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INNOVATIVE TREND ANALYSIS PRECIPITATION, TEMPERATURES AND SPI DROUGHT INDEX OF LAHORE

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By

Hafiz Raziullah[1], Sohail Ali Naqvi[1], Masood Arshad[1], Muhammad Ahmad[1], Muhammad Imran Azam[1]

Abstract:

The rising of temperature and shifting precipitation patterns due to climate change are likely to intensify droughts throughout the world. The drought characteristics of possible future condition under climate change verify the past drought events using appropriate drought indices. This study investigates the impacts of climate change on precipitation patterns, temperature, and drought condition in Lahore, Pakistan, the standardized precipitation index (SPI) and precipitation pattern characterize historical droughts, precipitation trends and their impact on climate change in Lahore city. The results show significant changes in precipitation patterns, with a 12% increase in average annual rainfall, a 30-35% increase in extreme rainfall events (>100 mm/day), while average monsoon season rainfall has decreased by 25%. A shift in precipitation patterns, with more frequent and intense events in winter and pre-monsoon seasons. Additionally, temperature has risen by 1.5°C on average annually, with a 2.5°C increase in summer temperatures and a 1°C increase in winter temperatures. Drought frequency and severity have also increased by 20-25%, as measured by the Standardized Precipitation Index (SPI), with a notable increase in prolonged droughts (>6 months), values indicating moderate to severe droughts becoming more common (SPI -1.5 to -2.5)., and dry spells (>10 consecutive days without rainfall) have increased by 10%. These changes have significant implications for Lahore's water resources, agriculture, and urban infrastructure, and suggest that climate change is exacerbating precipitation variability, leading to more frequent and intense flooding and droughts. Therefore, this study highlights the need for adaptive measures to mitigate the impacts of climate change on precipitation patterns in Lahore and ensure sustainable water management and urban planning strategies.

Introduction:

Drought is a complex and recurring phenomenon that has detrimental impacts on agriculture, the economy, water supply, and ecosystems. It is

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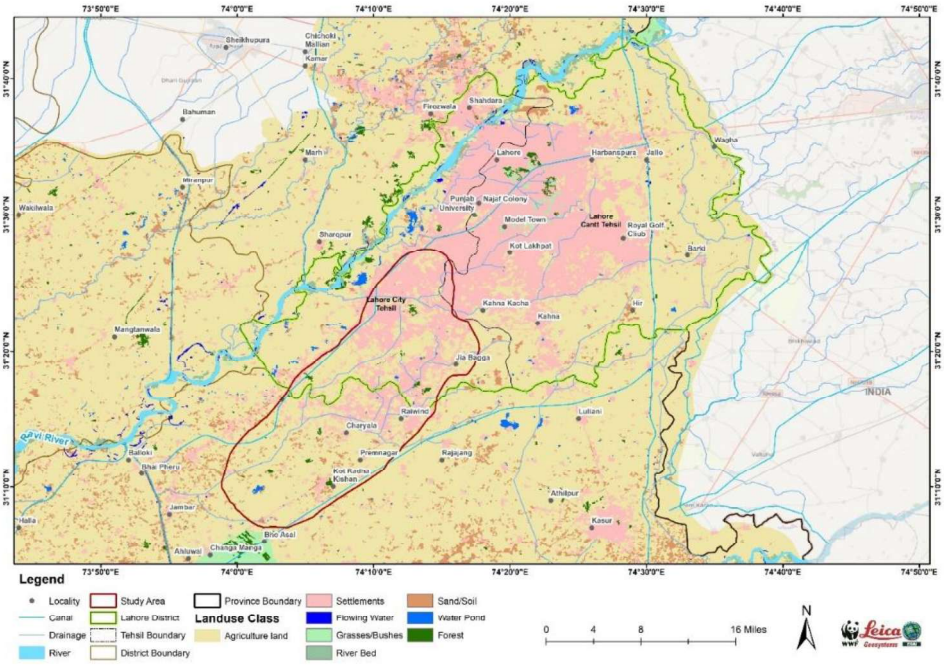
considered one of the least understood environmental disasters despite significant progress in hydrological sciences [1]. The definition of drought varies depending on the study's objectives and the concerned types of water usage. Unlike other natural hazards, such as floods, the onset and cessation of droughts are not clearly defined, making them more challenging to characterize [2,10]. The advent of global climate change is likely to further aggravate drought conditions, leading to severe consequences due to accelerated hydrological processes in landscapes [3,19]. Lahore, Pakistan, is one of the regions that have experienced significant changes in precipitation patterns and increased drought severity due to climate change. The increase in global temperature has altered the spatiotemporal pattern of drought events, which has been observed through various drought indices such as the Standardized Precipitation Index (SPI) [4,8,12]. SPI is widely used to assess drought severity because of its simplicity, ease of understanding, and comparability across different climates [5,9]. Droughts are generally classified into four categories: meteorological, hydrological, agricultural, and socioeconomic. The SPI is particularly useful in evaluating meteorological droughts by analyzing precipitation deficits over different timescales [6,11]. Lahore's climate is heavily influenced by the monsoon, and any changes in monsoon patterns significantly affect the region's water availability. This study focuses on analyzing the changes in annual and seasonal rainfall, extreme rainfall events, monsoon season rainfall, average temperatures, and the Standardized Precipitation Index (SPI) in Lahore to understand the impacts of climate change on drought conditions. Previous studies have shown an increase in both rainfall and temperature over Pakistan in the last 70 years, with more severe and frequent extreme events, such as droughts and floods, due to global warming [7]. The effects of climate change on drought characteristics in Lahore are crucial for policymakers and water managers to develop effective adaptation strategies.

