INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 15, No. 2, p. 539-546, 2019

RESEARCH PAPER OPEN ACCESS

The use of Holt–Winters' method for forecasting rainfall of Quetta region

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Key words: Holt-Winters, Quetta.

http://dx.doi.org/10.12692/ijb/15.2.539-546 Article published on August 30, 2019

Abstract

This paper aims to model and forecast monthly average rainfall of Quetta region. Due to arid nature of this zone, groundwater is one of the major resources for domestic, agriculture, commercial and industrial utilization. Sustainability of groundwater table cannot be maintained because of extreme weather condition. Quetta has faced severe drought situation in the past. It is important to observe the imbalance in precipitation and temperature and forecasting rainfall in Quetta region is of great importance. This study uses multiple regression method to explore the relationship between rainfall and temperature (maximum and minimum). Furthermore, Holt-Winters methods (multiplicative and additive) are employed to forecast the precipitation. Average monthly rainfall from January, 1980 to December, 2016 is used for model building and data from January, 2017 to December, 2017 is used to validate the developed model. Negative relationship is observed between mean maximum temperature and precipitation whereas positive relationship is found between rainfall and minimum temperature. Root mean squares error and Mean absolute error are used as validation measures. Empirical analysis displays that Holt-Winters additive method is appropriate for future forecasting. Moreover, January, 2018 to December, 2020 is forecasted. A decline pattern is observed in future rain fall.

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Introduction

Pakistan being a blessed country enjoys all four seasons in a year. It has two major seasons of rainfall summer monsoon (July to September) and winter December to March by Rasul *et al.* (2012). Approximately 60 percent rainfall of the Pakistan comes from the monsoon season according to meteorological department of Pakistan Rasul *et al.* (2012). Thar and Balochistan of Pakistan and Dasht of Iran passes through the southern half of Pakistan. Northern areas receive heavy rainfall of over 508mm annually, whereas the southern region receives less rainfall near about 127 mm annually. The remaining south-west areas are less fertilized because of less rainfall. In another paper, Salma *et al.* (2012) studied rainfall trend in different climate zones of Pakistan using data from 1976 to 2005. They found a significant decreasing pattern all over the country.

The issue of environmental change has been arisen very strongly during the last few years on worldwide scale in perspective on its anticipated ramifications on the earth of vulnerable states.

Pakistan has also faced a number of natural disasters such as cyclones, floods, drought, intense rainfall, and earthquakes due to climate change by Hussain *et al.* (2010). Furthermore, in the country due to unpredictable behavior of rainfall patterns it is difficult for inhabitants to make indispensable arrangements for the safety of their crops and livestock. Increasing temperature and limited precipitation, which are responsible for drought incidence as a result of global warming, are posing serious threats to food security (Lobell *et al.*, 2013). The forecasting of these two quantities using statistical methods is, therefore, of immense importance.

Three decades earlier, exponential smoothing types of models were considered for extrapolating various kinds of univariate time series. The past literature shows that Simple exponential method is commonly employed to forecast business and industry data with non-constant trends. However, it was less popular among the statisticians as it does not have a well-defined statistical foundation. These methods initiated between 1950s to 1970s of Hlot (1957), Brown (1959) and Winters (1960), Brown (1959) and Box, & Jenkins (1970).

Holt–Winters technique was applied to forecast non-stationarity seasonal rainfall and temperature data by Kamruzzaman *et al.* (2011). Their analysis showed that Holt–Winters method was capable to explain changes in all three equations which were used to explain the forecast equations. Single exponential and double exponential smoothing techniques were applied to model and forecast the monthly lime price of Thailand Booranawong & Booranawong, (2017). Various forms of data such as average, median, linear weighting factor, exponential weighting factor were used as input for the models. Furthermore, Holt–Winters additive and multiplicative methods were applied. It was found that Single exponential and double exponential models give minimum forecast error than Holt-Winters method based on the MAE. In another paper, Pongdatu, & Putra, (2018) compared SARIMA and Holt-Winter's methods for sales transaction data at store X covering the period 2013 to 2017. Result depicted that SARIMA model outperforms than Holt-Winter's method. Gundalia, & Dholakia (2012) applied Holt Winters method to predict daily maximum and minimum temperature of Junagadh region. Precipitation and daily temperature data were modeled and forecasted by Murat *et al.* (2018). Four European sites namely Jokioinen, Dikopshof, Lleida and Lublin covering the period from 1st January 1980 to 31st December 2010 were used. They used various models such as polynomial, regress on Fourier, ARIMA Fourier and SARIMA models. The result obtained from the analysis provides valuable insights to understand the structures of the data which was helpful in agriculture and environmental planning and for decision-making. South region of Iran (Shiraz), ARIMA model was used to model fifty years temperature data Balyani *et al.* (2014). Fatima & Khan (2018) forecasted Rainfall of Potohar Region of Pakistan using SARIMA models in the perspective of drought.

