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Temporal Analysis of Rainfall Characteristics in Response to Climate Change in the Special Region of Yogyakarta Province

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Abstrak

Perubahan iklim telah menyebabkan variasi curah hujan yang tidak merata. Analisis temporal curah hujan di Daerah Istimewa Yogyakarta dilakukan melalui perhitungan rata-rata bulanan, rata-rata musiman, dan tren tahunan menggunakan Climate Data Operator (CDO) dan aplikasi Microsoft Excel selama 60 tahun dari 1961 hingga 2020, dengan menggunakan data ERA5. Rentang waktu dibagi menjadi dua periode: 1961-1990 dan 1991-2020, dengan tujuan mengamati karakteristik curah hujan seperti perubahan, pola, dan tren yang terjadi selama periode tersebut. Rata-rata curah hujan bulanan tertinggi terjadi pada bulan Januari untuk kedua periode, mencapai 378 mm untuk 1961-1990 dan 370 mm untuk 1990-2020. Sebaliknya, rata-rata bulanan terendah terjadi pada bulan Agustus, dengan nilai 51 mm untuk 1961-1990 dan 38 mm untuk 1991-2020. Rata-rata curah hujan musiman tertinggi terjadi selama periode DJF, dengan nilai 945 mm untuk 1961-1990 dan 1022 mm untuk 1991-2020. Namun, rata-rata musiman terendah terjadi selama periode JJA, dengan nilai 228 mm untuk 1961-1990 dan 191 mm untuk 1991-2020. Tren curah hujan menunjukkan peningkatan untuk periode pertama (1961-1990), sedangkan penurunan terjadi pada periode kedua (1991-2020), termasuk musim hujan, musim kemarau, dan tahunan. Hasil ini dapat dikaitkan dengan perubahan iklim, di mana terjadi musim hujan yang sangat basah dan musim kemarau yang sangat kering. Secara keseluruhan, Provinsi Daerah Istimewa Yogyakarta mengalami curah hujan tahunan yang terus menerus dari tahun 1961 hingga 2020.
Kata kunci: Hujan, Perubahan Iklim, Tren

Abstract

Climate change has resulted in uneven rainfall variations. The temporal analysis of rainfall in the Special Region of Yogyakarta Province was conducted through the calculation of monthly averages, seasonal averages, and annual trends using the Climate Data Operator (CDO) and Microsoft Excel application over 60 years from 1961 to 2020, utilizing ERA5 data. The time frame is divided into two periods: 1961-1990 and 1991-2020, aiming to observe rainfall characteristics such as changes, patterns, and trends that occurred during these intervals. The highest monthly average rainfall occurs in January for both periods, registering 378 mm for 1961-1990 and 370 mm for 1990-2020. In contrast, the lowest monthly average occurs in August, with values of 51 mm for 1961-1990 and 38 mm for 1991-2020. The highest seasonal average rainfall occurs during the DJF period, with values of 945 mm for 1961-1990 and 1022 mm for 1991-2020. However, the lowest seasonal average occurs during the JJA period, with values of 228 mm for 1961-1990 and 191 mm for 1991-2020. The rainfall

trend shows an increase for the first period (1961-1990), whereas decreases in the second period (1991-2020), including wet seasons, dry seasons, and annual. The result can be associated with climate change, where there are occurrences of extremely wet and extremely dry seasons. Overall, the Special Region of Yogyakarta province experienced continuous yearly rainfall from 1961 to 2020.
Keywords: *Climate Change, Rainfall, Trend*

1. INTRODUCTION

The issue of climate change has become a hot topic discussed worldwide. Climate represents the average weather conditions over a long period, with parameters such as air temperature, rainfall, air pressure, humidity, and wind direction[1]. One of the climate parameters with significant impacts is rainfall. Extremely rainfall can lead to disasters such as floods and landslides, while low rainfall makes an area susceptible to drought [2] [3]. In 2023, the Intergovernmental Panel on Climate Change (IPCC) reported heavy precipitation and flooding events are projected to intensify and become more frequent in most regions in Africa and Asia [4]. Additionally, climate change has resulted in uneven rainfall variations[5]. Climate change also makes rainfall in a region challenging to predict[6].

The climate in different regions is influenced by several factors, including latitude, the presence of oceans, wind patterns, topography, and the density and type of vegetation[7]. The Special Region of Yogyakarta is one of the provinces on Java Island with many historical and tourist sites. The geographical condition of the Yogyakarta Province is appealing, with highlands to the north bordering Mount Merapi and lowlands to the south directly bordering the Indian Ocean. The topographical differences in this region cause variability in rainfall, as orographic rainfall occurs in the mountainous areas [8]. Air masses that are lifted when they encounter the mountains cool and condense, leading to higher precipitation on the windward side of the mountains [9]. The rainfall pattern in Java Island, including Yogyakarta Province is generally unimodal, characterized by a single peak and a single trough[10]. The peak of the dry season usually occurs in the June-August period (JJA), while the peak of the rainy season occurs in the December-January period (DJF)[11]. The rainfall pattern is caused by the activity of the wet Asian monsoon and the dry Australian monsoon [12].

