

Modelling and Forecasting the Impact of Air Temperature on Global Warming: Karachi as a Case Study

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Modelling and Forecasting the Impact of Air Temperature on Global Warming: Karachi as a Case Study

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ABSTRACT: The world has experienced extreme climate changes and global warming. It also causes high temperature, droughts, rising sea level and flooding. In Karachi, the construction activities and transportation caused most of the Green House Gases (GHG) and carbon dioxide (CO₂) emission. In the paper, the data under consideration is 60 years mean monthly maximum and minimum air temperature of Karachi ranging from 1961 to 2020 has been used to forecast the temperature impact over time. The minimum and maximum temperature data were observed, forecasted city temperature. ARMA (p, q) model used to modelling and forecasting the behaviour of Karachi maximum and minimum air temperature using Pakistan Metrological Department (PMD) data. The results show that the Theil's U-Statistics values of each month lie approaches to zero shows that the air temperature is strongly correlated to previously observed values. The results of this study are very beneficial for observing the influence of air temperature on the global warming.

Keyword: ARMA (p, q) model, air temperature, Root Mean Square Error, Skewness, Kurtosis.

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1. INTRODUCTION

Global warming jeopardizes our environment and human health. It also causes high temperature, droughts, rising sea level and flooding. There are various contributing factors however transportation activity and transportation during the construction process contribute to high GHG in the metropolitan city Karachi [1]. The United Nation (UN) office on Disaster Risk Reduction (UNDRR) between 2000 and 2019, heatwave resulted in 13% all disaster deaths (91pc) worldwide. Additionally, United Nations (UN) experts warned Karachi to prepare for unusual heatwave as the global temperature increased 1.1°C and would continue to cause such calamities [2]. Historically Temperature rise can directly affect agriculture, sea level and frequency of extreme weather incident. Last few years particularly from 2015 to 2020 Karachi city has experienced extreme weather conditions. Usually, May to June supposed to be the hottest months before monsoon rain starts in Karachi. Unseasonal heatwave waves with Day temperature rise to 40 to 42 °C over parts of Sindh, including Karachi. According to German watch, a German think-tank in its recent global climate risk index 2016 report listed Pakistan number 05 in the list of top 10 countries most affected by climate change [3]. Karachi may be one of the most impacted cities of Pakistan due to Climate change. This metropolitan city cannot resist the impact of global rising temperatures. There is a number of contributing factors causing global warming and CO₂ emission. However, construction activity is responsible for about 39% of all carbon emission in the world [4] with operation emission of the building such as the energy required accounting for about 28%. While 11% CO₂ emitted from the construction process, material transport/manufacturing process, operation lifecycle and demolishing process.

Among the process air transport release extreme heat and particulates which further increase global warming. Similarly, land transport does the same, releasing gases like hydrocarbon, carbon dioxide, sulfur oxides, nitrogen and black carbon etc to the environment causing temperature rise. CO₂ is emission only from construct and manufacturing industry the total percentage of fuel consumption in Pakistan was 23.84 as of 2014 which was the highest in 43 years. Concrete, on the other hand, is the common construction material in Pakistan, known as the largest CO₂ emitters which generate environmental hazardous waste during the processes related to its production, construction, maintenance ace and demolition [5].

The contributing factors to weather change for Karachi may be different and hence difficult to measure until and unless all factors are elevated or properly. In the past few decades, Karachi experienced unexpected maximum and minimum impact of air temperature as presented in Table 01.

On 11 March 2020, World Health Organization (WHO) declared COVID-19 a pandemic, the virus spared from Chain to Europe, The United States and other Asian courtiers [6]. Effect of Covid 19: The noble COVID 19 has wreaked havoc in all developed and developing countries causing major health crisis and shutting/slow down many industries due to strict standard operating procedures (SOPs). China has experienced a sharp decrease in economic activities and CO₂ emission due to strict lockdown particularly at Wuhan and Nanjing [7][8]. On the other hand, this pandemic has intriguing effects on the environment. As the virus spreads around the globe many countries closed their borders to limit air and land transport system. Daily activity at country, province or city lever

has shown substantial decreasing CO₂ emission [9]. Only in Pakistan air transport system causes 40% CO₂ emission [10].

During the Pandemic transportation and construction activities were discontinued but the question is how much these activities are causing global warming in the metropolitan city Karachi. Major offices, transportation were closed during the lockdown as most of the employees work from home. The energy consumption would not be that high as the energy required to cool and the light building was not high during the lockdown period. Therefore, In this paper, the data under consideration is 60 years mean monthly maximum and minimum air temperature of Karachi ranging from 1961 to 2020 has been used to forecast the temperature impact over time. The minimum and maximum temperature data were observed for forecasted city temperature. the temperature effect during the pandemic was compared using Pakistan Metrological data when transportation and construction industry operation was restricted during lockdown compared to other years. The minimum and maximum temperature data were observed, compared and analysed with the average city temperature.

2. METHODOLOGY

The best fitted ARMA (p, q) models are selected by Akaike information criterion (AIC), Bayesian Schwarz information criterion (SIC) and Hannan Quinn information criterion (HIC). The forecasting ability of each model of Karachi maximum and minimum temperature of each month will be judged by diagnostic checking tests like Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and Theil's U-Statistics. Mean maximum likelihood estimation is used to evaluate ARMA (p, q) model. The Statistical EViews version 9.0 software is used for calculation and analysis of ARMA (p, q) model and respective graphs.

BASIC EQUATIONS OF STATISTICAL ANALYSIS

This section consists of short statistical analysis.

