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MODELLING RAINFALL VARIABILITY, TREND AND ANOMALY IN JHELUM RIVER BASIN, WESTERN HIMALAYA

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Abstract: This paper aims to analyze rainfall patterns and its trend in the Jhelum River Basin to determine the possible effects of climate change. The Jhelum River Basin lies in the Western Himalayas. These analyses were executed using rainfall data of the selected meteorological sites, i.e. Jhelum, Kotli, Murree, Muzaffarabad and Rawalakot meteorological stations. Alongside, the necessary statistical analysis was accomplished by using Addinsoft excel states i.e. ARIMA model. This research study focuses on rainfall trend detection and anomalies prediction. The analysis of temporal data for the period 1993-2022 demonstrated an increase in the annual rainfall variability, the shift toward more frequent extreme years both in terms of rainfall and drought conditions. The relative linear regression coefficient reveals that stations such as Kotli, Rawalakot and Murree had greater fluctuation showing increased unpredictability in the rainfall pattern, however more stable regions like Jhelum had lower variations. This implies that with increase in altitude or with variation in climates can be observed in the meteorological station of Murree. Using ARIMA model, the analysis express that the met station of Jhelum received greater quantity of rain such 1335 mm and 1232 mm respectively during the years 1997 and 2006. Similarly, the years-2009 and 2002 had a les amount of rain such as 543 and 532 mm showing comparatively greater variability. The anomalies were computed for Jhelum basin reveal the deviation of rainfall in all the met stations. Additionally, Kotli recorded the highest amount of rainfall i.e. 1504 mm during the year-1994. Likewise, Murree has great flux has been noted i.e. the years 2004 and 2015 confirmed relatively high annual rainfall i.e. 2417 mm and 2307 mm respectively. Moreover, Balakot station received comparatively greater total annual rain in 2004 i.e. 2316 mm. In case of Garhi Dupatta, great fluctuation was observed such as 1812 mm of rain in 1994. In terms of Rawalakot station during the period 2004-2022, there were noted high and low rainy spell. This research will help enhance knowledge on how climate change is impacting precipitation regimes in the Western Himalayas.

Keywords: Climate Change, Rainfall variability, Anomaly, ARIMA model, Jhelum Basin

1. INTRODUCTION

Generally, climate change is causing substantial changes to hydrologic processes and climatic conditions across the world with changes to increase frequency of extreme weather conditions based on continued warming (Dawood et al., 2021; Sui et al., 2024). In the context of climatic change, rainfall is greatly influenced and rainfall pattern becomes very unpredictable. For some areas, it can be extremely rainy and flood-prone, while for other areas it can be very dry and long intervals between rain (Pant et al., 2024; Barendrecht et al., 2024). Such changes provoke alterations in the water cycle affecting water supply and demand, with implications to aquatic ecosystems agriculture, water policies and management (Rosinska et al., 2024). Precipitation is influenced by climate change, and consequently there are high fluctuations in rainfall rates (Dawood et al., 2017; Feldman et al., 2024). Some areas have the probability of higher rainfall than others and higher frequency flooding than others have less rainfall or experiencing longer dry seasons compared to others (Dawood et al., 2018). Such changes affect water cycle and put pressure on water supply and demand, destabilizing ecosystems, agricultural production, water management systems, strategies. Knowledge of such dynamics is useful in preparing for future water problems (Mahto, 2024).

These changes involve shifts in both average climate and climatic variability for the frequency of climate extremes, although the processes involved are ambiguous in recent time (Taye & Dyer, 2024; Dawood & Shirazi, 2023). This investigation applies probability ratio in large-scale climate models to allocate variations in the characteristics of precipitating events due to either mean climate shifts or extreme climate fluctuations (Abbas et al., 2024; Arregocés et al., 2024; Dawood et al., 2020). Unfavorable changes in climatic conditions are expected to occur resulting in wet and dry-precipitation anomalies that change the precipitation-net primary productivity relationship from a linear one (Swai, 2024). There are thousands of publications on climate change for global, regional, and national contexts, yet few provide knowledge for local response to mitigation and adaptation (Khojasteh et al., 2024; Dawood and Rahman, 2017; Rosińska and Jurasz, 2024). This study aims to determine the trend in the climate change in the form of standardized precipitation and anomaly index (Arregoces et al., 2024). In recent decades, the spatial patterns and temporal dependence between rainfall and stream flow have turned to be non-stationary (Brunner and Gilleland, 2024). One method of evaluating the effects of climate variability on flow, especially in the relatively undeveloped catchments, is to compute the elasticity of stream flow with respect to precipitation (Ahmad et al., 2024).

2. STUDY AREA

Jhelum river basin (Western Himalaya) has approximately 34,775 sq. km area (Nadeem et al., 2024). The study area of the Jhelum River basin is situated in the western part of Himalayan region (Dawood et al., 2024; Bashir et al., 2024). Besides, Punjab is located with latitudes 32° 58’ 42// N to 35° 08’ 02// N and longitudes 73° 23’ 32” E to 75° 35’ 57// E (Rani and Chamber, 2024). The Jhelum River starts from the varying spring and it flows in NW from Wular Lake (Figure 1). Flowing through the Indian occupied Kashmir, the river enter in Azad Kashmir which is controlled by the Pakistan and continues in Punjab (Bose, 2024). The Jhelum River is developed on the high mountain peak of Himalayas and a productive place of Punjab, Pakistan. After measuring, the total length of the Jhelum River is about 725 Kilometers (Rahman et al., 2024). This region is made up of steep slopes, valleys and high mountains i.e. Nanga Parbat and K2. Today environmental threat such as, rising the temperature, changing in the precipitation pattern and other are evident in this region (Kalvoda & Novotna, 2024).