Over the years, various studies have been conducted to analyze the patterns and trends of rainfall changes using different methods. The previous research found high spatial and temporal variations in the average annual rainfall in the Baram River (BR) region in Sarawak (Borneo Malaysia) characterized through cluster analysis and multivariate statistics over 25 years from 1990 to 2014 [13]. On the other hand, the research[14] revealed a decreasing trend in most stations in the Syrian region from 1991 to 2009 using the Mann-Kendall method. The research aims to analyze the temporal characteristics of rainfall such as pattern and trend in the Special Region of Yogyakarta Province during the periods 1961–1990 and 1991–2020.

2. RESEARCH METHOD

The research was located in the Special Region of Yogyakarta Province with astronomical coordinates of 7°33' - 8°20' South Latitude and 109°40' - 111°0' East Longitude. The province covers an area of approximately 3,185 square kilometers, consists of one city

and four regencies, which are further divided into 78 subdistricts. The data utilized were reanalysis ERA5 data with the total precipitation parameter for 60 years from 1961 to 2020, downloaded from the website https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form. The 60-year data were divided into two periods: the first period from 1961 to 1990 and the second period from 1991 to 2020. The use of ERA5 data is due to the limitations of observational data at local stations and its ability to depict climatological phenomena. For further detail, refer to Table 1 and Figure 1.

Table 1. Information of Observation Station

Observation Station	Latitude	Longitude	Elevation
DI Yogyakarta Climatology Station	-7,7310	110,3540	182 m

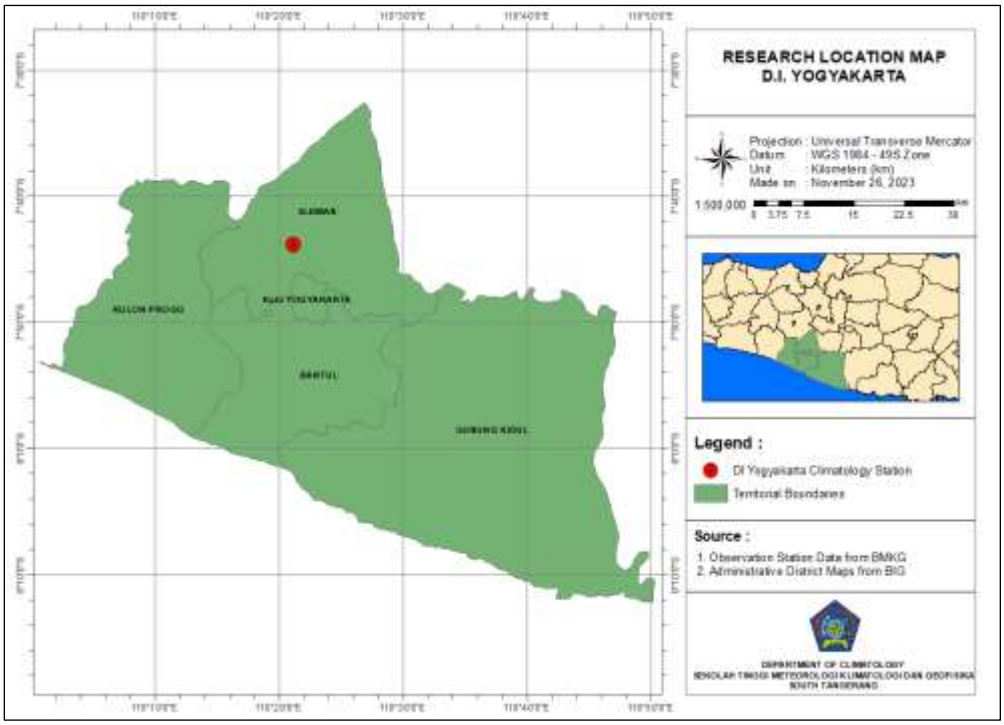


Figure 1. Research Location

The method is a temporal analysis using the Climate Data Operator (CDO) application with the ymonmean feature to calculate monthly averages and yseasmean to calculate seasonal averages during the first and second periods with the following script:

cdo ymonmean fileinput fileoutput (1)

cdo yseasmean fileinput fileoutput (2)

The mathematical equation for calculating the average is[15]

$$\bar{x} = \frac{\sum f_i.x_i}{\sum f_i} \quad (3)$$

where, $\bar{x}$ is the mean value; $f_i.x_i$ is a product of f_i at each data interval with the signing class (x_i); f_i is the sum of data or samples. The categorization of monthly rainfall by BMKG into four groups as follows

Table 2. Monthly Rainfall Categorize[16]

