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Precipitation Assessment of Kabul City from 2006-2020

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Abstract

Assessment of precipitation conditions is a crucial factor in determining an area's current and future climatic conditions. This study investigates precipitation conditions in Kabul City from 2006 to 2020, covering the last 15 years. Research shows that 50% of precipitation occurs in the winter season in Kabul and varies from year to year. The trend line of precipitation has shown a minimal increase of 0.64mm/yr, which is insufficient due to the dense urban population's high-temperature increase and daily water usage. The study aims to assess the precipitation conditions in Kabul for the past 15 years. For this purpose, climatic data from the Afghanistan Meteorological Department (AMD) and daily precipitation data were analyzed. Standard deviation equations were applied to determine the dry and wet years from the average (normal) year. The analysis of the precipitation data demonstrated two periods of severe droughts and one moderate rainy period. The first severe drought occurred from 2007 to 2008, the second period of severe drought occurred from 2016 to 2018, and one moderate rainy period occurred from 2011 to 2014. The results indicate that Kabul City's precipitation is not enough due to the usage of groundwater by the dense urban population, car wash companies, public baths, and the recent establishment of too many greenhouses in the suburbs of Kabul City.

Consequently, the water balance is negative, leading to a shortage. Understanding the precipitation condition of Kabul City and its trends over the past 15 years is crucial for policymakers and stakeholders when making decisions on water resources management, agriculture, food production, and environmental challenges incorporation projects. This research provides valuable information that can support evidence-based decision-making to address the challenges posed by the changing climate patterns in Afghanistan.

Keywords: *Kabul city, Precipitation, Drought, Rainfall Anomaly, Trend line, Annual Average.*

Introduction

Afghanistan is landlocked in the desert world belt [1], with an annual precipitation of 256mm in arid and semi-arid climate regions. Most of its rainfall occurs in the fall and winter as snow between November and April, with peaks in February and March. Since 1960, mean rainfall over Afghanistan has slightly decreased at an average rate of 0.5mm per month or 2% per decade. This decrease is mainly due to a 2.7mm per month, 6.6% per decade decrease in spring rainfall, with a slight increase in summer and autumn [2].

Afghanistan is the most vulnerable to climate change and was ranked 175th out of 182 countries in the 2020 ND-GAIN Index [3]. This means that Afghanistan is the eighth most vulnerable country to climate change despite having no role in the emission of greenhouse gases (GHG) and paying the highest cost.

Precipitation is one of the climatic parameters that determine the type of climate and weather in a region. It regulates people's lifestyles, food, and habitation and creates a specific biome for all animals and plants. Climate change has impacted the weather in Afghanistan, with increased temperatures and decreased precipitation. Projections suggest that by 2100, the country will generally experience drier conditions, and precipitation during March, April, and May could decrease by 10-40 mm [4]. Some studies show that precipitation has not significantly changed throughout Afghanistan. However, it varies from season to season, with spring precipitation significantly decreasing and winter precipitation slightly increasing [5]. Although much research has been conducted on climate change in Afghanistan, none has specifically focused on a regional scale. This paper evaluates the precipitation conditions of Kabul city over the past fifteen years, from 2006 to 2020.

Precipitation, the most valuable factor, will determine the future of a region's climate, weather, agriculture, and water resource conditions, so it is more necessary to understand the recent precipitation conditions, even projections to make and implement policy accordingly in the study area. The questions are as follows: What were the precipitation conditions of Kabul city in the past fifteen years? Does the precipitation trend line show an increase, decrease, or constant? During the study period, which years were normal, above the normal (wet), and below the normal (drought)? To answer these questions, the study aims to evaluate the recent past precipitation conditions, trends, and percentages to determine the wet and dry years over the study time.

