Journal of Environmental Statistics

September 2018, Volume 8, Issue 8. http://www.jenvstat.org

On Identifying the Probability Distribution of Monthly Maximum Temperature of Two Coastal Stations in Bangladesh

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Abstract

Rising temperature in the atmosphere causes sea level rise and affects low lying coastal areas and deltas of the world. The last decade of the twentieth century was globally the hottest since the beginning of worldwide temperature measurement during the nineteenth century. Many PDFs have been proposed in recent past, but in present study Weibull, Lognormal, Gamma, GEV, etc are used to describe the characteristics of maximum temperature. This paper attempts to determine the best fitted probability distribution of monthly maximum temperature. To identify the appropriate probability distribution of the observed data, this paper considers a data set on the monthly maximum temperature of two coastal stations (Cox's Bazar and Patuakhali) over the period January, 1971 to November, 2015 and January, 1973 to November, 2015 respectively. To check the accuracy of the predicted data using theoretical probability distributions the goodness-of-fit criteria like KS, R^2, χ^2, and RMSE were used in this paper. According to the goodness-of-fit criteria and from the graphical comparisons it can be said that Generalized Skew Logistic distribution (GSL) provides the best fit for the observed monthly maximum temperature data of Cox's Bazar and Weibull (W) gives the best fit for Patuakhali among the probability distributions considered in this paper.

Keywords: Temperature, Probability Distribution, Model Selection, Coastal Area, Bangladesh.

1. Introduction

Climate change is an important issue nowadays. Various human activities are making the world warmer. The ultimate result is global warming, i.e. climate change. Rising temperature in the atmosphere causes sea level rise and affects low lying coastal areas and deltas of the world. In 1990, Intergovernmental Panel on Climate Change estimates that with a business-as-usual scenario of greenhouse gas emission, the world would be 3.3^0C warmer by the end of twenty first century (Warrick, Bhuiya, and Mirza 1993). In light of recent climate trends and current predictions for the twenty-first century, climatic change is becoming a major concern for scientists and society in general. There is an increasing interest in different parts of the world in research on extreme temperatures and their variation. Temperature extremes are an important aspect of any climate change because ecosystems and societal responses are most sensitive to them. Mearns, Katz, and Schneider (1983) and Hansen, Fung, Lacis, Rind, and Lebedeff (1988) concluded that relatively small changes in the mean temperature could produce substantial changes in the frequency of temperature extremes. The last decade of the twentieth century was globally the hottest since the beginning of worldwide temperature measurement during the nineteenth century.Alexander, Zhang, Peterson, Caesar, and Others (2006) showed that annual trends in the lowest and highest daily minimum and maximum temperatures in the latter half of the twentieth century increased at many locations throughout the world.

In the past, a number of studies have been carried out on trend of climatic parameters like temperature in Bangladesh. Chowdhury and Debsharma (1992) and Mia (2003) pointed out that temperature has been changing over time. Parthasarathy, Sontake, Monot, and Kothawale (1987) and Mehrotra and Mehrotra (1995) reported mean annual temperature of Bangladesh has increased during the period of 1895-1980. Karmakar and Shrestha (2000)using the 1961-1990 data for Bangladesh projected that annual mean maximum temperature will increase to 0.4^0C and 0.73^0C by the year of 2050 and 2100 respectively. Ahmad, Warrick, Ericksen, and Mirza (1996) reported an increase of 0.5^0C in temperature over Bangladesh during past 100 years. Mondal and Wasimi (2004) analyzed the temperatures and rainfalls of the Ganges Delta within Bangladesh and found an increasing trend and increased by 0.5^0C and 1.1^0C per century in day-time maximum and night-time minimum temperatures, respectively. Rahman and Alam (2003) found that the temperature is generally increasing in the June-August period. Average maximum and minimum temperatures show an increasing trend of 5^0C and 3^0C per century, respectively. On the other hand, average maximum and minimum temperatures of December-February period show, respectively, a decreasing and an increasing trend of 0.1^0C and 1.6^0C per century. Regional variations have also been observed around the average trend (SMRC 2003). In a recent study, Climate-Change-Cell (2009) has analyzed the temperature and sunshine duration at all BMD stations of Bangladesh. Islam and Neelim (2010) analyzed the maximum and minimum temperatures of four months (January, April, May and December). The two months of April-May were considered as the summer season and the two months of December-January as the winter season in the study. The study found in general an increasing trend in both summer and winter temperatures. In a study at the International Rice Research Institute, Peng, Huang, Sheehy, Laza, Visperas, Zhong, Centeno, Khush, and Cassman (2004)found a 10% decrease in rice yield per 10C increase in growing season night temperature. Increased surface temperature tends to release more carbon from the top soils which in turn reduces fertility of lands. Wheat production is very vulnerable to temperature rise (WB 2000). Donat and Alexander (2012) shown that the distribution of global daily temperatures has indeed become ”more extreme” since the middle of the 20th century.