No	Categorize Rainfall	Intensity of Rainfall
1	Low	0-100 mm/month
2	Moderate	100-300 mm/month
3	High	300-500 mm/month
4	Very High	>500 mm/month

In addition, an annual trend analysis method is conducted during the first and second periods. Before conducting the trend analysis, one point needs to be determined as a sample using the Climate Data Operator (CDO) application with the remap nearest neighbor feature with the following script

cdo remapnn,lon=xxx_lat=xxx fileinput fileoutput (4)

The value of xxx is filled according to the astronomical coordinates of the observation station in Table 1. The mathematical equation for nearest neighbor is[17]

$$T = \frac{ju}{jh} \quad (5)$$

where, T is the index of the nearest neighbor spread; ju is the average distance measured between one point and its nearest neighbors; jh is the average distance obtained if all points have a random pattern.

The method used for trend analysis is Least Square using the Microsoft Excel application to obtain regression coefficients a and b, which minimize the sum of squared errors. The mathematical equation for linear regression is[18]

$$y = a + bx \quad (6)$$

where, y is the trend value; a is the constant; b is the slope; x is the independent variable (time).

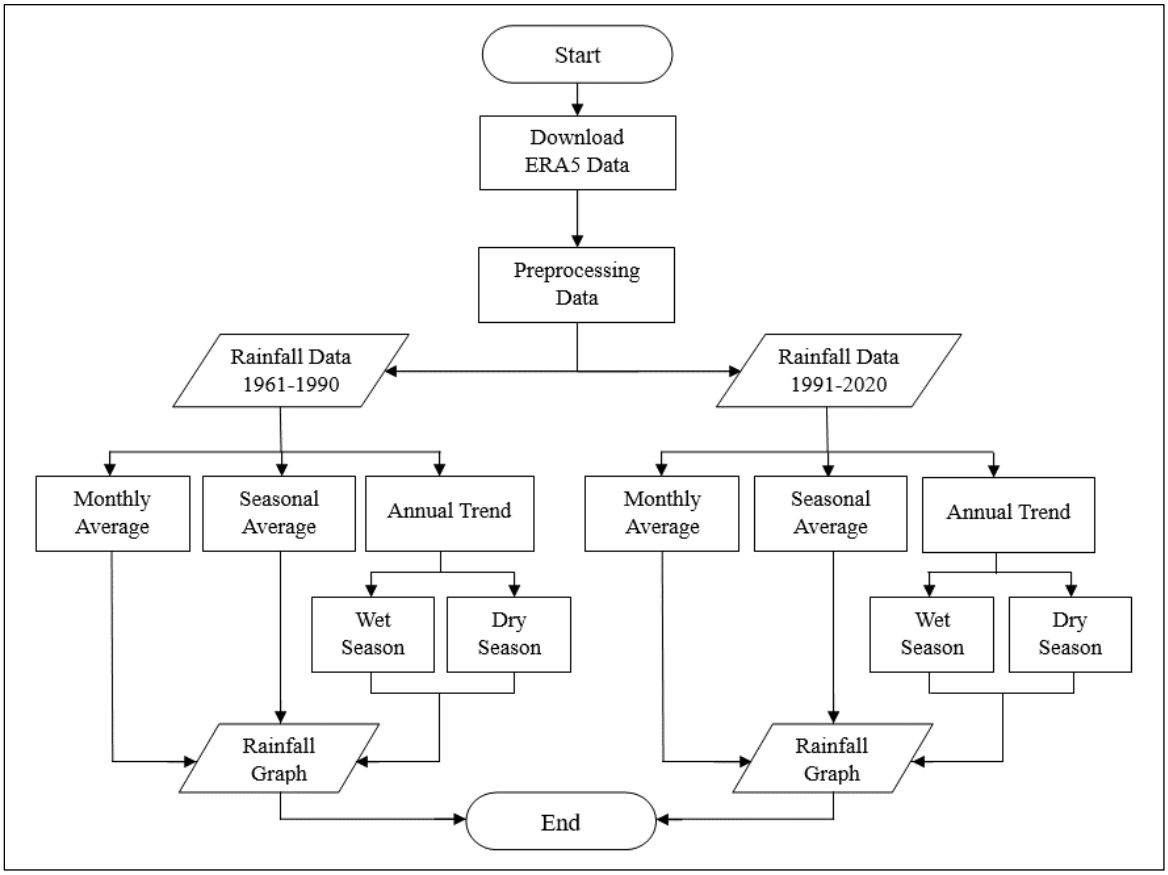


Figure 2. Flowchart

3. RESULT AND DISCUSSION

Temporal analysis was conducted to observe the patterns and trends of rainfall changes in each period, as described below.

3.1 Period of 1961-1990

Based on the calculation of rainfall data over 30 years from 1961 to 1990 in the Special Region of Yogyakarta Province, the following graph is generated.