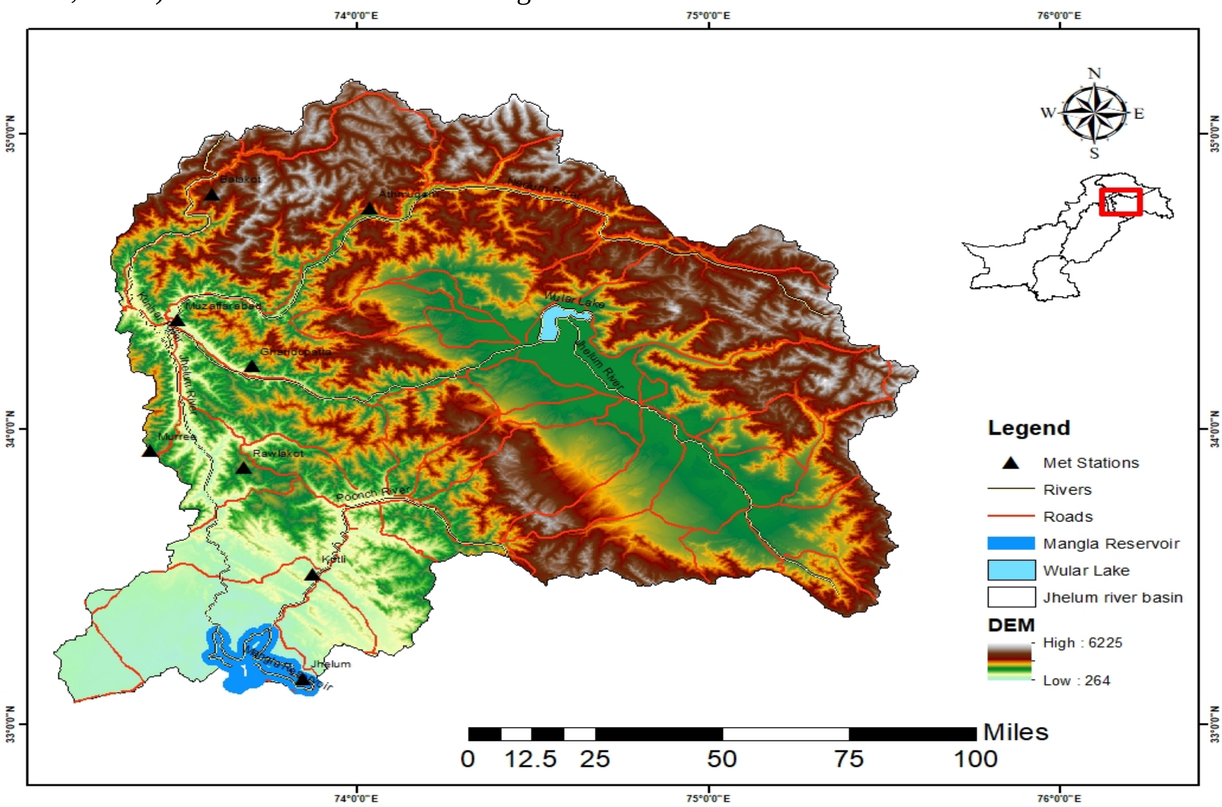

Figure 1. DEM of the study area

3. MATERIALS AND METHODS

This research examines variations, trends and anomalies in the scenario of precipitation extremes within the Western Himalayas, focusing on the Jhelum River Basin and key meteorological stations like Balakot, Garhi Dupatta, Jhelum, Kotli, Murree, Muzaffarabad, Rawalakot and Authmuqam. Precipitation is essential to study the climatology and stream flow of the study area. In this paper, ARIMA model (PDQ 1, 0, 0) applied in order to analyze rainfall fluctuation and trends with particular emphasis to changes in the amount of rainfall during winter and summer. Using SSE estimator, it assesses the consistency in precipitation in these stations, improving understanding of climate variability impacts and for water resource planning. Analysis brings into focus the collective aspects of extremes, trends and anomalies of precipitation with special reference to climatic change and water resources in Jhelum River Basin, the Western Himalayas. The well-known met stations are Jhelum, Kotli, Murree, Muzaffarabad, Rawalakot and Authmuqam. Moreover, precipitation is crucial for understanding the climate and stream flow in the study region. The study employs the ARIMA model to assess the rainfall variability and trend, and at the same time, to emphasize changes in winter and summer precipitation. Utilizing SSE estimator, it analyzes the stability of precipitation pattern across these stations, enhancing insights into climate change impacts and informing water management strategies.

This study highlights the importance of knowledge about climatic extremes, trends and anomalies regarding precipitation, climatic change and water resource management in the Jhelum River Basin (Western Himalayas). In the current research study, Kriging interpolation applied to measure daily and average monthly rainfall along with spatial distribution at seven meteorological stations whose precipitation differential is critical in evaluating climate effects on water supply. The long-term trends were pointed to a higher winter extreme, particularly from November to April due to higher frequency and intensity of low precipitation trend. On the other hand, rise in temperature has adversely affected monsoonal rainfall during the summer season.

Climate of the region is greatly defined by rainfall pattern that falls in the Jhelum River Basin. Regarding mean annual rainfall, Murree is considered the most productive station where mean annual rainfall recorded is 1661.6 mm per annum, indicating its presence in a high rainfall area. Next to Rawalakot with 1,568.7 mm rainfall and Muzaffarabad with 1,450.7 mm besides receiving considerable amount of rainfall. The first two regions in between Balakot and Authmuqam received rainfall of 1423.9 mm and 1418.6 mm (Figure 2). The meteorological stations of Kotli and Garhi Dupatta confirmed little rainfall as compared to the other stations i.e. 1,367.3 mm and 1,188.3 mm respectively. Moreover, Jhelum station receives the lowest amount of rainfall at an average of 885.3 mm per year.

This distribution shows that precipitation was inconsistent among the different places. Furthermore, to determine which met stations is the hottest and the most humid. For this, additional information in terms of temperature and humidity would be required. These differences are the snow and rainfall at Jhelum River Basin highlight spatial variability in relation between topography, elevation and atmospheric circulation. Nevertheless, this pattern is not fixed and ultimately, global warming has great impact on the temporal distribution and rate of snow and rainfall in the Western Himalayan region. Some existing data suggest that the region has shifted from earlier snow and prolonged rainfall or increased intensity rainfall events. This trend has considerable implications for future water supply, flood and for the general sustainability of ecosystems and societies in the region.

Decrease in glacier volume and durability of water continuity due to climate changes has a potential to increase the number of glacial lake outburst floods (GLOF) affecting the downstream population. According to Balakot temperature record, January only receives 33.5 inches snow and February has 2 inches of snow, while the period of March to December documented no snow. However, Murree recorded higher winter snowfall in the month of January (464.2 inches), while 465.2 inches in verified in February, however the month of March documented 92 inches. Furthermore, Murree verified no rainfall from April to October and records 9.5 inches in November and 133 inches in December pointing toward high intensity. However, Muzaffarabad is comparatively moderate as it gets an average snow as low as 6.5 inches in January and no snow in the rest of the year.

