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COMPARATIVE ANALYSIS OF MINIMUM AND MAXIMUM TEMPERATURE VARIABILITY IN DISTRICT KARAK AND TANK, KHYBER PAKHTUNKHWA, PAKISTAN

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ABSTRACT

Temperature variability is an important component of climate change, particularly in arid and semi-arid regions where agricultural production, livestock and water resources are highly climate-sensitive. This study comparatively examines minimum and maximum temperature variability in Districts Karak and Tank, Khyber Pakhtunkhwa, Pakistan, using 60 years of monthly observations from 1956 to 2015. The dataset comprised 720 observations for each temperature variable in each district. Monthly averages were used to investigate seasonal patterns, while alternative linear and non-linear regression models were evaluated to characterize long-term temperature behavior. The findings indicate pronounced seasonal temperature cycles in both districts. In Karak, minimum temperature increased from January to July and then declined, whereas maximum temperature increased from January to June and subsequently declined. In Tank, minimum temperature increased from January to June and declined afterward, while maximum temperature reached its highest level in June, followed by May and July. Seasonal models explained 94.60% and 93.70% of minimum and maximum temperature variation in Karak and 95.70% and 94.60%, respectively, in Tank. Long-term annual temperature series in both districts exhibited irregular and cyclic behavior. The fourth-order logarithmic model produced the lowest residual sum of squares for all four district-temperature combinations. The selected models had relatively low explanatory power for annual variation, indicating that time alone does not adequately explain long-term temperature variability. The findings are consistent with recent evidence of significant temperature variability and warming across Khyber Pakhtunkhwa and Pakistan. The study highlights the need for district-specific climate adaptation measures involving water conservation, heat-resilient agriculture, livestock management and improved climate information services.

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Introduction

Temperature is one of the most important indicators of climate variability and climate change. Changes in minimum and maximum temperature affect crop growth, evapotranspiration, water demand, livestock health, human thermal comfort and ecosystem functioning. These effects can be especially important in dry and semi-arid areas where climatic variability interacts with limited water availability. Recent international assessments indicate that Asia is experiencing particularly rapid warming. The World Meteorological Organization reported that Asia is warming at nearly twice the global average and that 2024 was the warmest or second-warmest year on record for the continent, depending on the dataset. Extreme heat, drought and other climate-related hazards are increasingly affecting regional economies and livelihoods (WMO, 2025). The latest WMO assessment for 2025 further indicates that extreme heat remained a defining climate hazard in Asia, while Pakistan experienced major impacts from extreme rainfall and other climate-related hazards (WMO, 2026). The IPCC has reported with high confidence that mean, minimum and maximum temperatures have increased over almost all of Pakistan, with faster warming in the southern parts of the country. Minimum temperatures have increased faster than maximum temperatures in several regions, indicating potentially important changes in the diurnal temperature range (IPCC, 2021).

Recent national observations reinforce these findings. Pakistan's climate assessment for 2025 reported a national mean temperature of 23.9°C, 1.09°C above the 1961–1990 average. Khyber Pakhtunkhwa recorded a mean annual temperature of 20.89°C, approximately 1.29°C above its reference average, and 2025 was reported as the highest-temperature year for the province during the assessed 65-year record (Government of Pakistan, 2026).

Recent empirical research has also focused specifically on Khyber Pakhtunkhwa. Gul et al. (2025), using monthly minimum and maximum temperature data from 1981–2020, found substantial spatial and temporal variability in temperature across KP and reported that a significant share of the region displayed unstable rather than uniformly stable temperature trends.

Similarly, recent research on temperature dynamics in Mardan Division has demonstrated that temperature conditions vary with landscape transformation and local environmental characteristics, highlighting the importance of sub-regional assessments rather than relying solely on national averages.

At the national scale, Ullah et al. (2026) reported persistent warming trends across Pakistan using bias-corrected CMIP6 climate projections and statistical and machine-learning techniques. Their findings emphasize the importance of region-specific assessments because Pakistan's complex terrain produces substantial spatial differences in climate behavior. Despite this growing body of evidence, long historical comparisons of temperature behavior between southern districts of Khyber Pakhtunkhwa remain valuable. Karak and Tank share broadly hot and dry climatic conditions but differ in geographical setting and local environmental characteristics. Comparing their historical temperature patterns can therefore provide useful information for district-level climate adaptation.

The present study compares the seasonal and long-term behavior of minimum and maximum temperature in Karak and Tank using 60 years of monthly observations from 1956 to 2015.