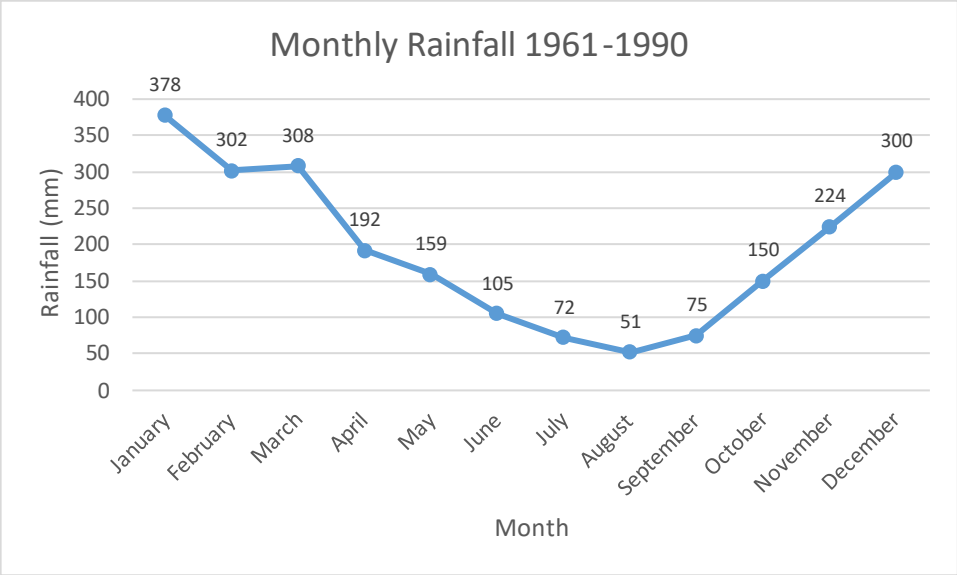


Figure 3. Monthly Rainfall Average for 1961-1990

Figure 3 depicts the fluctuating monthly average rainfall, showing an unimodal pattern with a peak in January and a trough in August. The highest monthly average rainfall is 378 mm in January, whereas the lowest is 51 mm in August. The monthly average rainfall consistently increases from August to January, while it experiences a continuous decrease from March to August. The rainfall pattern is monsoonal, characterized by one peak during the rainy season and one peak during the dry season [10]. This pattern influenced by the active Asian monsoon during the period of December to February and the active Australian monsoon during the period of June to August [19, 20]. Referring to Table 2 reveals that the average monthly rainfall over 30 years from 1961 to 1990 in the Special Region of Yogyakarta Province falls within the categories ranging from low to high.

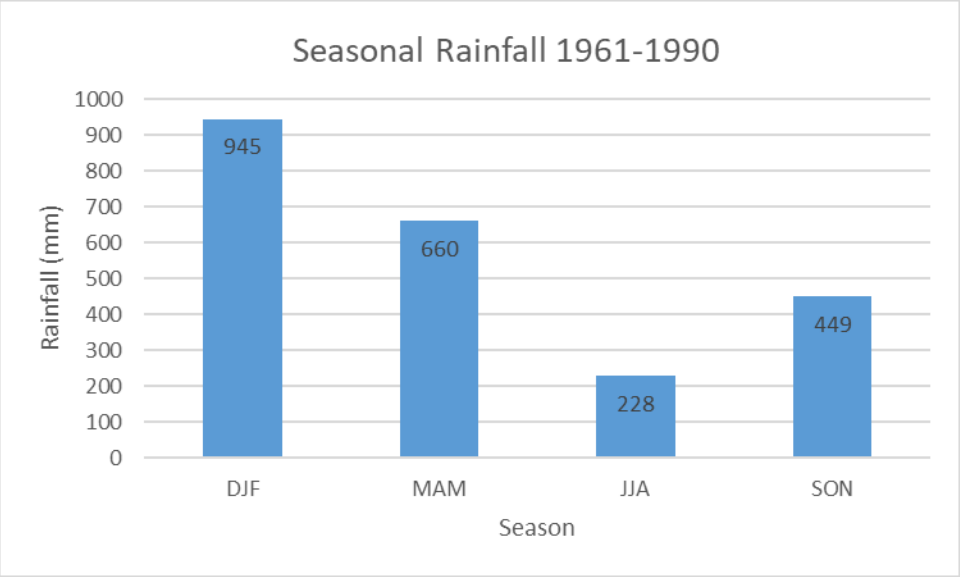
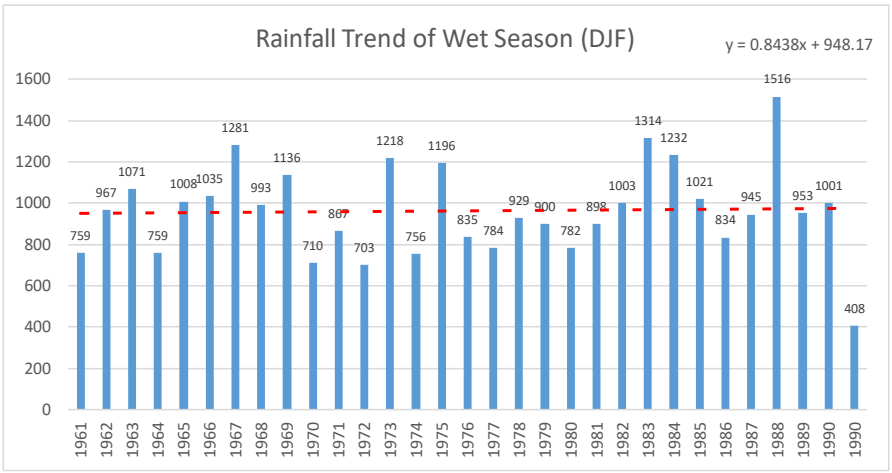
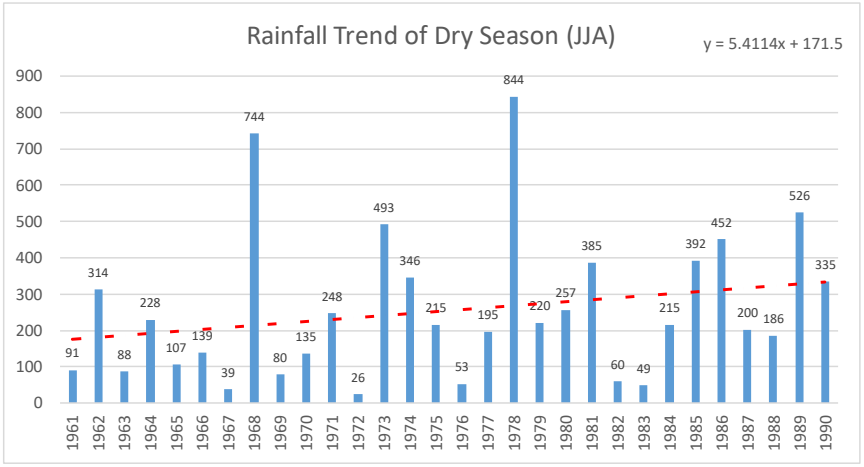