This study considers two coastal stations (Cox’s Bazar and Patuakhali). Cox’s Bazar is one of the world's longest uninterrupted natural sandy sea beaches. The beach in Cox's Bazar is an unbroken 125 km sandy sea beach with a gentle slope. It is located 150 km south of the industrial port Chittagong. Cox's Bazar is also known by the name Panowa, whose literal translation means "yellow flower". Today, Co"s Bazar is one of the most-visited tourist destinations in Bangladesh, though it is not a major international tourist destination, and has no international hotel chains. In 2013, the Bangladesh Government formed the Tourist Police unit to better protect local and foreign tourists, as well as to look after the nature and wildlife in the tourist spots of Cox's Bazar (for details see, `https://en.wikipedia.org/wiki/Cox's_Bazar`). Also, Patuakhali is a district in South-western Bangladesh. It is a part of the Barisal Division. This is the main entrance for the beach of Kuakata (for details see `https://en.wikipedia.org/wiki/Patuakhali_District`). Kuakata offers a full view of the sunrise and sunset from the same white sandy beach in the water of the Bay of Bengal. Locally known as Shagor Kannya (Daughter of ocean), the long strip of dark, marbled sand stretches for about 30 km. There is a long and wide natural beach at Kuakata. This sandy beach has gentle slopes into the Bay of Bengal. Kuakata is also a sanctuary for migratory winter birds. One may also visit the 100 years old Buddhist Temple where the statue of Goutama Buddha and two Wells of 200 years old are to be found. Nowadays, local people are more supportive to the tourists and communications have improved significantly (for details see, `https://en.wikipedia.org/wiki/Kuakata`). Impacts of climate change would result from changes in variability and extreme event occurrence rather than from an increase in mean temperature (Houghton, Filho, Callander, Harris, Kattenberg, and Maskell 1996; Watson, Zinyowera, Moss, and Dokken 1996; Parmesan, Root, and Willig 2000). This study considers two coastal areas because they are the two main attractive places for the tourist. The contribution of tourism has significant effect on the growth of GDP of Bangladesh. Nowadays, tourists try to conjecture about weather condition of a place before traveling. Temperature is the important variable. Impacts of extreme events are more serious when extreme weather conditions prevail over extended periods. That is why this study tries to fit the appropriate probability distribution of monthly maximum temperature. The Extreme-value data can be characterized by theoretical probability distributions. For the probability estimates of annual temperature extremes, the two-parameter Gumbel distribution and the three-parameter generalized extreme value (GEV) distribution are commonly applied (Farago and Katz 1990; Brown and Katz 1990; Zwiers and Kharin 1998; Kharin and Zwiers 2000) (Kharin and Zwiers, 2000). Hossain, Abadulla, and Rahman (2016) shown that the Generalized Skew Logistic distribution (GSL) provided the best fit for the observed monthly maximum temperature data of Dhaka station. This paper attempts to determine the most suitable probability distribution of monthly maximum temperature and check the accuracy of the fitted probability distributions using the goodness-of-fit criteria.

2. Materials and Methods

2.1. Data

This paper considers a data set on the monthly maximum temperature of two coastal stations namely Cox's Bazar and Potuakhali over the period January, 1971 to November, 2015 and January, 1973 to November, 2015 respectively. The required data was collected from the website of Bangladesh Agricultural Research Council (BARC).