DIAGNOSTIC TEST

The selection of best adequate models is tested by the Akaike information criterion (AIC), Bayesian Schwarz information criterion (SIC) and Hannan Quinn information criterion (HIC). Durbin-Watson Test also verify for significant appropriate model. Forecasts with the most appropriate model of Karachi maximum temperature and Karachi minimum temperature were verified for accuracy based on a Root mean square error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and Theil's U-Statistics. The highest view of these terminologies is given within the ensuing.

AKAIKE INFORMATION CRITERION: The AIC test was presented by Hirotogu Akaike in 1973 [11]. It is the delay of the greatest likelihood principle the selection criterion is pointing the smallest amount value of AIC.

$$AIC = - 2\text{Log (likelihood)} + 2S \quad (1)$$

Where S is that the model parameter numbers. The chances are that a measure of the appropriate model. Minimum values exhibit the best fitted.

SCHWARZ CRITERION: The SIC test is used to select the foremost appropriate model among finite models. The suitable model relies on the littlest amount value of SIC. Schwarz criterion (SIC) was introduced by Gideon E. Schwarz. It is closely related to the AIC.

$$\text{SIC} = -2\ln(\text{Likelihood}) + (S + S \ln(N)) \quad (2)$$

Where S is that the model parameter numbers. N exhibits the quantity of observations.

Hannan-Quinn criterion: The HIC is that the criterion for model selection. This test is an alternate to AIC and SIC.

$$\text{HQC} = -2 \text{Log}(\text{Likelihood}) + 2(S + S \ln(N)) \quad (3)$$

Where S is that the model parameter numbers. N exhibits the number of observations.

Durbin-Watson Test: The DW statistics might be a test for measuring the linear association between the adjacent residual from a regression model. The hypothesis of Durbin- Watson statistics is $\tau = 0$ is that the specification.

$$U_t = \tau U_{t-1} + \epsilon_t \quad (4)$$

Durbin-Watson (DW) is satisfactory 2 shows there is not any serial correlation. If Durbin- Watson (DW) has less than 2 indicate that correlation and consequently the range from 2 to 4 shows that negative correlation. The series is strongly correlated if the values nearly approach to zero.

Mean Absolute Error: The mean absolute error is stated as a mathematically formed.

$$\text{MAE} = \frac{1}{n} \sum_{t=1}^n |\epsilon_t| \quad (5)$$

Where n is that the number of observations. Mean Absolute Error (MAE) processes absolutely the deviation of forecasted values from real ones. It is also called Mean Absolute Deviation (MAD). It stated the magnitude of overall error caused by forecasting. MAE does not exterminate the effect of positive and negative errors. MAE does not definite the directions of errors. It should be as small as possible permanently forecasting. MAE depends on the information transformations and thus the dimensions of measurement. Extreme forecast error does not exist by MAE[12][25].

Mean Absolute Percentage Error (MAPE): The Mean Absolute Percentage Error (MAPE) is defined as

$$\text{MAPE} = \frac{1}{n} \sum_{t=1}^n \left| \frac{\epsilon_t}{X_t} \right| \times 100 \quad (6)$$

Mean Absolute Percentage Error (MAPE) offers the proportion of the everyday absolute error. It is independent of the scale measurement. MAPE does not trace the direction of Error. The acute deviation is not penalized by MAPE. During this measure, opposite signed errors do not offset each other in MAPE [1][13][14]. This implies that due to the benefits of freedom and commentary on absolutely the share error (MAPE) scale, one in every of the foremost extensively used measures of prediction accuracy. Whereas it is independent of the scale of measurement but full of data transformations [15].

Root Mean Squared Error (RMSE): The root mean squared error (RMSE) is defined as

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{t=1}^n \varepsilon_t^2} \quad (7)$$

RMSE calculates the common squared deviation of forecasted values. The choice signed errors do not counterbalance one another. RMSE provides the entire idea of the error that happened during forecasting. By using the accuracy measures, errors that are small and are getting good, such as 0.1 RMSE and 1% MAPE, can often be achieved. In RMSE, the full forecast error is ill with the large individual error. As an example, an oversized error is way dearer than small errors. It does not reveal the direction of overall errors. RMSE is laid low with the information transformation and the change of scale. RMSE may well be an honest measure of overall forecast error [13].

Theil's U-Statistics (U): Theil's U-Statistics is defined as

$$U = \frac{\sqrt{\frac{1}{n} \sum_{t=1}^n \varepsilon_t^2}}{\sqrt{\frac{1}{n} \sum_{t=1}^n f_t^2} \sqrt{\frac{1}{n} \sum_{t=1}^n X_t^2}} \quad 0 \leq U \leq 1 \quad (8)$$

Where f_t represent the forecasted value and X_t shows that the actual value. U is the normalized measure of the total forecast error. U is equal to 0 exhibits the perfect fit.

Tests for Normality

The normality test is executed to test whether the data into consideration is usually distributed or not. These tests are supported the analysis of two numerical measures, the shape skewness and the surplus kurtosis. The information sets are normally distributed if those measures are near zero. The acceptance of Jurque-Bera test also focused on skewness and kurtosis. Hence, the test of normality consists of checking the skewness and kurtosis on which the Jurque-Bera test relies.

Skewness: The skewness determines the degree of asymmetry of the information.

$$\text{Skewness} = \frac{\sum_{i=1}^n (X_i - \bar{X})^3}{(n-1)S^3} \quad (9)$$

Where \bar{X} is that the mean and S is that the variance and n is that the number of values (Christian and Jean-Michel 2004). The skewness of the normal distribution. If the knowledge is typically distributed, then the skewness shows that the following data is symmetry. If the knowledge is usually distributed if the symmetric distribution (skewness value is capable zero). The distribution is positively skewed, if it is greater than zero and negatively skewed if it is but zero.