Figure 4. Seasonal Rainfall Average for 1961-1990

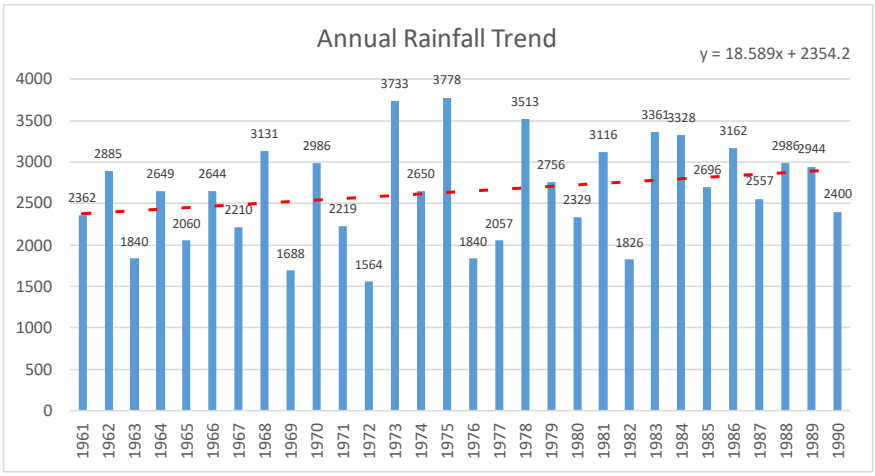
Figure 4 illustrates the temporal variation in the seasonal rainfall average over 30 years from 1961 to 1990 in the Special Region of Yogyakarta Province. The apex of the wet season is indicated by the highest average seasonal rainfall, transpiring during the December-January-February (DJF) interval at 945 mm. In contrast, the zenith of the dry season is denoted by the lowest average seasonal rainfall transpiring during the June-July-August (JJA) period, registering 228 mm. The months of September-October-November (SON) constitute a transitional period towards the wet season. In contrast, the months of March-April-May (MAM) serve as a transitional phase towards the dry season.



