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Analysis of the Historical Temperature of Different Cities of Pakistan to Determine the Trends and Shift in Temperature

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Antrhopogenic activities are responsible for exponential increase in temperature in recent dacades. To examine this variation, data from 30 meteorological stations in Pakistan's largest cities were examined to determine the annual average and highest temperatures between 1981 and 2020. A combination of parametric and non-parametric tests, including Sen's slope estimator, the Mann-Kendall trend test, and linear regression, were utilized for the analysis. NASA Power Data Access Viewer provides historical climatic datasets which are reliable and provide promising results. We extracted historical footprints of climatic data from NASA website and mapped the trends. About 90% of the meterological stations had rising annual temperature trends, whereas 10% had declining trends. The average annual temperature increased by 0.49 °C per decade in Gilgit, Hyderabad, Quetta, and Lasbela, which was the largest rate of change. Chitral, Gilgit, Nawabshah, and Quetta experienced the biggest increase in annual temperature that was 0.34 °C per decade. Various indicators e.g., simple linear regression and the Mann-Kendall test, respectively, revealed that the yearly average temperature was rising at a 0.001 % (at the 0.06 level). Annual temperatures were increasing at 27 stations and 23 stations were experiencing 0.002 level of significance (at the 0.06 level). Overall, the findings indicated that all climatic parameters were increasing, but during the study period, the annual average temperature was increasing more quickly than the annual maximum temperature.

Keywords: Climate change; Temperature Shift; Wheat; Crop Growing Season

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Introduction

Carbon dioxide, radioactive gases, and human activities are the main cause of rise in temperature since the 1950s and future climate changes are anticipated as a result of this [1], [2]. The identification of persistent or prolonged variations of mean attributes brought on by either natural variability or human activity is known as climate change [3]. According to regional climatic regimes, the global meteorological data demonstrate overall warming trends with various geographical and temporal differences [1], [4]. In the 20th century, the average surface temperature of the Earth has increased by 0.74 °C, according to the Fourth Assessment Report of the International Panel on Climate Change [5]. In the last five decades, warming trends have been observed as 0.13 0.03 °C every decade, which is about twice as higher as it became in the previous ten (0.07 0.02 °C/decade). By the end of the 21st century, it is predicted that the Earth's average surface temperature would increase by 1.8–4.0 °C, and in the worst case, by 6.4 °C [6]. Researches on climate change and temperature changes concluded that urbanization, industrialization, and greenhouse gases are responsible for this increase in temperature. The majority of the studies focused on climatic changes in urban areas and major commercial centers, including seasonal temperature trends [4], [6]–[8] effects of urbanization [5]–[7], [9] cloud cover, effects of suspended particulate matter [9], [10], trends in minimum or maximum temperature [1], [2], [7], and the range of daytime temperatures [11], [12].

The highest and lowest temperatures in the western Pakistan are increasing both annually and seasonally as a result of urbanization and emissions of greenhouse gases [1]. The annual air temperature is rising significantly. The arid and semi-dry regions of Pakistan presents the effects of climate change and global warming. The annual mean minimum and maximum temperature from June to November and from November to February, reveals a highly significant rising trend, according to Siddik and Rahman's [13]. Climate change has an impact on urban regions all over the world. According to Sajjad et al. [14], the annual mean temperature in Seoul, Korea was increased by 1.5 °C over the past 29 years, and the temperature in Sao Paolo, Brazil, has grown by 2 °C since 1993.

In premices of cities, the temperature varies considerably from year to year as compared to rural areas. The microclimate and high temperature in cities are initially impacted by urbanisation due to changes in land use [4], [9], [10], [14]. To understand how the climate is changing in cities that are growing larger and more industrialized, it is crucial to zanalyze the local temperature.