Kurtosis: The Kurtosis measures the degree of peakness of the data. Kurtosis has been calculated as

$$\text{Kurtosis} = \frac{\sum_{i=1}^n (X_i - \bar{X})^4}{(n-1)S^4} \quad (10)$$

Where \bar{X} is that the mean, S is that the variance and n is that the number of values of the statistical data. Kurtosis of an expected distribution is termed mesokurtic if it is up to 3. Whereas it is leptokurtic if the value is bigger than 3. It is Platykurtic if the worth is also a smaller amount than 3.

Jarque-Bera Statistics Test (JBS): The JBS is recognized with the normality of the information with skewness is adequate zero and excess kurtosis is additionally up to zero. Jarque-Bera test is defined as follows.

$$\text{Jarque-Bera test} = \frac{n(\text{Skewness})^2}{6} + \frac{n(\text{Kurtosis}-3)^2}{24} \quad (11)$$

Jarque-Bera test statistics are estimated as Chi-squared distribution with two degrees of freedom. Null hypothesis (Ho) could even be a traditional distribution with skewness zero and excess kurtosis zero (which is that the identical as a kurtosis is 3). Alternate hypothesis (HA) of given data is not normally distributed.

ARMA Model

In stochastic process, Autoregressive process AR (p) can be stated by a weighted sum of its previous value and a white noise. The generalized Autoregressive process AR (p) of lag p as follow

$$X_t = \alpha_1 X_{t-1} + \alpha_2 X_{t-2} + \dots + \alpha_p X_{t-p} + \epsilon_t \quad (12)$$

Here ϵ_t is white noise with mean $E(\epsilon_t) = 0$, variance $\text{Var}(\epsilon_t) = \sigma^2$ and $\text{Cov}(\epsilon_{t-s}, \epsilon_t) = 0$, if $s \neq 0$. For every t, suppose that τ_t is independent of the X_{t-1}, X_{t-2}, \dots . τ_t is uncorrelated with X_s for each $s < t$. AR (p) models regress is past values of the data set. Whereas MA (q) model relates with error terms as a descriptive variable (Hupal et. al. 1994). The generalized Moving Average process MA (q) of lag q as follows.

$$X_t = \epsilon_t + \beta_1 \epsilon_{t-1} + \beta_2 \epsilon_{t-2} + \dots + \beta_q \epsilon_{t-q} \quad (13)$$

The process X_t is defined by the ARMA Process.

$$X_t = \alpha_1 X_{t-1} + \alpha_2 X_{t-2} + \dots + \alpha_p X_{t-p} + \epsilon_t + \beta_1 \epsilon_{t-1} + \beta_2 \epsilon_{t-2} + \dots + \beta_q \epsilon_{t-q} \quad (14)$$

With ϵ_t is an uncorrelated process with mean zero. The prediction of ARMA (p, q) process shows the decay to be sinusoidally and exponential y to zero.

3. RESULTS AND DISCUSSION

This study focused to estimate modelling and forecasting the future Karachi maximum and minimum air temperatures with Box-Jenkins ARMA (p, q) models. In this regards, mean monthly Karachi maximum and minimum air temperatures ranging from 1961 to 2020 data are used. Each cycle consist of each monthly average (1961-2020) data are used. Table 2 demonstrates the descriptive statistics of mean monthly Karachi maximum air temperatures ranging from 1961 to 2020 which is consists of each month (1961-2020). Mean, median, standard deviation, skewness, kurtosis and Jarque-Bera test have been calculated of each cycle. January has mean \pm standard deviation with 26.158 ± 1.0980 . February has 28.190 ± 1.46098 . March has 32.0767 ± 1.42963 . April has 34.63833 ± 1.200295 . May has 35.45833 ± 0.906528 . June has 35.2400 ± 0.842927 . July has 33.38000 ± 0.791437 . August has 32.0633 ± 0.776556 . September has 32.94467 ± 1.097074 . October has 35.07667 ± 1.148524 . November has 32.2667 ± 0.95559 . December has 27.93500 ± 1.210662 . Most of the months show negative skewness which represent that the risk of left tail events and unpredictable. March, May, June, and September indicate positive skewness. Whereas different months shows maximum air temperature have different kurtosis behavior. Some months shows platykurtic which represents that flat tail (peakness) and remaining months evaluate leptokurtic (heavy tail). In Jarque-