Study Area

Kabul City is the capital and largest city of Afghanistan, located in the central part of Afghanistan, with a population of 4627304 in 2021 [6], with an area of 1023 km2. It is surrounded by the Paghman series mountain in the west, Qurough Mountain in the south, Sher Darwaza, Asmaie, and Ali Abad Mountains in the centre and north of the city. Koh-e Asmai, or "Asamayi Mountain," is located in the middle of the city. It is one of the most prominent landmarks of Kabul, rising to a height of approximately 2200 meters above sea level. It is situated east of the city centre, separating the neighbourhoods of Shar-e-Naw and Wazir Akbar Khan. Koh-e Asmai has a significant impact on Kabul's weather patterns. The mountain acts as a barrier to the prevailing westerly winds that bring moisture from the Mediterranean and other regions to the west. This results in a

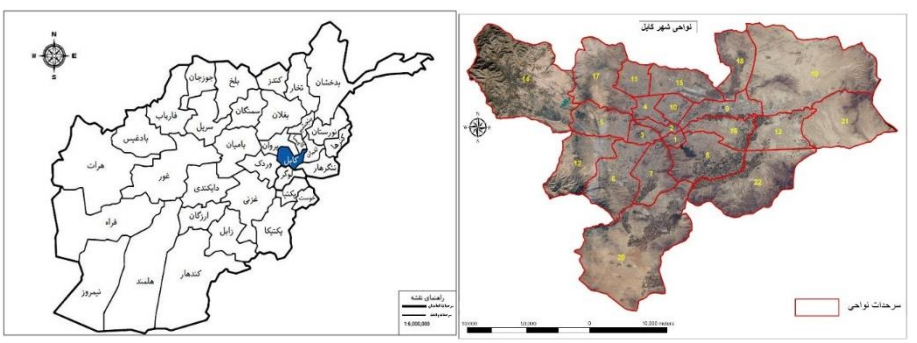

Figure 1: Study area, Kabul city topographic district map. **Source:** Author

semi-arid climate in Kabul, with hot summers and cold winters.
Kabul is situated at an altitude of 1,800 m above sea level in a narrow valley between mountains. The city is connected to Kandahar, Herat, and Mazar-e-Sharif via a circular highway that stretches across the country. It is also the starting point of the main road to Jalalabad and further to Peshawar, Pakistan.
The Kabul Province is surrounded by Logar-Wardak provinces to the southeast, Parwan and Kapisa to the north, and the Ningrahar and Laghman provinces to the west.
Kabul has a dry and semi-dry climate, and in winter, it receives precipitation in the form of snow. Summer, which lasts from May to August, is characterized by very low humidity, providing relief from the heat. Autumn is warm and dry, starting in September and ending in October. Winter is mildly cold, lasting from November to March. Spring in Kabul starts in March and is the wettest season of the year [7].

Data and Methodology

The precipitation data were collected from the Afghanistan Meteorological Department (AMD); at the beginning, a vast range of precipitation data from at least thirty years was needed to reveal a clear and reliable view of the past precipitation situation of the study area. However, due to the civil war and turmoil in Afghanistan, there were no consecutive records of precipitation data in the weather stations, or there were some missing observed data records, which made an error in analysis. After 2005, the Afghanistan Meteorological Department (AMD) recorded the precipitation data regularly and consecutively, and these data were used in this research.

Precipitation data was on daily records; daily rainfall was summed monthly and then totalled yearly for analysis. To determine the increase or decrease of precipitation, trend lines were plotted, and charts and graphs were drawn.

Linear regression equation formula is used to analyze the rate of changes in precipitation. Its general form is:

$$y=ax+b \qquad (1)\ [8]$$

In which (y) is the precipitation expressed in mm, (a) is the gradient, (x) is the time series, and (b) is the initial precipitation. The precipitation trend value correlates with the gradient. There are three possible scenarios: a) if the gradient is higher than zero – the trend is positive (growing); b) if the gradient is smaller than zero – the trend is negative (declining); c) if the gradient is equal to zero – there is no trend [9].

