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RAINFALL PROJECTIONS USING CMIP6 SCENARIOS IN THE CIRARAB WATERSHED

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ABSTRACT

Climate change has been identified in the Cirarab watershed by looking at records of extreme rainfall events. This study aims to develop a scenario of climate change impacts at the watershed scale, especially from the aspect of changes in rainfall patterns in the Cirarab watershed until 2050. This research uses a descriptive quantitative method with a spatial-temporal approach, using secondary data obtained from the official databases of BMKG, CMIP6, and relevant literature. The analysis technique used is statistical downscaling. The results stated that based on climate change scenarios, the annual rainfall pattern in the Cirarab watershed remains stable with a monsoon climate type, marked by a single peak in the rainy season. Spatial variations in monthly rainfall are minimal due to the watershed's flat topography. However, rainfall variability during the rainy season leads to a temporal shift in the peak, indicating changes in rainfall timing despite overall pattern stability.

A. INTRODUCTION

Climate change is a global issue that has been felt by many countries in the world. Iran feels the impact of climate change by identifying a temperature increase of up to 0.47°C (Barati et al., 2024). According to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) report, the global average temperature in 2011-2020 increased by 1.1°C compared to the period 1850-1900 and is predicted to increase beyond 1.5°C or even more than 2°C during the 21st century (IPCC et al., 2023). This increase in air temperature has the potential to increase the frequency and intensity of extreme events, such as floods, droughts and heat waves (Schillerberg and Tian, 2024).

Climate change has also altered rainfall patterns in the US state of Louisiana, leading to increased hydrometeorological disasters such as hurricanes, tornadoes and floods (Twumasi et al., 2022). In Southeast Asia, rainfall trends show an increase in extreme rainfall events in several countries, particularly Vietnam, Myanmar, Thailand, and the Philippines (Chen et al., 2023; Endo et al., 2009; Hariadi et al., 2024; Skliris et al., 2022, 2021; Supari et al., 2020). Based on observational data and climate models, annual rainfall in Vietnam has increased

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by more than 50%, particularly in northern Vietnam and northwest of Ho Chi Minh City. An increase in extreme rainfall has also occurred in Thailand, the eastern coast of Myanmar, and the Luzon Islands in the Philippines. In addition, a downward trend in rainfall has also been observed, including in northern Myanmar, in the southeastern part of Ho Chi Minh City in Vietnam, and in several areas in Thailand (Skliris et al., 2022; Khoi and Trang, 2016; Skliris et al., 2021).

According to (World Bank Group and Asian Development Bank, 2021), Indonesia's annual average temperature trend in 2010-2017 increased by 0.8°C from the period 1951-1980. The annual average of minimum and maximum temperatures is projected to increase by 3.4°C. The increase in temperature affects the hydrological system, especially rainfall patterns in various regions. On the islands of Kalimantan, Java, Sumatra and Papua there was an increase in rainfall in the period 1998 - 2010. The intensity of extreme rainfall is projected to increase along with the increase in temperature, but its distribution is uneven spatially and temporally (World Bank Group and Asian Development Bank, 2021).

Currently, Indonesia has been affected by climate change, which is characterized by an increase in the frequency of climate-related disaster events, due to the influence of changes in air temperature and rainfall patterns (Nufutomo, 2022; Satria and Setiawan, 2019; Solihin et al., 2021). Rising temperatures lead to an increase in extreme rainfall events, especially in watersheds, which can increase the risk of flooding, as water flow can increase when extreme rainfall occurs (Fowler et al., 2021; Huang et al., 2022; Wang et al., 2025a; Wasko et al., 2021; Wasko and Sharma, 2017; Zhu et al., 2022). Climate change affects the hydrological cycle (Chien et al., 2013; Dewi et al., 2023; McCabe and Wolock, 2002; Sipayung and Cholianawati, 2011) which makes watersheds very sensitive to changes, making it crucial to predict future climate change.

The Cirarab watershed, located in Banten Province and passing through Tangerang Regency and Tangerang City, is affected by flooding, especially during the rainy season. Climate change results in changes in rainfall patterns and extreme rainfall events that contribute to the frequency and intensity of flooding. Climate change has been identified in the Cirarab watershed by looking at records of extreme rainfall events. In August 2010, the maximum daily rainfall intensity reached 155 mm recorded at the BPP Caringin rain station, which is located upstream of the Cirarab watershed (BMKG, 2025). Extreme rainfall was also recorded at the East Malay - Teluk Naga BPP rain post in July 2013, reaching 151 mm, where this rain post is located in the lower reaches of the Cirarab watershed (BMKG, 2025). Extreme rainfall anomalies in the Cirarab watershed occur during the dry season, when July and August should be the lowest rainfall peaks. Increased rainfall intensity coupled with unplanned land use change and inadequate drainage infrastructure can make matters worse (Sumarauw et al., 2024).

Climate projections are very important to understand the impacts of climate change, especially in watersheds. Therefore, it is necessary to study climate change projections in the long term to determine changes in rainfall patterns in watersheds that can contribute to an increase in extreme events. Climate projections are needed to know the future climate based on a set climate scenario, so that it can identify potential and provide early warning to the community against climate change. Therefore, this study aims to develop scenarios of climate change impacts at the watershed scale, especially from the aspect of changes in rainfall patterns in the Cirarab watershed until 2050.

B. METHOD

This study was conducted in the Cirarab watershed (Figure 1), which passes through urban and sub-urban areas, namely, Tangerang City and Tangerang Regency. The Cirarab watershed has a flooding problem, where communities around the Cirarab watershed are often affected by flooding during the rainy season. Changes in rainfall patterns due to climate change can worsen the incidence of flood disasters. Therefore, this study focuses on changes in rainfall patterns as one of the components that can affect the amount and intensity of flooding in the study area.

This research uses descriptive quantitative research methods and designs with a spatial temporal approach. The analysis technique used is statistical downscaling to model climate change projections in terms of rainfall at the local scale based on climate change scenarios. The unit of analysis in this research is the Watershed (DAS).

The data used in this research is secondary data. Secondary data collection techniques are collected from literature sources and official websites of related agencies. The data used for climate change analysis were obtained through the official websites of related agencies, such as the Meteorology, Climatology and Geophysics Agency (BMKG) located at the Banten Climatology Station and the CMIP6 website (https://aims2.llnl.gov/search). The data from BMKG used in this study is rainfall data with a time span of 2008 - 2024. The rainfall data used is the accumulated monthly rainfall data at six rain post locations (Table 1) surrounding the Cirarab watershed (Figure 1). The CMIP6 data used in this study is rainfall projection data with a time span of 2024 - 2050.