3.1. Rainfall Variability

According to collected statistics, Murree leads with an average annual rainfall of 1,661.6 mm, making it the wettest among the studied cities. In contrast, Jhelum is the least fertile area, with an average annual rainfall of only 885 mm, and rank as the driest city with a significantly low figure of 383 mm (Figure 3). Regarding variability, both Murree and Muzaffarabad exhibit high fluctuations in

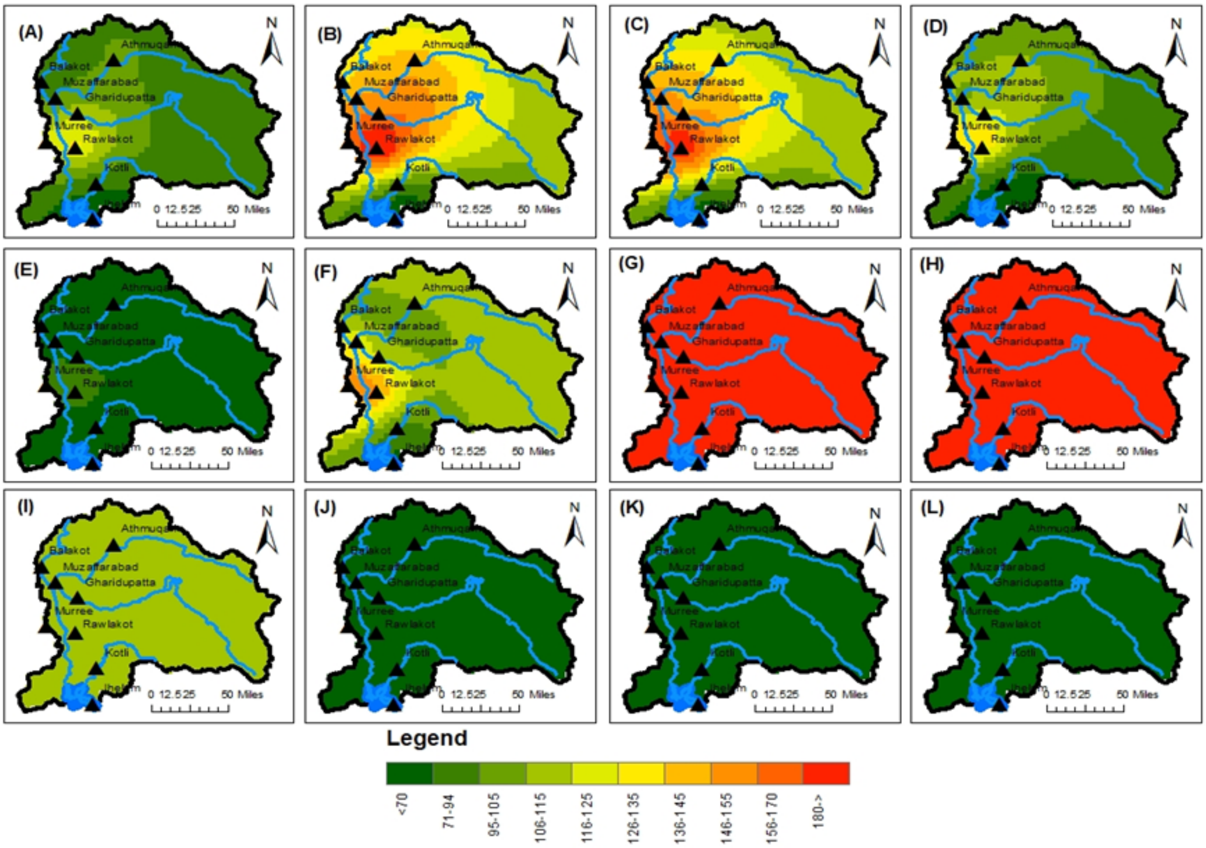

Figure 2. Spatial distribution of mean monthly rainfall in Jhelum river Basin.

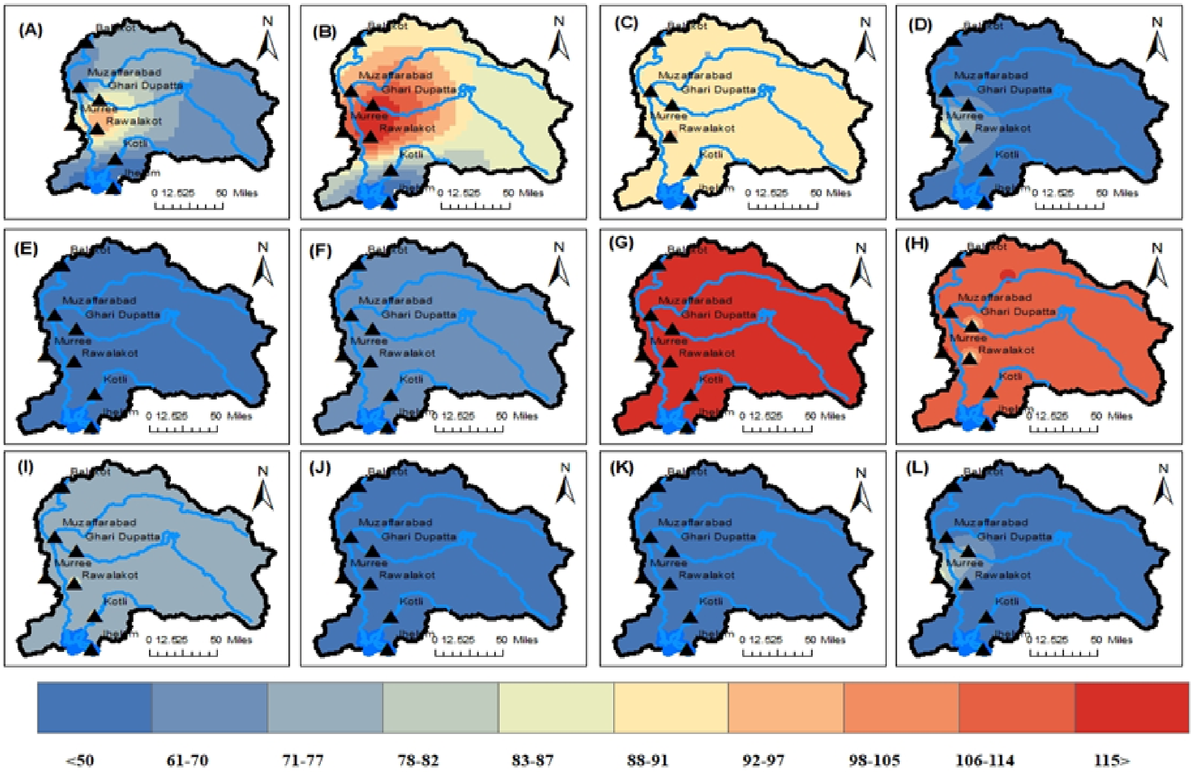

Figure 3. Standard deviation mean monthly of rainfall in the selected met stations.

precipitation, suggesting a potential for extremes over shorter periods. This indicates these regions may experience sharp increases in rainfall followed by noticeable decreases. Conversely, towns like Jhelum and Kotli show minimal annual variations in rainfall, reflecting a more consistent precipitation pattern. Thus, this analysis highlights the disparity in rainfall characteristics, underscoring Murree as the most humid city and Jhelum as the most arid, with the latter exhibiting less variability in comparison to others.