Material and methods:

Study area;

Lahore is located in the northeastern part of Pakistan, near the border with India. It is the capital city of the Punjab province and serves as one of the country's major cultural, economic, and political centers. The city is situated at approximately 31.5497° N latitude and 74.3436° E longitude (Figure-1). As of the most recent estimates, Lahore has a population of over 14 million people, making it the second-largest city in Pakistan. The city covers an area of approximately 1,772 square kilometers (684 square miles). Lahore is part of the alluvial plains of the Punjab region. The city is relatively flat,

with an average elevation of about 217 meters (712 feet) above sea level. The Ravi River flows on the northern side of the city, though it has shifted its course over the years and no longer flows through the city center. Lahore is surrounded by several important cities and towns. To the west lies Sheikhupura, while Kasur is to the south. To the east, across the border in India, lies the city of Amritsar. Other nearby cities include Gujranwala to the northwest and Faisalabad further west (Figure-2). Lahore experiences a semi-arid climate, characterized by extremely hot summers, mild winters, and a distinct monsoon season. The summer months, from May to September, are hot and humid, with average daytime temperatures ranging from 30°C to 45°C (86°F to 113°F). June is typically the hottest month. The winter season, from December to February, is mild, with average temperatures ranging from 5°C to 20°C (41°F to 68°F). January is the coldest month. The monsoon season occurs from July to September, bringing the majority of the annual rainfall. Lahore receives an average annual precipitation of approximately 600 to 800 millimeters (24 to 31 inches). The rainfall is highly concentrated in the monsoon season, with July and August being the wettest months. Outside the monsoon season, rainfall is sparse and inconsistent. This combination of geographical and climatic characteristics makes Lahore a vibrant and historically significant city, though it faces challenges related to urbanization and climate change.



(Figure-1), Showing the boundary of Lahore city-Pakistan

Standardized precipitation Index (SPI):

The Standardized Precipitation Index (SPI) is a widely used tool for assessing and monitoring drought conditions. Developed in the early 1990s by T.B. McKee, N.J. Doesken, and J. Kleist, the SPI offers a statistical method to determine the degree of drought or wetness by measuring the deviation of precipitation over a specific time period relative to a long-term average [4,8,12] shown in (Table-1). The index is valuable due to its flexibility and simplicity, making it a preferred choice for various hydrological and climatological studies. The SPI is based on the probability of observed precipitation occurring at a given time scale (e.g., 1 month, 3 months, 6 months, etc.) compared to historical precipitation data. The SPI is calculated by taking the difference between the observed precipitation and the long-term mean for a specified period, then dividing this difference by the standard deviation of the long-term data. The result is a normalized index, where positive SPI values indicate wetter than average conditions, and negative values indicate drier than average conditions [9,5]. The SPI is designed to quantify precipitation deficits or surpluses over various time scales, ranging from 1 month to 24 months or more. This allows for the assessment of both short-term and long-term droughts.

