RETURN LEVEL ESTIMATES OF MAXIMUM TEMPERATURE FOR DIFFERENT RETURN PERIOD

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Abstract

Since the problem of global warming and heat waves are the burning issues and became challenge for scientists in this era. Current analysis is also an attempt to solve this problem in Karachi Pakistan. This effort is to analyze frequency distribution by using daily maximum temperature data and then to find the best fitted probabilistic model for yearly maximum temperature series to see the possible return levels of maximum temperature in Karachi. After passing through a number of goodness of fit tests the Log-Logistic [3P] distribution is found to be the best fitted model to calculate return levels. Analysis also indicates that there is a chance of getting 44.3°C temperature return level in the next coming 5 years, 45.8°C in coming 20 years and 46.5°C return levels in coming 50 years return period. These return levels propose that the Government officials and planners to take notice on plantation, water supply system, to facilitate better public transport to reduce the number of vehicles, to update health system, to increase electricity production etc. The results of this analysis are also useful to agricultural and environmental research.

Keywords : Return level, Maximum Temperature, Return Periods, Heat waves, probabilistic model etc.

I. Introduction

“Extreme weather events are the heaviest and the lowest condition of atmospheric parameters for example thunderstorm, flood, tropical cyclone, heat waves, and cold waves etc., prevailed in a locality”. The extreme value theory has been developed in the mid of 20\textsuperscript{th} century (Gumbel, 1958and; Grant et al., 2014) and later on the application of this theory in different fields of life has been introduced by different scientists for example (Smith, 1989; Salim et al., 2015 & Iqbal et. al., 2012) presented its application in environmental sciences, (Coles, 2001) and (Katz et al., 2002) showed its application in hydrology. Probabilistic approaches are applicable on
stationary series of data (Parey et al., 2010). According to the prediction of Global Circulation Model (GCM) there will be an increment of temperature from 1.4 to 5.8 °C by the end of 21st century due to increment of greenhouse gases in atmosphere (Rootzén and Katz., 2013). Design life level: quantifying risk in a changing climate. Water Resources Research, 49 (9), 5964-5972. The rate of evaporation is increased due to the increment in temperature resulting the accumulation of clouds and hence the long wave radiation is being trapped resulting more increment in night temperature as compare to day temperature. On the basis of this shifting of temperature, the long term and short term period of heat stress is expected to be happen more frequently which has negative effect on crop growth, crop yield, and development. This heat stress reduces the crop production by slowing down the process of photosynthesis and growing the respiration rate, reducing floral bud development, causing male sterility and low pollen viability and accelerating crop maturity (Meehl & Tebaldi, 2004). Since crops are very subtle to the variation of temperature and when temperature exceeds the limit of tolerance of a crop then the yield of crops will reduce significantly. Scientists showed that there would be harmful changes in phenological stages crops even a rise of 1°C in temperature (Hatfield & Prueger, 2015). It is calculated that there is a 33% decrement in major crops in Sindh Province due to warm and dry condition of weather (Raza et al., 2019 and Abbas et. al., 2018). Literature also depicts that there is a high chances of promptly spreading harmful insects in summer season due to increase in temperature and humidity (Arreyndip et al., 2015). The production of wheat, rice, banana, mango, cotton and dates etc. in Sindh province are dependent upon extreme temperature (Mothupi et al., 2016). The extreme temperature events have become the burning issue among the researchers now a days due to its hazardous impact on mortality risks (IPCC, 2012). The summer temperature is very high in Sindh province and the beginning of monsoon season also add up high humidity, which collectively results heat wave in the region (Zahid et. al., 2015). The exceptionally warm and moist conditions may get fatal impacts and can also effect physical behavior of human being in this region (Pal and Eltahir 2015). (Sheridan and Allen, 2015) also concluded that the chances of occurring the maximum temperature events is increasing with time. The recent heat wave occurred in southern Pakistan in 2015 is an example of increasing maximum temperature which got devastating impact on this region. Analysis showed that approximately 1200 people lost their lives and 14000 people were hospitalized during this heat wave from 17 to 24 June 2015 (Zahid et. al., 2015). Literature also showed that the maximum temperature of 45.5°C to 49°C remained in different cities of Sindh during heat wave (Imtiaz and Rehman, 2015). (Chaudhary et. al., 2015) analyzed heat waves and concluded an early warning system in his technical report in order to minimize the losses. The parameters in the field of meteorology are interlinked with each other and strongly influential on climatic extremes (Kayes, I., et. al. 2019). Scientists have to face the challenge of global warming in 21st century and this climate change has affected on different climatic parameters such as atmospheric temperature of the globe, oceanic temperature, pattern of rainfall and wind etc. (Zahid et. al., 2015). Basically human body maintains its temperature approximately 37°C for which our skin works as a regulator to maintain the temperature at or below 35°C (Sherwood and Huber, 2010). When temperature increases above threshold with
high level of humidity in air then human body is unable to maintain temperature below 35°C and may get heat stroke and cardiac problems. These extreme events are very harmful for economic and social conditions of a locality (Orlowsky and Seneviratne., 2012). The event in 2015 prominently showed that how much vulnerable the province is, regarding heat waves. Current study focuses on the possible effects of heat waves in the province of Sindh especially in Karachi.