3.2. Standard Deviation for Mean Monthly Rainfall

This analysis presents mean monthly rainfall and standard deviation values from eight meteorological stations: Balakot, Garhi Dupatta, Jhelum, Kotli, Murree, Muzaffarabad, Rawalakot and Authmuqam (Figure 4). Every station provide monthly mean rainfall figures in millimeter for the twelve months of the calendar year. For instance, an average of 66.7 mm falls in Balakot in January, while 132.5 mm noted in July. Garhi Dupatta received the maximum rainfall in February i.e. 118.3 mm, whereas Jhelum receives the maximum rainfall in July such as 121.4 mm which highly supports the monsoon season. Similarly, the met station of Murree has a moderate precipitation throughout the year but significant precipitation in January 84.4 mm and March 104.3 mm not like other stations which contain typical monsoon period. Kotli has received an amount of 116 mm in July and Muzaffarabad 143.7 mm have equally been received in the same month of July. The figure shows highest rainfall received in March at Rawalakot having cumulative monsoon rainfall less than other stations of the region which makes it clear that in the regional level the monsoon varies. The stations, however records the highest rainfall of 130.8 mm in August attributed to monsoon season. This data relates to change in rainfall, which is important for studying the climate and its change, planning of agriculture and for the sake of water resource management. Mean monthly rainfall and standard deviation creates ideas about seasonal variation and measures the consistency of each station's rainfall.

Heterogeneity by location is evident when looking at the variability of annual rainfall by the standard deviation across meteorological stations. The standard deviation of Balakot is 22.3, which suggest a moderate amount of variability in rainfall and Garhi Dupatta with 19 developed the non-variability nature of rainfall. Out of all the stations, Jhelum recorded the least variation i.e. 14.4 mm indicating that the rainfall was equally distributed. Kotli city has also a moderate variation (20.6 mm). The standard deviation in Karachi is relatively not very high (8.7 mm) with a low mean annual rainfall of 166 mm which indicate that the city has a predictable pattern of rainfall. Out of the ten met stations, Murree and Rawalakot showed a comparatively higher deviation, which indicate a higher year to year variability. It is evident that

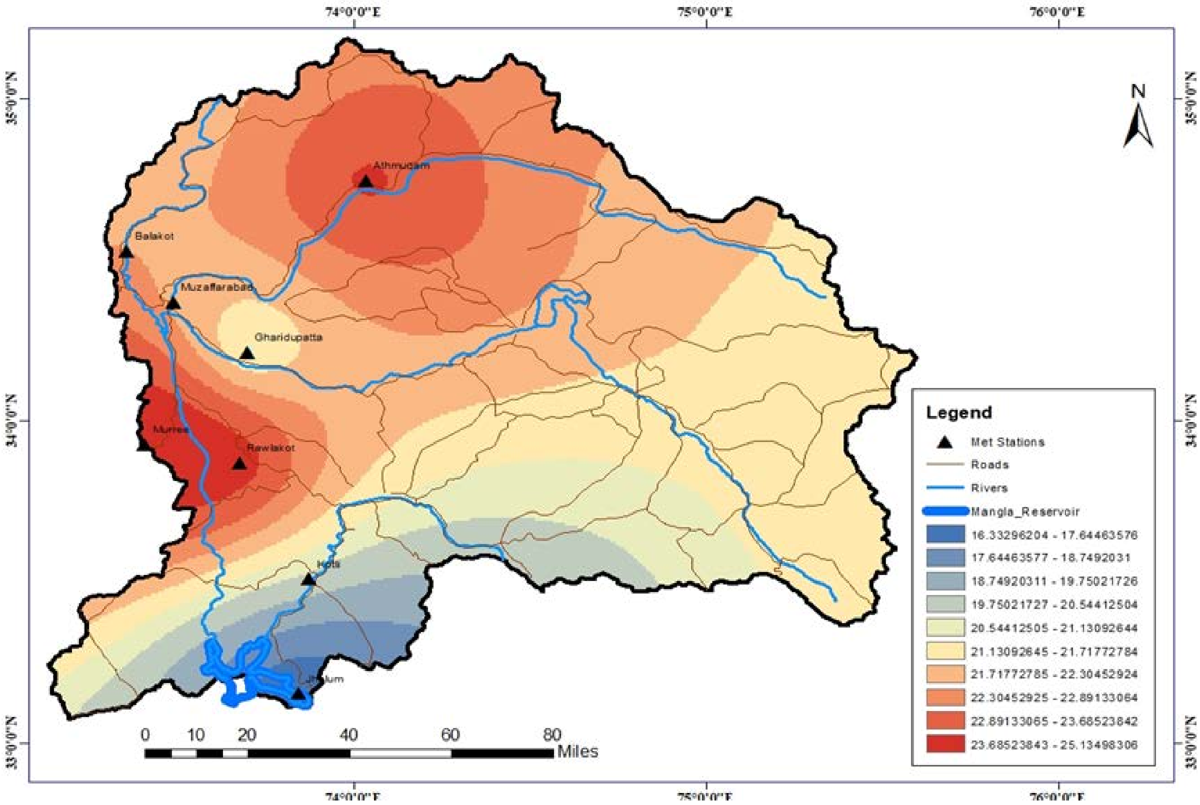

Figure 4. Standard deviation of mean annual rainfall in the selected met stations.

variability is also considerable in Muzaffarabad such as St. Dev 22 mm and Authmuqam with St. Dev 24.8 mm depending geographical and climatological factors. Thus, in terms of rainfall variability Murree and Rawalakot are opposite to the city of Jhelum.

3.3. Trend Analysis and ARIMA Model Applications

The analysis of rainfall data across various stations reveals notable changes over time. Trend analysis of Murree indicates a gradual increase in rainfall over recent decades, whereas Jhelum shows minor fluctuations and a slight upward trend in mean annual rainfall (Figure 5). The ARIMA PDQ model was applied to assess these trends and predict future rainfall, with Jhelum's rainfall fluctuating significantly from 1990 to 2020. The mean annual rainfall in Jhelum decreased from 1,031 mm (1994) to 702 mm (2003) with intermittent improvements but never returning to pre-1990 intensity. Predictions for 2020 to 2030 suggest stability with average annual rainfall around 1,000 mm but the external factors like climate change may influence the possible trend.

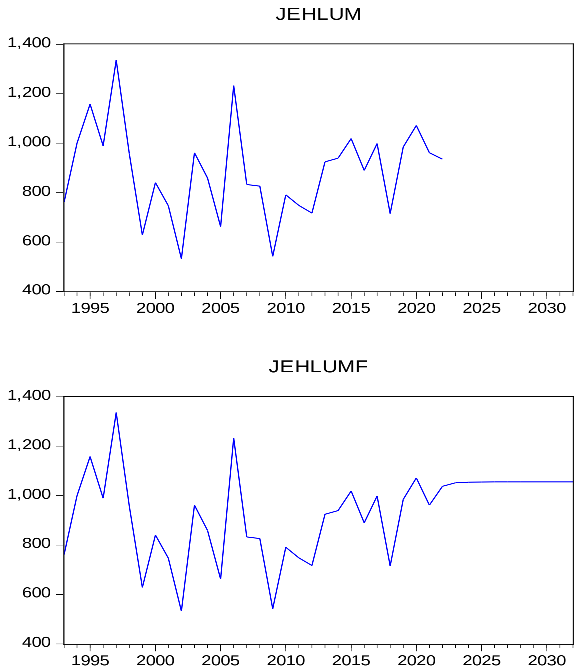

Figure 5. ARIMA of mean annual rainfall of Jhelum meteorological station.

