Long-term Spatiotemporal Trend Analysis of Precipitation and Temperature in Citarum Watershed, Indonesia

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Abstract. Analyzing meteorological variables such as precipitation and temperature can give valuable information regarding past and future climate variability. Citarum Watershed is one of the world's most threatened watersheds and the most degraded on Indonesia's Java Island. The Indonesian government regards it as the most strategically important river basin territory because it supplies 80 percent of the surface water supply to Jakarta. This study aims to analyze the precipitation and temperature trend in the Citarum Watershed. This study is preliminary research and intends to provide a better insight into the impacts of climate change on water availability in the tropical region. The detection was carried out with the use of a Mann-Kendall with Sen's slope. The results indicated that there are significant increasing trends of precipitation during the wet season. Whereas the increasing trend in temperature exhibits for all stations in the basin. The highest increasing trend is in Bandung City, the city with the highest urbanization rate in Indonesia. It is widely acknowledged that rising urbanization will have a considerable impact on the worldwide land warming trend.

Keywords: climate change, spatiotemporal, urbanization

1. Introduction
Precipitation and temperature are the most important climatic variables in the hydrology/climate domains and water resource management because of their considerable influence on water availability's temporal and geographical patterns. Precipitation is essential in the rainfall-runoff relationship, mitigation measures, and flood and drought assessments. In contrast, the temperature is vital in water availability, transpiration, and evaporation. Long-term variations in precipitation and temperature are essential for water resource planners and climatologists to comprehend climate change effects. [1][2][3].

Analyzing meteorological indicators like precipitation and temperature can give information about climate regime changes in the past and future [4][5]. The global warming trend is obvious, but precipitation varies by location because precipitation changes are more geographically and seasonally variable than temperature rises. In hydrological studies, precipitation is a crucial component. It is linked
to agriculture, disaster mitigation, and preparedness, and it is crucial in water resource planning and management [6]. The regional and temporal distributions of precipitation have recently been crucial elements in climate change research [7][8].

Data gathering from rain gauges is difficult in many places due to a range of administrative and technological issues [9]. Because many river basins have few rain gauges and short record lengths, the regional and temporal distribution of observed precipitation is imprecise. Errors occur in transmitting data, instrument operation, human operators, and outages for various reasons [10]. To overcome these issues, alternative precipitation datasets have been created during the last two decades that may be more suitable for hydrological modelling and climate change research [8]. These datasets include GPCP (Global Precipitation Climatology Project), TMPA (Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis), APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation), CSFR (Climate Forecast System Reanalysis), PERSIANN-CDR (The Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks- Climate Data Record), and CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data). Several research has been conducted to compare these precipitation datasets to in-situ measurements and to investigate their relevance in hydrological studies.

Citarum Watershed is one of the world's most threatened watersheds and the most degraded on Indonesia's Java Island. [11]. The Citarum Watershed is 6.090 km² in size and is located in the province of West Java. The Indonesian government considers it the most significant river basin region since it supplies 80 percent of Jakarta's surface water. In 2008, the Citarum Watershed was home to over 15 million people and produced 20% of the country's industrial output. Three hydroelectric dams totaling 1,400 megawatts are located in the upper basin. The river provides water to irrigation systems that cover about 400,000 hectares and provide 5% of the country's rice production. Over the last two decades, urbanization and industrial expansion have put increasing strain on the basin's water supplies, resulting in severe water contamination, acute stress, and groundwater depletion in numerous regions. Flooding has become much more vulnerable as a result of rapid urbanization and climate change. Environmental degradation has also reached levels that jeopardize public health, particularly among the poor. River and groundwater management in the basin has proven critical to the country's social and economic development.[12].

For these reasons, it is critical to understand the scope and direction of future hydrological processes as they are influenced by current climatic trends such as precipitation and temperature. This research is preliminary and aims to understand better the effects of climate change on water availability in tropical areas.

2. Study Area
Citarum Watershed (6.080 km²) is one of the largest watersheds in Java, Indonesia. It is situated on the island's western side. With more than 150 million people, Java is one of the world's most densely populated islands (as of 2019). The Citarum Watershed is critical for the existence of almost 15 million people who reside within its boundaries. A tropical monsoon climate prevails in the Citarum Watershed, with distinct dry and wet seasons. The dry season lasts from May to October and is influenced by Australian continental masses. In contrast, the rainy season lasts from November to April and is influenced by Asian and Pacific Ocean wind masses. The spatial precipitation pattern is most likely dictated by orography, with greater precipitation in the upstream than in the downstream area.

For the past two decades, the international development agencies and the Indonesian government have classified the Citarum River as one of the world's most polluted rivers. Flooding, sedimentation, deforestation, pollution, and over-pumping of groundwater, along with a lack of policy enforcement and inadequate coordination between government agencies, are endangering Indonesian livelihoods.