Bera test, maximum air temperature of each months (1961-2020) represent that rejected the null hypothesis (normally distributed by any mean and variance). Table 3 depict that the descriptive statistics of mean monthly Karachi minimum air temperatures ranging from 1961 to 2020 which is consists of each month (1961-2020). January has 11.2 ± 1.5821 . February has 13.7350 ± 1.828014 . March has 18.4867 ± 1.295686 . April has 22.9967 ± 1.365801 . May has 26.4367 ± 0.990115 . June has 28.2300 ± 0.616249 . July has 27.60500 ± 0.629077 . August has 26.30833 ± 1.106727 . September has 25.58333 ± 0.821360 . October has 21.98000 ± 1.833104 . November has 16.84667 ± 1.898391 . December has 12.43500 ± 1.497209 . Most of the months show positive skewness (right tail). Different months have different kurtosis behavior. Some months shows leptokurtic (heavy tail) which represents the strong correlation among pervious values, and rest of months evaluate platykurtic which represents that flat tail (peakness). In Jurque-Bera test, minimum air temperature of each months (1961-2020) represents that the null hypothesis (normally distributed by any mean and variance) is rejected. The ARMA model is a tool for analysis and calculating of the fundamental structures or getting the predictions of future values in time series. The appropriate models for Karachi maximum and minimum air temperatures are selected based on Durbin-Watson statistics test. The Durbin- Watson (DW) approach to zero is describe the series are positively correlated. The value 2 shows that the series has no correlation. If DW is ranged between 2 and 4 indicates negative correlation. Least square estimation is used to estimate ARMA process. The coefficient of determination R² range scale indicated value (from 0 to 1), a large value of R² shows that models reveal a closer fit to the time series data. Table 4 depicts the appropriate model for each months of Karachi maximum air temperatures (1961-2020). Least square estimation is used to estimate ARMA (p, q) model. Adequacy of the models is checked by AIC, SIC, HQC and Maximum log likelihood tests. The criteria of choose most appropriate model is less values of AIC, SIC, HQC and DW value is less than 2. According to Durbin- Watson (DW) test and AIC, SIC and HQC represent that April, August and December follow the best fitted model, are ARMA (3, 3). January shows most appropriate model is ARMA (8, 8). February indicate ARMA (5, 5) is best fitted model. March explore ARMA (5, 8) is appropriate model. May shows most appropriate model is ARMA (4, 4). June explore ARMA (2, 1) is best fitted model. July has ARMA (1, 4) is appropriate model. September indicate ARMA (9, 7) is best fitted model. October explore ARMA (1, 1) is appropriate model and November shows most appropriate model is ARMA (2, 2). Table 5 describe that the appropriate model for each months of Karachi minimum air temperatures (1961-2020). Most of the months indicate that the most appropriate model is ARMA (1, 1). Remaining months explore the best fitted model is ARAM (2, 2). Whereas the forecasting evolution of each month maximum Karachi air temperature is analysis in the view of diagnostic checking by Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and U tests in Table 6. MAE is least among MAE, RMSE, and MAPE of all the months. According to RMSE shows that August has least value with 0.787744. MAE shows July has least value with 0.613130 and MAPE represent that June has least value (1.837062). Theil's U-Statistics is also applied evolution of forecasting of each month Karachi maximum air temperature. According to Theil's U-Statistics is equal to 0 exhibits the perfect fit. Each month has Theil's U-Statistics value near to zero which is shows that month air temperature is correlated to previous one. Theil's U-Statistics explain that October has ARMA (1, 1) is best fitted model with 0.016096 value. Table 7 also shows the forecasted evolution of Karachi minimum air temperature of each month analysis and ARMA (p, q) equation in the view of diagnostic checking. MAE is least among MAE, RMSE, and MAPE of all the months. The smallest values of MAE, RMSE, MAPE and Theil's U-Statistics exist for the June, which is 0.432525, 0.591310, 1.524124 and 0.010490 respectively. Figure (1-6) shows actual vales of maximum and minimum Karachi air temperature.

4. CONCLUSION

Global warming and climate change describe to an increase in average global temperatures. Human activities and Natural events are main contributors to such increases in average global air temperatures. The change in climate is caused by increasing emissions of carbon dioxide from vehicles, factories, and power stations, will not affects only the sea and atmosphere but also will alter the Earth geology. Emissions of carbon dioxide due to our fossil energy usage will change the climate and the air temperature is estimated to increase by 2 to 6o Celsius within year 2100, which is a remarkable increase from our current average air temperature of 1.7o Celsius as predicted.

The novelty of this study is a preliminary experiment on know how Karachi maximum and minimum air temperature behave and climate change. ARMA (p, q) model used to modelling and forecasting the behaviour of Karachi maximum and minimum air temperature. In this regard, the data under consideration is that mean monthly maximum and minimum air temperature of Karachi ranging from 1961 to 2020 (each month wise). Descriptive studies of each month (1961-2020) are described. Finding the most appropriate models is depends on the least value of Akaike information criterion (AIC), Bayesian Schwarz information criterion (SIC) and Hannan Quinn information criterion (HIC). Durbin-Watson Test also apply for knowing most appropriate model. Root mean square error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and Theil's U-Statistics are used to calculate the forecast accuracy of the best-fitted model of Karachi mean monthly maximum and minimum air temperature. Minimum air temperature, most of months follows the most appropriate model is ARMA (1, 1) and some months shows the best adequate model is ARMA (2, 2) process apart from January has the best fitted model is ARMA (3, 3), April shows the most fitted model is ARMA (2, 3) and October follows the most appropriate model is ARMA (9, 6). Although, in the maximum air temperature shows most of the months follows the most appropriate model is ARMA (3, 3) remaining months express the different ARMA (p, q) process is best. MAPE values is less as compare to other forecast evaluations like RMSE and MAE. Theil's U-Statistics also demonstrate for the maximum and minimum air temperature of each months. The Theil's U-Statistics values of each months lies approaches to zero shows that the air temperature is strongly correlated to previous one. With rising in the Earth's global mean air temperature i.e., global warming, the various effects on climate change pose risks that rises. It is also found that during Pandemic despite transportation and construction activities were discontinued the temperature difference was not affected much however air quality was improved..

DECLARATION

This study is supported by Sir Syed University of Engineering & Technology. The authors declare they have no financial interests. The authors have no conflicts of interest to declare that are relevant to the content of this article.