Standard deviation is a tool to calculate the dispersion of various data from its average and was used to measure the spread of precipitation data from its average in respective years [10] and determine the intensity of dry or rainy years in the study area, and its formula is as:

$$\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{N}}$$

Where

- σ is the standard deviation.
- X is the total amount of precipitation with respect to years.
- $\overline{X}$ is the average
- N is the number of years.

Result and Discussion

A region with equal or less than 400 mm/yr precipitation in years is arid. The annual average of precipitation in Kabul City is about 312.71 mm for the study period from 2006 to 2020, which indicates an arid climatic region. The total precipitation (snow + rain) was 4690 mm in the study year. Figure (2) shows a fluctuation of precipitation. The rainiest year was 2009, with 385.6 mm of precipitation (rain + snow), and the driest year was 2008, with 184.8 mm of precipitation (rain + snow).

Table 1. General Precipitation Information of Kabul City

Time span	15 years
Annual average	312.71 mm
Max precipitation	385.6 mm
Mini precipitation	184.8 mm
Total precipitation	4690.7 mm

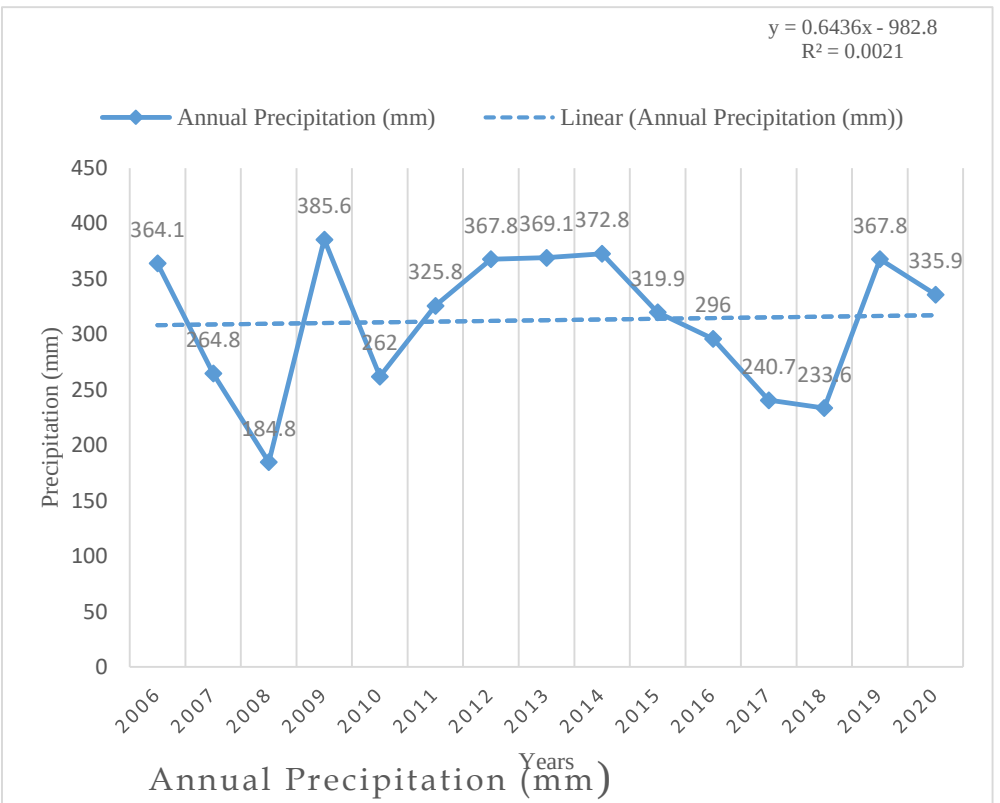

Figure 2: Annual Average Precipitation in Kabul City from 2006-2020

Analysis of the meteorological data has shown that precipitation fluctuates greatly from year to year. Figure (2) reveals that there was more precipitation in 2006 with 364.1 mm, 2009 with 364.1 mm, 2014 with 372.8 mm, 2013 with 369.1 mm, and 2012 with 367.8 mm, while in 2008 with 184.8 mm, 2018 with 233.6 mm, 2017 with 240.7 mm, and 2010 with 262 mm had less precipitation, while the annual average precipitation is 312.71 mm, max precipitation is 385.6 mm and mini precipitation is 184.8 mm. Additionally, Figure (2) indicates a slight positive trend, suggesting a small increase in precipitation in Kabul city from 2006 to 2020 at a rate of 0.6436 mm per year. However, the severity of dry years outweighs the rainy years, with an average of -65.72 mm less than the total average in dry years, while rainy years had an average of 42.82 mm above the total average precipitation.