3. Materials and Methods
From 1981 through 2019, this research examines annual and seasonal precipitation totals and maximum, minimum, and mean temperatures in the Citarum Watershed. CHIRPS gridded precipitation data is used
to represent observed data. CHIRPS daily data has 0.25°x0.25° grid resolution that can describe the spatial distribution of precipitation over the watershed. The annual and seasonal precipitation trends are analyzed for 17 grids in Citarum Watershed (Indonesia) during 1981-2019. For temperature trend analysis, five stations are used to describe the change in maximum, minimum, and mean temperature over the watershed.

![Figure 1. Map of Citarum Watershed](image)

The purpose of trend analysis is to see if the mean annual and seasonal precipitation (P) and temperature (T) have changed considerably over time (long-term). For determining trend and slope magnitude, the nonparametric Mann-Kendall test (MK) [13][14] using Sen's slope estimator is used. The Mann-Kendall test is a rank-based method for determining trends in hydrological variables that have been used in numerous previous research. The use of this test has two advantages. It's a nonparametric test, which means the data doesn't have to be regularly distributed. Second, due to inhomogeneous time series, the test has a low sensitivity to abrupt breaks. Sen [15] proposed a nonparametric method for calculating a time series trend's magnitude (slope). The Mann-Kendall test with Sen's slope estimator is as follows:
\[ Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases} \] (1)

Where \( Z \) is a transformation of the statistic \( S \):

\[ S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(X_j - X_i) \] (2)

\[ \text{sgn}(X_j - X_i) = \begin{cases} 1, & X_j - X_i > 0 \\ 0, & X_j - X_i = 0 \\ -1, & X_j - X_i < 0 \end{cases} \] (3)

4. Results and Discussion

4.1. Precipitation Trends

In general, the average annual precipitation in the Citarum Watershed is between 1.771 mm in the relatively flat north to 3.560 mm in the mountainous south (Fig.2). The rainy season lasts from October to April, while the other months are dry. The highest rainfall occurs from January to February, while the lowest occurs from July to August (Fig.3). More than 70% of total precipitation occurs in the wet season (Nov-Apr). The spatial analysis of precipitation uses IDW (Inverse Distance Weighting) interpolation analysis.

![Spatial distribution of Citarum Watershed Precipitation](image-url)
The annual precipitation in Citarum Watershed from 1981 to 2019 shows an increasing trend (Fig 4). Dry years occurred in 1982, 1997, 2002, 2003, 2006, 2015, 2018, and 2019 with precipitation below 2500 mm/year. In contrast, wet years occurred in 1992, 2001, 2010, 2013, and 2016 with annual precipitation above 3500 mm/year.

The annual precipitation time-series was analyzed using the MK test, which revealed that 82.3 percent of grids/stations had a positive trend (14 of 17 stations) while the rest had a negative trend. The Z value revealed 14 stations with an insignificant growing trend and three stations with an insignificant declining trend (Table 1). The watershed's increasing tendency can be seen primarily in the southern and eastern parts. In contrast, the declining trend can be observed in a tiny portion of the western area (Fig 5c). In general, the Citarum Watershed region shows a rising tendency in precipitation. In contrast, a tiny fraction of the western half shows a declining trend. The magnitude of the trend varies between -3.72 mm/year to 6.53 mm/year.


| Grid | Wet | Z | Slope | Trend | Dry | Z | Slope | Trend | Annual | Z | Slope | Trend |
|------|-----|---|------|-------|-----|---|------|-------|--------|---|------|-------|
| 1    | 1.26| 5.41| I    |       | -1.23| -3.37| D    | 0.44  | 2.00  | I  |       |       |
| 2    | 1.57| 3.98| I    |       | -0.92| -2.25| D    | 0.36  | 1.74  | I  |       |       |
| 3    | 19.94| 5.81| I    |       | -1.19| -5.88| D    | -0.05| -0.34| D  |       |       |
| 4    | 2.1 | 6.05| SI   |       | -1.06| -4.37| D    | 0.22  | 1.84  | I  |       |       |
| 5    | 2.27| 6.97| SI   |       | -1.72| -13.10| D    | -0.39| -3.72| D  |       |       |
| 6    | 2.59| 8.30| SI   |       | -1.67| -10.76| D    | -0.12| -1.00| D  |       |       |
| 7    | 2.69| 8.96| SI   |       | -1.11| -7.72| D    | 0.17  | 2.64  | I  |       |       |
| 8    | 2.03| 8.77| SI   |       | -0.92| -5.91| D    | 0.6   | 6.53  | I  |       |       |
| 9    | 2.71| 10.40| SI |     | -1.4 | -11.31| D    | 0.15  | 1.46  | I  |       |       |
| 10   | 2.42| 7.95| SI   |       | -1.31| -8.61| D    | 0     | 0.16  | I  |       |       |
| 11   | 2.49| 8.89| SI   |       | -1.23| -7.79| D    | 0.48  | 4.86  | I  |       |       |
| 12   | 2.47| 6.85| SI   |       | -1.02| -4.30| D    | 0.85  | 3.56  | I  |       |       |
| 13   | 2.23| 7.73| SI   |       | -0.87| -5.24| D    | 0.6   | 4.80  | I  |       |       |
| 14   | 2.15| 7.57| SI   |       | -1.4 | -9.44| D    | 0.02  | 0.48  | I  |       |       |
| 15   | 2.59| 10.43| SI|   | -1.21| -8.32| D    | 0.44  | 3.59  | I  |       |       |
| 16   | 2.69| 9.45| SI   |       | -1.16| -6.49| D    | 0.58  | 5.14  | I  |       |       |
| 17   | 1.67| 6.45| I    |       | -1.26| -7.31| D    | 0.05  | 0.34  | I  |       |       |