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Figures

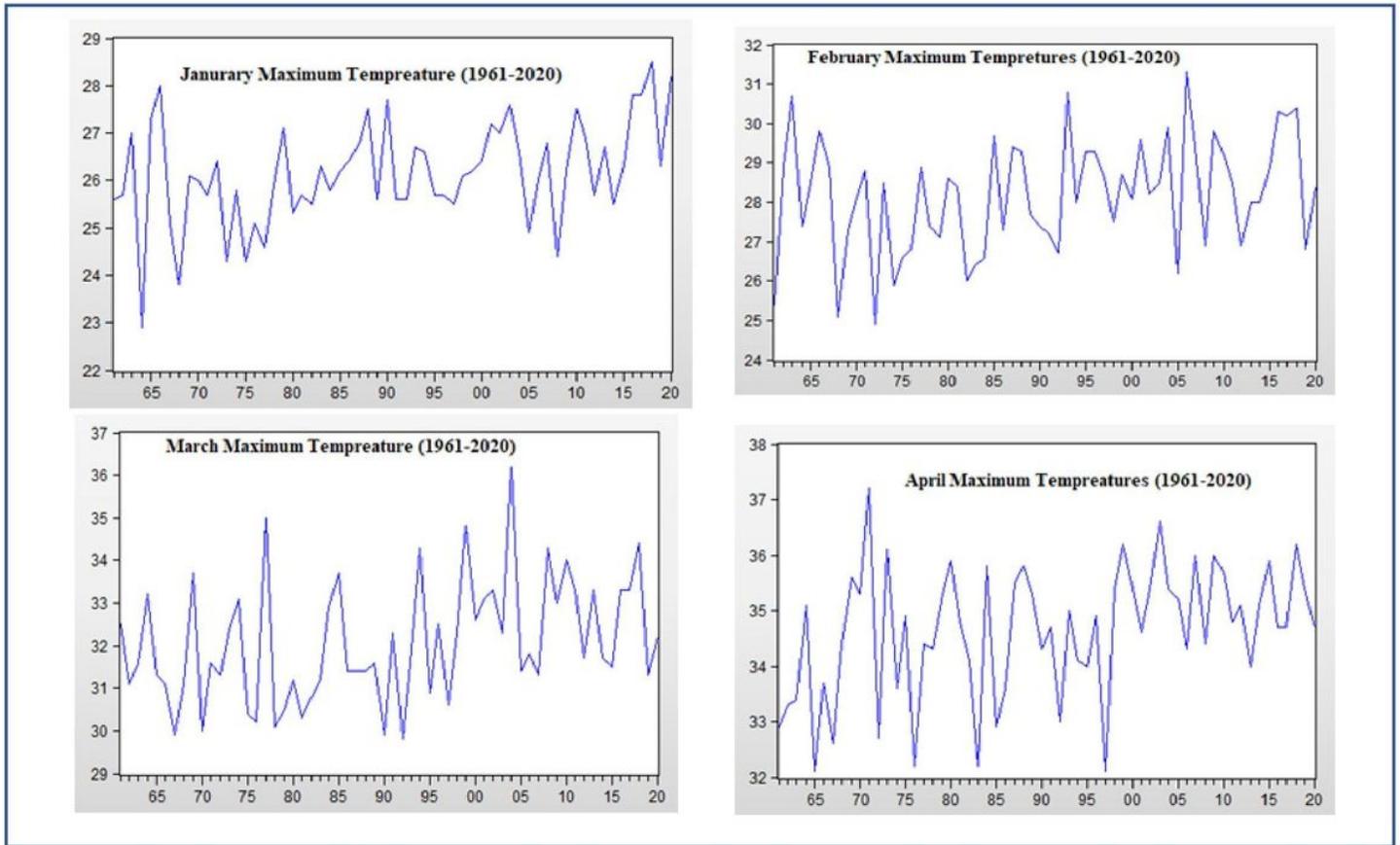


Figure 1

Karachi Maximum Air Temperature January-April (1961-2020)

