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Assessing the Adequacy of Probability Distributions for Estimating the Extreme Events of Air Temperature in Dabaa Region

Ghada I. El-Shanshoury
Nuclear and Radiological Regulatory Authority (NRRA), Cairo, Egypt

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ABSTRACT

Assessing the adequacy of probability distributions for estimating the extreme events of air temperature in Dabaa region is one of the pre-requisites for any design purpose at Dabaa site which can be achieved by probability approach. In the present study, three extreme value distributions are considered and compared to estimate the extreme events of monthly and annual maximum and minimum temperature. These distributions include the Gumbel/Frechet distributions for estimating the extreme maximum values and Gumbel/Weibull distributions for estimating the extreme minimum values. Lieblein technique and Method of Moments are applied for estimating the distribution parameters. Subsequently, the required design values with a given return period of exceedance are obtained. Goodness-of-Fit tests involving Kolmogorov-Smirnov and Anderson-Darling are used for checking the adequacy of fitting the method/distribution for the estimation of maximum/minimum temperature. Mean Absolute Relative Deviation, Root Mean Square Error and Relative Mean Square Deviation are calculated, as the performance indicators, to judge which distribution and method of parameters estimation are the most appropriate one to estimate the extreme temperatures. The present study indicated that the Weibull distribution combined with Method of Moment estimators gives the highest fit, most reliable, accurate predictions for estimating the extreme monthly and annual minimum temperature. The Gumbel distribution combined with Method of Moment estimators showed the highest fit, accurate predictions for the estimation of the extreme monthly and annual maximum temperature except for July, August, October and November. The study shows that the combination of Frechet distribution with Method of Moment is the most accurate for estimating the extreme maximum temperature in July, August and November months while the Gumbel distribution and Lieblein technique is the best for October.

***Key Words:** Extreme temperature/ Gumbel distribution/ Frechet distribution/ Weibull distribution/ Lieblein technique/ Mehod of moments (MOM)/ Goodness of fit tests/ Performance indicators*.

INTRODUCTION

Estimating extreme value of temperature is one of meteorological parameters which is a pre-requisite for design basis of Nuclear Power Plants (NPPs) and its facility. Estimation of extreme value maximum and minimum temperature is one of the meteorological parameters that plays a major role in the design of the nuclear facilities[1].). High temperature may cause low steam turbine effectiveness (low temp. reservoir, low pressure). Low temperature, heavy snow and ice storm may cause extra weight load on power lines and towers, freezing structures and blocking access to NPPs site[2]. Dabaa has been chosen as a suitable site under investigation since 1982 for building a first nuclear power plant in Egypt. So, the estimation of extreme value of monthly and annual maximum/minimum temperature data, recorded in Dabaa region, will be investigated to predict the extreme events of temperature in this area. Design maximum and minimum temperature are determined from historical records using extreme value theory to predict future extreme maximum/minimum temperature. The collected data of the daily maximum/minimum temperature are measured (in Celcius) at latitude 30.93'N and longitude 28.46'E [3-5]. Years from 2000 to 2013 are considered in this work because this is the longest available period, therefore, the data size may give some uncertainty results.

Extreme annual values of meteorological variables, may be characterized by specific probability distributions. In principle, the data set should be analyzed with probability distribution functions appropriate to the data sets under study. Research studies indicated that the extreme value distributions are widely applied for the assessment of meteorological variables; and therefore are adopted in the present study. In probabilistic theory, generalized extreme value distribution is identified as a family of continuous probability distributions that include Gumbel, Frechet and Weibull. The Gumbel maximum and Fréchet models relate to maxima (*largest* extreme value), while the Gumbel minimum and Weibull models relate to minima (*smallest* extreme value).