SPI Value Range	Category
SPI > 2.0	Extremely wet
1.5 < SPI ≤ 2.0	Very wet
1.0 < SPI ≤ 1.5	Moderately wet
-1.0 ≤ SPI ≤ 1.0	Near normal
-1.5 ≤ SPI < -1.0	Moderately dry
-2.0 ≤ SPI < -1.5	Severely dry
-SPI < -2.0	Extremely dry

Table-1: showing the SPI values range, on the base of that categories the condition of wet or dry.

This table provides a clear and concise way to interpret the SPI values in relation to drought and wetness conditions. These categories help in defining the intensity and frequency of droughts in a particular region [13]. The SPI is widely used by meteorologists, hydrologists, and water resource managers to monitor drought conditions and manage water resources. In agriculture, the SPI helps farmers and agricultural planners assess crop water needs and predict potential impacts of drought on food production. In hydrology, it assists in monitoring river flows and reservoir levels, which are

critical for maintaining water supply and planning for water scarcity [14]. While the SPI is a powerful tool, it does have some limitations. It only considers precipitation and does not account for other factors that may influence drought conditions, such as temperature, evapotranspiration, or soil moisture. Consequently, it might not fully capture the severity of drought in certain contexts, particularly in regions where temperature plays a significant role in water availability [18,6].

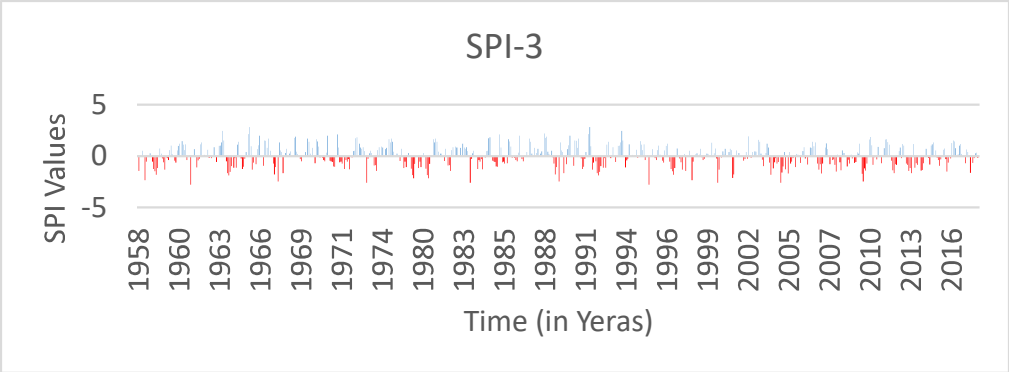
Temperature and Precipitation:

Temperature is a fundamental physical quantity that measures the degree of warmth or coldness of an object or environment. It plays a crucial role in various scientific, environmental, and daily contexts, influencing everything from weather patterns and climate to biological processes and industrial operations. Temperature is commonly measured using scales such as Celsius, Fahrenheit, or Kelvin, each serving different purposes in different fields. In essence, it reflects the average kinetic energy of particles in a substance, providing insight into the energy state and behavior of materials and systems. Understanding temperature and its variations is vital for predicting weather, managing ecosystems, and ensuring the efficiency and safety of numerous technological and chemical processes. Additionally, temperature significantly impacts drought conditions, as higher temperatures can increase evaporation rates, reduce soil moisture, and elevate water demand from plants. This exacerbates the severity and duration of droughts, particularly in regions with limited precipitation. Over recent decades, the global rise in average temperatures driven by climate change has led to more frequent and severe droughts. This trend is evident in areas like Pakistan, where elevated temperatures have intensified the effects of reduced rainfall, resulting in prolonged drought periods and notable socio-economic challenges, and Rainfall, a primary form of precipitation, is essential to the Earth's hydrological cycle, playing a crucial role in replenishing freshwater resources, sustaining ecosystems, and shaping weather patterns. It occurs when atmospheric moisture condenses into water droplets that become too heavy to remain suspended in the air, leading them to fall to the ground. The distribution, intensity, and frequency of rainfall can vary significantly based on geographical location, climate, and weather conditions, resulting in regions with abundant rainfall while others may face prolonged dry spells or droughts. Changes in rainfall patterns, often driven by climate change, can have profound effects on both natural and human systems. These shifts can impact agriculture by altering crop yields, influence water availability, and increase the frequency and severity of natural disasters such as floods and droughts. Understanding and