The cities are forming urban clusters in the region as a result of population growth and urban pressure. People moved from the rural to the city between the 1960s and the 1990s as a result of more open economies, sweeping land reforms, and the establishment of new businesses in and around urban areas. Resources were being exploited excessively and the environment was not being protected. The Pakistan Environmental Protection Agency (PAK-EPA) started operations in 1997. Cities in Pakistan are particularly susceptible to climate change and other environmental hazards [15]. The urban heat island effect got stronger as the cities expanded in an arbitrary manner. Because these industrial areas used poor-quality fuels and produced a lot of greenhouse gases, which result to alter the local climate. The exponential increase in number of cars and generators used fuel that result to add penalty of harmful gases in atmosphere. As a result, the environment has become piousneous and the existing infrastructure has been under additional strain. Massive deforestation across the nation, particularly in the north, exacerbates climate change. There have been several instances of fatal heat waves during the past few decades especially in the provinces of Sindh and Balochistan. As a subtropical region, Pakistan has seasonal and regional variations in weather.

Climate change in Pakistan's cities have not yet received much attention [16], [17]. According to Hussain et al. [18], sub-mountain regions are becoming warmer with warmer

days and cooler nights. Sultana et al. [19] observed that yields in arid, semi-arid, and sub-humid climate zones have decreased significantly due to rising temperatures and CO_2 emissions, these seasonal variations have an impact on the water supply and food security. Regarding global warming and climate change, Zahid and Rasul [20] discovered a positive trend for heat waves of magnitude 40 °C and 45 °C for 5 and 7 consecutive days, respectively; a heat wave of 40 °C and 45 °C occurred in Punjab and Sindh for 10 consecutive days, and a rising trend was observed throughout the period in Balochistan. According to Kostopoulou and Jones [21], the weather in the Eastern Mediterranean had temperatures that were 5°C higher than average. However, Sadiq and Qureshi [15] discovered that Quetta experienced the greatest increase in annual mean temperature (0.057 °C) and Peshawar experienced the least (0.019 °C). Ahmad, Fatima, Awan, and Anwar [17] claim that prolonged monsoon occurred in the 1990s, caused a decreasing trend in Lahore's peak temperature. Karachi is a heavily populated, zindustrialized economic center. According to Sajjad, Hussain, Ahmed Khan, Raza, Zaman, and Ahmed [14], the mean temperature of Karachi increased between 1976 and 2005, but the mean minimum temperature remained constant. According to Ambreen et al. [22], the mountainous regions of Pakistan experienced a slightly rising temperature trend in December that varied from place to place in comparison to the plains.

To examine the temperature variations, it would be better to comprehend regional temperature dynamics, water management, and the effects of climatic variations shortly. Pakistan's cities are under a lot of strain due to population increase, unplanned urbanization and industry, usage of fuel, and rising levels of air pollution, which directly impacts the microclimate. There shasn't been any systematic research done to look at the climatic patterns in these urban regions, even though recent heat waves, droughts, and floods whichdemonstrate that the climate is changing.

The purpose of this study is to determine changes in yearly maximum and average temperatures in Pakistan's major cities between 1981 and 2020. The objectives of this study are to 1) examine and discuss temperature variations in urban areas to see whether they may be related to climate change or global warming; and 2) apply linear regression and the Mann-Kendall test to identify patterns in regional and local climates.