Moreover, Kotli exhibit high variability, peaking above 1,600 mm in 2005 and 2015-2020 but falling below 800 mm during dry spells in the early 2000s and around 2010 (Figure 6).

The ARIMA model forecast a relatively constant rainfall of slightly below 1,200 mm for Kotli from 2020 to 2030, suggesting less fluctuation than in previous years, though this prediction comes with uncertainties due to broader climate fluctuations. The rainfall data regarding Murree from 1990 to 2020 also show variability, notably increasing in 2015 before declining in 2016. The Murree "F" model, based on ARIMA analysis, predict decreased annual rainfall in future that poses risks to water resources, agriculture and ecosystems. From 1990 to 2020, the rainfall in Murree peaked at around 2,000 mm in 2005 but

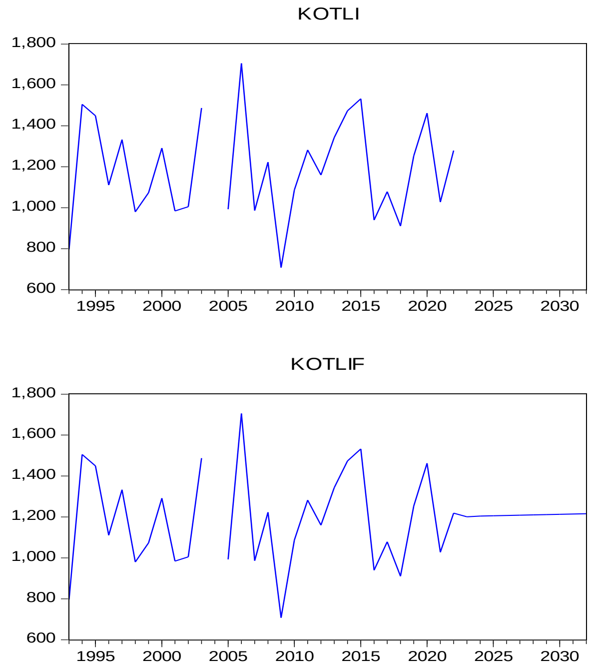

Figure 6. ARIMA of mean annual rainfall of Kotli meteorological station.

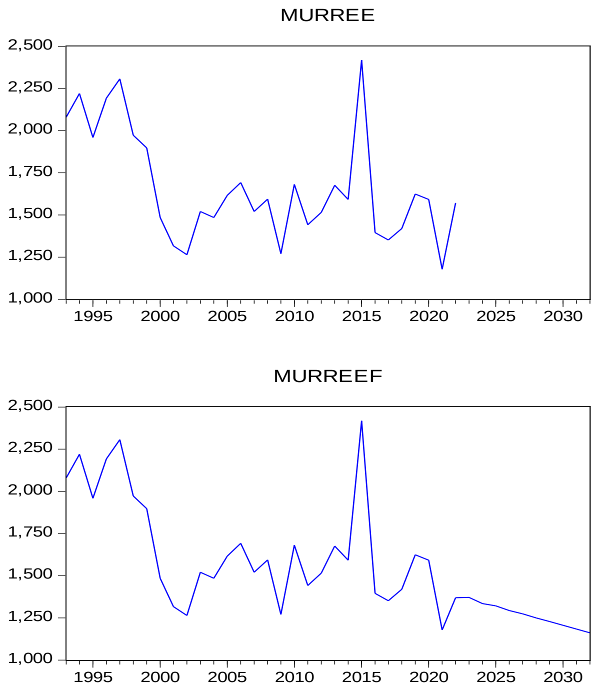

Figure 7. ARIMA of mean annual rainfall of Murree meteorological station.

stabilized near 1,200 mm by the year-2020 (Figure 7). Continuing this trend could signal challenges for Muzaffarabad, particularly in water and agriculture (Figure 8).

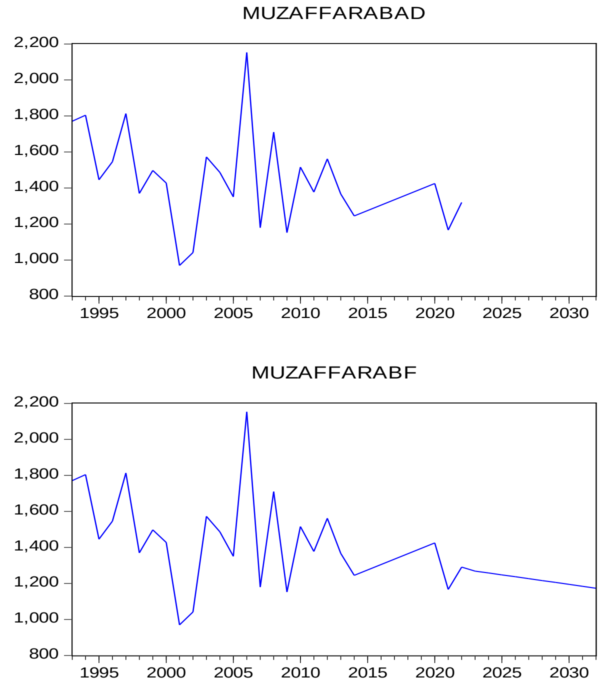

Figure 8. ARIMA of mean annual rainfall of Muzafarabad meteorological station.

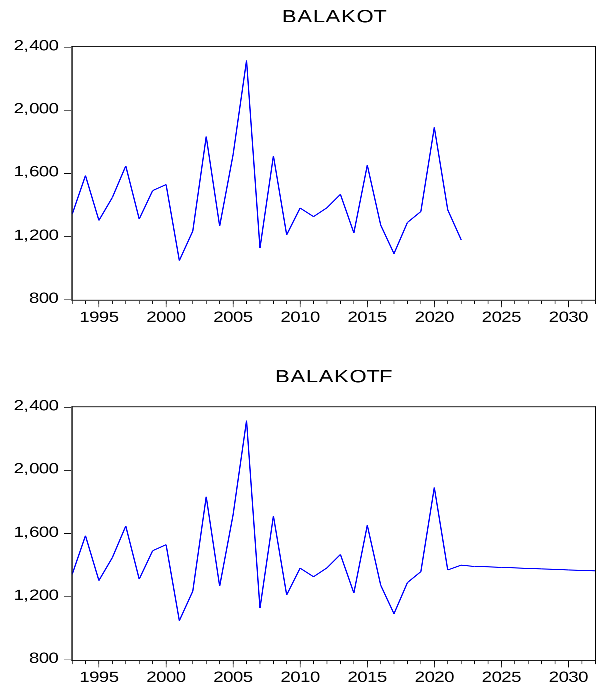

Figure 9. ARIMA of mean annual rainfall of Balakot meteorological station.