(a)



(b)



(c)

Figure 5. Rainfall Trend for 1961-1990 (a) Wet Season (b) Dry Season (c) Annual

Figure 5 depicts the rainfall trends in the Special Region of Yogyakarta province over 30 years, from 1961 to 1990. The rainfall trend during the wet season, as shown in Figure 5(a), shows an annual increase of 0.843 mm. The highest rainfall during the wet season occurred in 1988, reaching 1516 mm, while the lowest rainfall was recorded in 1972 at 703 mm. In 1990, there are two bars for the DJF period; the last bar graph represents only the rainfall in December, excluding the lowest rainfall. The difference in rainfall values during the DJF period over the 30 years ranges from 202 to 813 mm. Nevertheless, the rainfall trend during the dry season, as shown in Figure 5(b), experiences an annual increase of 5.411 mm. This is in line with research indicating that rainfall tends to increase during the wet season [21]. The highest rainfall during the dry season was in 1978, with a value of 844 mm, while the lowest rainfall occurred in 1972 at 26 mm. The difference in rainfall values during the

JJA period over 30 years ranges from 100 to 818 mm. The result can be associated with climate change, where there are occurrences of extremely wet and extremely dry seasons [4].

The annual rainfall trend, as shown in Figure 5(c), increases every year by 18.589 mm. The year 1975 recorded the highest annual rainfall at 3778 mm, while 1972 had the lowest at 1564 mm. The difference in annual rainfall values over 30 years ranges from 45 to 2214 mm. The volatility of climate change is expected to increase, leading to more frequent and unpredictable rainfall patterns [22]. Overall, the Special Region of Yogyakarta province experienced continuous yearly rainfall from 1961 to 1990. The increase in rainfall, both during the wet season, the dry season, and annual can be linked to global warming. Atmospheric warming increases the air's capacity to hold water vapor, leading to more precipitation when condensation occurs [23]. Additionally, global warming also affects the distribution of atmospheric pressure, which can alter regional wind and rainfall patterns [24, 25].

3.2 Period of 1961-1990

Based on the calculation of rainfall data over 30 years from 1991 to 2020 in the Special Region of Yogyakarta Province, the following graph is generated.

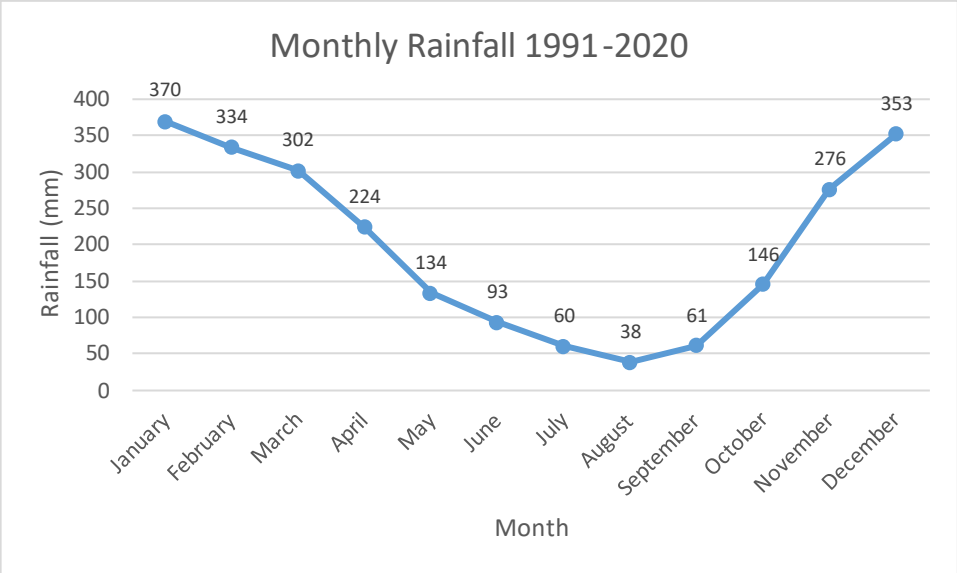


Figure 6. Monthly Rainfall Average for 1991-2020

Figure 6 depicts the fluctuating monthly average rainfall, showing an unimodal pattern with a peak in January and a trough in August. The highest monthly average rainfall is 370 mm in January, whereas the lowest is 38 mm in August. The rainfall pattern is monsoonal, characterized by one peak during the rainy season and one peak during the dry season [8]. This pattern influenced by the active Asian monsoon during the period of December to February and the active Australian monsoon during the period of June to August [16, 17]. The monthly average rainfall consistently increases from August to January, while

it experiences a continuous decrease from January to August. In the second period from 1991 to 2020, there were notable changes in the average monthly rainfall. January experienced a decrease of 8 mm compared to the preceding period of 1961-1990. February saw a more substantial decline of 32 mm, while March showed a modest increase of 4 mm. April witnessed a significant decrease of 32 mm, contrasting with May, which demonstrated an increase of 25 mm. June recorded a notable rise of 12 mm, whereas July experienced a decrease of 12 mm. August saw a reduction of 13 mm, and September followed suit with a decrease of 14 mm. October showed a decrease of 4 mm, whereas November and December both displayed considerable increases of 52 mm and 53 mm, respectively. Reffering Table 2 reveals that the average monthly rainfall over 30 years from 1991 to 2020 in the Special Region of Yogyakarta Province falls within the categories ranging from low to high.