Materials and Methods

Study Areas

District Karak

District Karak is located in southern Khyber Pakhtunkhwa. It was established as a separate district in 1982 after being separated from Kohat. The district covers approximately 3,372 square kilometers and consists of Karak, Banda Daud Shah and Takht-e-Nasrati tehsils. The landscape consists of sandy plains and hilly areas. The climate is generally dry, with hot summers and comparatively cool winters. The district has a predominantly rural population and agricultural and livestock activities are therefore sensitive to climatic conditions.

District Tank

District Tank is located in the Dera Ismail Khan Division of Khyber Pakhtunkhwa. It became a separate district in 1992 after previously being part of Dera Ismail Khan. It is bordered by Lakki Marwat, Dera Ismail Khan, the former Frontier Region Tank and South Waziristan.

Tank experiences hot and relatively dry conditions. Its rural population and dependence on climate-sensitive livelihoods make historical temperature assessment particularly relevant.

Data and Analytical Framework

Data Sources

Monthly secondary data for minimum and maximum temperature from 1956 to 2015 were used for both districts. Each variable consisted of 720 monthly observations.

Monthly averages were calculated to characterize seasonal behavior, while the annual series was examined to investigate long-term variation.

Comparison of District Tank and Karak

In order to compare the average climatic parameters within the districts, one-way ANOVA with a multiple comparison test will be applied. One-way ANOVA, based on F-ratio will test the significant differences in each of the climatic parameters within the district at a specified level of probability. A multiple comparison test, more specifically the least significant difference (LSD) test will be used for identifying the means (mean climatic parameters) that are significantly different, across the three selected parts of the data. For convenience, the statistical model of one-way ANOVA is given in equation.

$$y_{ij} = \mu + \alpha_j + \varepsilon_{ij}$$,

where, y_{ij} is the value of climatic parameter subject to i-th observation (time) and j-th period (one of the four parts), μ is the overall mean, α_j is the effect of j-th period and ε_{ij} is known as random error and assumed to follow a normal distribution with zero mean and constant variance i.e. $\varepsilon_{ij} \sim N(0, \sigma^2)$.

Similarly, the LSD test uses the formula as mentioned in equation for mean comparison.

$$LSD = t_{\alpha/2(df)} \sqrt{MSE / r_1 + MSE / r_2}$$,

where, MSE is the mean square of error that will be obtained from ANOVA, degree freedom indicate the error degrees of freedom, $t_{\alpha/2(df)}$ is the t-tabulated value that is taken from the table of t-distribution, r_1 and r_2 indicate the size of sample-1 and sample-2 respectively.

Results and Discussion

Seasonal Minimum Temperature

In Karak, average minimum temperature was lowest in January and increased toward July before declining toward December. The quadratic relationship explained **94.60% of the variation**. In Tank, minimum temperature also began at its lowest level in January and increased toward the summer months. The seasonal quadratic model explained **95.70% of the variation**, slightly higher than the corresponding Karak model.

These findings demonstrate strong seasonal regularity in minimum temperature in both districts.

Seasonal Maximum Temperature

In Karak, maximum temperature increased from January to June and then declined toward December. The quadratic model explained **93.70% of the variation**.

In Tank, maximum temperature also increased toward June. June represented the highest average maximum temperature, followed by May and July. The seasonal model explained **94.60% of the variation**.

Table 1. Seasonal Model Performance

District	Variable	Seasonal R^2
Karak	MINT	0.946
Karak	MAXT	0.937
Tank	MINT	0.957

Tank	MAXT	0.946

Tank therefore showed slightly stronger seasonal explanatory power than Karak for both minimum and maximum temperature.

Long-Term Minimum Temperature in Karak

The 1956–2015 annual minimum temperature series in Karak showed irregular and cyclic behavior.

Table 2. Best-Fitted Models for Karak MINT

Rank	Model	RSS	R^2
1	Fourth-order logarithmic	13.56782	0.06899
2	Fourth-degree polynomial	13.56835	0.06896
3	Fourth-order inverse logarithmic	13.56850	0.06895
4	Fourth-order inverse polynomial	13.57347	0.06861
5	Third-order inverse polynomial	13.58372	0.06895

The fourth-order logarithmic model provided the best fit based on RSS and R^2.

Long-Term Maximum Temperature in Karak

Karak's maximum temperature also showed irregular and cyclic behavior.

Table 3. Best-Fitted Models for Karak MAXT

Rank	Model	RSS	R^2
1	Fourth-order logarithmic	16.36948	0.05678
2	Fourth-order inverse logarithmic	16.37154	0.05666
3	Fourth-degree polynomial	16.40795	0.05456
4	Fourth-order inverse polynomial	16.44734	0.05229
5	Fifth-order logarithmic	16.45842	0.05166

The fourth-order logarithmic model again ranked first.

Long-Term Minimum Temperature in Tank

Tank minimum temperature displayed irregular and cyclic behavior across 1956–2015.