II. Data Description and Methodology

The daily maximum temperature of Karachi from 1979 to 2018 have been collected from Pakistan Meteorological Department (PMD) to analyze the heat wave situation in Karachi. The monthly maximum and yearly maximum temperature have been extracted from this daily data to use probabilistic modelling in this analysis. The time series plot of monthly values of summer seasonal maximum temperature shows no trend in the data as shown in (Fig. 1). This can also be verified mathematically by calculating autocorrelation coefficient ($R_h$) which should be in between -1 & 1.

![Fig. 1: Scatter plot of Monthly Max. Temperature of Karachi from 1979 to 2018.](image)

II.i. Data Homogeneity Test

Determination of autocorrelation coefficient and its plot is generally used in research to check the homogeneity of the data. If the data is homogeneous then this coefficient must be near to zero (Mayooran & Laheetharan, 2014) for varying time lag (h). So mathematically:

$$R_h = \frac{c_h}{c_0}, \quad -1 \leq R_h \leq 1$$  \hspace{1cm} (1)

Where $c_h$ is an auto covariance function and $c_0$ is the variance function, mathematically defined as;

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The calculated autocorrelation coefficient by using the above equations is $R_h = -0.143$, which also depicts that current data has no trend in it.

II.i. Frequency Analysis of seasonal Maximum Temperature

Threshold value of maximum temperature is defined first as the average maximum temperature of each month plus standard deviation of that month. These threshold values of temperature for each month are shown in (Fig. 2). Now all the values of monthly maximum temperature greater than threshold have been extracted and defined the frequency of each event in every month. Yearly analysis of these frequency distribution shows that highest number of extreme events i.e. 53, took place in 2007 while those of lowest (10 events) in 1990. Yearly analysis also inculcate that there is an increasing trend in the frequency of monthly maximum temperature events as shown in (Fig. 3). Monthly analysis depicts that June is the most vulnerable month for heat waves while September is the least among the months of summer season in Karachi.

![Threshold](image)

**Fig. 2:** Estimated monthly threshold Values of Maximum Temperature.
II.iii. Probabilistic Model Fitting to Maximum Temperature Data

Sixty probabilistic models have been applied to monthly maximum temperature Karachi station by using Easy-Fit software to find the best fitted model. Three prominent goodness of fit tests, Kolmogorov-Smirnov (KS), Anderson-Darling (AD) and Chi-Squared ($\chi^2$) test at 0.01 level of significance have been employed to compare and get the best fitted model (Sharma et al., 2016 and Rizwan et al., 2018). Each test ranks the fitted distributions on the basis of minimum value of test statistics. As per ranks of these goodness of fit tests the topmost five ranked distributions for each test have been selected as shown in (Table 1). Goodness of fit indicates that Log Logistic [3P] distribution is the most suitable distribution for yearly maximum temperature series.