Rainfall projection analysis in this study uses statistical downscaling. This analysis technique is used to project climate change in terms of rainfall elements based on the CMIP6 climate change scenario until 2050. Statistical downscaling climate change projection analysis is done by downscaling global rainfall data to local scale through rainfall stations. Global rainfall is obtained from CMIP6 rainfall data with EC-Earth3-Veg-LR model and SSP5-8.5 scenario processed using GrADS software. The results of CMIP6 rainfall data processing produce grid / pixel data with a resolution of 100 km which represents rainfall values over a large area. This data is then downgraded to the local scale through rainfall stations to detail it to the local scale.

Tabel 1. List of Rainfall Station

No.	Name of Rainfall Station	Location
1.	Curug Meteorological Station	Banten Climatology Station
2.	Uptd Mauk	Banten Climatology Station
3.	Uptd Sindangjaya	Banten Climatology Station
4.	BPP Kp Melayu Timur – Teluk Naga	Banten Climatology Station
5.	Uptd Sepatan	Banten Climatology Station
6.	Bpp Caringin	Banten Climatology Station

(Source: BMKG, 2024)

Data from the rainfall stations used were monthly rainfall data from six BMKG rainfall stations that cover the Cirarab watershed (Figure 1). Rainfall data analysis was conducted for each BMKG rainfall station, where the rainfall data for each rainfall station was calculated as an overall average for the years 2008-2023. CMIP6 data is calculated as an average following the number of years of data availability from each BMKG rain station. The average value of rainfall from BMKG and CMIP6 rain stations will be used as a scaling factor (Alvin Galih Aditya et al., 2025). The scaling factor serves to convert global rainfall data to a local scale so that the results are more representative of local conditions. The result of the scaling factor is multiplied by the global rainfall projection data from CMIP6 (equation 1). This process is used to produce local level rainfall projections.

$$\text{Prj} = p_{CMIP6}\left[\frac{\bar{p}_{BMKG}}{\bar{p}_{CMIP6}}\right] \text{.........(1)}$$

Information :

Prj = The corrected precipitation

p_{CMIP6} = The raw precipitation output from the CMIP6

$\bar{p}_{BMKG}$ = The mean observed precipitation from BMKG

$\bar{p}_{CMIP6}$ = The mean model precipitation from CMIP6

Source : (Jaiswal et al., 2022)

The results of data processing will be presented in the form of graphs. This graph will be used to visualize the future climate change trends spatially and temporally in terms of rainfall patterns. The results obtained are used to identify projected climate change in terms of changes in rainfall patterns in the Cirarab watershed.

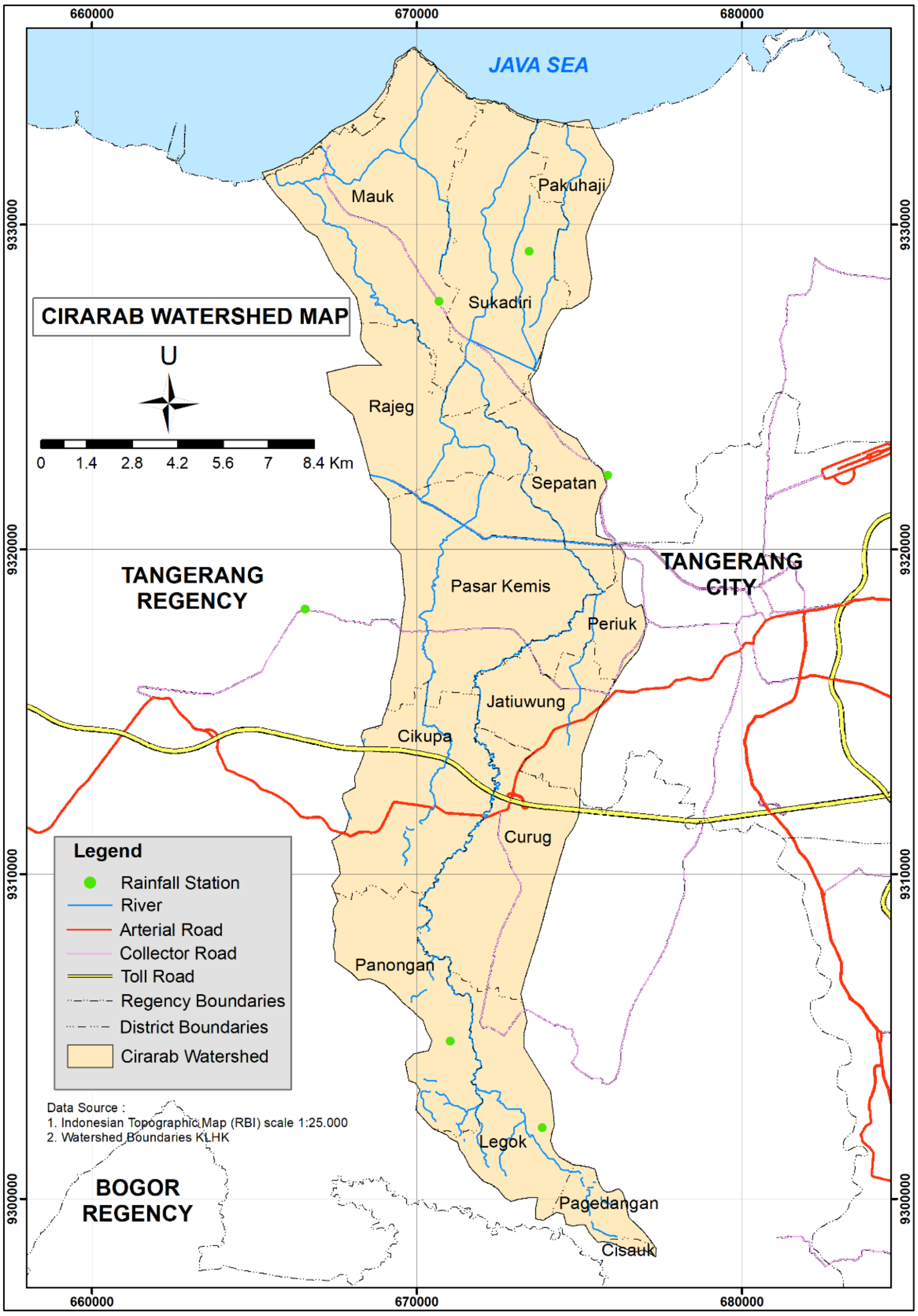


Figure 1. Research Location.
(Source: Processed by the author, 2025)

C. RESULT AND DISCUSSION

C.1. RESULT

Climate change analysis in this study was conducted by focusing on one of the climate elements, namely rainfall. Studies on long-term rainfall trend analysis play an important role in identifying areas that experience changes in rainfall patterns as a result of climate change (Alahacoon et al., 2022). Based on the trend analysis of local climate change projections at six rainfall posts in the Cirarab watershed, the distribution of rainfall for the period 2008 - 2050 in the Cirarab watershed is described.