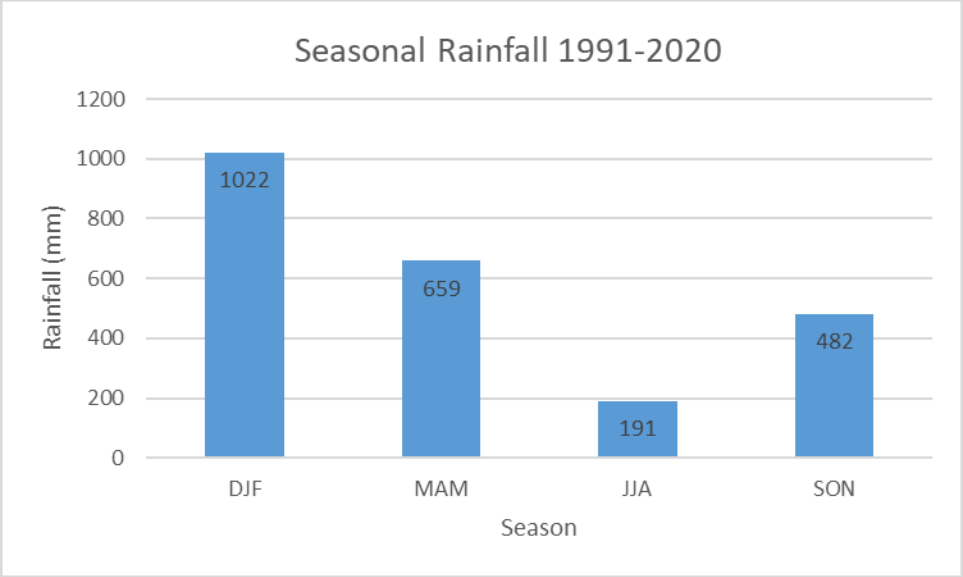
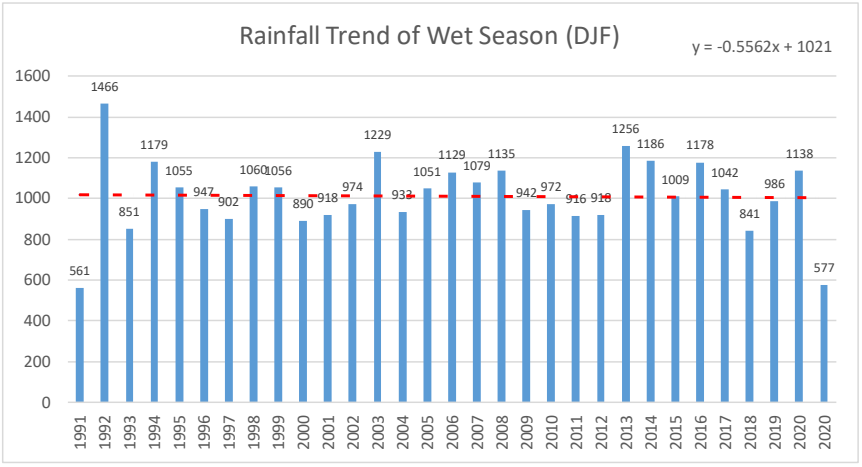
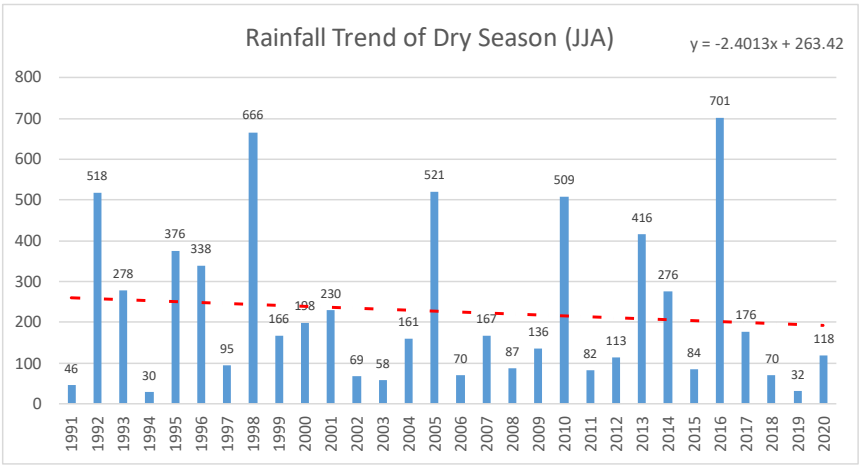


