 1990 to 2016.

2.3 Methods

Data processing was performed using RStudio software to determine the spatial distribution of rainfall and evapotranspiration of the Kapuas watershed.
2.3.1 Spatial analysis of rainfall. The spatial analysis of seasonal rainfall was carried out using CRU data input for the years 1901 - 2019 [11]. This rainfall analysis consists of two things, namely an analysis of monthly rainfall, and an analysis of seasonal rainfall. The analysis was carried out using R studio software by averaging the CRU monthly rainfall data for the years 1901 - 2019.

2.3.2 Analysis of rainfall trends. Rainfall trend analysis is a technique used to determine the increase and decrease in rainfall trends and the magnitude of the value of the trend and its significance [12]. This analysis of rainfall trends was carried out using the Mann-Kendall formulation. The Mann-Kendall test is a non-parametric technique that is applied to long-term data to determine the trend of the significance of an event [13]. The following is a formulation for determining the value of the trend of rainfall using the Mann-Kendall test:

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(X_j - X_i) \]  
(1)

\[
\text{sgn}(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases} \]  
(2)

\[
V(S) = \frac{1}{18} \left[ n(n - 1)(2n + 5 - \sum_{p=1}^{q} tp(tp - 1)(2tp + 5) \right] \]  
(3)

\[
Z = \begin{cases} \frac{S - 1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases} \]  
(4)

Hypothesis H0 shows that there is no trend of rainfall from time to time, while hypothesis H1 shows that there is a trend (up and down) from time to time. The values of Xi and Xj are time series data, the value of n shows the length of the time series. A positive Z value indicates an increasing trend in rainfall, while a negative Z value indicates a decreasing trend in rainfall.

2.3.3 Calculation of water balance. Water balance is a calculation used to analyze the amount of water entering and leaving a system, so that it can be seen whether the state of a system is excess (water surplus) or deficient (water deficit). The water balance calculation is done by looking for the difference between rainfall and evapotranspiration as shown by the following formula [14]:

\[
D_i = P_i - PET_i \]  
(5)

This difference value will show the state of a watershed, where when the rainfall value is greater than evapotranspiration, a water surplus will occur. On the other hand, if the rainfall is less than evapotranspiration, there will be a water deficit.

2.3.4 Land cover analysis. The land cover analysis is carried out using image analysis from image maps sourced from USGS, then the image analysis is combined using the on-screen digitization method. The resulting image is then layouted using the ArcMap application.

3. Result and discussion

3.1. Seasonal rainfall conditions in the Kapuas watershed
Based on the climate classification according to Koppen, the Kapuas watershed has an Af climate type with rainfall criteria in the driest month having an average monthly rainfall of more than 60 mm.
Seasonal rainfall conditions in the Kapuas watershed are shown in Figure 2. Based on Figure 2, the seasonal rainfall conditions in June-July-August (JJA) are the driest condition. Meanwhile, the seasonal rainfall in December-January-February (DJF) is the wettest condition, especially in the eastern part of the Kapuas watershed.

![Figure 2](image)

**Figure 2.** Seasonal rainfall conditions in the Kapuas watershed.

### 3.2. Rainfall trends in the Kapuas watershed

In Figure 3 it can be seen that most of the Kapuas watershed has a significant increase in dry months (Figure 3.a) for 119 years. However, in the southern part of the Kapuas watershed, the increase in dry months is not significant. Meanwhile, the magnitude of the dry months (Figure 3.b) has decreased but is not significant in most of the Kapuas watershed. The decrease in the magnitude of the dry month is significant in the southern part of the Kapuas watershed. In addition, in a small part of the watershed area, there is also an increase in the magnitude of the dry month, but it is not significant.