The Cirarab watershed is dominated by flat topography with a slope of between 0-8% (Figure 2). These conditions contribute to the spatial distribution pattern of rainfall in the Cirarab watershed. Furthermore, the temporal distribution of rainfall shows a consistent seasonal pattern, but there is climate variability and anomalies in the dry season and a shift in the onset of the rainy season.

In general, the Cirarab watershed has two distinct seasons, namely the rainy and dry seasons. The peak of the rainy season occurs in December-January-February (DJF) and the peak of the dry season occurs in June-July-August (JJA). There are also transitional seasons, consisting of the transition to the dry season, which occurs in March-April-May (MAM), and the transition to the rainy season, which occurs in September-October-November (SON). This pattern has been relatively consistent throughout the historical period (2008-2023) and projections (2024-2050).

Monthly rainfall at Curug Meteorological Station from 2008 to 2050 (Figure 3) shows that historically, the highest average monthly rainfall at the peak of the rainy season (DJF) occurred in February, reaching 306 mm. Meanwhile, during the peak of the dry season (JJA), the lowest average rainfall was 131 mm/month. However, extreme rainfall anomalies were identified in 2010, marked by an increase in rainfall at the peak of the dry season (JJA) exceeding 200 mm/month to reach > 300 mm/month in August. Similar phenomena were also recorded in the following years with medium to high intensity.

Annual rainfall for 2024-2050 is projected to be relatively stable, but shows interannual climate variability. There is a spike in monthly rainfall values at the peak of the rainy season, reaching >500 mm. This illustrates an increase in climate variability, such as El Nino, La Nina, changes in global sea surface temperature, air pollution, changes in land use, and the influence of regional topography on rainfall (Muter et al., 2025), which increases the occurrence of extreme rainfall.

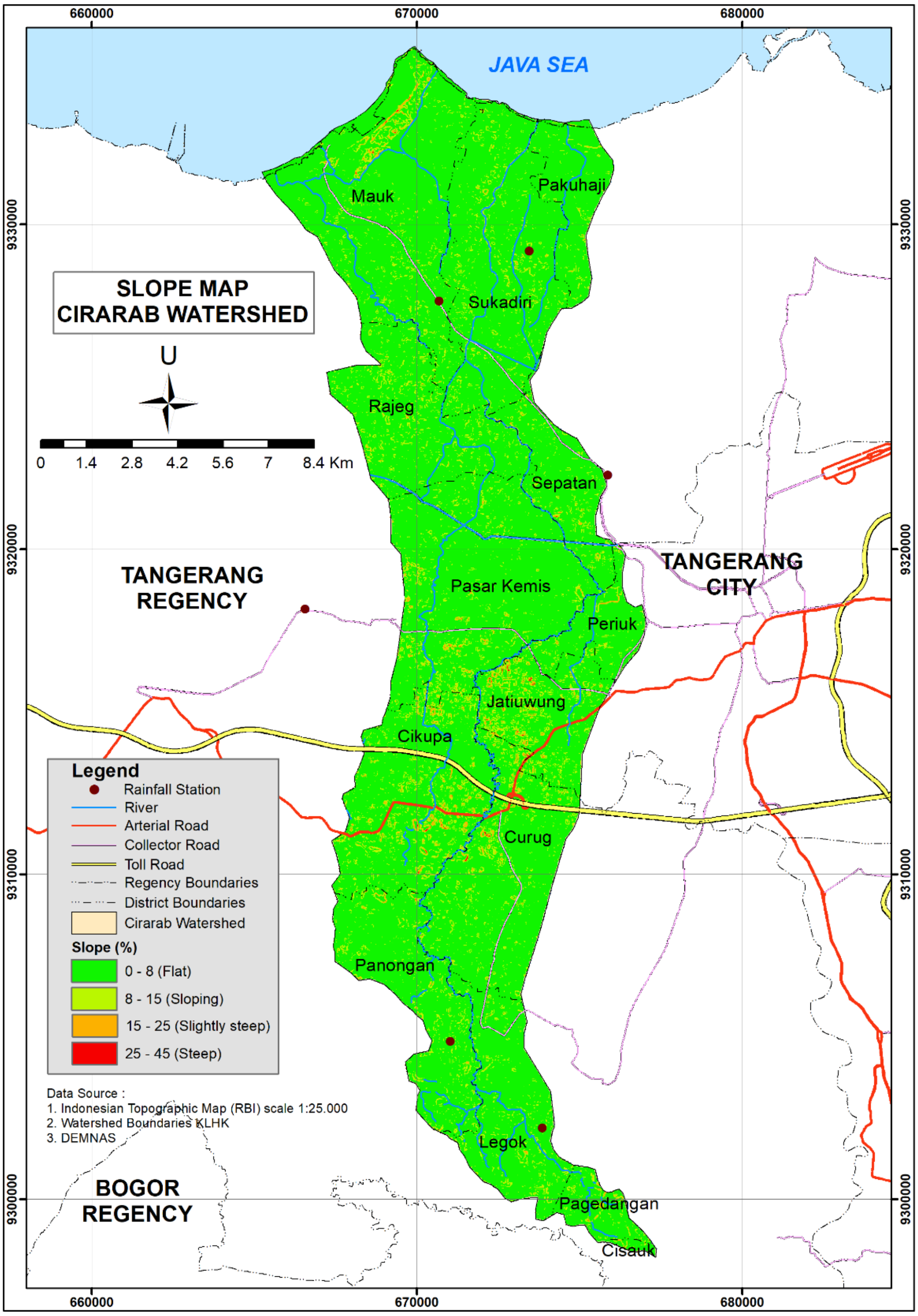


Figure 2. Slope Map
(Source: Processed by the author, 2025)