Figure 7. Seasonal Rainfall Average for 1991-2020

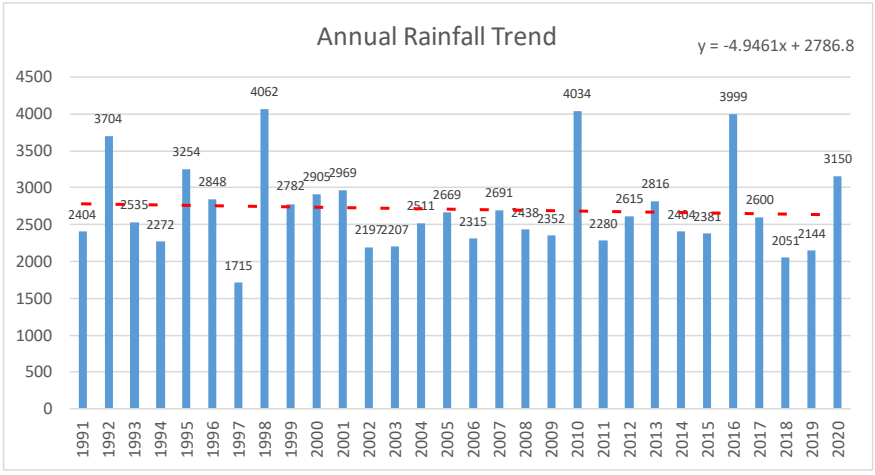
Figure 7 illustrates the temporal variation in the seasonal rainfall average over 30 years spanning from 1991 to 2020 in the Special Region of Yogyakarta Province. The apex of the wet season is indicated by the highest average seasonal rainfall, transpiring during the December-January-February (DJF) interval at 1022 mm. In contrast, the zenith of the dry season is denoted by the lowest average seasonal rainfall transpiring during the June-July-August (JJA) period, registering 191 mm. In the second period (1991-2020), the average seasonal rainfall for DJF increased by 77 mm compared to the first period (1961-1990), while MAM saw a slight decrease of 1 mm. JJA recorded a notable decline of 37 mm, and SON experienced an increase of 33 mm compared to the corresponding seasons in the first period. The months of September-October-November (SON) constitute a transitional period towards the wet season. In contrast, the months of March-April-May (MAM) serve as a transitional phase towards the dry season.



(a)



(b)



(c)

Figure 8. Rainfall Trend for 1991-2020 (a) Wet Season (b) Dry Season (c) Annual

Figure 8 depicts the rainfall trends in the Special Region of Yogyakarta province over 30 years, from 1991 to 2020. The rainfall trend during the wet season, as shown in Figure 8(a), shows an annual decrease of 0.556 mm. The highest rainfall during the wet season occurred in 1992, reaching 1466 mm, while the lowest rainfall was recorded in 2018 at 841 mm. In 2020, there are two bars for the DJF period; the last bar graph represents only the rainfall in December, excluding the lowest rainfall. Similarly, there is a bar in 1990 representing the cumulative rainfall in January and February, excluding the lowest rainfall. The difference in rainfall values during the DJF period over the 30 years ranges from 237 to 625 mm. Nevertheless, the rainfall trend during the dry season, as shown in Figure 5(b), experiences an annual decrease of 2.401 mm. The highest rainfall during dry season was in 2016, with a value of 701 mm, while the lowest rainfall occurred in 1994 at 30 mm. The difference in rainfall values during the JJA period over 30 years ranges from 35 to 671 mm. The result can be associated with climate change, where there are occurrences of extremely wet and extremely dry seasons [4].

The annual rainfall trend, as shown in Figure 5(c), decreases every year by 4.946 mm. The year 1998 recorded the highest annual rainfall at 4062 mm, while 1997 had the lowest at 1715 mm. The difference in annual rainfall values over 30 years ranges from 28 to 2347 mm. The highly variable annual precipitation can be attributed to global warming[4]. Overall, the Special Region of Yogyakarta province experienced continuous yearly rainfall from 1991 to 2020. The main factor behind the declining rainfall trend is the impact of global climate change, which causes shifts in regional rainfall patterns. Global warming affects the distribution of rainfall, with some areas experiencing reduced rainfall due to changes in atmospheric circulation, such as the intensification of the Hadley Cell [26]. Additionally, the El Niño-Southern Oscillation (ENSO) phenomenon may play a significant role, particularly during El Niño phases, which often lead to reduced rainfall in some tropical regions [27, 28]. The decrease in rainfall during the dry season can exacerbate extreme drought conditions, amplifying the regional impacts of climate change.

4. CONCLUSION

The monthly average rainfall from 1961 to 1990 fluctuated more than from 1991 to 2020, with both periods showing unimodal pattern. The highest rainfall occurred in January for both periods, while the lowest was in August. The highest seasonal average was during the DJF period, and the lowest was in the JJA period. The rainfall trend in the first period showed an annual increase, while the second period showed a decrease, reflecting the effects of climate change with extreme wet and dry seasons. The Special Region of Yogyakarta experienced continuous annual rainfall from 1961 to 2020. Given the trends of extreme rainfall, it's crucial to develop water management strategies, including better flood control and irrigation systems. Regular monitoring and early warning systems should be implemented to help with agriculture and disaster preparedness.

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