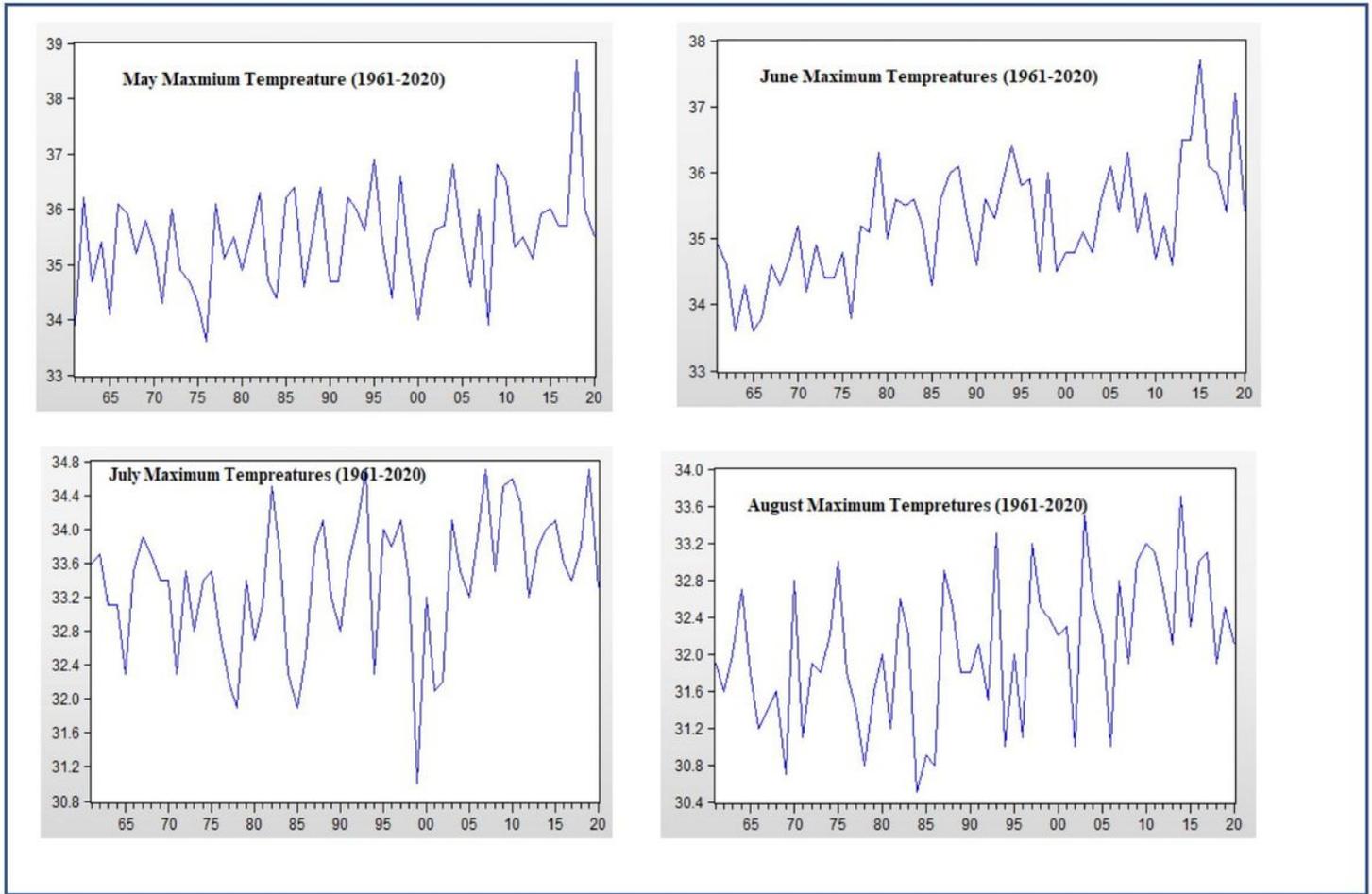


Figure 2

Karachi Maximum Air Temperature May-August (1961-2020)

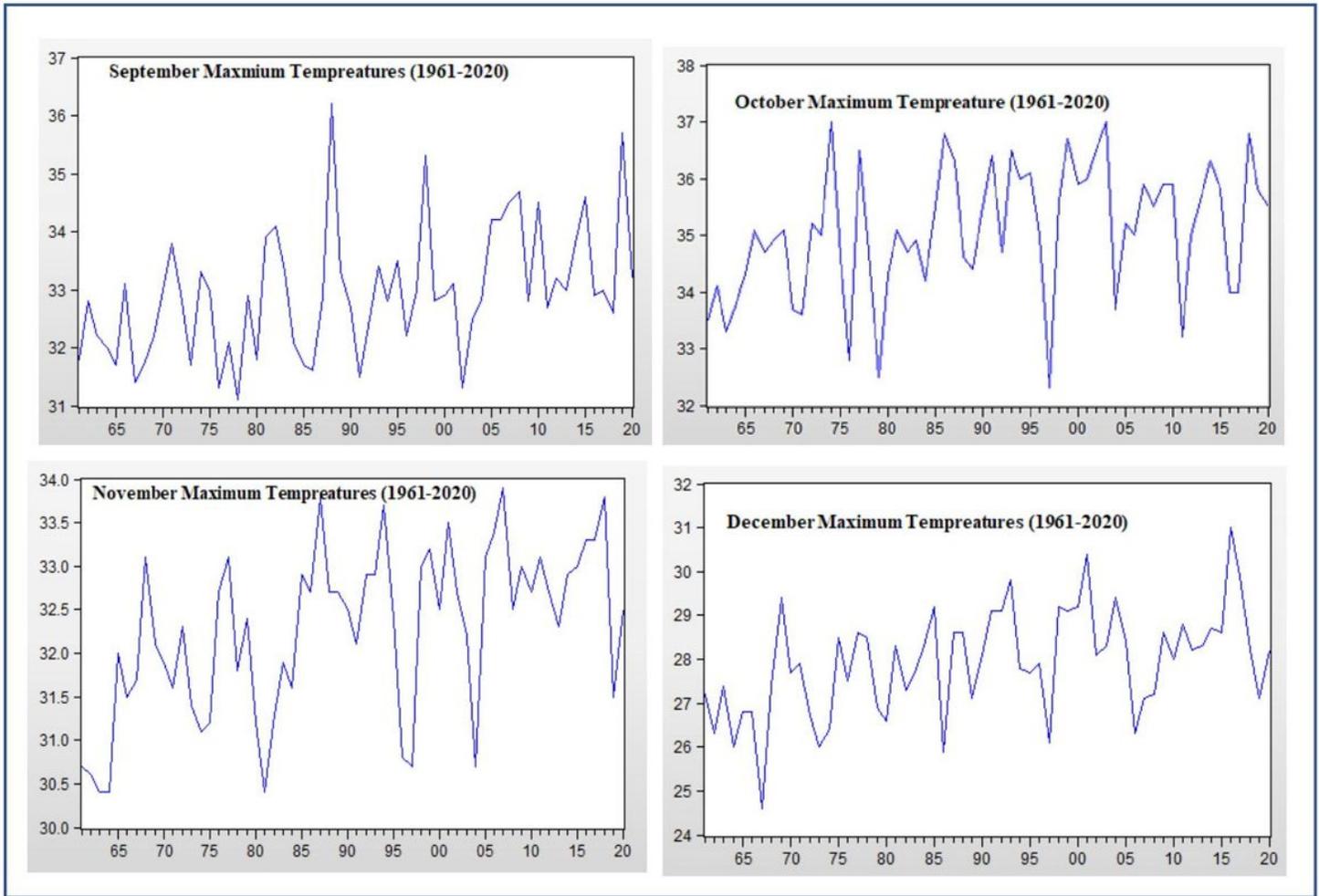


Figure 3

Karachi Maximum Temperature September-December (1961-2020)