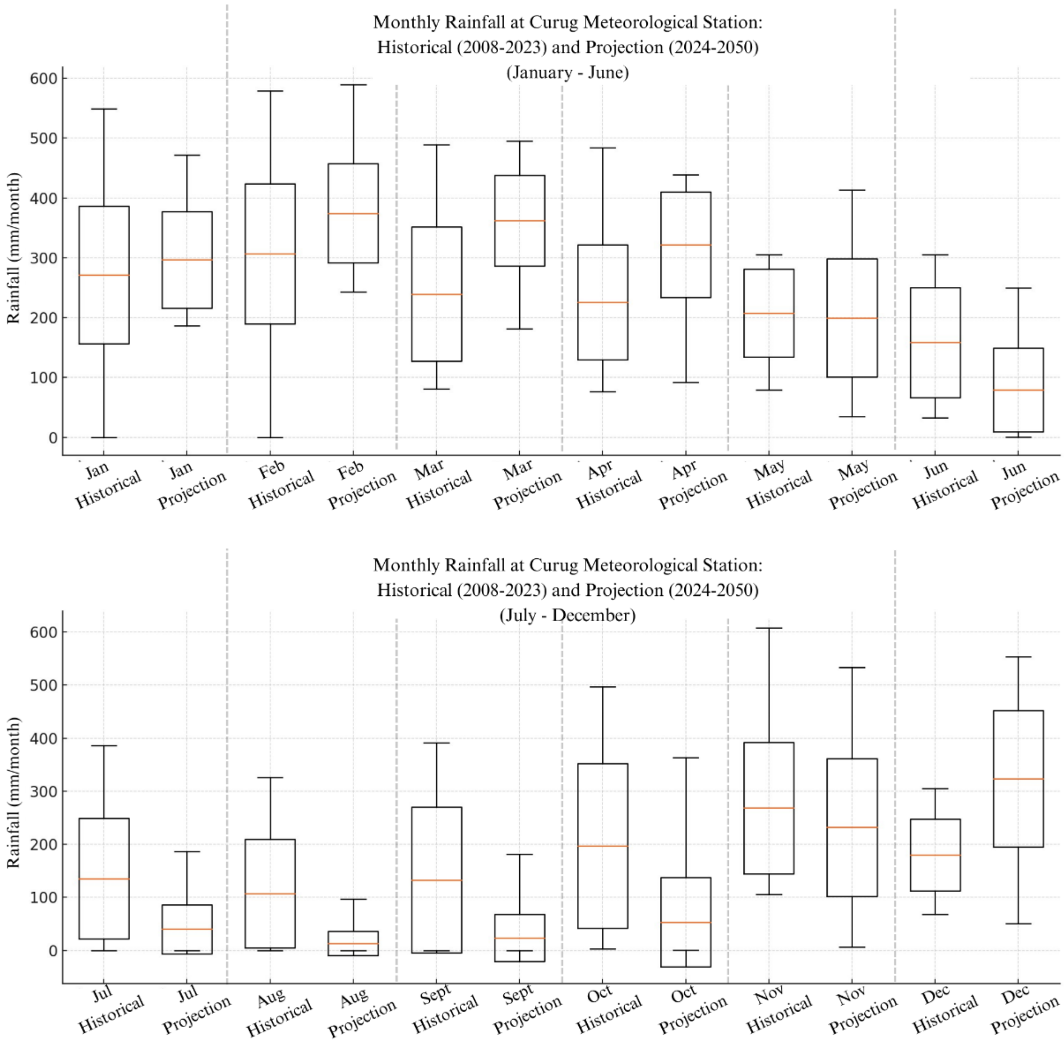


Figure 3. Historical and Projected Monthly Rainfall at Stamet Curug
(Source: Processed by the author, 2025)

Monthly rainfall in the area around Uptd Mauk rainfall station from 2008 to 2050 (Figure 4) shows that historically, the highest average monthly rainfall occurs in January, reaching 727 mm. The lowest rainfall intensity occurs in August at 51 mm/month. Anomalies in extreme rainfall events were recorded during the peak of the dry season, with monthly rainfall reaching 428 mm in July.

The monthly rainfall projection in Uptd Mauk area has the highest rainfall intensity at the peak of the rainy season (DJF), reaching 391 mm. Meanwhile, in the JJA period, the average rainfall tends to be low at 30 mm/month. The low rainfall intensity continues until the SON period, with an average rainfall of 70 mm/month.