Material and Methods

Since Pakistan's economic development, many metropolitan areas have transformed into industrial agglomerations and have become a source of pollutants to the environment that include Nitrogen Oxide (NOx), Sulphur Dioxide (SO_2), and Particulate Matter (PM10) [23]. Pb, Zn, Cd, and PM10 concentrations in Pakistan's cities are 4.4 gm^3, 12 gm^3, 0.077 gm^3, and 340 gm^3, respectively, as a result of the burning of industrial coal and biomass. This goes much beyond the recommended standards of the World Health Organization (WHO). Because the average amounts of suspended particulate matter (160.28 gm^3), SO_2 (15-50 gm^3), NOx (97 gm^3), Lead (3800.6 gm^3), and carbon monoxide (3800.6 gm^3) were all greater than what was deemed safe [24]–[26]. Megacities faced high concentration of carbon dioxide (CO_2) released into the atmosphere and boost global GDP. Additionally, large amount of CO_2 was releases along with other atmospheric pollutants in Karachi due to considerable expansion in industrial zones at a rate of 6.5% annually. In last few decades, the number of country's automobile increased by400%, from 0.8 million to 4.0 million. According to GoP [27], these cities have large populations and high CO_2 emissions. The average number of people per square kilometer increased from 80 to 220, while CO_2 emissions increased from 4 to 32 million metric tonnes.

At 30 meteorological stations located in Pakistani cities, the average and highest temperatures for each year between 1981 and 2020 were zutilized to analyze potential trends. Pakistan Meteorological Department in Islamabad is responsible to archieve the temperature data for every station in the national database. Data quality was taken into consideration because outliers have a significant impact on the size of a potential trend based on parametric

tests while outliers can be handled adequately by non-parametric testing [7]. Any outliers or missing values were manually searched and plotted on the graph. The normal ratio approach was applied by [28] for suspicious values, but as the data set had no missing values.

The Mann-Kendall (Z) test is a non-rules-based method for identifying trends. Non-parametric trend identification methods may handle outliers and are not sensitive to the assumption of a normal distribution [1][8][16][29]. In other words, the data need not have a normal distribution to be meaningful. It has been widely utilized to identify significant trends in hydro-meteorological time series. Non-parametric approaches are considered to be the most effective because these time series are frequently not normal [6], [16], [29].

A normal distribution with a mean of 0 and a standard deviation of 1 describes the Mann-Kendall Z statistic value [16]. While negative Z values indicate that trends are declining, positive Z values indicate that trends are increasing. The strength of the trend in this study was graded as "extremely strong" (p = 0.000), "strong" (p 0.05), and "low" (p = 0.10) at various levels of significance.

The data series must be unrelated to one another to perform the Mann-Kendall test. The trends may be overstated or underestimated if there is a positive or negative serial correlation in the time series that jeopardizes the trend's significance level[16], [30]–[32]. We performed the Breusch-Godfrey serial correlation LM test on each station at a significance threshold of = 0.05. The original series was used to analyze the data because none of the test statistics were crucial.

Result and Discussions

The annual variation in temperature is mapped in Figure 1.