The main objective purpose of this study is to identify an appropriate probability model which represents the Monthly/Annual maximum temperature (MT_{max}/AT_{max}) and Monthly/Annual minimum temperature (MT_{min}/AT_{min}) at Dabaa region. This model can be used in estimating the extreme maximum/minimum temperature. This implies that sufficient information needs to be available to determine which distribution best fits the data. The MT_{max}/AT_{max} recorded at Dabaa area is modeled using both Gumbel (G_{max}) and Frechet (F) distributions. The MT_{min}/AT_{min} recorded at Dabaa area is modeled using both Gumbel (G_{min}) and Weibull (W) distributions. Standard analytical procedures such as Method of Moments (MOM) and Lieblein technique are generally considered for determination of parameters of extreme value distributions. Once the statistical distribution and its parameters is determined, the quantile estimate (return level, (x_T)) for any distribution can be obtained by inverting its Cumulative Distribution Function (CDF).The frequency analysis of meteorological extremes requires fitting a probability distribution to the observed data to suitably represent the frequency of occurrence of extreme events. Therefore, Goodness-of-Fit tests like Kolmogorov-Smirnov (KS) and Anderson-Darling (AD) are calculated for checking the adequacy of fitting of these distributions and their estimators to the recorded temperature data. Model Performance Indicators (PI) such as: Mean Absolute Relative Deviation (MARD), Root Mean Square Error (RMSE) and Relative Mean Square Deviation (RMSD) are used for selection of a suitable extreme value distributions and the estimation method of the distributions parameters for estimating the extreme maximum/minimum temperatures.

METHODOLOGY

1. Probability Distributions:

The Gumbel, Frechet and Weibull distributions used in this study have a wide variety of applications for estimating extreme values of given data sets. The Cumulative Distribution Functions (CDFs) of two parameters extreme values distributions (Gumbel, Frechet and Weibull)[6-8] for the series containing maximum and minimum extreme values are given in Table 1.

Table (1): CDFs of Gumbel, Frechet and Weibull Distributions

Distribution	Maximum values	Distribution	Minimum Values
Gumbel($G_{max.}$)	$F(x)=e^{-e^{-\left(\frac{x-\alpha_G}{\beta_G}\right)}}$ $-\infty \prec x \prec \infty$	Gumbel($G_{min.}$)	$F(x)=1-e^{-e^{\left(\frac{x-\alpha_G}{\beta_G}\right)}}$ $-\infty \prec x \prec \infty$
Frechet	$F(x)=e^{-\left(\frac{x}{\beta_F}\right)^{-\lambda_F}}$ $x \succ 0$	Weibull	$F(x)=1-e^{-\left(\frac{x}{\beta_W}\right)^{\lambda_W}}$ $x \leq 0$

where, $F(x)$ is the CDF of distributions, α_G and β_G are the location and scale parameters of Gumbel distribution. β_F and λ_F are the scale and shape parameters of Frechet distribution. β_W and λ_W are the scale and shape parameters of Weibull distribution. The value of x is the monthly and annual maximum/minimum temperature.

2. Methods of parameters estimation:

A common statistical tool to estimate distribution parameters is to use maximum likelihood estimators (MLE) or method of moments (MOM). The method of MLE is known as asymptotically unbiased and optimal for extreme value distribution. However, there is no guarantee that the MLE is the best in small samples. In this study, Lieblein technique and MOM are used for determination of Gumbel, Frechet and Weibull estimators for assessing the MT_{max}/AT_{max} and MT_{min}/AT_{min} for Dabaa region.

2.1. Lieblein Technique:

Lieblein[9] suggested Order Statistics Approach (OSA) for estimating the parameters of Gumbel and Frechet distributions to model the meteorological data. He also described that the OSA estimators are unbiased and having minimum variance [10,11].