Despite the annual trend, the MK trend found a very larger number of stations with a significant increase (13 of 17 stations or 76.4%) in the wet season. All of the grids/stations show an increasing trend (Table 1). Significant increasing trends are mostly found in the central and southern part of the watershed (Fig 5a), the middle and upper part of the basin. The increasing magnitude varies from 3.98 mm/year to 10.43 mm/year.

In the dry season, the MK test found an insignificant decreasing trend for all grids/stations (Table 1). The magnitude of decreasing trends varies from -2.25 mm/year to -11.31 mm/year, with a small portion of the western part of the basin showing the highest decreasing trend (Fig 5b).

\[\text{Figure 5. Seasonal and Annual Spatial trend of Precipitation in Citarum Watershed}\]

4.2. Temperature Trends

Based on the analysis of the average temperature from 1985 to 2019 for five stations, the Mean temperature of Citarum Watershed varied from 22.8 °C to 28.4 °C. There were no big differences in monthly temperature. The highest temperature was recorded in October with 26.5°C, and the lowest
temperature was in January with 25.2°C (Fig 7). It is due to the watershed’s location in the tropical area and is also influenced by the ocean.

The mean annual and seasonal temperatures for each station have been obtained. The regional distribution of mean annual temperature from 1985 to 2019 is depicted in Figure 6. The maximum temperatures (28.4 °C) are found along the coast, while the lowest (22.8 °C) are found at higher elevations. The warmest places are the flat fields in the north, close to Jakarta and Bekasi, which have urban areas and a long agricultural tradition.

Figure 6. The monthly average temperature of Citarum Watershed

Trend detection can be accomplished using a variety of statistical approaches. The nonparametric Mann–Kendall test for trend detection was utilized in this investigation. The 95 percent confidence level and serial autocorrelation were evaluated. Without making any assumptions about the distribution features, this test detects the presence of a trend. In addition, spatial analytic techniques will be utilized to confirm the existence of a geographic pattern in temperature trends. Table 2, Table 3, and Table 4 describe the results obtained for seasonal and annual data of min, max, and mean temperature, respectively.

The annual minimum temperature in Citarum Watershed from 1985 to 2019 shows an increasing trend. The magnitude of the increase is 1.54 °C (Fig 8). The lowest minimum temperature occurred in 1985 with 20.6 °C, and the highest minimum temperature occurred in 2016 with 22.7 °C. Table 2 shows the seasonal and annual trends of minimum temperature for five stations. The results show that all the stations exhibit increasing seasonal (wet and dry) and annual trends. 40% (2 of 5 stations) shows a significant increasing trend at a 95% confidence level.

Table 2. MK Trend Analysis of minimum temperature in Citarum Watershed

| Station    | Wet Z | Wet Slope | Wet Trend | Dry Z | Dry Slope | Dry Trend | Annual Z | Annual Slope | Annual Trend |
|------------|-------|-----------|-----------|-------|-----------|-----------|----------|--------------|--------------|
| Bandung    | 0.33  | 0.067     | I         | 1.57  | 0.067     | I         | 0.89     | 0.066        | I            |
| Bogor      | 2.05  | 0.021     | SI        | 2.64  | 0.021     | SI        | 3.41     | 0.022        | SI           |
| Citeko     | 1.75  | 0.043     | I         | 1.19  | 0.024     | I         | 1.39     | 0.033        | I            |
| Kertajati  | 1.9   | 0.036     | I         | 2.58  | 0.042     | SI        | 2.05     | 0.04         | SI           |
| Tanjung Priok | 3.08  | 0.05      | SI        | 1.42  | 0.06      | I         | 1.78     | 0.056        | I            |
The annual maximum temperature in Citarum Watershed from 1985 to 2019 shows an increasing trend with a magnitude of increasing is 0.7 °C (Fig 9). The lowest maximum temperature occurred in 1986 with 29.6 °C, and the highest minimum temperature occurred in 2019 with 31.1 °C. Table 3 shows the seasonal and annual trends of maximum temperature for five stations. The results show that most stations exhibit increasing seasonal (wet and dry) and annual trends. 60% (3 of 5 stations) shows a significant increasing trend at a 95% confidence level. Surprisingly, Tanjung Priok, located in the coastal
area, shows a significant decrease in the dry season. It might be influenced by the interaction of the atmosphere and ocean in the Java Sea.