Table 4. Best-Fitted Models for Tank MINT

Rank	Model	RSS	R^2
1	Fourth-order logarithmic	11.88836	0.10985
2	Fourth-order inverse logarithmic	11.88885	0.10981

3	Fourth-degree polynomial	11.89861	0.10908
4	Fourth-order inverse polynomial	11.90921	0.10829
5	Third-degree polynomial	11.96420	0.10417

The fourth-order logarithmic model produced the lowest RSS and highest R^2.

Long-Term Maximum Temperature in Tank

Tank maximum temperature also demonstrated irregular and cyclic variation.

Table 5. Best-Fitted Models for Tank MAXT

Rank	Model	RSS	R^2
1	Fourth-order logarithmic	15.872815	0.08641
2	Fourth-order inverse logarithmic	15.87438	0.08632
3	Fourth-degree polynomial	15.954062	0.08173
4	Fourth-order inverse polynomial	16.01412	0.07828
5	Third-degree polynomial	16.41637	0.05512

Again, the fourth-order logarithmic model was ranked first.

Comparative Discussion

The results demonstrate that Karak and Tank have strong and broadly similar seasonal temperature cycles. Minimum temperature increases from winter toward summer, while maximum temperature generally peaks around June. The strongest seasonal relationship was observed for Tank minimum temperature, with $R^2 = 0.957$. The lowest seasonal R^2 was observed for Karak maximum temperature, although it remained high at 0.937.

The long-term results present a different picture. All four annual series exhibited irregular and cyclic behavior. Fourth-order logarithmic models consistently produced the lowest RSS.

Table 6. Comparative Performance of Selected Long-Term Models

District	Variable	Best Model	RSS	R^2
Karak	MINT	Fourth-order logarithmic	13.56782	0.06899
Karak	MAXT	Fourth-order logarithmic	16.36948	0.05678
Tank	MINT	Fourth-order logarithmic	11.88836	0.10985
Tank	MAXT	Fourth-order logarithmic	15.872815	0.08641

Tank's selected models produced somewhat lower RSS and higher R^2 values than the corresponding Karak models. Nevertheless, the explanatory power remained modest. This suggests that time alone is insufficient to explain most of the long-term annual temperature variability.

This result is consistent with recent studies showing that temperature trends in Khyber Pakhtunkhwa are spatially and temporally heterogeneous. Gul et al. (2025) reported stable and unstable temperature behavior across different areas of KP rather than a single uniform trend.

The results also reinforce the importance of distinguishing **seasonal variation from long-term warming**. The high seasonal R^2 values indicate that the annual cycle is highly predictable, whereas the low long-term R^2 values indicate substantial interannual variability and/or model limitations.

The broader climate evidence, however, establishes that the absence of a strong time-only regression should not be interpreted as evidence against warming. IPCC assessments identify significant warming across Pakistan, particularly in southern areas, while recent observations show exceptionally high temperatures in Khyber Pakhtunkhwa.

The latest Pakistan-wide research by Ullah et al. (2026) similarly emphasizes the need for region-specific and non-linear approaches to capture temperature changes across the country.

Climate and Agricultural Implications

The results have important implications for the predominantly rural populations of Karak and Tank. Strong summer temperature increases can increase evapotranspiration and crop water requirements, potentially increasing pressure on already limited water resources.

Recent WMO evidence indicates that extreme heat is becoming an increasingly important hazard across Asia, while Pakistan continues to experience significant climate-related risks.

Conclusion

The comparative analysis of Karak and Tank demonstrates pronounced seasonal variation in both minimum and maximum temperature. Tank showed slightly stronger seasonal model performance than Karak, while the long-term annual series of both districts displayed irregular and cyclic behavior. Fourth-order logarithmic models provided the best fit among the tested alternatives for all four district-temperature combinations. However, the relatively low R^2 values demonstrate that time alone cannot explain most long-term annual temperature variability. The results are consistent with recent research emphasizing spatially heterogeneous temperature behavior in Khyber Pakhtunkhwa and with national and international evidence of continued warming across Pakistan and Asia.

The study therefore supports a two-level interpretation: seasonal temperature variation is strong and highly predictable, whereas long-term annual variability is more complex and requires additional climatic and environmental variables for robust explanation.

Future studies should incorporate precipitation, relative humidity, solar radiation, wind speed and land-use changes and should apply robust trend-estimation methods such as Mann–Kendall and Sen's slope alongside regression models.

Policy Recommendations

1. Develop district-specific climate adaptation plans for Karak and Tank.
2. Promote water-efficient irrigation and water-harvesting technologies.
3. Encourage adoption of heat- and drought-tolerant crop varieties.
4. Improve livestock shelters and summer heat-management practices.

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