![Frequency analysis of summer seasonal Max. Temperature above threshold.](image)

**Fig. 3:** Frequency analysis of summer seasonal Max. Temperature above threshold.

**Table 1: Goodness of Fit Test for Yearly Extreme Temperature of Karachi.**

| Top Five Ranked Probability Distributions based on the minimum value of test statistics | Kolmogorov Smirnov (K-S) | Anderson Darling (A-D) | Chi-Square ($\chi^2$) | Ranks |
|---|---|---|---|---|
| Distribution | Statistic | Distribution | Statistic | Distribution | Statistic | |
| Log-Logistic (3P) | 0.10934 | Burr (4P) | 0.58388 | Pareto | 0.08103 | 1 |
| Burr | 0.11195 | Burr | 0.60602 | Exponential (2P) | 0.21426 | 2 |
| Burr (4P) | 0.11528 | Error | 0.61664 | Cauchy | 2.3973 | 3 |
| Dagum (4P) | 0.11717 | Laplace | 0.61664 | Logistic | 2.4453 | 4 |
| Hypersecant | 0.11753 | Hypersecant | 0.65579 | Rayleigh | 2.5569 | 5 |
II.iii.a. Log Logistic Distribution [3P]

A distribution of a non-negative random variable whose logarithm has a logistic distribution is known as log-logistic distribution (Omer et al., 2019). The probability density function of the distribution is:

\[
f(x) = \frac{\alpha}{\beta} \frac{(x-\gamma)}{\beta}^{\alpha-1} \left[1 + \left(\frac{x-\gamma}{\beta}\right)^\alpha\right]^{-2}
\]

Now analytical integration of eq. (2) gives cumulative distribution function as:

\[
F(x) = \left[1 + \left(\frac{x-\gamma}{\beta}\right)^\alpha\right]^{-1}
\]

Where \(\alpha\), \(\beta\) and \(\gamma\) are continuous shape \((\alpha > 0)\), scale \((\beta > 0)\) and location parameter \((\gamma \equiv 0)\) whose calculated values are shown in (Table 2).

**Table 2: Parameter Estimates of the selected top Five Ranked Distributions by K-S, A-D and \(\chi^2\) Goodness of Fit Tests.**

| # | Distribution | Parameters |
|---|-------------|------------|
| 1 | Burr | \( k=0.89567, \quad \Box=46.644, \quad \square=42.571 \) |
| 2 | Burr (4P) | \( k=0.78172, \quad \Box=3.9961E+5, \quad \Box=3.4525E+5, \quad \Box=-3.4521E+5 \) |
| 3 | Cauchy | \( \Box=0.75743, \quad \Box=42.425 \) |
| 4 | Dagum (4P) | \( k=0.98895, \quad \Box=6.3754E+5, \quad \Box=6.1047E+5, \quad \Box=-6.1043E+5 \) |
| 5 | Error | \( k=1.0, \quad \Box=1.903, \quad \Box=42.753 \) |
| 6 | Exponential (2P) | \( \Box=0.14179, \quad \Box=35.7 \) |
| 7 | Hypersecant | \( \Box=1.903, \quad \Box=42.753 \) |
| 8 | Laplace | \( \Box=0.74314, \quad \Box=42.753 \) |
| 9 | Log-Logistic (3P) | \( \Box=73816.0, \quad \Box=70557.0, \quad \Box=-70514.0 \) |
| 10 | Logistic | \( \Box=1.0492, \quad \Box=42.753 \) |
| 11 | Pareto | \( \Box=5.5778, \quad \Box=35.7 \) |
| 12 | Rayleigh | \( \Box=34.112 \) |
II.iii.b. Return Levels

The main purpose of this analysis is to find the return levels of maximum temperature, with satisfactory significance level after getting the best fitted model. Now inverting the CDF of Eq.(5) gives quantile function (Rust et al., 2011 and Rust et al., 2010);

\[ X = F^{-1}(p) = \gamma + \beta \left( \frac{1}{1 - F(x)} \right)^{1/\alpha} \]  

(6)

Where \( P = F(x) = \frac{1}{T} \)  

(7)

In this equation T is called return period of the concerned data, depending on cumulative distribution function which will be calculated as;

\[ F(x) = 1 - p \]  

Equation (6) is used to calculate return levels of summer seasonal maximum temperature in Karachi.