The purpose of the study is to investigate the relationship between rainfall and temperatures (minimum and maximum) of Quetta region. This region is well known for fruit and dry fruit production. So, modeling and forecast the rainfall is important for fruit and dry fruit production and it will also help in reducing frequent occurrence of drought in this region.

Material and methods

Materials and methodology is essential part of any research. The study includes different steps to acquire the results using secondary data of climatic variables. Furthermore, Minitab software 17 was used for analyzing the data.

Study area

The study has been conducted for “Quetta Valley” in northwest Baluchistan with longitude 66.88oE, latitude 30.25oN and elevation of 1600m from mean sea level. Quetta is the provincial capital of Balochistan, and is known as the city of the "Fruit Garden of Pakistan". Climatically, Quetta has the dry semi-arid agro-climatic characteristics. These agriculture activities depend on rain fall and ground water irrigation. Unlike more easterly parts of Pakistan, Quetta does not have a monsoon system. Therefore, winter season (start from November and continues till April) produces heavy rain fall than summer season. However, Monsoon rain fall systems do not play any significant role in this region. Resulting summer season contributed meager in total annual precipitation. Quetta has faced severe drought situation from 1999 to 2001, during which the city had below normal rains. After three years, the city received normal rains in 2004, and 2005. Being an agrarian country, this province cultivates a large number of crops, vegetables, deciduous, and tropical fruits by Bajoi (2004). There are two types cropping Rabi and Kharif seasons in the study area. Kharif crops are fruits, melons, vegetables, potato, fodder, onion etc. While Rabi crops are wheat, barley, vegetable and fodder. Furthermore, this region also produces Plums, peaches, pomegranates, apricots, apples, guavas, some exceptional types of melon like "Garma" and "Sarda, the quality of fruit produced is exceptionally good. Beside this, pistachios and almonds are all grown in abundance. Livestock is another important sector of the region.

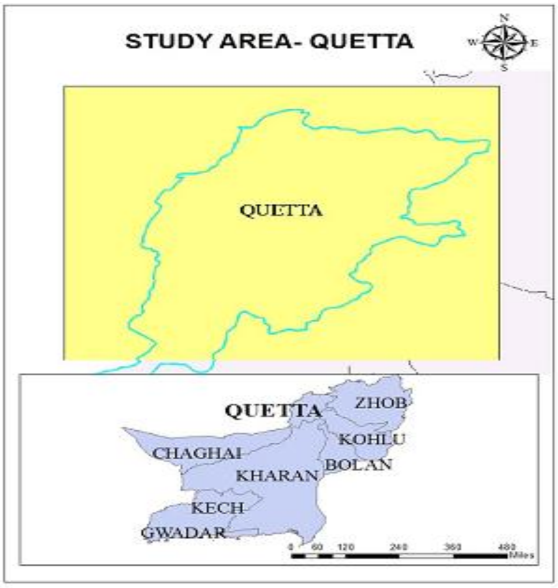

Fig. 1. Map of the study area.

Climatic Variables

Rainfall

Rainfall is an important part of life because the agricultural crops are completely depends upon the average rainfall in the study area. The instrument which is used to measure rainfall is rain gauge and unit measurement is millimeter (mm).

Temperature

Temperature is defined as the measurement of hotness and coldness in terms of degree Celsius or Fahrenheit. Generally, the instrument which is used to measure temperature is known as thermometer with standard unit as Celsius.

The average monthly rainfall and temperature (maximum and minimum) data consist of January, 1980 to December 2017 making a total of 457 observations acquired from Pakistan Meteorological Department (PMD).

Methods for Modeling Rainfall Data

To forecast rainfall data Exponential smoothing methods are employed. During 1957 to 1960, Holt (1957), Brown (1959) and Winters (1960) developed exponential smoothing for point forecast which is known as Holts’ and Winter method. This method is further categorizes into Holt-Winters’ multiplicative seasonality method or Holt-Winters’ additive seasonality method.