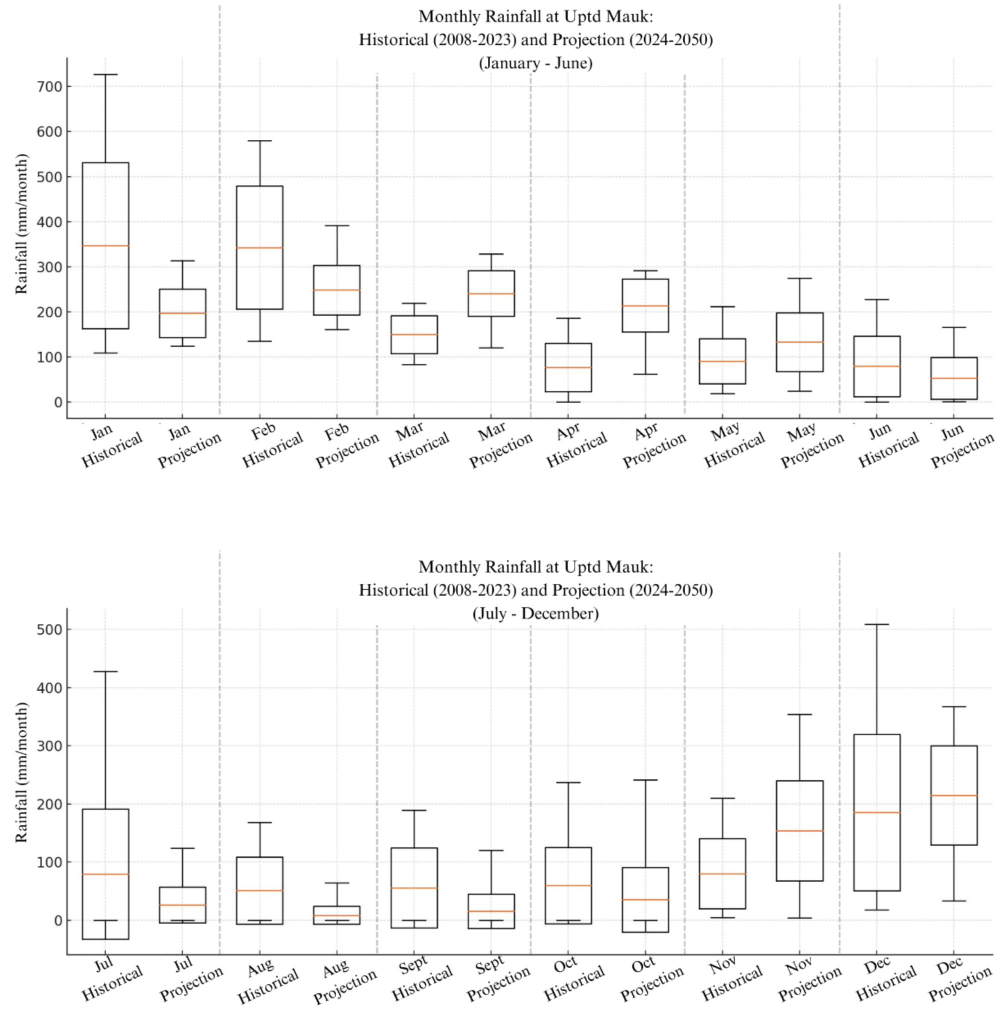


Figure 4. Historical and Projected Monthly Rainfall at Uptd Mauk
(Source: Processed by the author, 2025)

Rainfall patterns in the area around Uptd Sindangjaya (Figure 5) historically show that the rainy season lasts from November to March, with peak rainfall in February exceeding 700 mm/month. The MAM period has a high average monthly rainfall of 273 mm in May. This indicates a climate anomaly that prolongs the wet period and causes a shift in the onset of the dry season. The JJA period has an average rainfall of 71 mm/month.

The rainfall projection trend in Uptd Sindangjaya (Figure 5) shows that the DJF period has a rainfall intensity of 194 mm/month. High-intensity rainfall events were identified in the SON to DJF period with maximum monthly rainfall values for each period of 313 mm/month, and 345 mm/month. This illustrates the early shift in the rainy season, as one of the signs of climate change on a local scale.

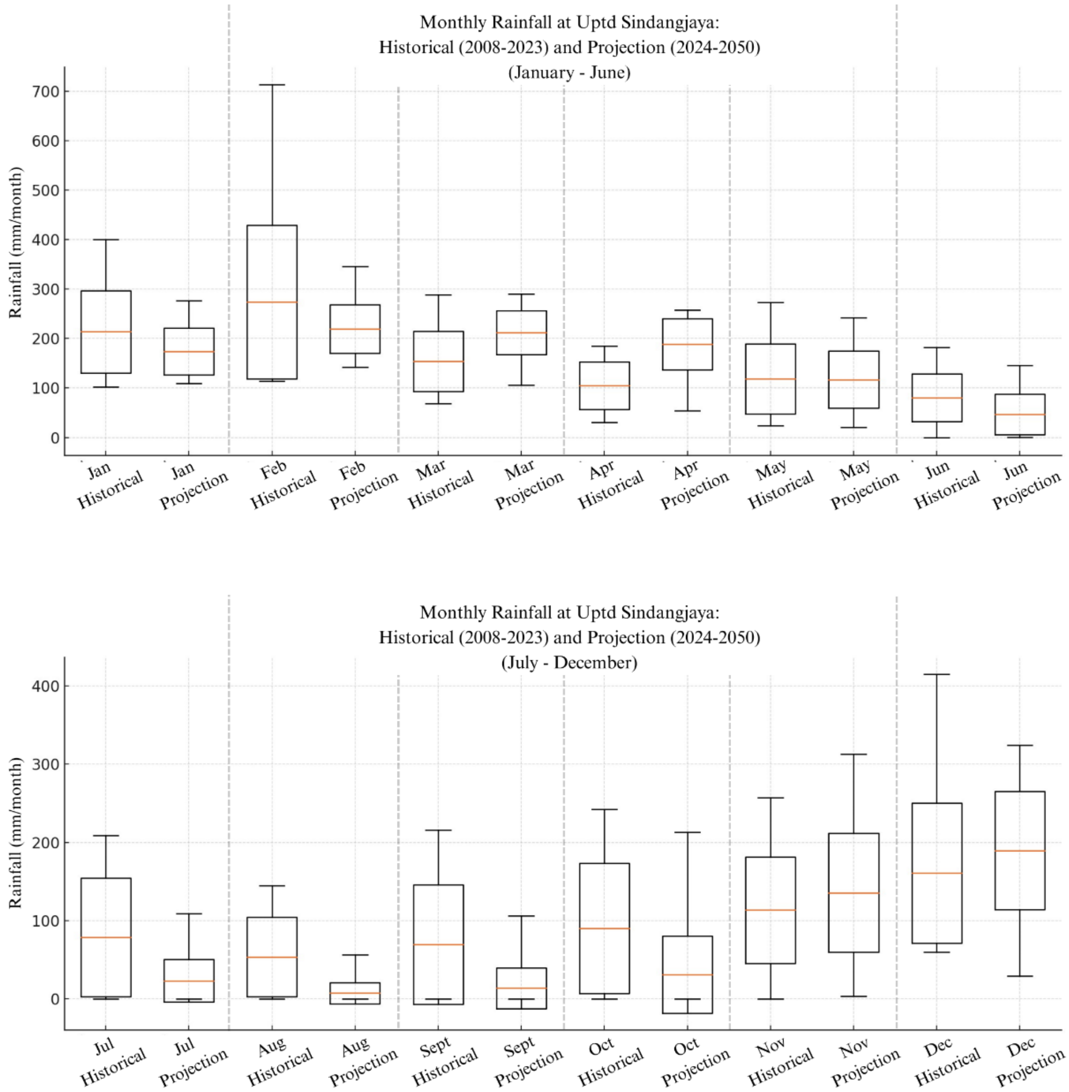


Figure 5. Historical and Projected Monthly Rainfall at Uptd Sindangjaya
(Source: Processed by the author, 2025)

The pattern of monthly rainfall distribution around the BPP Kp Melayu Timur - Teluk Naga area (Figure 6) shows that during the historical peak of the rainy season (DJF), the average rainfall was 284 mm/month. Extreme rainfall anomalies were identified in January with an intensity of 1032 mm/month, while the JJA period recorded rainfall of 640 mm/month. In addition, there were seven random years where rainfall in December had a value of <100 mm/month, which is close to the rainfall characteristics of the dry season.