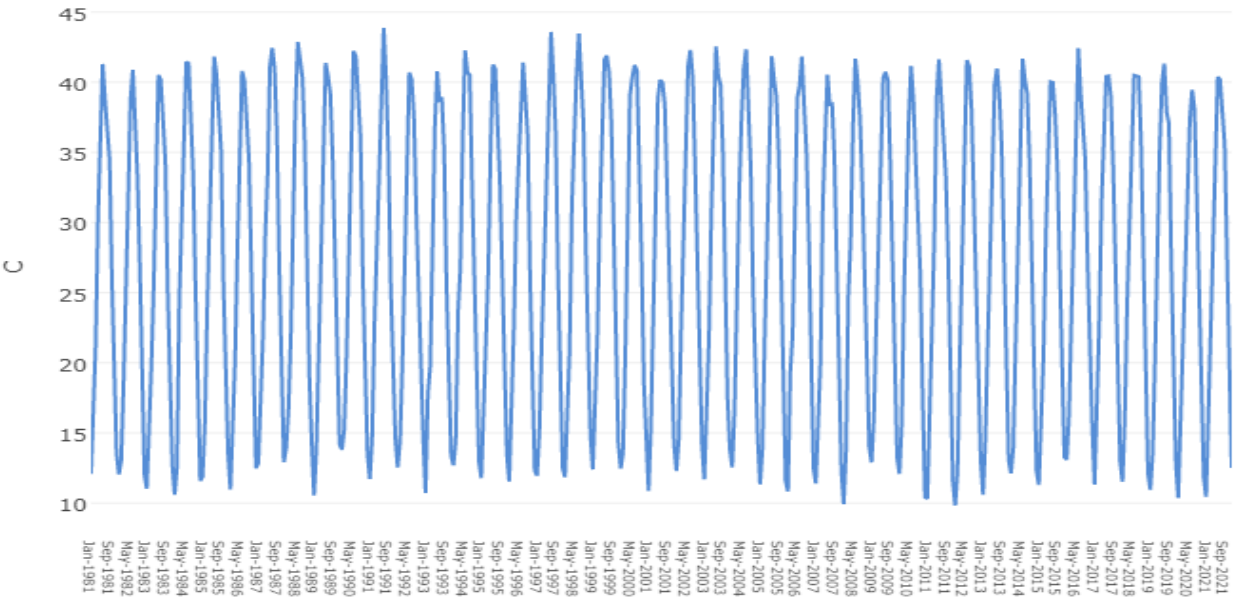

Figure1. Annual temperatre variations (Source: NASA Power Data Access Viewer)

Numeric form of this data was analzed and all tests including We examined trends in the annual average and highest temperatures using simple linear regression (r), the Mann-Kendall trend test (Z), and Sen's slope estimator (Q). The investigation revealed that all of the approaches for trend estimation were quite similar.

Seven meteorological stations at the 93% significance level and thirteen at the 98% significance level demonstrated significant increases in yearly average temperature using the Mann-Kendall trend test and Sen's slope estimator method. The average annual temperature was increased by 0.28°C per decade at Nawabshah, 0.47°C per decade at Gilgit, Hyderabad, Quetta, and Lasbela, and 0.63°C per decade at Quetta, according to Sen's slope estimator. On

the other hand, the trend of decreasing average yearly temperatures in Lahore, Kakul, and Faisalabad was not statistically significant. Over the previous ten years, the average annual temperature in the northern region of the country has increased as 0.15°C at Dir and Drosh, 0.32°C at Chitral and Astor, and 0.42°C at the Gilgit station. Bahawalnagar, Badin, Jacobabad, Khanpur, and Karachi were found to be warming up in the middle and lower Indus basin valley at a pace of 0.33 °C per decade, while Hyderabad's average temperature was rising at a rate of 0.47 °C per decade. In the Balochistan province, the average annual temperature increased by 0.48 °C each decade in Lasbela and Quetta but remained constant in Sibi, Panjgur, and Pasni. The findings of this study concur with those of Ambreen, Ahmad, Sultan, Sun, and Nawaz [22], who claimed that Pakistan's mountainous regions experience a greater isothermal shift and temperature variance than plain regions do. This is because the northern regions and the province of Balochistan's weather stations have a clear rising temperature trend, indicating that both are becoming warmer. Zahid and Rasul [20], who discussed historical incidents and predicted that Sindh and Balochistan could experience more severe heat waves, provided a history of heat waves in Pakistan. According to Galdies [33], heat waves are responsible for the Mediterranean fluctuating temperatures. Extraterrestrial Solar Radiation (ESR) levels in Pakistan dropped from south to north, according to Ambreen et al. [34]. ESR in coastal areas ranged from 11,221 to 12,413 Megajoule (MJ/m^2), while the Balochistan Plateau and northern regions of the lower Indus plain received between 11,524 and 11,659 (MJ/m2), which was the second-highest ESR. The findings of this investigation supported the upward trend that the weather stations in the cities of Balochistan and Sindh are showing. Sajjad, Hussain, Ahmed Khan, Raza, Zaman, and Ahmed [14] discovered that the average yearly temperature is rising in Karachi, a densely urbanized and industrialized city. Additionally, albeit not significantly, there was a slight increase in Peshawar and Islamabad.