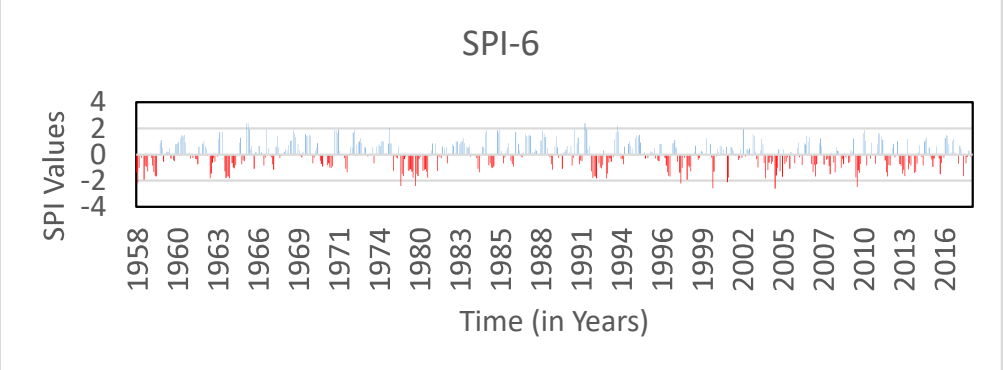
managing rainfall trends is critical for predicting weather events, ensuring water security, and mitigating the challenges posed by a changing climate.

Results and Discussion:

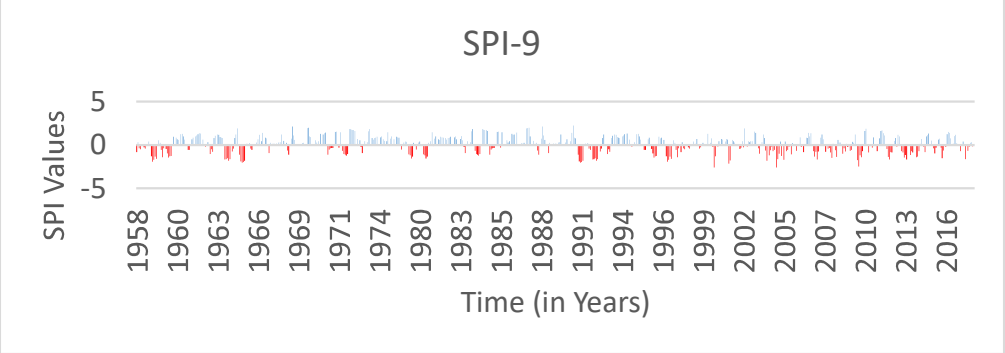
This study was conducted on meteorological drought assessment based on Standardized Precipitation Index (SPI) from the historical data of rainfall for the Lahore city. 1959, 1964, 1980, 1984, 1998, 2004, 2010, and 2014 were the precipitation deficit, warm and drought years of Lahore city as shown in (Figure-2) a, b, c & d. The condition of wet and dry periods is shown by red and blue colors in the given figures, in which red color is showing the dry condition “drought represented” and blue color to the wet condition with the values of SPI (table-1), on the base of these value we categories the condition severity (normal to extreme) of wet and drought period. In 1964, 1991, 2000, and 2010 were facing the extremely condition of drought as shown in Fig 5a. Whereas 2010 was the worst drought affected year. SPI value of warm years reached between -1.5 to -2.0, indicated extreme dry weather of Lahore Fig 6. Years 1988, 1990, 1997, 2006 and 2015 were the wet years shown in (Figure-2) c & d. According to SPI category (Table1) these years fell under the extreme wet to near normal conditions. From the result in 1997, Lahore received much rain including surrounding area. According to SPI value, wet years reached to 1.35 to 2.5 category indicated very wet to extreme wet weather in Lahore as shown in (Figure-2). As shown in the given graphs, we can clearly see the trend of precipitation in the past for Lahore city that how can it change. From the study we have observed that significant changes in precipitation patterns, a 30-35% increase in extreme rainfall events (>100 mm/day), while average monsoon season rainfall has decreased by 25%. A shift in precipitation patterns, with more frequent an. Additionally, temperature has risen by 1.5°C on average annually, with a 2.5°C increase in summer temperatures and a 1°C increase in winter temperatures. Drought frequency and severity have also increased by 20-25%, as measured by the Standardized Precipitation Index (SPI), with a notable increase in prolonged droughts (>6 months) and (>9 months) (Figure-2) b & d, values indicating moderate to severe droughts becoming more common (SPI -1.5 to -2.5). Trend of precipitation have changed from past to present condition of Lahore due to the effect of global warming, which clearly give the picture of change in the climate condition of Lahore. Long term time series satellite data could significantly be helpful in determining onset of drought, its severity and spatial extent. An operational drought monitoring and mitigation method can be used with satellite-based data and this could be achieved through a well-defined drought monitoring system.