Holt-Winters' Multiplicative method

Holt-Winters' additive method is applied for the data in which seasonal variation is assumed to be constant throughout. The basic equations namely Overall smoothing, Trend smoothing and Seasonal smoothing are as follows,

Overall smoothing: $L_t = \alpha X_t / s_{t-m} + (1-\alpha)(m_{t-1} + b_{t-1})$

Trend smoothing: $b_t = \beta(m_t - m_{t-1}) + (1-\beta)\, b_{t-1}$

Seasonal smoothing: $S_t = \gamma X_t / (m_t + b_{t-1}) + (1 - \gamma) S_{t-m}$

Forecast: $\hat{Y}_{t+1} = (m_t + b_t h)\, S_{t-m+} h_m^+$

Whereas, Ord *et al.* (1997) modified seasonal smoothing such that $S_t = \gamma Y_t / (L_t) + (1 - \gamma) S_{t-m}$ which is same as Arcibald's (1990). This modification is also supported by Wheelwright *et al.* (1998), Bowerman *et al.* (2005). The parameter α, β and γ are smoothing parameters of each equation usually lies between 0 to1. However, the frequency of the seasonality is denoted via 'm', if m= 4, m=12 represent quarterly and monthly data respectively.

Holt-Winters' Additive method

This method is useful for data with trend and seasonality which changes with time. In this method trended forecast are incorporated into seasonality factor and the resulting forecast shows seasonal changes in the data. The seasonal component is treated additively but practically this method is less commonly used. Following are the equations of Holt-Winters' Additive method,

Overall smoothing: $L_t = \alpha(X_t - s_{t-m}) + (1-\alpha)(m_{t-1} + b_{t-1})$

Trend smoothing: $b_t = \beta(L_t - L_{t-1}) + (1-\beta)\, b_{t-1}$

Seasonal smoothing: $S_t = \gamma(X_t - L_{t-1} + b_{t-1}) + (1 - \gamma) S_{t-m}$

Forecast: $\hat{Y}_{t+1} = L_t + b_t h + S_{t-m+} h_m^+$.

Trend equation for both additive and multiplicative Holt-Winters' method is same whereas seasonal and overall smoothing equations are different.

Result and discussion

In this section rainfall pattern is identified and modeled. Moreover, relationship between rain fall and maximum temperature and minimum temperature has been discussed.

Rainfall

Rainfall data converted into inches from millimeter (mm) to stabilize high and low peeks, while this conversion does not affect model building. Fig. 2 displays average monthly rain fall data of Quetta region. A clear seasonal pattern can be observed from the graph. Furthermore, in February 1982 it has highest rain fall i.e. 9.29 inches and minimum zero. Most of rain fall occurs during 1980 to 1992. However, from 1996 to 2010 is observed as a less rain fall period, this period also consists of drought situation.

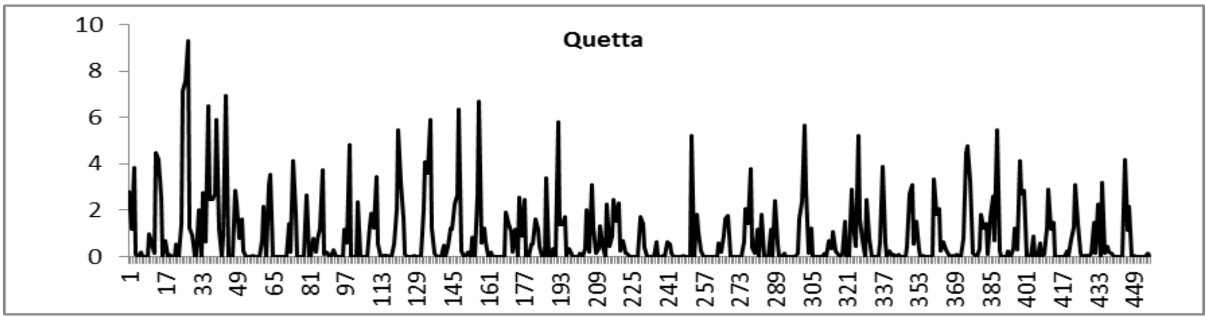

Fig 2. Plot of average monthly rainfall of Quetta 1980-2017.