![Fig. 4: Return levels of Karachi maximum temperature against different Return periods.](image)

II.iv. Goodness of Fit Tests to Classify the Best Fitted Distribution:

Sixty probabilistic distributions are to summer extreme temperature of Karachi using Easy-Fit package to find the best fitted distribution. Herethree goodness of fit tests are used i.e. K-S, A-D and \( \chi^2 \) at 0.01 level of significance to check, if the sample of data came from population with specific distribution or not. Null hypothesis (Ho) shows the statement that the yearly maximum temperature of Karachi follow the identified distributions.

Each GoF tests ranks the fitted distributions as per its criteria from 1 to 60 from which the first five ranked probabilistic models are picked up as per each GoF test, based on least test statistic value as shown in (Table 1). All the parameters of these selected distributions are estimated and shown by (Table 2).

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Now to select the best one among these selected models, the absolute deviations for each selected models are calculated and shown in (Table 3), by using formula defined by (Mayooran & Laheetharan, 2014);

\[
\text{Absolute Deviation} = AD = \left| \sum_{i=1}^{n}(T_i - \hat{T}_i) \right|
\]

(9)

Where \(T_i\) is the actual value and \(\hat{T}_i\) is the estimated value of maximum temperature by selected models. This method indicates that Log-Logistic [3P] distribution is the best fitted distribution for the maximum temperature data of Karachi. Having the more area covered by Log-Logistic [3P] distribution than others by histogram with fitted probability density function, (Fig.5) also verifies the above result which is further strengthened by the result of P-P plot, Q-Q Plot as well. Hence Log-Logistic [3P] distribution is the best fitted one for maximum temperature data of Karachi.

**Table 3: Absolute Deviation (AD) for the selection of the best fitted distribution.**

| S. No. | Distribution    | Absolute Deviation (AD) |
|--------|-----------------|-------------------------|
| 1      | Log-Logistic 3p | 1.45                    |
| 2      | Error           | 1.56                    |
| 3      | Laplace         | 1.77                    |
| 4      | Hypersecant     | 2.03                    |
| 5      | Burr            | 2.10                    |
| 6      | Cauchy          | 2.17                    |
| 7      | Logistic        | 2.33                    |
| 8      | Burr 4P         | 2.59                    |
| 9      | Dagum (4P)      | 3.30                    |
| 10     | Exp. (2P)       | 5.77                    |
| 11     | Pareto          | 5.85                    |
| 12     | Rayleigh        | 19.44                   |
Fig. 5: Comparative Study of Probability density function $f(x)$ of Top ranked Probabilistic Models fitted to yearly Max. Temperature $[x]$ of Karachi.

III. Results and Discussion

Scatter plot of maximum temperature of Karachi indicates that there is no trend in the data series. Standard deviation of the data is added with average maximum temperature and defined threshold value (Fig. 2), on the basis of which frequency of extreme temperature is defined during the study period. Monthly analyzes of extreme temperature shows that the month of June is the most vulnerable month and also indicates the worst heat waves of 2015 with highest frequency of 14 events shown in Table (1). Yearly analysis of maximum temperature above threshold indicates increasing trend with time as depicted in (Fig. 3), which is a sign of ultimatum for research scholars.