2.2. Probability Distributions

Many Probability Distribution Functions (PDFs) have been proposed in recent past, but in this paper Weibull, Lognormal, Gamma, and GEV are used to describe the characteristics of maximum temperature. Parameters defining each distribution function are calculated using maximum likelihood method.

Weibull (W) Distribution

The probability density function (PDF) of the Weibull distribution with two parameters is given by (Weibull 1951):

$$f(v,k,c) \propto \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right]; 0 < v < \infty, k > 0, c > 0 \tag{1}$$

where, k and c are the shape and scale parameters respectively.

Lognormal (LN) Distribution

Lognormal distribution is a probability distribution of a random variable whose logarithm is normally distributed. The probability density function (PDF) of the Lognormal distribution is given by (Johnson et al. 1994):

$$f(v,\mu,\sigma) \propto \frac{1}{v\sqrt{(2\pi\sigma^2)}} \exp\left[\frac{-\left(\ln(v)-\mu\right)^2}{2\sigma^2}\right]; 0 < v < \infty, 0 < \mu < \infty, \sigma > 0 \tag{2}$$

where, μ and σ are the mean and standard deviation of the normal random variable $ln(v)$ respectively.

Gamma (G) Distribution

Lancaster (1966) quotes from Laplace (1836) in which the latter obtains a Gamma distribution. The probability density function (PDF) of the gamma distribution is given by:

$$f(v,a,b) \propto \frac{v^{a-1}}{b^a\Gamma(a)} \exp\left(\frac{-v}{a}\right); v > 0, a > 0, b > 0 \tag{3}$$

The parameters a and b are the shape and scale parameters respectively.

Generalized Extreme Value (GEV) Distribution

GEV distribution is a flexible model that combines the Gumbel, Frechet and Weibull maximum extreme value distributions (Ying and Pandey 2007). For, GEV the probability density function is given by:

$$f(v,\mu,\sigma,\xi) \propto \frac{1}{\sigma}\left[1+\xi\left(\frac{v-\mu}{\sigma}\right)\right]^{\left(\frac{-1}{\xi}\right)-1} \exp\left[-\left[1+\xi\left(\frac{v-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right]; \xi \neq 0 \tag{4}$$

again, for $v > (\mu - \frac{\sigma}{\xi})$ in the case $\xi > 0$, and for $v < (\mu - \frac{\sigma}{\xi})$ in the case $\xi > 0$ where $\mu \in \mathbf{R}$ is the location parameter, $\sigma > 0$ the scale parameter and $\xi \in \mathbf{R}$ is the shape parameter.

Generalized Gamma (3-P G) Distribution

The generalized gamma also known as three parameters gamma distribution is a continuous probability distribution with three parameters. For non-negative v , the probability density function of the generalized gamma is (Stacy 1962):

$$f(v, a, d, p) \propto \frac{\frac{p}{a^d} v^{d-1} \exp - \left(\frac{v}{a}\right)^p}{\Gamma(\frac{d}{p})}; v > 0, a > 0, d > 0, p > 0 \tag{5}$$

where, $\Gamma(.)$ denotes the gamma function.

Three Parameters Lognormal (3-P LN) Distribution

The lognormal distribution derives its name from the relationship that exists between random variables V and $Y = ln(V - a)$. If Y is distributed normally(b, c) , then V is lognormal(a, b, c). Accordingly, the probability density function of V may be written as (Cohen and Whitten 1980):

$$f(v, a, b, c) \propto \frac{1}{(v-a)c\sqrt{(2\pi)}} \exp\left[\frac{-\left[\ln(v-a) - b\right]^2}{2c^2}\right]; a < v < \infty, 0 < a < \infty, \gtrsim 0 \tag{6}$$