$$y = ax + b$$

$$y = 0.6436 + 982.8$$

In the above equation, (a) is the gradient, which is equal to 0.6436 mm precipitation, is higher than zero and indicates a positive trend (growing) in precipitation. In contrast, this small increase in precipitation due to the high surface air temperature increase and accumulation of people in Kabul City made it ineffective.

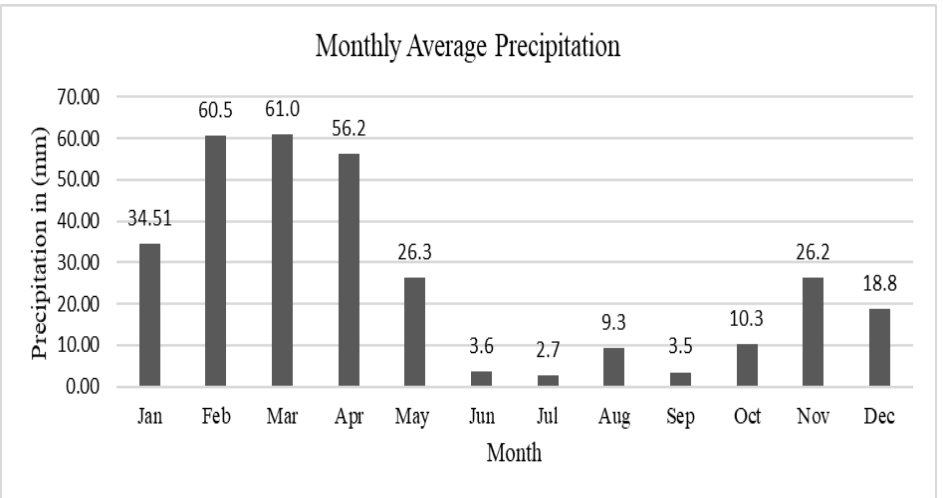

Figure 3: Monthly Average Precipitation from 2006-2020

As per Figure 2, the annual average of precipitation for Kabul City is 312.71mm, which provides a general idea of the typical amount of precipitation that Kabul City receives over the year. The maximum precipitation value of 385.6mm occurred during some years, while the minimum precipitation value of 184.8mm was recorded during another year. These values indicate the extremities of precipitation values for Kabul City. The figure-4 shows that the winter season, from December to March, has the highest average monthly precipitation, with February and March having the highest percentage of precipitation, at 19.32% (60.5mm) and 19.47% (61.0mm), respectively. From April to October, the precipitation decreases significantly, with June and July having the lowest percentage of precipitation, at 1.14% (3.6mm) and 0.86% (2.7mm), respectively. There is a slight increase in precipitation in November and May, with November having 8.37% (26.2mm) and May having 8.39% (26.3mm) of average monthly precipitation.

Overall, the chart shows that Kabul City has a high variation in monthly precipitation values, with the winter season being the wetter and the summer season relatively drier.

