Rainfall variability based on the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) in Lesti watershed, Java Island, Indonesia

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Abstract. Rainfall fluctuates spatiotemporally. Availability of rainfall data is essential in watershed management planning. The lack of accessibility causes watersheds in Indonesia to have insufficient rain gauges. The Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) provides free global rainfall data sets available on the web ranging from 1981 to the near-present. This paper aims to validate the CHIRPS model and analyze dry and wet event severity in Lesti watershed, the upper part of Brantas watershed. This study compared data during 1990-2011 obtained from the CHIRPS and three observed rainfall stations. The validation was examined by calculating the Nash and Sutcliffe Efficiency (NSE), while dry and wet event severity was analyzed using the Standardized Precipitation Index (SPI). The validation showed that the CHIRPS model has a good performance in representing the actual data. The R² value was 0.656, which means the rainfall data obtained from the CHIRPS can be used for further analysis in a similar location. The rainfall temporal distribution analysis showed over 91% of the annual rainfall occurs during the rainy season. It means only less than 9% of the annual rainfall occurs during the dry season. These significant difference variations potentially lead to hydrometeorological disasters, such as floods and drought. Lesti watershed experienced the driest year in 1997 and vice versa in 2010. Repetition of both wet and dry events needs to be identified to reduce the risk of potential disasters.

1. Introduction
Rainfall is one of the most important climatic variables, and it is difficult to change or control [1]. It is the primary water source of water resources, especially for tropical regions such as Indonesia. As a dynamic variable, rainfall fluctuates both spatially and temporally. Global warming that occurs during the last few decades causes changes in those fluctuations. Some regions will experience additional rainfall, while others will receive less. This phenomenon triggers various hydrometeorological disasters. Reducing the amount of rainfall can lead to drought; on the contrary, it can also be a flooding agent [2]. Information concerning rainfall fluctuation is essential for flood and drought predictions, irrigation planning, and water management in Indonesia [3]. Rainfall variation has a potent influence, especially for those who have highly dependent on natural resources [4]. For rural communities, the impact size is also influenced by the surrounding ecosystems that determine the local livelihood [5]. For example, agricultural areas in Indonesia will highly depend on the amount of rainfall as the primary water source. Changes in rainfall fluctuations cause crop failure. Therefore, Indonesia faces a more complex challenge
in climate change adaptation. It is projected that rainfall in Southeast Asia will increase with different trends [6]. Rainfall fluctuation becomes more volatile with certain patterns that result in an increase in natural disasters [7].

Rainfall is the foremost input in the hydrological system. Unfortunately, the number and distribution of rain gauges are often insufficient. It causes the data to be less qualified to reflect actual conditions. The lack of accessibility causes rain gauges to rarely be installed, especially if they are far from the settlement. The upstream usually have steeper slopes and less population than the downstream area, but it plays an essential role as a recharge area. Therefore, the absence of a rain gauge would be a weakness. Floods hit Lampung in February 2018 due to heavy rainfall in the upstream area, which eventually inundated ten sub-districts [8]. Unmonitored river blockage of the upper stream of Glondong watershed and triggered by light rainfall was noted to have caused flash floods in June 2018 that damaged 1,721 hectares of agricultural area and 328 houses [9]. This flash flood even occurred in the dry season. Huge losses due to hydrometeorological disasters begin with the absence of monitoring tools such as rain gauges.

The Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) can be used as an alternative in monitoring rainfall. The CHIRPS provides a free global rainfall dataset spanning from 50°S to 50°N [10]. It also gives a wide range of rainfall data, which is over 35 years. This wide time span makes it easy to monitor rainfall events in the areas that are difficult to access without taking direct measurements. Rainfall and land use/land cover (LU/LC) are essential aspects to consider in watershed planning and management. The interactions between both aspects are highly crucial. Monitoring rainfall is as significant as monitoring land cover changes to determine the impact of watershed management on the environment, especially in terms of water availability to minimize hydrometeorological disasters. This study is vital since it will produce a method of predicting rainfall, especially for the areas without measuring instruments. The prediction was built using the CHIRPS data and examined utilizing direct measurement data from three rainfall gauges. The CHIRPS data and the actual measurement will be used to assess the severity of dry or wet events of the study. Based on that, this paper has two research questions: how was the performance of CHIRPS in providing rainfall data, and how were dry and wet event severity fluctuations at the research site. The objectives of this study were: (1) to validate the CHIRPS model and (2) to analyze dry and wet event severity in research locations. This information is an essential element in planning and managing a watershed, especially in controlling the negative impact of rainfall fluctuation.