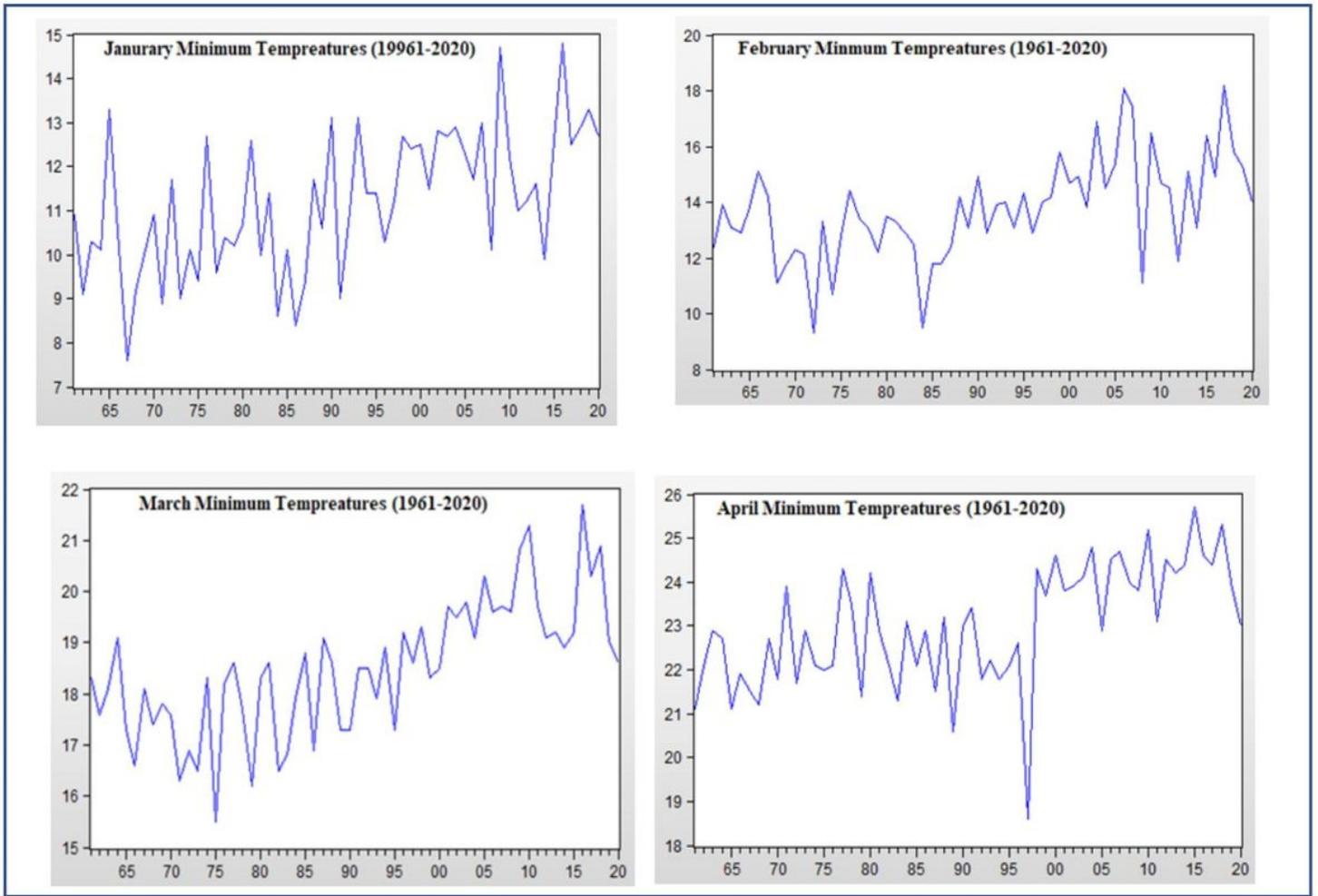


Figure 4

Karachi Minimum Temperature January-April (1961-2020)