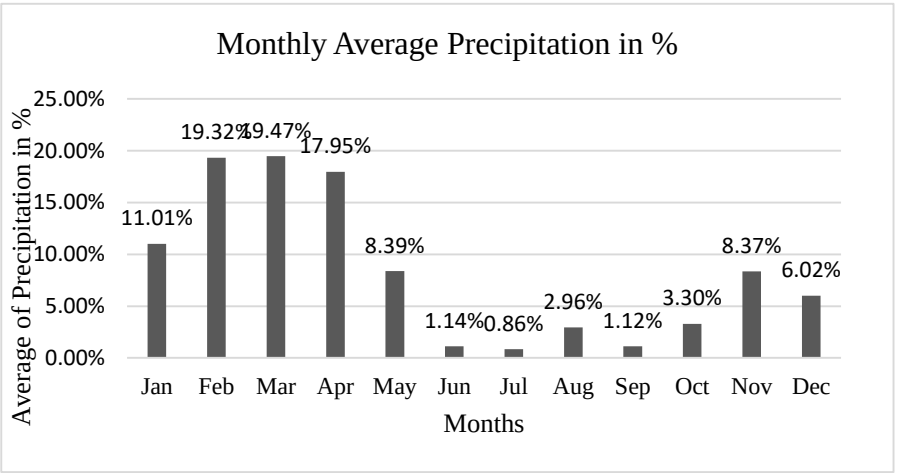

Figure 4: Monthly Average Precipitation in Percent from 2006-2020

An analysis of the figures 5 and 6 indicates that the winter season had the highest total precipitation, with an average of approximately 156mm and accounting for 50% of the total precipitation over the 15 years. Spring was the second-wettest season, with an average of approximately 86mm, accounting for 27% of the total precipitation.

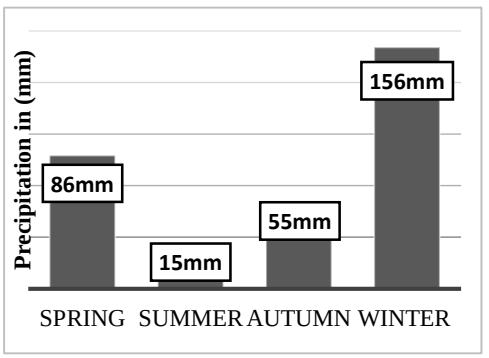

Figure 5: Seasonal Precipitation from 2006-2020

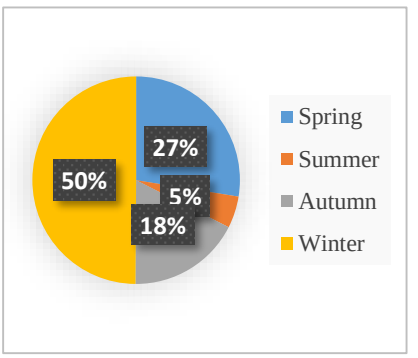

Figure 6: Seasonal Precipitation in percent from 2006-2020

Autumn was the third-wettest season, with an average of approximately 55mm, accounting for 18% of the total precipitation. Summer had the lowest amount of precipitation, with an average of approximately 15mm, accounting for only 5% of the total precipitation.

These findings indicate that, in general, most of the precipitation in Kabul city is concentrated during the winter and spring months, while summer and autumn receive much less precipitation. This seasonal precipitation pattern is typical of a westerly wave cyclonic system climate, which originates in the Mediterranean region and moves eastward across the Middle East and Iran. As the system approaches Afghanistan, it typically brings rainfall and snowfall to the region, particularly in the higher elevations of the Hindu Kush and Pamir mountain ranges. The Westerly Wave system is most active during the winter months, which is why winter typically receives the highest amount of precipitation in Kabul City and other parts of Afghanistan [12]. It is worth noting that

Figures 5 and 6 provide both numerical and percentage data for each season. The numerical data gives specific values for the average precipitation received during each season over the entire 15-year period, while the percentage values show the proportion of total precipitation that occurred during each season.

For more determination of precipitation conditions, dry and rainy years, a standard deviation formula was applied to distribute how far from the average, and the Figure below comes out.