The monthly rainfall projection trend at the BPP Kp Melayu Timur – Teluk Naga shows that extreme rainfall events were identified in the DJF period, such as in 2032, with an intensity of 438 mm/month. The transitional month of MAM and SON show high average rainfall, with 367 mm/month and 396 mm/month, respectively. This indicates a shift in rainfall patterns (the beginning and end of the rainy season).

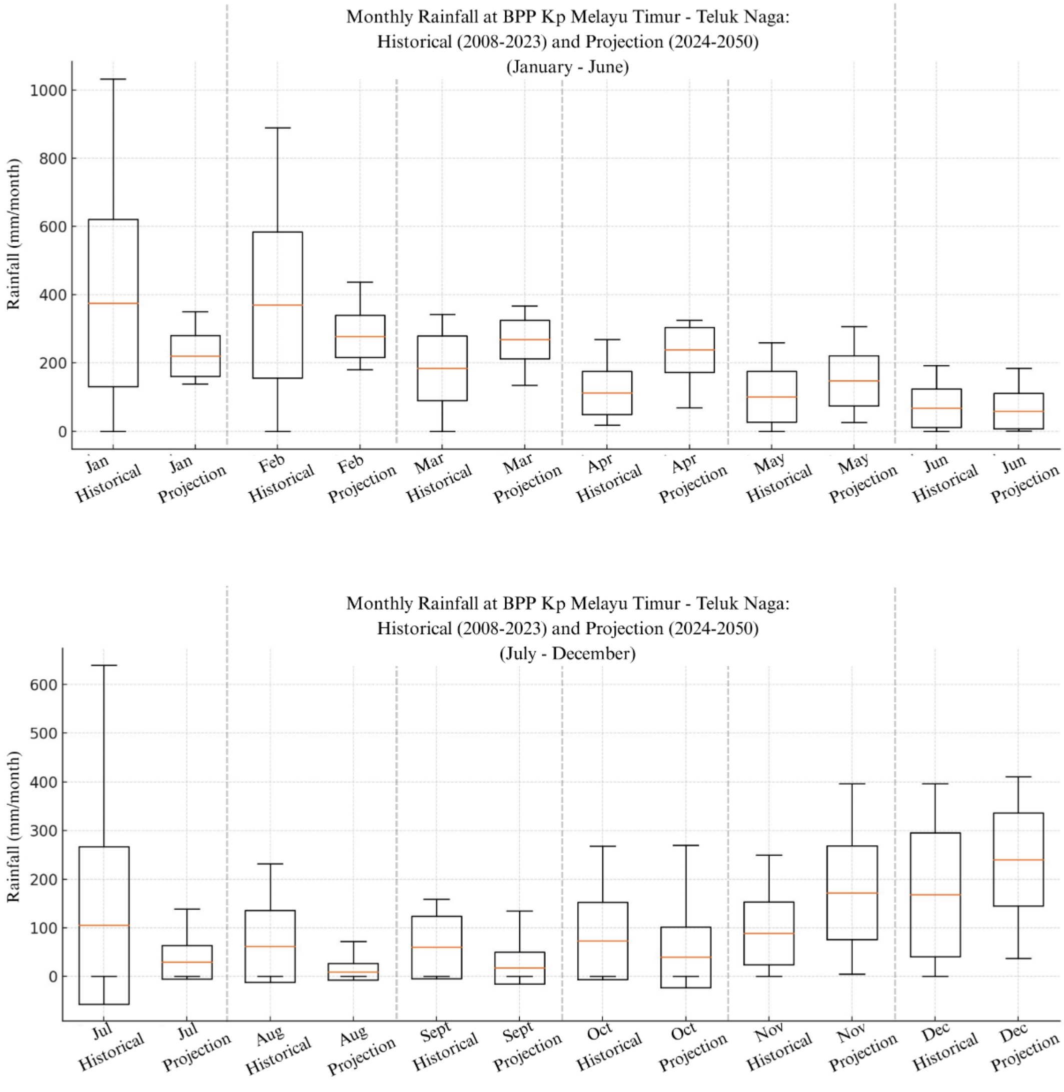
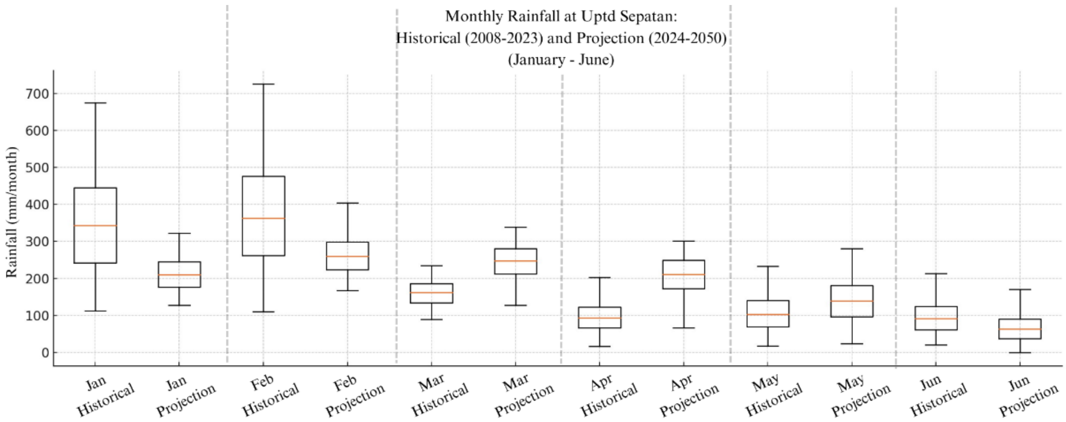


Figure 6. Historical and Projected Monthly Rainfall at BPP Kp Melayu Timur-Teluk Naga

(Source: Processed by the author, 2025)

Monthly rainfall at the Uptd Sepatan (Figure 7) historically shows that February has the highest monthly rainfall, reaching 732 mm/month. The dry season is quite long in the middle of the year, from April to October, with the lowest average monthly rainfall occurring in August, at 49 mm/month. During the JJA period, rainfall intensity reached 483 mm/month.

Rainfall projection trends around the Uptd Sepatan rainfall station show an average rainfall during the peak rainy season of 226 mm/month. In 2032, extreme rainfall is projected to occur, marked by monthly rainfall intensity in the DJF period reaching 405 mm/month. Meanwhile, the JJA period has a relatively low average rainfall of 31 mm/month.