![Figure 3](image)

**Figure 3.** Trends in duration (a) and magnitude (b) of dry months for 119 years in the Kapuas watershed.

### 3.3. Calculation of water balance in the Kapuas watershed

Rainfall and evapotranspiration are two important parameters in determining the water balance in a watershed. The average potential seasonal evapotranspiration conditions in the Kapuas watershed are shown in Figure 4. The lowest average potential evapotranspiration occurs in DJF, which ranges from 2.8 to 3.2 mm / day while the highest average potential evapotranspiration occurs in MAM (March-April-May) which ranges from 3.2 to 3.6 mm / day. When viewed spatially, the average value of potential evapotranspiration in the eastern part of the Kapuas watershed is lower than that in the western part of the Kapuas watershed. This is influenced by the type of land cover in each part of the Kapuas watershed. In the eastern part of the Kapuas watershed, the land cover type is dominated by dry and
secondary forests (Figure 6) which results in a lower evapotranspiration value. Meanwhile, the western part of the Kapuas watershed is dominated by primary and secondary swamp forests, where the availability of water is more so that the potential evapotranspiration value is higher.

![Figure 4](image-url). Average seasonal potential evapotranspiration (mm / day) conditions in the Kapuas watershed.

The condition of the monthly water balance in the Kapuas watershed is shown in Figure 5. Based on Figure 5, in general, the Kapuas watershed has a water surplus but the water surplus conditions vary every month. October, November, December, and January are the months that have the largest water surplus, which is more than 200 mm in the entire Kapuas River Basin. Meanwhile, July is the month with the least water surplus, which is less than 100 mm in the entire Kapuas watershed. The eastern part of the Kapuas watershed has a greater water surplus value than the western part of the Kapuas watershed. This is because the eastern part of the Kapuas watershed has higher rainfall than the western region, while the average potential evapotranspiration value is lower than that of the western part of the Kapuas River Basin.

![Figure 5](image-url). Monthly Water Balance (Recharge) of the Kapuas watershed.

3.4. Effect of land cover conditions on water availability in Kapuas watershed

Changes in land use into a plantation area, industrial area, and settlements on a large scale can cause rainwater that should be infiltrated, turning into a surface flow which generally flows into rivers and
lakes. So that it can affect the balance of water and the environment around it [15]. The land cover factor is used to calculate the rate of evapotranspiration and water infiltration in a watershed, as well as to identify the rate of movement of water in a landscape [16].

Figure 6. Condition of land cover in the Kapuas watershed.

The conditions of land cover change in the Kapuas watershed from 1990 to 2016 are shown in Figure 6. In general, the eastern part of the Kapuas watershed is dominated by dry land forests, both primary and secondary, the central part of the Kapuas watershed is dominated by agricultural land, while the southwestern part of the Kapuas watershed is dominated by swamp forest. Swamp forests, both primary and secondary, also exist in the northeast part of the watershed. Land changes can be seen in the decrease of swamp forests in the southwestern and northeastern parts of the Kapuas River Basin. The swamp forest has been converted into agricultural and plantation land. This condition is very clearly seen in the distribution of land cover in 2016.

Changes in land cover affect changes in the water balance in the Kapuas watershed. This can be seen in Figures 4 and 5, when the dry season (July-August-September) the recharge value of the western and southern Kapuas watershed is very low, while the evapotranspiration process that occurs is very high. The land cover condition also affects the climatic conditions in the Kapuas watershed area. This can be seen from the correlation between Figure 3 and Figure 6 where the increase in land conversion that occurred in the Kapuas watershed was also followed by a significant increase in the incidence of dry months.

4. Conclusion
The Kapuas watershed with the Af climate type has the driest seasonal rainfall conditions in June-July-August (JJA), while the wettest seasonal rainfall conditions occur in December-January-February (DJF). The Kapuas watershed experienced a significant increase in the dry month trend, but the trend of the magnitude of the dry month decreased but not significantly. The lowest average potential evapotranspiration occurred in DJF, while the highest potential evapotranspiration occurred in MAM. The Kapuas watershed always experiences a water surplus, with the lowest water surplus occurring in July. Swamp forest in the southwestern and northeastern part of the Kapuas watershed has decreased in area, this is because the swamp forest has turned into agricultural land and plantations, so this condition influences a significant increase in the incidence of dry months in the Kapuas River Basin.
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