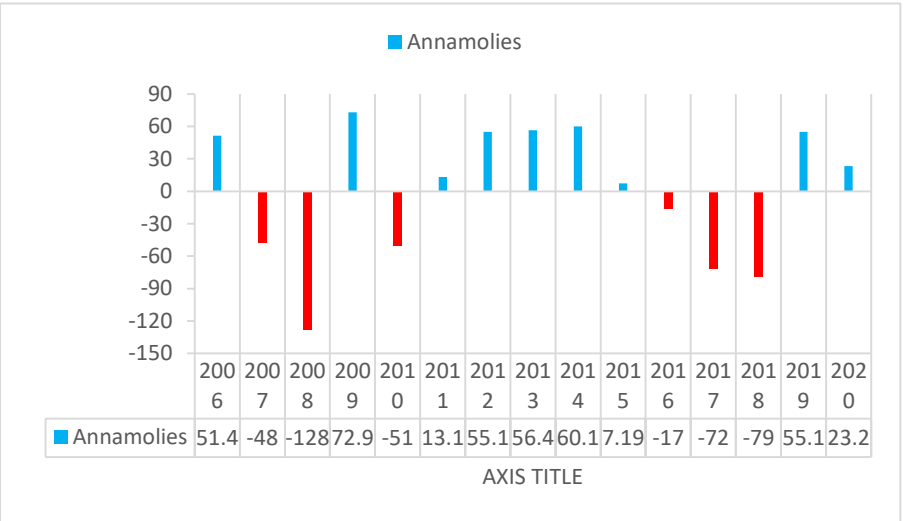

Figure 7: Wet and Dry years 2006-2020

Based on the standard deviation and anomaly values, the chart graph shows the precipitation conditions and dry/wet years from 2006 to 2020. The positive values represent years with above-average precipitation, while negative values represent below-average precipitation.

There were 9 years with positive anomalies, ranging from 7.19 mm to 72.89 mm above average, and 6 years with negative anomalies, varying from -16.7 mm to -128 mm below average. 2008 had the lowest precipitation, with an anomaly of -128 mm, while 2009 had the highest, with an anomaly of 72.89 mm.

The chart shows that rainy years were more frequent than dry years, but some years had severe droughts. The first period of dry years occurred between 2007 and 2008, and the second period of drought began in 2016 and lasted until 2018. The most intense rainy years were between 2013 and 2015, while the year 2020 had a moderate degree of precipitation.

Conclusion

This study aimed to assess the precipitation conditions in Kabul City from 2006-2020, determine the dry and wet years, and analyze the precipitation trends over the past 15 years. The findings indicate that during the winter, the anti-cyclone or cold front of Siberia is responsible for the precipitation in Afghanistan, including Kabul City. The precipitation season starts in autumn, peaks in winter, and ends in the spring season.

The rainfall anomaly analysis indicates three severe droughts in Kabul City, in 2008, 2017, and 2018, along with many normal and moderate years with a small increase above the average. As the largest and most populous city in Afghanistan, Kabul heavily relies on precipitation to recharge its groundwater surface due to the daily water usage of its population. Therefore, ensuring adequate precipitation is crucial to maintaining a sustainable water supply for the city.

Based on statistical analysis, the trend line for precipitation has shown a small increase; however, this increase in precipitation is not significant enough to cause an obvious change in the climatic conditions. The findings also indicate a significant change during droughts or below-normal periods, with a rate of -65.72 mm precipitation lower than normal. However, during rainy or above-normal periods, there were no significant changes in precipitation.

Statistical analysis showed that the precipitation seasons in Kabul City were during winter, with 50% of the precipitation occurring as snow. February and March had more than 40% of the precipitation, which mainly manifested as snowfall. On the other hand, June and July were the driest months, with less than 2% of precipitation, making summer the driest season in the city.

Afghanistan is the most vulnerable country to climate change impacts, ranking 175th out of 182 countries in the 2019 ND-GAIN Index. Given this vulnerability, climate parameters such as temperature and precipitation changes must be considered during decision-making and policy formulation for socio-economic development projects, including water resources management, agriculture, food production, and environmental incorporation challenges.

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