2. Lesti watershed description
This study was undertaken in Lesti watershed, the upper part of Brantas watershed. Brantas is the second-largest watershed on Java Island. This river flows in almost all areas of the East Java province, i.e., eight districts and six cities. Lesti is the biggest upper part of Brantas. It covers 608.86 km², extending from 112.52 to 112.92 East longitude and 8.04 to 8.30 South latitude (Figure 1). Administratively, almost these sites are in Malang regency, East Java province, Indonesia. The mean altitude from this catchment is about 634 m asl, ranging between 292 and 3,654 m asl. The land is characterized by flat to very steep slopes ranging from 0 to 51%. Lesti river flows to its outlet in the Karangkates Sengguruh reservoir.
The soil types obtained from Regional Physical Planning Programme for Transmigration (RePPPROT) show that Lesti watershed comprises calsiustolls, dystrandepts, dystropepts, rendolls, tropudalfs, tropudults, and ustropepts soil types. According to the Ministry of Environment and Forestry (MoEF), Republic of Indonesia, the major LU/LC in 2019 was agriculture area (69.8%) that comprised dry-land agriculture, mixed dry-land agriculture, and rice fields. The others were forest (15.6%) and estate/settlement (11%), while the rest were water bodies, shrubs, and bare land.

3. Methods
This study used daily rainfall data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) between 1981 and 2019 [10]. In comparison, this study utilized rainfall data during 1990-2011 from three rainfall stations in Lesti watershed, i.e., Gondanglegi, Dampit, and Poncokusumo (Table 1). These stations are maintained by Brantas Major River Basin Organization [11]. The CHIRPS daily data on each grid was calculated into monthly data, then averaged to become regional rainfall.

| No | Rainfall station | Altitude (m asl) | Average multi annual rainfall (mm/yr) |
|----|------------------|-----------------|--------------------------------------|
| 1  | Poncokusumo      | 838             | 2,280.82                             |
| 2  | Gondanglegi      | 350             | 2,000.91                             |
| 3  | Dampit           | 415             | 1,969.84                             |

Analyses were conducted, including (1) the CHIRPS rainfall data validation and (2) dry and wet event severity.

Figure 1. Lesti watershed is overlaid by topography, stream order, and rain gauges.
3.1. The CHIRPS rainfall data validation
The validity of the CHIRPS is examined by calculating the Nash and Sutcliffe Efficiency (NSE) using equation (1). In the equation, $R_{obs}$ is observed rainfall, $R_{mod}$ is CHIRPS, and $\bar{R}_{obs}$ is average observed rainfall.

$$\text{NSE} = 1 - \frac{\sum (R_{obs} - R_{mod})^2}{\sum (R_{obs} - \bar{R}_{obs})^2}$$  \hspace{2cm} (1)

The NSE value indicates how well the measured data against the predicted data is in line with the 1:1 graph. NSE ranges from $-\infty$ to 1. NSE of 1 is the optimal efficiency, while the values 0 to 1 are normally the accepted level. NSE less than 0 indicates that the observed data average is a better predictor than those from the model, representing an unacceptable condition. NSE, which is close to 1, indicates that the model has a value close to the observed data [12]. Statistical analysis was performed to determine whether the model is feasible to be applied. The coefficient of determination ($R^2$) was calculated that explains the proportion of actual measured data variance. $R^2$ is between 0 and 1. The higher $R^2$ values indicate the smaller error. $R^2 > 0.5$ is usually acceptable [12].

3.2. Dry and wet event severity
This study used the Standardized Precipitation Index (SPI) to calculate the severity of dry and wet events. According to solely rainfall data, SPI can also identify meteorological drought [13]. SPI can be calculated for various cumulative periods, for example, 1, 3, 6, 9, 12, 18, and 24 months. This period of selection can be adjusted according to the objectives of the SPI analysis. This study utilized a 1-month SPI period to identify dry and wet event severity.

The SPI value reflects the standard deviation of rainfall data (Equation 2) [14]. In the equation, $x$ is the rainfall and $\sigma$ is the standard deviation, while $i$ is the time dimension. Table 2 presents the classification of wet and drought severity [13].

$$SPI = \frac{x - \bar{x}}{\sigma}$$  \hspace{2cm} (2)

| Category   | SPI value          | Class            |
|------------|--------------------|------------------|
| Wet        | $SPI \geq 2,0$     | Extremely wet    |
|            | $1,5 \leq SPI < 2,0$ | Severely wet     |
|            | $1,0 \leq SPI < 1,5$ | Wet             |
|            | $-1,0 \leq SPI < 1,0$ | Normal         |
| Drought    | $-1,5 \leq SPI < -1,0$ | Drought        |
|            | $-2,0 \leq SPI < -1,5$ | Severe drought |
|            | $SPI < -2,0$       | Extreme drought  |

4. Results and discussion

4.1. The CHIRPS validity test
The results of the NSE analysis obtained a value of 0.655. In other words, the CHIRPS model has a good performance in representing the actual data [12]. Simple regression analysis showed a positive correlation between observed and the CHIRPS rainfall data. The $R^2$ between the CHIRPS and the observed data was 0.656. Figure 2 explains the correlation for rainfall stations. According to these two analyses, the data obtained from the CHIRPS can be used for further analysis.
Figure 2. Correlation between the CHIRPS and observed data

Compared to the validity test in Java Island [15], the $R^2$ value in Malang regency (Figure 2) was lower than that in Surabaya, Jakarta, and Semarang, but the value was almost the same as the value in Bandung. Its possibly due to the altitude differences in the rainfall station locations. It was mentioned that the CHIRPS is unique due to the physiographic indicators, such as elevation, latitude, and longitude [10]. Each grid will show different performances to represent the actual rainfall data. Although $R^2$ values in Java were varied, the CHIRPS was categorized as good or even very good in presenting rainfall data. In the future, good watershed management can still be performed even in the limited gauged area. It is necessary to measure the number and density of rainfall gauges in most locations to obtain rainfall trends [16]. The CHIRPS is also efficient for capturing rainfall trends over the entire watershed area. It is crucial to face global climate change.