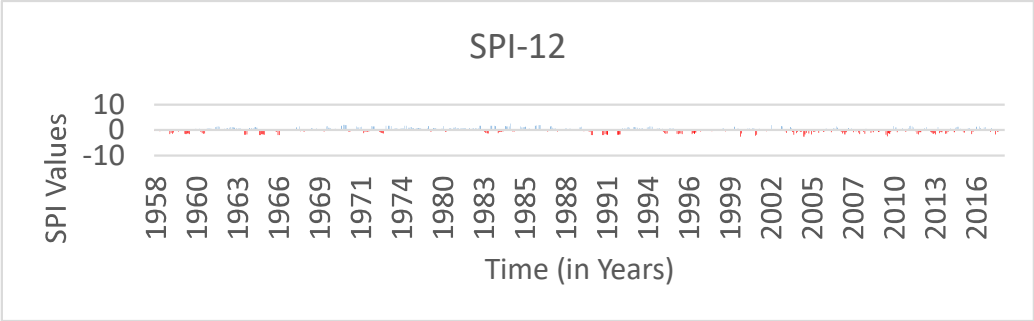
(Figure-2), a



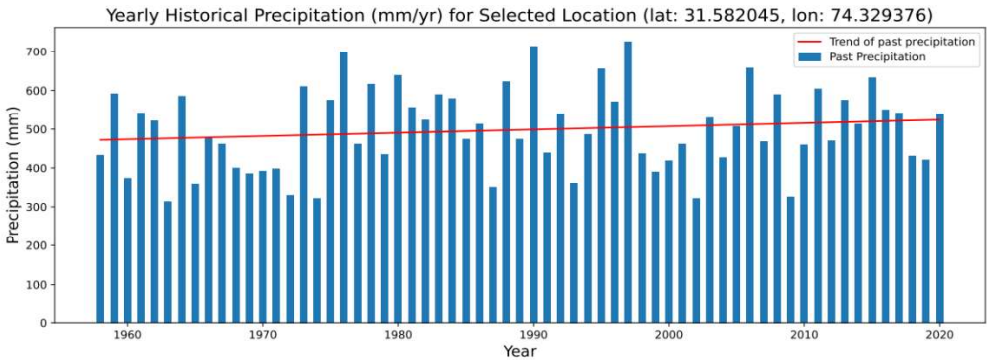
(Figure-2), b



(Figure-2), c



(Figire-2), d



(Figure-3), showing the trend of precipitation from 1958-2020

Conclusion:

This study investigated different drought characteristics, including drought duration, severity, intensity, peak, and events in Lahore city of Pakistan spanning about 58 years, from 1958 to 2016. The drought characteristics were analyzed in two time slices, i.e., pre and post periods, to analyze the climate change effects. The results indicating that the maximum duration, severity, intensity, and peak of drought have increased in the period for SPI in most zones are in line with the anticipated effects of climate change on drought characteristics. The trend analysis using the R-language was carried out to identify significant trends in the SPI. The analysis revealed that the SPI has generally decreased, indicating a decrease in precipitation and consequently, an increase in the vulnerability to drought. We considered the 3- , 6-, 9- and 12-month SPI to cover both short-term and long-term meteorological drought characteristics.

Recommendations:

To address the significant impacts of climate change on Lahore, it is essential to integrate climate resilience into urban planning, focusing on infrastructure that can withstand extreme weather events such as floods and droughts. Sustainable water management practices including rainwater harvesting and efficient irrigation. The development of early warning systems for droughts and floods along with reforestation and urban area which will help mitigate rising temperatures and improve urban resilience. Strengthening agricultural adaptation strategies, promoting public awareness and education, and fostering collaboration with international and national agencies are also crucial steps. These measures collectively aim to build a sustainable and climate-resilient future for Lahore.

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