Now in order to find the return levels of maximum temperature for different return periods, more than fifty distributions have been applied to yearly maximum temperature of Karachi. Three prominent goodness of fit tests, Kolmogorov-Smirnov (KS), Anderson-Darling (AD) and Chi-Squared ($\chi^2$) test at 0.01 level of significance have been employed to compare and get the best fitted model. As per fitting criteria of goodness of fit tests the topmost five ranked distributions have been selected for each test as revealed in (Table 1). Estimated parameters of each selected distribution are shown in (Table 2). In order to find the best fit distribution among these five ranked distributions, the absolute deviations of each model have been estimated and compared. From this comparison Log Logistic [3P] distribution is found to be the most suitable, having least absolute deviations for yearly maximum temperature of Karachi as shown in (Table 3). To increase the level of confidence, Histogram with fitted probability distribution have also been plotted in (Fig. 5), which strengthen the above goodness of fit result. Now after selecting the best fitted distribution, we find return levels estimate by using equation (6) as shown in (Table 4). Now analysis of these return levels show exponential growth as revealed in (Fig. 4).
Table 4: Expected Return levels of Annual extreme Temperature of Karachi.

| Return Period (T) (years) | Probability of Occurrence p =1/T | Cumulative Probability F(x) =1-p | Return Levels Estimates [X= F^{-1}(p)] (°C) |
|---------------------------|----------------------------------|----------------------------------|---------------------------------------------|
| 2                         | 0.5000                           | 0.5000                           | 43.000                                      |
| 5                         | 0.2000                           | 0.8000                           | 44.325                                      |
| 10                        | 0.1000                           | 0.9000                           | 45.100                                      |
| 15                        | 0.0667                           | 0.9333                           | 45.522                                      |
| 20                        | 0.0500                           | 0.9500                           | 45.814                                      |
| 25                        | 0.0400                           | 0.9600                           | 46.038                                      |
| 30                        | 0.0333                           | 0.9667                           | 46.220                                      |
| 35                        | 0.0286                           | 0.9714                           | 46.370                                      |
| 40                        | 0.0250                           | 0.9750                           | 46.502                                      |
| 45                        | 0.0222                           | 0.9778                           | 46.618                                      |
| 50                        | 0.0200                           | 0.9800                           | 46.720                                      |

IV. Conclusion

The purpose of current work is to estimate the return levels of extreme temperature for different return period. As the selected study area is Karachi Pakistan where maximum temperature plays vital role in climatic conditions. The people of this area also faced the worst condition of heat waves recently in June, 2015. This cruel condition of heat waves also took thousands of lives in 2015 leaving a big question mark for research scholars. For this purpose the daily maximum temperature series of Karachi from 1979 to 2018 have been analyzed. The increasing trend of maximum temperature events per year is also alarming for researchers and planners to work on it for the betterment of human being living in this area.

Return level estimation against different return period plays vital role in urban planning especially in extreme value analysis. Current analysis is also an attempt to solve this problem in Karachi Pakistan. The efforts in this work is to analyze frequency distribution by using daily maximum temperature data and then to find the best fitted probabilistic model for yearly maximum temperature of Karachi in order to see the most possible conditions of temperature in future through the estimation of return levels. The frequency analysis of extreme temperature above threshold per year indicates positive trend with time. For this purpose more than 50 probabilistic models have been tested by passing through step by step Goodness of Fit Tests (GoFT) to achieve the highest level of confidence. These GoFT include Kolmogorov-Smirnov (KS), Anderson-Darling (AD), Chi-Squared ($\chi^2$) test at 99%
level of confidence, Histogram with fitted probability plot, P-P plots, Q-Q plots and absolute deviation method. First of all on the basis of least value of test statistics, the topmost five probabilistic models have been selected for each test and also calculated the parameters of each distribution. By using these parameters, random numbers have been generated for each distribution and then absolute deviations have been calculated using to find the best fitted one. These GoFT concludes that Log Logistic [3P] distribution is the best model to explain the behavior of Karachi maximum temperature. Now the formula of probability distribution function and quantile function of Log-Logistic [3P] distribution are found to calculate the future return levels against different return periods. From the analysis of these calculated return levels it can be shown that there is a chance of getting 44.3°C return level in the next coming 5 years while 45.8°C in the next 20 years return period. Analysis also depicts that the rate of increment slows down upon increasing return period and becomes approximately constant if rounded up to on decimal place. In this way approximately 46.5°C of return level is expected in coming 50 years and above return period. These return levels propose that the Government officials and planners to take serious notice on plantation, water supply system, facility of public transport to reduce the number of vehicles, to update health system, to increase the capacity of electricity production etc.

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