Balakot rainfall pattern indicate fluctuations, peaking around 2,200 mm before 2005 and showing potential stabilization at about 1,200 mm by 2030 (Figure 9). The ARIMA model forecast a gradual decrease in rainfall up to 2027, suggesting a shift from a volatile climate to a drier, more predictable one, impacting water availability for domestic and agricultural use. Overall, the analysis highlights significant fluctuations in rainfall across regions, highlighting the urgency for adaptive water management strategies to mitigate the effects of declining rainfall on vulnerable sectors like agriculture. Long-term planning is essential to address the anticipated impacts on water availability and the economy, emphasizing the critical need for sustainable practices.

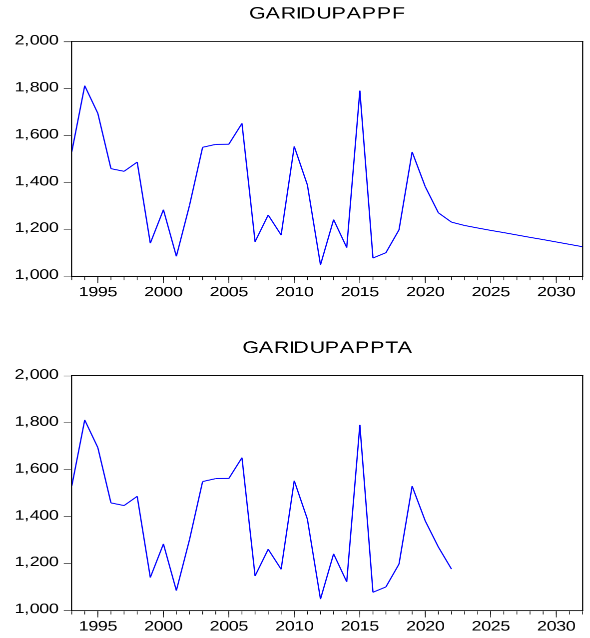

Figure 10. ARIMA of mean annual rainfall of Garhi Dupatta meteorological station.

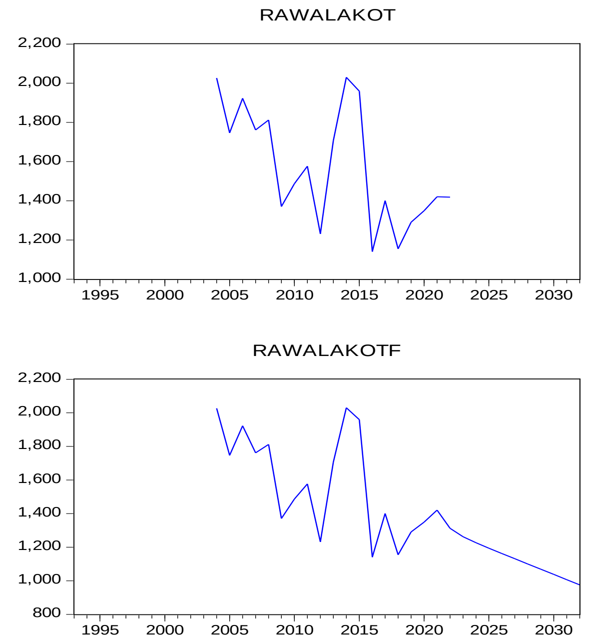

Figure 11. ARIMA of mean annual rainfall of Rawalakot meteorological station.

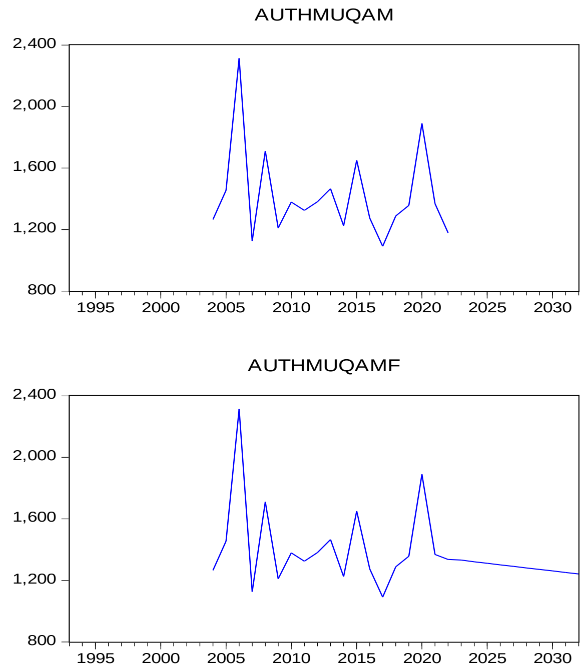

Figure 12. ARIMA of mean annual rainfall of Authmuqam meteorological station.

Forecasting trend and pattern of precipitation data at the meteorological station has been calculated using "F" label from the resultant analysis of ARIMA (Autoregressive Integrated Moving Average Model). This is shown by the plotted lines of the following graphs which show a real past precipitation trend over the previous years. Such conclusions help predict changes in future precipitation patterns and contribute to the management of water resources. Moreover, Garhi Dupatta (Figure 10), Rawalakot (Figure 11) and Authmuqam (Figure 12) shows fluctuation.

3.4. Trend Analysis and ARIMA Model Applications

The evidences concerning climate change are shown by increasing quantity of rainfall anomaly with higher fluctuation in Jhelum (Figure 13), Kotli (Figure 14), Murree (Figure 15) and Muzaffarabad (Figure 16). Rawalakot, Authmuqam, Garhi Dupatta and. Balakot (Figure 17) and Rawalakot (Figure 19) experienced heavy rainy phases both in the 2005 and 2013 and dried up in the 2008 and 2015. It shows that improved water management and climate change mitigation should be implemented soon. Contribution rates that were considerable in the year 2006 and 2020 for moisture provide high rainfall and less possible rainfall in the year-2007 and 2009. Garhi Dupatta (Figure 18) and Authmuqam (Figure 20) experienced more rain than the neighboring districts express great variability indicating that the area is vulnerable to both flood and drought situation. Similarly, at Jhelum,

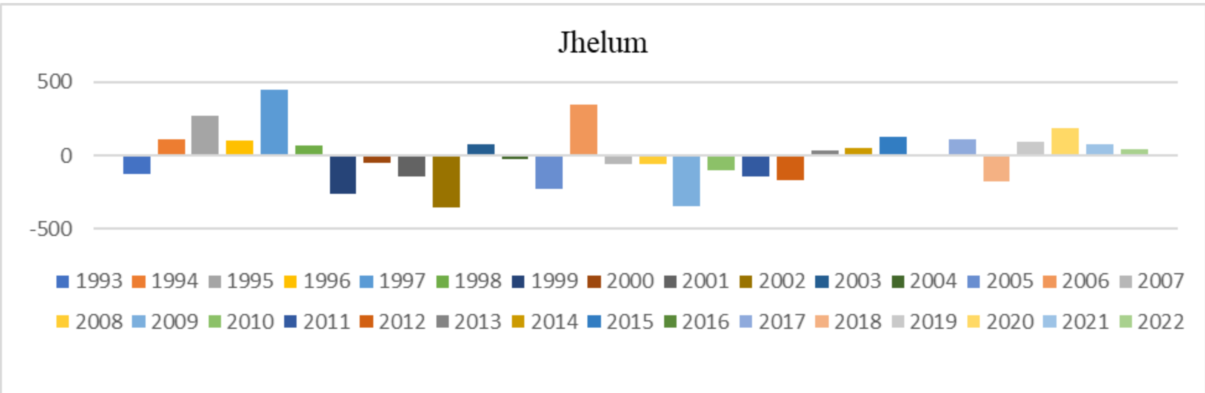

Figure 13. Anomaly of mean annual rainfall of Jhelum meteorological station.