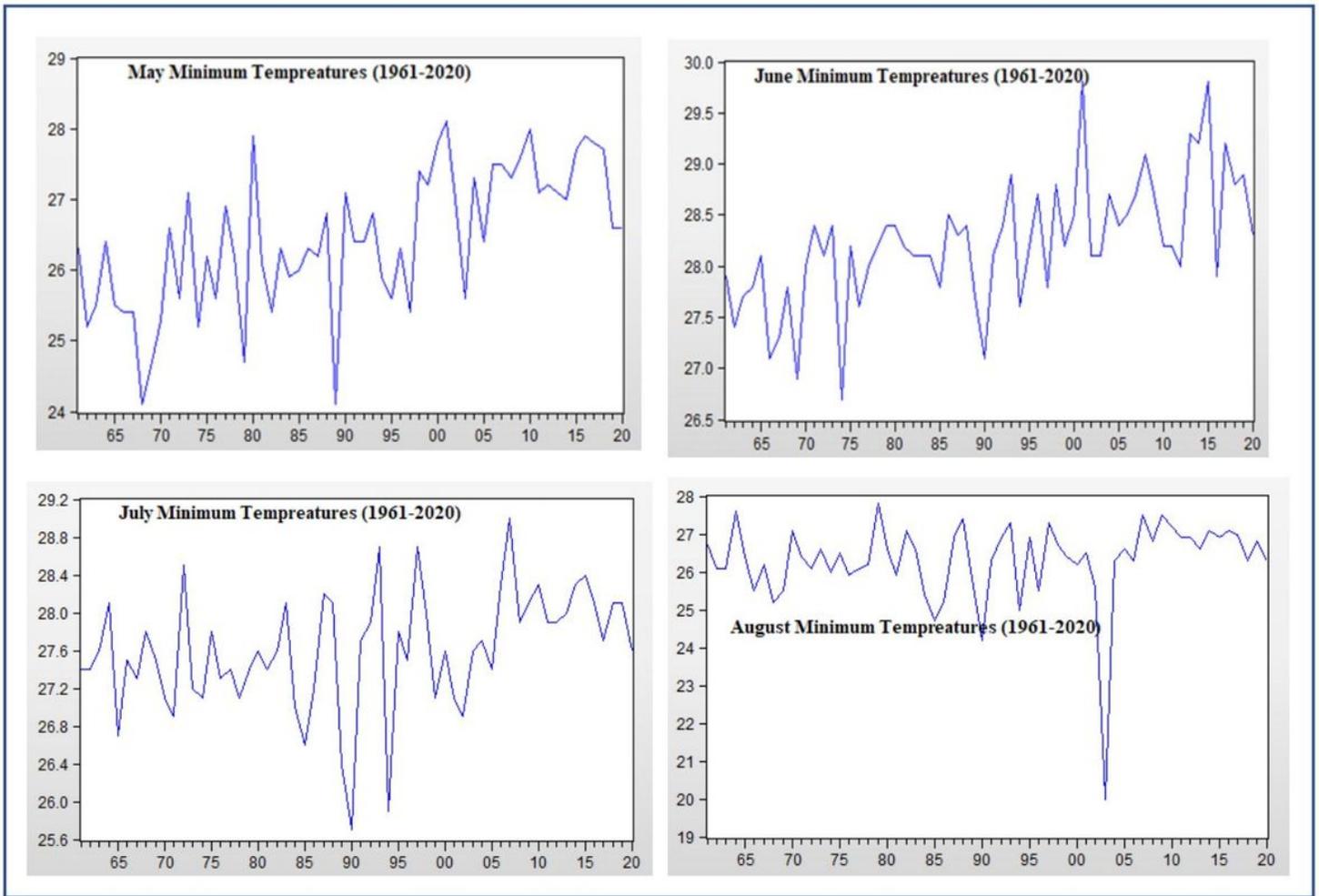


Figure 5

Karachi Minimum Air Temperature Ma y-August (1961-2020)

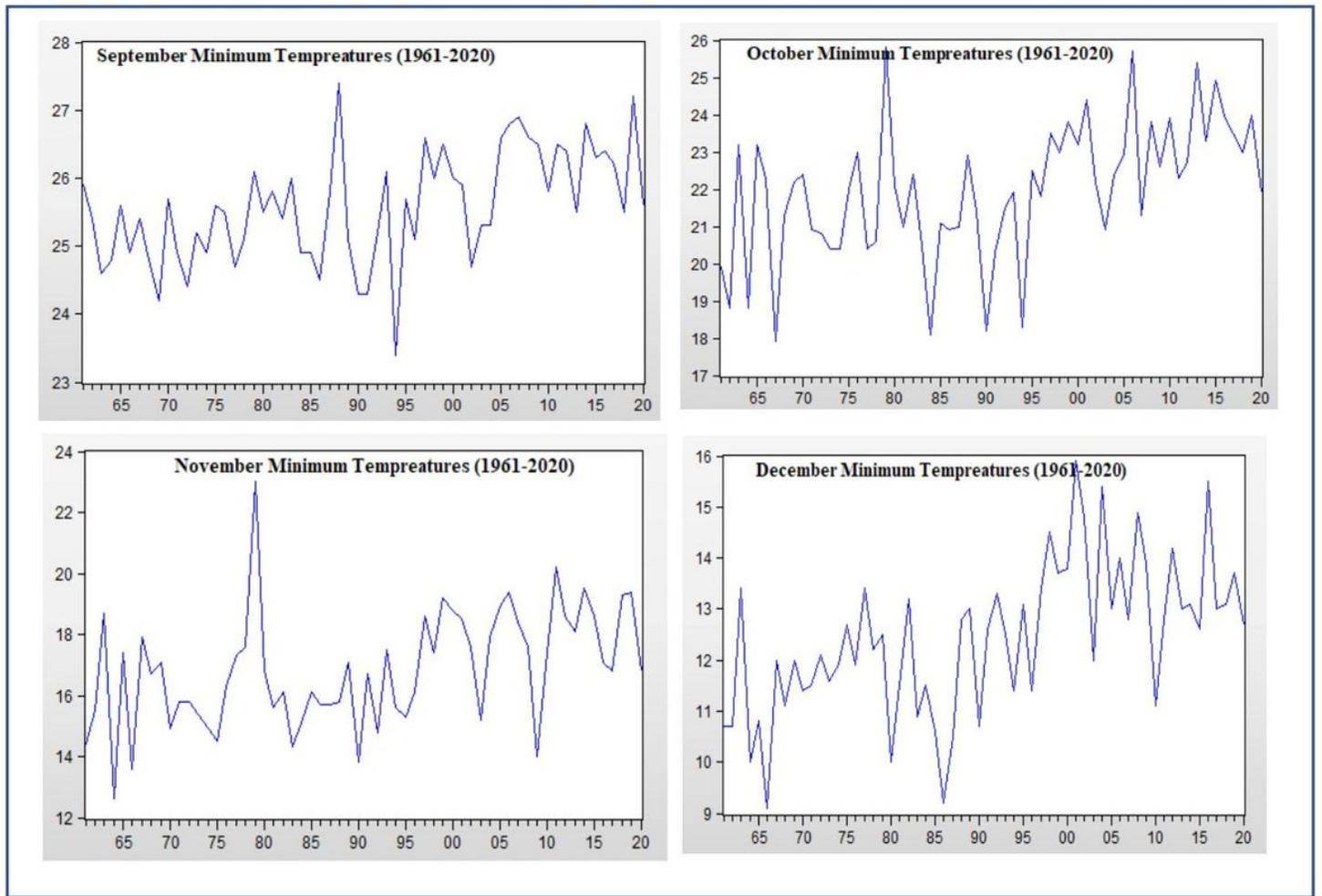


Figure 6

Karachi Minimum Air Temperature September-December (1961-2020)