In order to observe the clear yearly rain fall pattern annual average rainfall is computed and presented in Fig. 3. It shows that year 1982 has highest average rainfall i.e. 3.29 milliliters. Furthermore, period 1984 to 1990 and period 1993 to 2010 are considered lowest rainfall periods. Besides this, the period 2014 to 2017 has also less rain fall. Only years 1982, 1983 and 2011 have highest average rainfall overall and for the rest of years the average rain fall is below 1.2 (millimeters) Fig. 3. Based on the graphical analysis less rainfall is expected in future in the study area due to global changes being observed worldwide. This phenomenan will be confirmed by future forecast using Holt-Winters' methods, discuss in the section of forecasting rainfall.

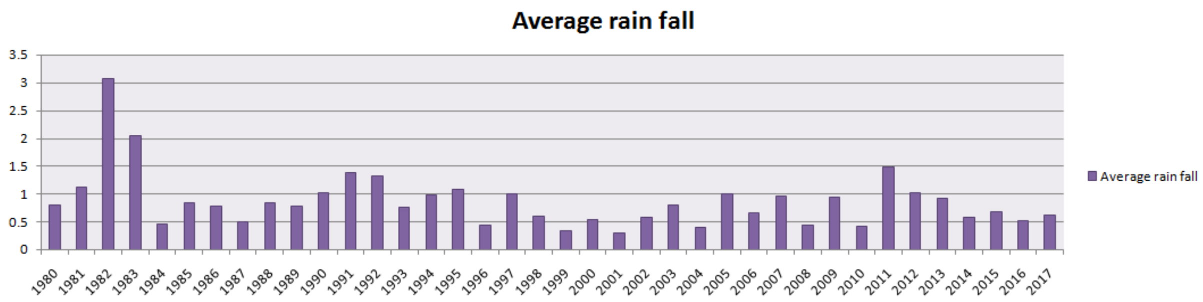

Fig 3. Average yearly rainfall.

Maximum and Minimum temperatures

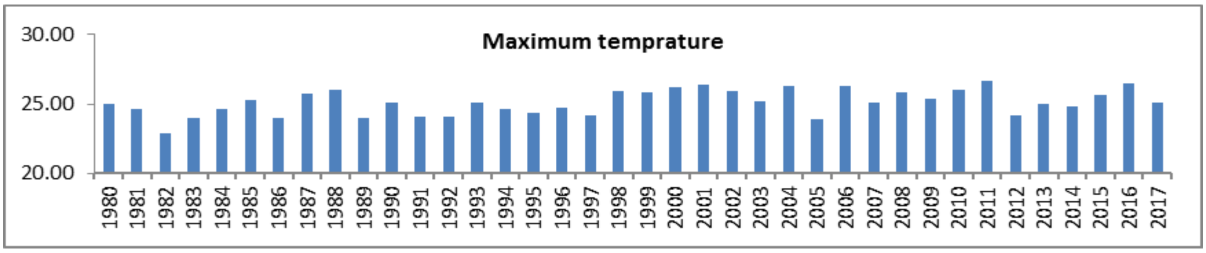

Fig 4. Average yearly maximum temperature.

Fig. 4 shows average annually maximum temperature that is approximately 27C°, similarly the average annual minimum temperature is 10C° Fig. 5. The increasing and decreasing temperatures are quite smooth.

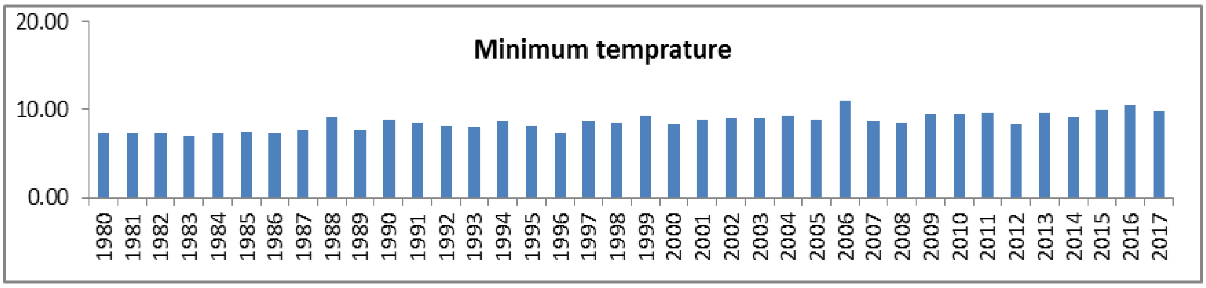

Fig 5. Average yearly minimum temperature.