2.1.1. Gumbel distribution:

Lieblein technique is based on the assumption that the set of extreme values constitutes a statistically independent series of observations. The Lieblein technique estimators of Gumbel distribution are given by:

$$\sim_G = t^{'}\sim_m^{'} + t^{"}\sim_m^{"} \qquad (1)$$

$$_G = t^{'}\ _m^{'} + t^{"}\ _m^{"} \qquad (2)$$

where $t^{'}$ and $t^{"}$ are proportionality factors, which can be obtained from the selected values of *k, n* and $n^{'}$ using the relations as follows: $t^{'} = \frac{kn}{N}$ and $t^{"} = \frac{n^{'}}{N}$

where *N* is the sample size containing the basic data that are divided into *k* sub groups of *n* elements each leaving $n^{'}$ remainders. $\sim_m^{'}$ and $_m^{'}$ are the distribution parameters of the groups, and $\sim_m^{"}$ and $_m^{"}$ are the parameters of the remainders, if any. These can be computed from the following equations:

$$\sim_m^{'} = \frac{1}{k}\sum_{i=1}^{n}\sim_{ni} s_i \quad , \quad \sim_m^{"} = \frac{1}{k}\sum_{i=1}^{n}\sim_{ni}^{'} s_i^{'} \quad \text{and} \quad _m^{'} = \frac{1}{k}\sum_{i=1}^{n}\ _{ni} s_i \quad , \quad _m^{"} = \frac{1}{k}\sum_{i=1}^{n}\ _{ni}^{'} s_i^{'}$$

where, $s_i = \sum_{i=1}^{k} x_{ij}$, $s_i^{'} = x_i$, $j = 1,2,3,\ldots,n$

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2.1.2. Frechet distribution:

Frechet and Weibull distributions can be transformed to Gumbel distribution through logarithmic transformation using natural logarithm of the actual variable. Under this transformation, the scale β and shape λ parameters of Frechet and Weibull distributions are determined by Lieblein technique for estimation of extreme temperatures using $x_T = Exp(x_G)$, $\beta = Exp(\alpha_G)$ and $\lambda = 1/\beta_G$.
Table 2 gives the weights of $\sim_{ni}$ and $_{ni}$ used in determination of Lieblein technique estimators of Gumbel and Frechet distributions.

Table (2): Weights α_{ni} and β_{ni} for determination of Lieblein technique estimators of Gumbel and Frechet distributions

α_{ni}/β_{ni}	i					
	1	**2**	**3**	**4**	**5**	**6**
α_{2i}	0.916373	0.083627	-	-	-	-
α_{3i}	0.656320	0.255714	0.087966	-	-	-
α_{4i}	0.51099	0.263943	0.153680	0.071380	-	-
α_{5i}	0.418934	0.246282	0.167609	0.108824	0.058350	-
α_{6i}	0.355450	0.225488	0.165620	0.121054	0.083522	0.048867
β_{2i}	- 0.721348	0.721348	-	-	-	-
β_{3i}	- 0.630541	0.255816	0.374725	-	-	-
β_{4i}	- 0.558619	0.085903	0.223919	0.248797	-	-
β_{5i}	- 0.503127	0.006534	0.130455	0.181656	0.184483	-
β_{6i}	- 0.459273	- 0.035992	0.073199	0.126724	0.149534	0.145807

2.2. Method of Moments (MOM):

The average or expectation of a function of a random variable *x* can be found by weighting the function by its density or mass function. This procedure is called the method of moments.

2.2.1. Gumbel distribution ($G_{max.}$) for maximum values:

The Gumbel distribution is a particular form of Type I extreme value distribution. To compute the estimated values of α_G and β_G, one must estimate the mean μ and standard deviation σ of the population based on the sample.
Hence, the mean and the variance of *x* are given respectively as[12]

$$\mu = E[x] = \alpha_G + \gamma\beta_G \quad , \quad \sigma^2 = \mathrm{var}[x] = \frac{\pi^2\beta_G^2}{6}$$