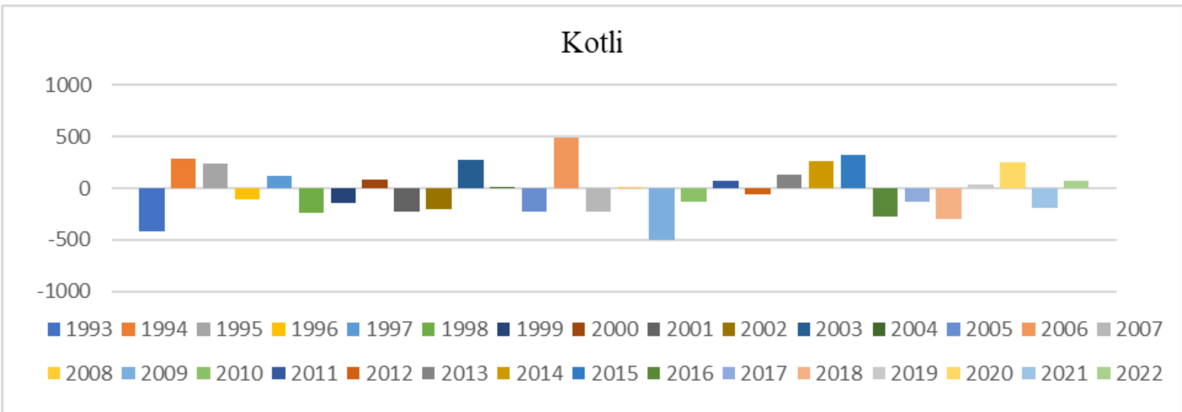

Figure 14. Anomaly of mean annual rainfall of Kotli meteorological station.

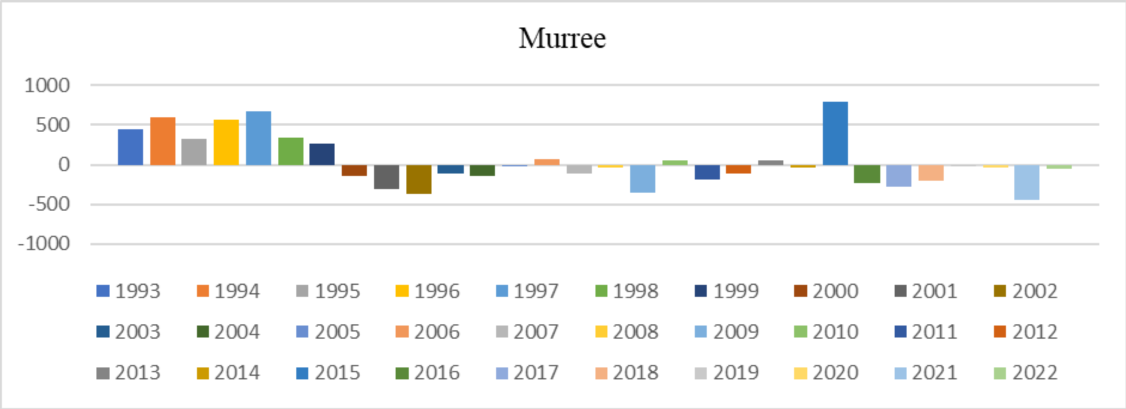

Figure 15. Anomaly of mean annual rainfall of Murree meteorological station.

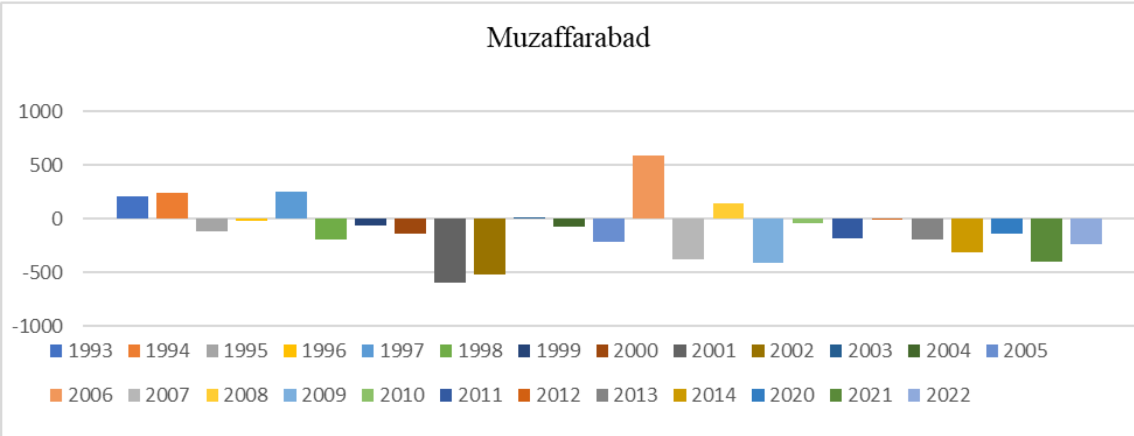

Figure 16. Anomaly of mean annual rainfall of Muzaffarabad meteorological station.

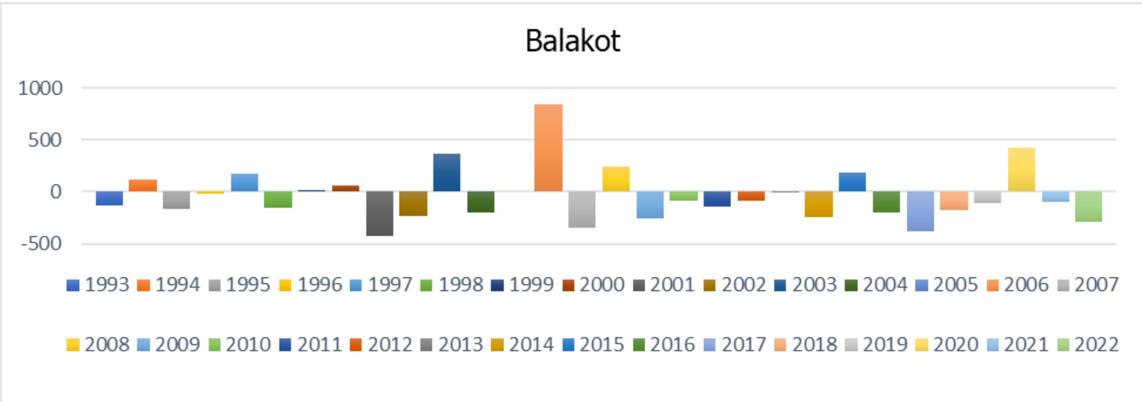

Figure 17. Anomaly of mean annual rainfall of Balakot meteorological station.