### Table 3. MK Trend Analysis of maximum temperature in Citarum Watershed

| Station      | Wet Z | Wet Slope | Wet Trend | Dry Z  | Dry Slope | Dry Trend | Annual Z  | Annual Slope | Annual Trend |
|--------------|-------|-----------|-----------|--------|-----------|-----------|-----------|---------------|--------------|
| Bandung      | 2.46  | 0.03      | SI        | 2.37   | 0.043     | SI        | 2.22      | 0.037         | SI           |
| Bogor        | 2.67  | 0.041     | SI        | 2.61   | 0.037     | SI        | 2.43      | 0.038         | SI           |
| Citeko       | 1.9   | 0.023     | I         | 3.01   | 0.026     | SI        | 1.51      | 0.023         | I            |
| Kertajati    | 2.36  | 0.018     | SI        | 1.73   | 0.015     | I         | 2.36      | 0.018         | SI           |
| Tanjung Priok| 1.08  | 0.009     | I         | -2.7   | -0.037    | SD        | -1.22     | -0.013        | D            |

![Figure 9. Maximum temperature trend of Citarum Watershed](image)

The annual mean temperature in Citarum Watershed from 1985 to 2019 shows an increasing trend with a magnitude of increasing is 1.15 °C (Fig 10). The lowest mean temperature occurred in 1986 with 25.2 °C, and the highest mean temperature occurred in 2019 with 26.6 °C. Table 4 shows the seasonal and annual trends of minimum temperature for five stations. The result shows that all the stations exhibit increasing seasonal (wet and dry) and annual trends. 80% (4 of 5 stations) shows a significant increasing trend at 95% confidence level in the wet season, whereas 40% (2 of 5 stations) shows a significant increasing trend in the dry season and annual.

### Table 4. MK Trend Analysis of mean temperature in Citarum Watershed

| Station      | Wet Z | Wet Slope | Wet Trend | Dry Z | Dry Slope | Dry Trend | Annual Z | Annual Slope | Annual Trend |
|--------------|-------|-----------|-----------|-------|-----------|-----------|----------|---------------|--------------|
| Bandung      | 1.25  | 0.051     | I         | 0.68  | 0.048     | I         | 0.92     | 0.049         | I            |
| Bogor        | 1.99  | 0.031     | SI        | 1.48  | 0.029     | I         | 1.66     | 0.03          | I            |
| Citeko       | 2.08  | 0.032     | SI        | 1.66  | 0.025     | I         | 1.39     | 0.029         | I            |
| Kertajati    | 2.76  | 0.028     | SI        | 2.31  | 0.027     | SI        | 2.37     | 0.029         | SI           |
| Tanjung Priok| 2.79  | 0.03      | SI        | 2.22  | 0.011     | SI        | 2.46     | 0.021         | SI           |
The inverse distance weighted (IDW) interpolation method spatially interpolate the trend test confidence levels and slopes, resulting in a raster surface.

Figure 10. Mean temperature trend of Citarum Watershed

Figure 11. Spatial distribution of mean temperature trend in Citarum Watershed

Figure 11 shows the highest increasing temperature trend in Citarum Watershed, located in the southeastern part of the basin. This area is the location of the city of Bandung, which is the city with the highest urbanization rate in Indonesia. It is widely acknowledged that rising urbanization will have a considerable impact on the worldwide land warming trend.
Conclusion
Understanding historical precipitation and temperature patterns are crucial but insufficient for designing climate change adaptation methods to preserve vulnerable ecosystems in tropical locations, like the Citarum River watershed on Java Island, Indonesia. The goal of this study was to discover such patterns in this watershed over a lengthy period. The detection was done by the use of a Mann-Kendall with Sen's slope. The results indicated that there are significant increasing trends of precipitation during the wet season. Whereas the increasing trend in temperature exhibits for all stations in the basin. The highest increasing trend is in Bandung City, the city with the highest urbanization rate in Indonesia.

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