4.2. Dry and wet event severity
Rainfall in a watershed varies greatly, along with the coverage area. Obtained from the CHIRPS, the 39-years mean rainfall was 2,013 mm/yr. A similar value was described according to the 22-years ground observation data; it was 2,081 mm/yr. The temporal distributions were 136-167 mm in the dry season and 1,827-1,935 mm in the wet season (Figure 3). Two monsoons strongly influence this season. The Wet Northwest Monsoon causes rainy season, while the Dry Southeast Monsoon leads to a dry season [17]. Rainfall in the wet season reaches 91 - 93% of the total annual rainfall.

Figure 3. Monthly rainfall in Lesti watershed
According to the CHIRPS, annual rainfall varied from 1,306 to 3,181 mm/yr. Lesti watershed experienced the driest year in 1997 and the wettest year in 2010 (Figure 4). This wettest and driest year applied both to the CHIRPS and observed data. The wet and dry severity is influenced by the wet and dry years. The dry year is when the amount of monthly and annual rainfall is under normal conditions, and vice versa if it is the wet year. The dry and wet years arise due to the El Niño/La Nina phenomenon [18,19].

According to the local rain gauges and the CHIRPS, the Lesti Watershed experienced dry to the extreme severity of wet events. Figure 5 shows that the SPI value for a 1-month period varied between -1.4 (dry) to 3.8 (extremely wet). Based on the data, January 2013 had the highest SPI value, while the lowest value occurred in August 2019. It is because the total rainfall in January 2013 was the highest of its normal conditions that the SPI value was the highest. Meanwhile, in August 2019, the rainfall was the lowest of its normal conditions; consequently, the SPI value was also the lowest.
In the analysis of rainfall variability, this study can use the SPI value as a justification for the number of inputs in the hydrological system. For an upstream area, variations in SPI values are essential information. Changes in the number of inputs (in this case, rainfall) cause different responses in the hydrological system. It might lead to an increase in disaster occurrence. As an upstream sector of the Brantas watershed, Lesti plays a vital role in reducing runoff caused by the rainfall in order that more water can be absorbed into the soil. Accordingly, the community can use it as a water resource reserve during the dry season. It is also known as a recharge process [20]. If rainfall at a certain time is very different (both greater and less) from its normal conditions, then the role of this upstream area will be increasingly important in reducing the risk of disasters that may arise.

Figure 5 displays the distribution of wet and dry events. It reflects that Lesti watershed faces the threat of flooding in the rainy season and drought in the dry season. In the SPI analysis, wet events are associated with the rainy season, while dry events are connected to the dry season. A high value of SPI increases the potential for flooding, while the low value will have the potential for drought. The potential for flooding in Lesti watershed was greater than drought (Figure 5). It was because of the temporal distribution of rainfall concentrated in the rainy season (about 91-93%). The low potential for drought was due to the rainfall that occurred throughout the year. At the recession of the dry season, it was less than 100 mm/month (Figure 3). From this analysis, the Lesti watershed management can simultaneously focus on the efforts to minimize flooding and drought.

SPI is only applicable under normal conditions if there is no extreme event such as El Niño. It is a warming phenomenon of Sea Surface Temperature (SST) above normal conditions that occurs in the Central Pacific Ocean. This SST warming increases the potential for cloud growth in the Central Pacific Ocean and reduces rainfall. In 1982/1983, 1997/1998, and 2015/2016, Indonesia experienced El Niño events. Due to these anomalous conditions, the dry event in that year is not reflected in Figure 5. The extreme climates are based more on the duration of the rainy-dry day [21]. In addition, this model used the basis of monthly average rainfall.

The World Meteorological Organization (WMO) defines the climatological time span as 30 years. Changes in that period can be considered as climate variability. Unfortunately, this time span is rarely available by direct measurement. Frequently, there is a lot of empty data that has to be generated using other methods. At this moment, CHIRPS is highly effective because it is available for free. It also combines some information from several satellite products [10]. The availability of rainfall data is no longer an obstacle in watershed management.

5. Conclusions
Data generated from the CHIRPS can be used to predict annual and monthly rainfall in the study area. It has a good performance in representing the actual data, which means that the rainfall data obtained from the CHIRPS can be used for further analysis. The temporal distribution showed that 91% to 93% of the annual rainfall occurs during the rainy season. This difference variation potentially leads to hydro-meteorological disasters, such as floods and drought. According to rainfall variations, Lesti watershed experienced the driest year in 1997 and the wettest year in 2010. Repetition of both wet and dry years needs to be identified to reduce the associated risk of disasters that might arise. Standardized Precipitation Index (SPI) could not reflect the severity of dry and wet events in extreme conditions such as El Niño.

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