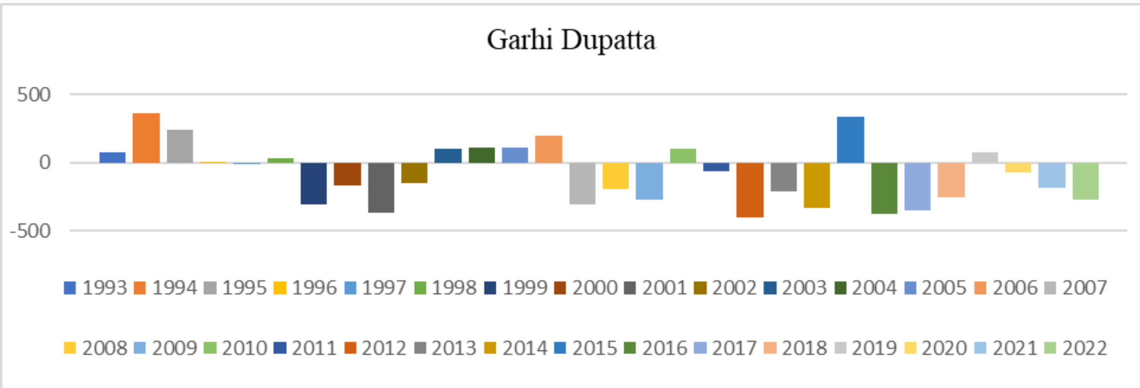

Figure 18. Anomaly of mean annual rainfall of Garhi Dupatta meteorological station.

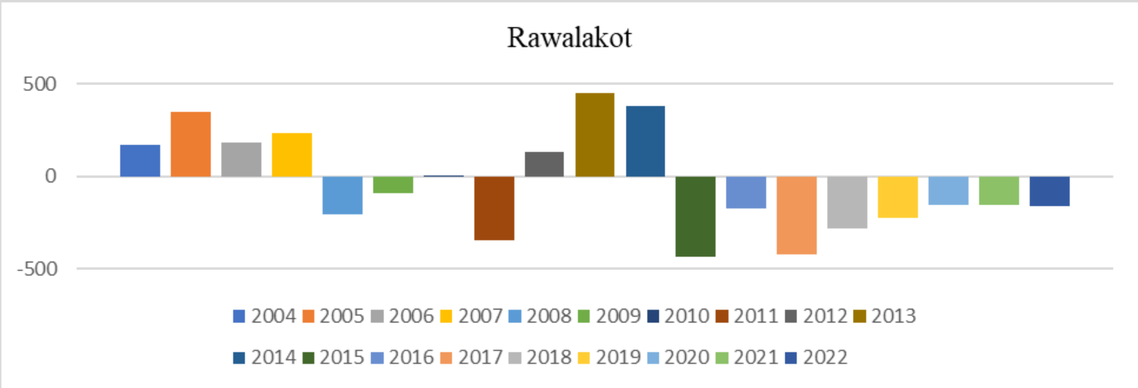

Figure 19. Anomaly of mean annual rainfall of Rawalakot meteorological station.

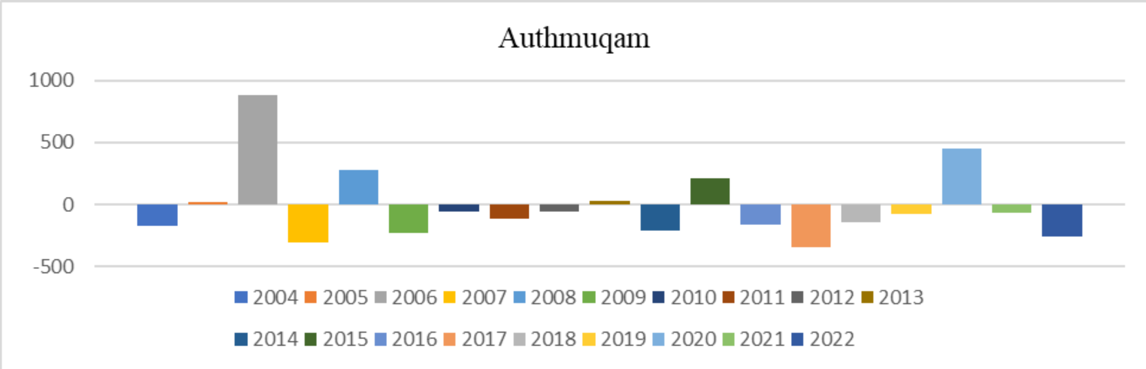

Figure 20. Anomaly of mean annual rainfall of Authmuqam meteorological station.

the highest positive rainfall anomaly verified in 1997 followed by the year 2006, while the lowest positive anomaly noted 2010. The rainfall in Muzaffarabad still continues to follow the sharp intra annual variability of wet and dry years. They reaffirm the structural realities which require policies in water, agriculture and infrastructure due to climate change.

4. CONCLUSION

The analyzed rainfall variability, anomaly and modeling by using ARIMA model across the stations including Jhelum, Kotli, Murree, Muzaffarabad, Balakot, Garhi Dupatta, Rawalakot and Authmuqam. In Jhelum, the year-1997 and 2006 expressed highest rainfall values for Jhelum. Likewise, Kotli registered high value of rainfall in 1994. Even though Murree has a reputation for higher amount of rainfall. Balakot range of values of rainfall was experienced between 2316 mm (2004) to 1127 mm (2013). This support the hypothesis that the regional degree of rainfall variability is increasing. The pattern was similar in Rawalakot and Authmuqam. The study further reveal that these areas are likely to experience even worse fluctuations in both wet and dry seasons as a result of climatic change at world level. The fluctuation in the seasonality pattern observed is also in agreement with the current global dynamic systems where a rise in temperatures is closely related to unpredictable weather, including rainfall trend. It causes the issues of water management, agriculture we need for our environment and development. Heavy rainfall results in increased floods, soil erosion and structural blindness. Low levels of precipitation on the other hand contribute to deepened risk in drought situation that has implications for the availability of water and agricultural produce. These patterns make the regions more vulnerable to climate-related disasters. As conclusion, the governments and communities need to follow proper water management systems and develop the techniques for agriculture as well as the development of necessary infrastructure. The statistics presented indicate that tremendous shifts in climate are already occurring and some action must be taken. If these were solved, climate change effects can be minimized and efforts towards a sustainable future in the region can be enhanced.

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