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Skewed t (ST) Distribution

There are different parameterizations for the skewed generalized t distribution and the skewed generalized t distribution was first introduced by Panayiotis Theodossiou in 1998 (Theodossiou 1998). For details about Skewed t distribution please visit: https://en.wikipedia.org/wiki/Skewed_generalized_t_distribution#skewed_t_distribution. Also, Indhumathy et al. (2014) and Davis (2015) used the following probability density function (pdf) for Skewed t distribution:

$$f(v) \propto \frac{2}{2\theta_1 \theta_2^{\frac{1}{2}} \beta\left(\frac{1}{2}, \theta_2\right) \left[1 + \frac{|v-\theta_0|^2}{\theta_2 \theta_1^2 [1 + sgn(v-\theta_0)\theta_3]^2}\right]^{\frac{1}{2}+\theta_2}}; -\infty < v < \infty, \theta_1 > 0, \theta_2 > 0, -\infty < (\theta_0, \theta_3) < \infty \tag{7}$$

where, θ_0 and θ_1 are the location and scale parameters respectively, θ_2 and θ_3 are the degrees of freedom and shape parameters respectively and β is the beta function.

Generalized Skewed Logistic (GSL) Distribution

Perks (1932) first introduced the generalized logistic distribution. Zeileis and Windberger (2014) wrote a R Package 'glogis' for Fitting and Testing Generalized Logistic Distributions and they used the following probability density function (pdf) of the generalized skew logistic distribution:

$$f(v, a, b, c) \propto \frac{\gamma}{\sigma} \frac{\exp\left(-\frac{v-\mu}{\sigma}\right)}{\left[1 + \exp\left(-\frac{v-\mu}{\sigma}\right)\right]^{\gamma+1}}; 0 < v < \infty \tag{8}$$

where, μ, σ and γ are the location, scale and shape parameters respectively.

2.3. Goodness-of-fit Tests

Goodness-of-fit tests are used to check the accuracy of the predicted data using theoretical probability function. To evaluate the goodness-of-fit of the PDFs to the monthly maximum temperature data, KS, R^2, χ^2, RMSE, AIC and BIC were used.

Kolmogorov-Smirnov (KS) Error Test

The KS test computes the largest difference between the cumulative distribution function of the model and the empirical distribution function. The KS test statistic is defined as $D = max_{1<i<n}|F_i - \hat{F}_i|$ where, $\hat{F}_i$ is the predicted cumulative probability of the i^{th} observation obtained with the theoretical cdf and F_i is the empirical probability of the i^{th} observation are obtained with the Cunnane (1978) formula: $F_i = \frac{i-0.4}{n+0.2}$ where, $i = 1, ..., n$ is the rank for ascending ordered observations.

R^2 Test

The R^2 test is used widely for goodness-of-fit comparisons and hypothesis testing because it quantifies the correlation between the observed cumulative probabilities and the predicted cumulative probabilities of a monthly maximum temperature distribution. A larger value of R^2 indicates a better fit of the model cumulative probabilities $\hat{F}$ to the observed cumulative probabilities F. The R^2 is defined as: $R^2 = \frac{\sum_{i=1}^{n}(\hat{F}_i - \bar{F})^2}{\sum_{i=1}^{n}(\hat{F}_i - \bar{F})^2 + \sum_{i=1}^{n}(F_i - \hat{F}_i)^2}$; $\bar{F} = \frac{\sum_{i=1}^{n}\hat{F}_i}{n}$.

Chi-Square Error Test

Chi-Square test is used to assess whether the observed probability differs from the predicted probability. Chi-Square test statistic is defined as $\chi^2 = \sum_{i=1}^{n} \frac{(F_i - \hat{F}_i)^2}{\hat{F}_i}$.

Root Mean Squared Error (RMSE) Test

Root mean square error (RMSE) provides a term-by-term comparison of the actual deviation between observed probabilities and predicted probabilities. A lower value of RMSE indicates a better distribution function model. Root mean square error (RMSE) is defined as $RMSE = \left[\frac{\sum_{i=1}^{n}(F_i - \hat{F}_i)^2}{n}\right]^{\frac{1}{2}}$.