Relationship between Rainfall and Temperature (Maximum and Minimum)

The relationship between rainfall and temperatures is estimated via regression equation. The table below reports the output of regression equation. The coefficient of maximum temperature has positive value indicates that 1°C rise in maximum temperature will increase rainfall 0.253 inches (see Table 1). Whereas, the coefficient of minimum temperature has negative value indicates that 1 C° fall in minimum temperature will decrease rainfall 0.304 inches (see Table 1). The coefficients are significant at 5% level. Value of R^2 suggests that rainfall is explained by temperature (minimum and maximum) only 44%.

Table 1. Output of Regression equation.

Predictor	Coefficient	S.D	T-statistic	P-value
C	6.3663	0.3153	20.19	0
AV Max .Tep	0.25361	0.0205	12.37	0
AV Min .Tep	-0.30476	0.01889	-16.14	0
S = 1.105	R-Sq	0.44	R-Sq(adj) =	44%

Forecasting Rainfall

Average monthly rainfall from January, 1980-December, 2016 is considered for modeling whereas remaining data from January 2017 to December 2017 is used for validation of the model. Furthermore, January 2018 to December 2020 are forecasted. In this study Holt-Winters methods (additive and multiplicative) are used to model and forecast. First, Holt-Winters additive method is applied, different value of parameter such as level (α), trend (β) and seasonal (γ) smoothing are chosen between 0 to1. To assess performance of models two measures such as mean absolute deviation (MAD) and mean squares error (RMSE) are used. For all the selected measures, the smaller value indicates a more accurate prediction. The MAD and RMSE are defined as follows;

$$\text{MAD}=\frac{\sum_{i=1}^{m}\left|Y_t-\hat{Y}_t\right|}{m}$$

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{m}\left(Y_t-\hat{Y}_t\right)^2}{m}}$$

Where, Y_t and $\hat{Y}_t$ follows actual and predictive rainfall respectively and 'm' represent the number of observations. The results of Holt-Winters' Multiplicative method are presented in Table 2.

Table 2. output of Holt-Winters' Multiplicative techniques.

Multiplicative				
α (level)	γ (trend)	δ (seasonal)	RMSE	MAD
0.2	0.2	0.2	24.62	15.3
0.2	0.2	0.3	370.1	116.12
0.2	0.2	0.4	5.74	3.3
0.2	0.2	0.5	2.22	1.61
0.2	0.2	0.6	1.43	0.82
0.2	0.3	0.2	1.42	0.77
0.2	0.4	0.2	1.96	1.03
0.2	0.5	0.2	12.9	6.4
0.2	0.6	0.2	21.63	9.6
0.3	0.2	0.2	1.78	1.07
0.4	0.2	0.2	2.73	1.88
0.5	0.2	0.2	11.79	6.06
0.6	0.2	0.2	298.38	107.42

Above table shows that Holt-Winters' Multiplicative model with α = 0.2, γ = 0.3 and δ=0.2 has minimum value among all developed models.

Table 3, reports that Holt-Winters' Additive model has minimum validation error for the α = 0.2, γ = 0.4 and δ=0.2. However, overall performance of Holt-Winters' Additive method is much better than Multiplicative method. Using estimated values of the parameter by Holt-Winters' Additive and Multiplicative methods average monthly rainfall from January 2018 to December 2020 is forecasted. Fig. 6 & 7, show the actual and estimated values of both methods and also forecasted 2018 to 2020. Comparing Fig. 6 & 7 Holt-Winters' additive method gives much better forecast. A declining behavior is observed, negative or zero value of rainfall indicates drought situation will happen in future.

Table 3. Output of Holt-Winters' Additive technique.

Additive				
α (level)	γ (trend)	δ (seasonal)	RMSE	MAD
0.2	0.2	0.2	1.03	0.644
0.2	0.2	0.3	1.04	0.59
0.2	0.2	0.4	1.04	0.57
0.2	0.2	0.5	1.05	0.6
0.2	0.2	0.6	1.06	0.63
0.2	0.3	0.2	1.034	0.65
0.2	0.4	0.2	1.02	0.56
0.2	0.5	0.2	1.04	0.615
0.2	0.6	0.2	1.32	1.17
0.3	0.2	0.2	1.06	0.77
0.4	0.2	0.2	1.24	1.02
0.5	0.2	0.2	1.2	0.94
0.6	0.2	0.2	1.2	1.007