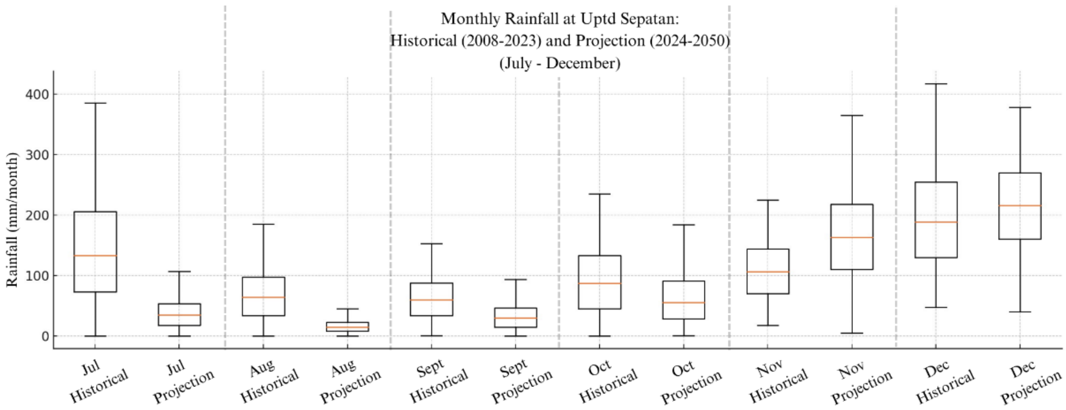


Figure 7. Historical and Projected Monthly Rainfall at Uptd Sepatan
(Source: Processed by the author, 2025)

Based on Figure 8, historically, the area surrounding BPP Caringin has been identified as extreme rainfall in April (MAM period), with monthly rainfall reaching 1095 mm. In May, the average monthly rainfall was 327 mm/month. While, the JJA period have a low average rainfall of 171 mm/month. However, during the dry season, there was an anomaly in July, which was recorded in three different years with monthly rainfall of more than 400 mm. In addition, August also recorded one of the years with monthly rainfall reaching 613 mm.

The results of rainfall projection trends for the 2024-2050 period in the area around BPP Caringin show that the peak rainfall does not always occur in the same month every year. From 2026 to 2050, for example, the peak rainfall did not occur in the DJF period but in the transitional months of MAM and SON. The highest rainfall intensity can reach 959 mm/month in the DJF period. The peak of the dry season (JJA), in several years, such as 2026, 2044, and 2045, shows rainfall anomalies with high intensity of >300 mm/month.

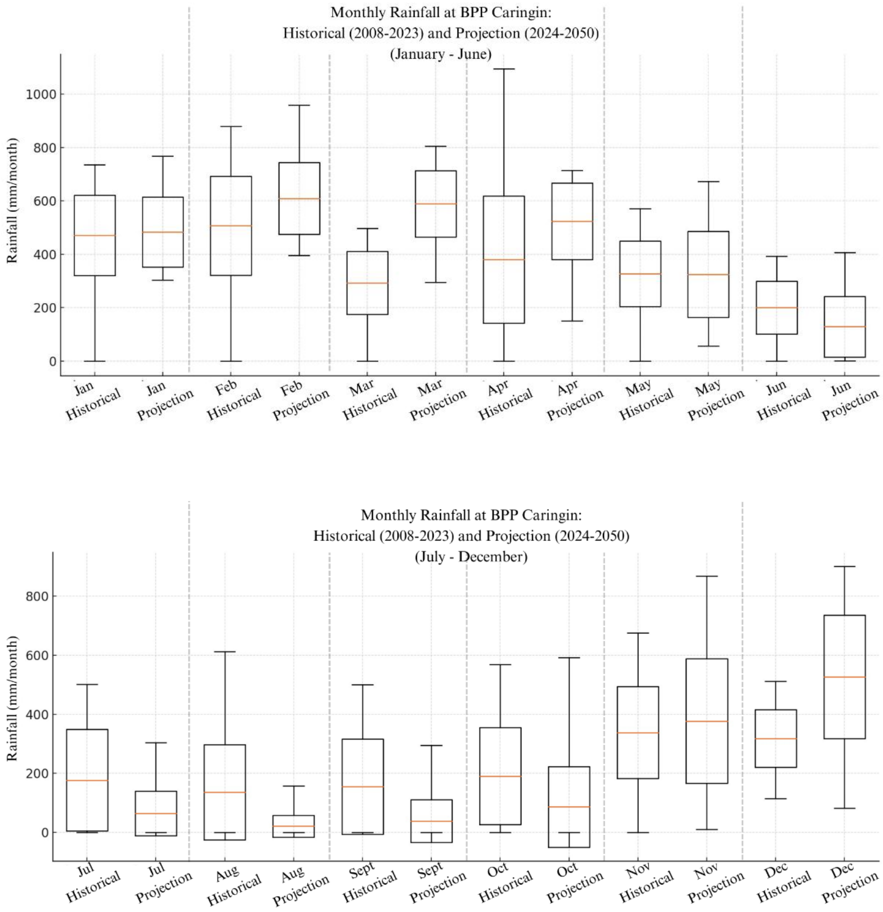


Figure 8. Historical and Projected Monthly Rainfall at BPP Caringin
(Source: Processed by the author, 2025)

C.2. DISCUSSION

Based on the analysis of monthly rainfall from the six rainfall stations that cover the Cirarab watershed, the Cirarab watershed has a monsoon climate type with one one rainy season peak occurring in the DJF months and a dry season peak marked by a decrease in rainfall intensity in the JJA months. Rainfall distribution in the Cirarab watershed shows temporal variation between months in line with the characteristics of a monsoon climate.

Rainfall variability causes temporal changes in rainfall patterns in the Cirarab watershed. Changes in rainfall patterns indicate a shift in the peak of the rainy season, which usually occurs in December, January, and February, to the following month. Based on observation data from rain stations in the upper and middle parts of the Cirarab watershed, the shift in the peak of the rainy season occurs until April–May. This shift in the rainy season indicates changes in atmospheric dynamics influenced by global phenomena, such as the El Niño-Southern Oscillation (ENSO) (Nizamani et al., 2025; Taschetto et al., 2020).