Akaike Information Criterion (AIC) Test

The Akaike Information Criterion (AIC) is defined as $AIC = e^{\frac{2k}{n}} \frac{\sum_{i=1}^{n} \hat{u}_i{}^2}{n}, \sum_{i=1}^{n} \hat{u}_i{}^2 = \sum_{i=1}^{n} \left(F_i - \hat{F}_i\right)^2$ where, k is the number of estimated parameters and n is the number of observations.

Bayesian Information Criterion (BIC)

The Bayesian Information Criterion (BIC) is defined as $BIC = e^{\frac{k}{n}} \frac{\sum_{i=1}^{n} \hat{u_i}^2}{n}, \sum_{i=1}^{n} \hat{u_i}^2 = \sum_{i=1}^{n} \left(F_i - \hat{F_i}\right)^2$, where, k is the number of estimated parameters and n is the number of observations.

3. Results and Discussion

The estimation of parameters of all the PDFs considered in this study were carried out using maximum likelihood method and estimated parameters of different PDFs used for all the two stations are presented in Table 1.

Table 1: Estimated parameters of different PDFs considered in this study

PDF	Parameters	Cox's Bazar	Patuakhali
W	Shape (k)	18.76948	15.59206
	Scale (c)	34.01523	34.60186
LN	Mean (μ)	3.4980276	3.50737493
	Standard Deviation (σ)	0.0611655	0.07842159
G	Shape (a)	270.8040483	165.6146131
	Scale (b)	0.1222704	0.2020447
GEV	Shape (α)	-0.2801754	-0.3840931
	Scale (β)	2.0697560	2.7013427
	Location (μ)	32.3859317	32.6599623
3-P G	Shape(d)	298.3898516	309.8808294
	Scale (a)	0.1163229	0.1476378
	Threshold(p)	-1.6020772	-12.2885730
3-P LN	Shape(c)	0.01247783	0.01379678
	Scale(a)	5.07457534	5.22640735
	Threshold(b)	-126.80538016	-152.66088863
ST	Location(θ_0)	35.081945	36.412805
	Scale(θ_1)	2.736866	3.905972
	Degrees of Freedom (θ_2)	42.499686	9206.526343
	Shape(θ_3)	-1.927098	-2.896610
GSL	Location(μ)	34.1347548	35.3931769
	Scale(σ)	0.8490717	0.8829194
	Shape(γ)	0.5408998	0.3744999

The statistical parameters for fitness evaluation of PDFs currently analyzed are presented in Table 2 and Table 3.

Table 2: Values of Statistical tests for different distribution of Cox's Bazar (419920) Station

PDF	$K-S$ Error	R^2 Error	χ^2 Error	$RMSE$ Error	AIC	BIC
W	0.037086	0.995852	0.555428	0.017889	0.000322	0.000328
LN	0.059985	0.984284	2.824071	0.035611	0.001278	0.001298
G	0.055752	0.986543	2.460100	0.033007	0.001098	0.001115
GEV	0.059470	0.985930	1.941757	0.032793	0.001087	0.001114
3-P G	0.056055	0.986440	2.453763	0.033160	0.001112	0.001139
3-P LN	0.049827	0.989374	2.000314	0.029395	0.000874	0.000895
ST	0.024887	0.998928	0.288257	0.009411	0.00009	0.000093
GSL	0.023819	0.999008	0.269846	0.009223	0.000086	0.000088

Table 3: Values of Statistical tests for different distribution of Patuakhali (419600) Station

PDF	$K-S$ Error	R^2 Error	χ^2 Error	$RMSE$ Error	AIC	BIC
W	0.03178	0.99753	0.62023	0.0144	0.00021	0.00021
LN	0.09335	0.97025	4.29643	0.05052	0.00257	0.00261
G	0.08823	0.97362	3.87563	0.04763	0.00229	0.00232
GEV	0.06034	0.98839	1.52866	0.03087	0.00096	0.00099
3-P G	0.08545	0.97533	3.56028	0.04598	0.00214	0.00219
3-P LN	0.07771	0.97953	3.27955	0.04197	0.00178	0.00183
ST	0.03393	0.99745	0.65866	0.01471	0.00022	0.00023
GSL	0.03465	0.99722	0.87656	0.01559	0.00025	0.00025