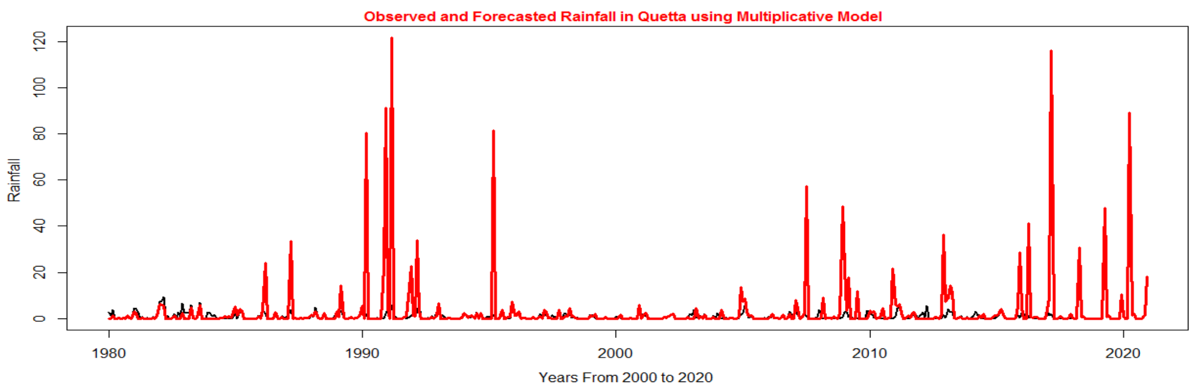

Fig 6. Plot of Actual and estimated values of rainfall by Holt-Winters' multiplicative method.

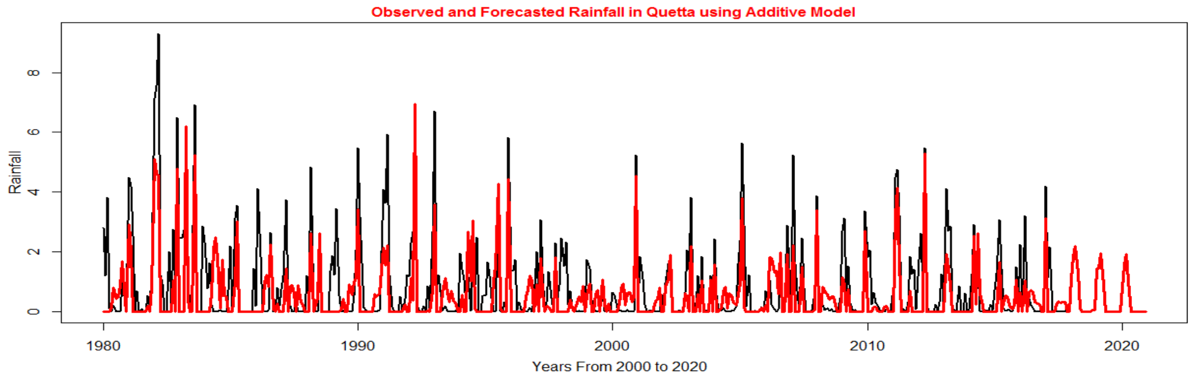

Fig 7. Plot of Actual and estimated values of rainfall by Holt-Winters' additive method.

Conclusion

Precipitation is an important element in maintaining the atmospheric balance since without this the globe would be an enormous desert. The quantity and length of precipitation both have significant importance. One of its positive impact is that it helps farmers to grow crops, on contrary it may cause severe flood situation. Therefore, it is important to note how rainfall series typically changes with respect to temperature showing statistical behavior over long time periods. This study investigates relationship between rainfall and temperatures via regression equation. Empirical analysis demonstrates that one unit change in maximum temperature causes 2.5% inches increase in rainfall. Whereas, one unit increase in minimum rainfall will decreases 3% precipitation. Furthermore, average monthly rainfall 2018 to 2020 is forecasted via Holt-Winters' multiplicative and additive methods. RMSE and MAD have minimum value in Holt-Winters' additive method. Therefore, Holt-Winters' additive process is suggested appropriate as compared to Holt-Winters' multiplicative method for future forecast. The forecasted values will helpful to the disaster management to understand the future rainfall patterns either drought or flood situation will happen. Moreover, it will also helpful to farmers in order to take decision regarding for sowing crops, fruit and dry fruit on appropriate time.

Acknowledgement

Authors are highly grateful to Pakistan Meteorological Department for data provision. Authors are very thankful to anonymous reviewers/ experts for their valuable comments and feedback.

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