In 2010, there was a moderate to high rainfall anomaly at the peak of the dry season in the Cirarab watershed area. This phenomenon was in line with the strong La Nina in 2010, which contributed to increased rainfall in Indonesia (Agustiarini et al., 2022; Mulyaqin, 2020). Rainfall anomalies during the dry season can be caused by variations in sea surface temperature (SST) in the Pacific Ocean associated with the La Nina phenomenon, which is part of the ENSO phenomenon (Islam, 2025; Taschetto et al., 2020; Wibowo et al., 2024) .

The decline in rainfall occurred in 2015, lasting from June to October. This decline in rainfall indicated a disturbance in the atmospheric circulation system. Based on climatological data, it was known to coincide with the active phase of the El Nino phenomenon in that year (Yananto and Sibarani, 2016). The El Niño phenomenon caused a decrease in rainfall intensity in the Indonesian region (Arjasakusuma et al., 2025), which resulted in a decrease in monthly rainfall in the Cirarab watershed.

Spatially, rainfall intensity varies across regions due to various factors, such as evaporation sources, temperature differences, wind direction, elevation, and mountain ranges. The upper reaches of the Cirarab watershed tend to receive the highest rainfall, while the lower reaches receive less rainfall. In general, highland areas receive higher rainfall than lowland areas. However, lowland areas can also experience increased rainfall influenced by local factors, such as anthropogenic activities (urbanization), the presence of large bodies of water, sea breezes, and atmospheric dynamics, which can cause greater rainfall variability in lowlands (Bojago et al., 2024; Hussain et al., 2021;

Ruqoyah et al., 2023; Sahilu et al., 2024). Local factors, such as the distance of an area to sources of water evaporation (lakes and seas), will affect the intensity and frequency of rainfall in an area. If a place is closer to a source of evaporation, it will experience more frequent rainfall. This is because the water evaporation process is more intensive, resulting in more optimal cloud formation and increasing the chance of rain. Conversely, if an area is further away from the evaporation source, the water vapor is carried by the wind and undergoes dispersion and a decrease in water vapor accumulation, so that the process of rain cloud formation is not optimal and the frequency is lower (Ruqoyah et al., 2023). In the downstream section of the Cirarab watershed, there are different results, where coastal areas close to the coastline show higher rainfall intensity. This condition is influenced by local geographical factors close to the source of evaporation and reinforced by the presence of sea winds that carry water vapor to the mainland and create convergence of moist air, thereby increasing condensation into the atmosphere, which can increase the potential for rainfall in the downstream area (Dou et al., 2024; Mostamandi et al., 2022; Yang et al., 2024).

Overall, the rainfall projection results in the Cirarab watershed until 2050 show spatial variations in rainfall in the watershed. The increase in rainfall intensity is influenced by climate variability, such as global atmospheric circulation patterns (e.g., ENSO), and local factors such as topography, land use change, and urbanization, which can alter local rainfall patterns (Tong et al., 2024).

The reliability of the projection results using the EC-Earth3-Veg-LR model from CMIP6 is reinforced by an in-depth statistical evaluation conducted by the in Southeast Asia (Pimonsree et al., 2023). The study used comprehensive performance metric evaluations, including Root Mean Square Error (RMSE) and Correlation Coefficient, which showed that the EC-Earth3-Veg-LR model is effective in representing and simulating regional rainfall in Southeast Asia. Therefore, this model can be implemented on a local scale to describe spatial variations in rainfall until 2050.

Based on projections in the Cirarab watershed, there will be spatial variations in rainfall in the upper, middle, and lower parts of the watershed until 2050. The upper region is projected to receive the highest rainfall until 2050, with peak monthly rainfall intensity reaching more than 800 mm/month in the 2030s. Rainfall anomalies were also found in the upstream area, where at the peak of the dry season (JJA) it received relatively high rainfall reaching more than 300 mm/month in 2026 and the 2040s.

Rainfall in the central watershed area is projected to be relatively stable until

2050, with rainfall intensity around 100–400 mm/month. The generally gentle topography in the central watershed area plays a role in stabilizing rainfall distribution (Wu et al., 2024) and although increased rainfall is still possible, this area does not experience extreme rainfall spikes. In the 2030s, rainfall intensity during the rainy season is projected to be higher than normal, at 400-450 mm/month. This indicates that the central watershed area will continue to receive high rainfall, but the fluctuations will not be extreme.

The downstream area is projected to experience higher inter-monthly fluctuations, especially in coastal areas close to the coastline. This region is dominated by convective rainfall, which causes local and uneven rainfall distribution, so that rainfall intensity can vary between nearby observation stations. One observation station may record high rainfall, while other stations in the vicinity do not record similar rainfall .

Rainfall projections in the Cirarab watershed show fluctuations between months. High monthly fluctuations indicate changes in rainfall patterns. These changes take the form of shifts in the timing of rainfall (the beginning and end of the rainy season), a shorter rainy season, and the concentration of rainfall accumulated in one or two specific months. However, the spatial variation in monthly rainfall between parts of the Cirarab watershed tends to be insignificant. This is because the topography of the watershed is predominantly flat (Figure 2), so there are no significant spatial differences in rainfall distribution (Al-Hussein et al., 2022; Gorjizade and Shahbazi, 2025). The relatively small variation in rainfall still shows spatial variation between locations, with the upstream area receiving more rainfall than the middle and downstream areas. Changes in rainfall patterns are the result of climate change, which affects the intensity, duration, and distribution of rainfall. Global climate change can trigger an increase in seasonal rainfall and the potential for flooding (Williams and King, 2020; Wu et al., 2024).

D. CONCLUSION

Climate change has caused a shift in rainfall patterns in the Cirarab watershed. Rainfall projections for 2025-2050 show an increase in rainfall during the transition months (March-April-May) with an average increase in monthly rainfall of 47-146 mm/month s compared to the historical period. The transition months (September-October-November) experienced a decrease in average monthly rainfall with a range of 30–90 mm/month. The average monthly rainfall at the peak of the dry season (June-July-August) decreased by 40–100 mm/month. At the peak of the rainy season (December-January-February), rainfall was relatively stable with an average change of around 3 mm/month, although there were spatial variations. The upstream area experienced an increase, the middle area tended to be stable, and in the downstream area of the watershed near the coastline, there was an increase in rainfall due to local factors. The rainfall pattern in the Cirarab watershed shows a concentration of rainfall in certain months and a shift in the beginning and end of the rainy season, thereby increasing the risk of flooding and drought during the dry season. This research is important as a basic step in planning strategies for climate change mitigation and adaptation in the Cirarab watershed.

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