Considering K-S error, χ^2 error, RMSE, AIC and BIC, the probability functions Weibull, Lognormal, Gamma, Generalized Extreme Value, three parameters Gamma, three parameters Lognormal and Skewed t have large errors indicating their inadequacy in modeling monthly maximum temperature of Cox's Bazar station. On the other hand, Lognormal, Gamma, Generalized Extreme Value, three parameters Gamma, three parameters Lognormal, Skewed t and Generalized Skew Logistic distribution are inadequacy in modeling monthly maximum temperature of Patuakhali station. The higher value of R^2 and the lower values of K-S error, RMSE, AIC, BIC and chi square error indicate that Generalized Skew Logistic distribution (GSL) distribution is more accurate than other PDFs in modeling wind speeds of Cox's Bazar station whereas for Patuakhali station Weibull give the best fit among the probability distribution considered in this paper. The graphical comparisons of different probability distribution considered in this study and the histogram of the observed monthly maximum temperature for Cox's Bazar and Patuakhali Stations are presented in Figure 1 and Figure 2.

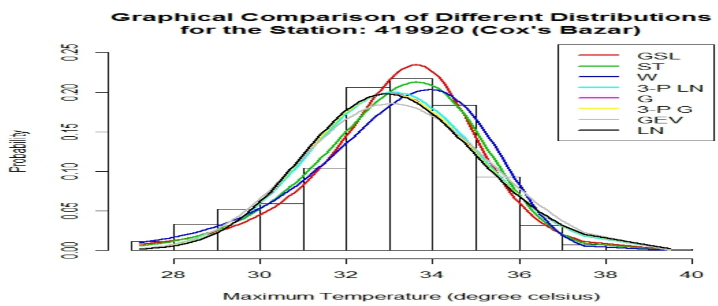

Figure 1: Graphical Comparison for different distribution of Cox's Bazar Station

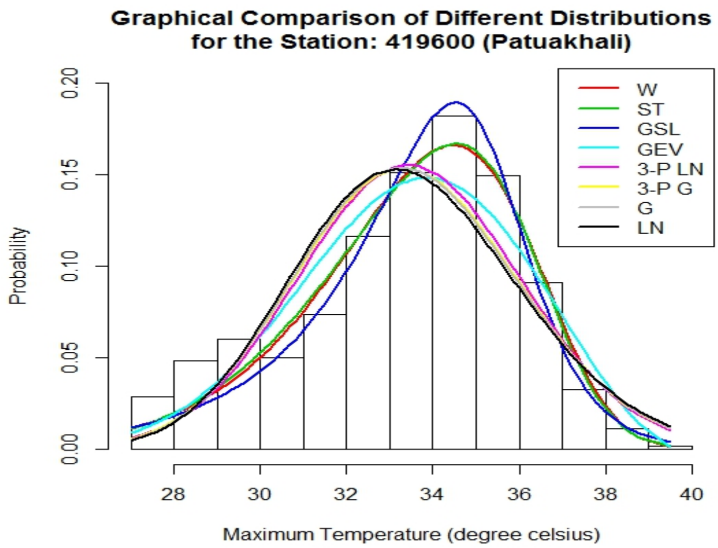

Figure 2: Graphical Comparison for different distribution of Patuakhali Station

As seen from Figure 1 and Figure 2 and also statistical parameters from Table 2 and Table 3, Generalized Skew Logistic distribution (GSL) provided the best fit for the observed monthly maximum temperature data of Cox's Bazar station whereas for Patuakhali station Weibull (W) gives the best fit among the probability distribution considered in this paper.

4. Conclusion

This paper identified that the Generalized Skew Logistic distribution (GSL) provided the best fit for the observed monthly maximum temperature data of Cox's Bazar station whereas for Patuakhali station Weibull (W) gives the best fit among the probability distribution considered in this paper. Weibull (W) distribution also has almost similar to Skewed t (ST) for the monthly maximum temperature in Patuakhali.

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Journal of Environmental Statistics http://www.jenvstat.org
Volume 8, Issue 8 Submitted: 2016-01-07
September 2018 Accepted: 2016-10-28