On the other hand, a significant trend of an increasing annual maximum temperature was observed at 9 meteorological stations at the 97% significance level and 7 meteorological stations at the 98% significance level. The considerable increase in annual maximum temperature, as calculated by Sen's slope estimator, ranged from 0.15°C per decade in Karachi to 0.34°C per decade in Chitral, Gilgit, Nawabshah, and Quetta. There was no statistically significant decline in the hottest temperature of the year at Kakul, Faisalabad, or Lahore. The hottest temperature of the year was increasing at a rate of 0.36°C each decade in the northern mountains at the stations of Chitral, Gilgit, and Murree. The hottest temperature of the year increased by 0.25°C every decade at Bahawalnagar and Hyderabad and by 0.3°C per decade at Nawabshah in the middle and lower reaches of the Indus Valley. The annual maximum temperature increased by 0.4°C every decade in Quetta, held constant at 0.3°C in Lasbela, and increased by 0.2°C per decade in Sibi and Pasni in the Balochistan province. The increase in the peak temperature could be attributed to a higher ESR, more frequent heat waves, dense, unplanned urban development, and historical pollution from industry and autos. Sami et al. and Ilyas et al. [25], [35] discovered that cities have higher concentrations of lead and suspended particles. Additionally, Tabari and Hosseinzadeh Talaee [2] discovered that the annual mean maximum temperature was rising in the nearby dry and semi-dry regions of Iran. The hottest temperature of the year was observed to be slightly rising at other stations. At Kakul, Lahore, and Faisalabad, a surprisingly insignificant negative tendency for annual average and maximum temperature was discovered. This unexpected trend was explained by the heavy monsoon rainfall, particularly in the 1990s for Lahore and the nearby city of Faisalabad [15], [17][36]. The Himachal Pradesh region adjacent to Lahore in the Indian portion of the Sutlej River basin, where Singh et al. [37] discovered an insignificant negative trend for the annual maximum temperature at Kasol and Sunni stations, which explained the regional trend variation along the Pakistan-India border, supports the findings. In Pune, India's industrialised and urbanised city, the annual maximum temperature has been falling for a while.

According to [10], the cause of this is cloud cover and aerosols produced by humans.

Conclusion.

From 1981 to 2020, the annual average temperature in the northern region of the nation increased significantly at Gilgit and Chitral, at rates of 1.41 °C and 1.21 °C, respectively. Hyderabad had a somewhat higher rate of 1.43 °C over the research period than Bahawalpur, Jacobabad, and Khanpur, which all showed a significant trend of 1.21 °C. At Lasbela, Quetta, and Pasni in the Balochistan province, the average yearly temperature trend was 1.62°C and 1.23°C, respectively. Gilgit and Chitral, on the other hand, had a noticeable rise in annual maximum temperature throughout the research period, at a pace of 1.24 °C in the north. Nawabshah experienced a 1.26°C warming, Bahawalnagar and Hyderabad experienced a 0.83°C warming. The rate of the growing trend was found to be 0.84 °C in Pasni and 1.22 °C in Quetta, both in the Balochistan province, over the study period. Urban areas are where climate change occurs. Regional variations in annual average and maximum temperatures are a result of a variety of factors, including unplanned urban and population growth, industrialization, emissions, deforestation, and the general lack of concern for the environment among the general public, which will have detrimental effects on future generations. The amount of water that flows from the country's mountains, the productivity of agriculture, and the amount of biodiversity that is lost nationwide are all impacted by changes in temperature in the north [38]. From 1960–1970, the environment in urban areas was poor and the temperature has gone up as a result of expanding populations, a lot of development, and increased particulate matter and greenhouse gas emissions. Heat waves that frequently occur in the country's south and southwest demonstrate the unsettling and urgent need to alter the climate. To ensure that people may live and develop healthily, the infrastructure in these cities must be updated and ecologically friendly cpractices must be employed. This is due to urbanization, a growing population, and changes in the local climate.

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