The two equations that can be used to estimate α_G and β_G if a finite sample of the values taken by *x*, such as the annual maximum/minimum temperatures for a period of *T* years, are

$$\beta_G = \frac{\sigma\sqrt{6}}{\pi} \qquad (3)$$

$$\alpha_G = \mu - \gamma\beta_G \qquad (4)$$

3.2.2. Gumbel distribution (G_{min}) for minimum values :

The mean and the variance of *x* are given respectively as[13,14]

$$\mu = E[x] = \alpha_G - \gamma\beta_G \quad , \quad \sigma^2 = \mathrm{var}[x] = \frac{\pi^2\beta_G^2}{6}$$

$$\alpha_G = \mu + \gamma\beta_G \qquad (5)$$

Where, β_G will be calculated using Eqn 3, μ and σ are the mean and standard deviation of monthly and annual maximum and minimum temperature, respectively. $\gamma \cong 0.577216$ is Euler's constant. The scale parameter *(β_G) > 0*.

2.2.3. Frechet distribution:

The Frechet distribution is a particular form of Type II extreme value distribution. The kth moment μ_k for the Frechet distribution is given by(12,15): $\mu_k = {}_F^{k}\Gamma(1-k/\alpha_F)$.
In particular, the mean μ (the first moment) and the variance σ^2 are given by the following equations:

$$\mu = E[X] = {}_F\Gamma(1-1/\alpha_F)$$

$$\sigma^2 = Var[X] = {}_F^2[\Gamma(1-2/\alpha_F) - (\Gamma(1-1/\alpha_F))^2]$$

where, ${}_F > 0$ denotes a scale parameter, $\alpha_F > 0$ is a shape parameter and Γ is gamma function.
The shape parameter α_F depends only on the square of the coefficient of variation C*V* which is given by

$$CV^2 = \frac{\sigma^2}{\mu^2} = \frac{\Gamma(1-2/\alpha_F)}{(\Gamma(1-1/\alpha_F))^2} - 1 \qquad (6)$$

$${}_F = \frac{\mu}{\Gamma(1-1/\alpha_F)} \qquad (7)$$

After C*V* is estimated as the ratio of the sample standard deviation to the sample mean, the value of α_F in (6) can be solved via numerical iterations. Then, substituting the sample mean and the estimate of α_F into (7), one can estimate the value of scale parameter ${}_F$.

2.2.4. Weibull distribution:

The procedure for the estimation of Weibull distribution parameters is similar as that of Frechet distribution. The kth moment μ_k for the Weibull (Extreme value type III) distribution is given by(15):

$$\mu_k = {}_W^{k}\Gamma(1+k/\alpha_W)$$

The mean μ (the first moment) and the variance σ^2 are given by the following equations:

$$\mu = E[X] = {}_W\Gamma(1+1/\alpha_W)$$

$$\sigma^2 = Var[X] = {}_W^2[\Gamma(1+2/\alpha_W) - (\Gamma(1+1/\alpha_W))^2]$$

Since the basic Weibull model has two parameters, estimation of the parameters can be obtained using the sample mean and sample variance. Using the expression for the mean and variance, α_W was obtained by the solution of Equation 8.

$$CV^2 = \frac{\sigma^2}{\mu^2} = \frac{\Gamma(1+2/\alpha_W)}{(\Gamma(1+1/\alpha_W))^2} - 1 \qquad (8)$$

$${}_W = \frac{\mu}{\Gamma(1+1/\alpha_W)} \qquad (9)$$

where, ${}_W > 0$ denotes a scale parameter, $\alpha_W > 0$ is a shape parameter.

3. Design Values (x_T) and Return Period (T):

Return period is frequently used as alternative descriptions of the probabilities of extreme events. It is simply the inverse of the complementary cumulative of the distribution. The inverse of the complementary cumulative distribution function (CDF) is the inverse of the exceedance probability $(X \geq x_T)$,

$$T = \frac{1}{P(X \geq x_T)} = \frac{1}{1 - P(X < x_T)} = \frac{1}{1 - F(x_i)}$$

For predicting magnitude of an extreme event x_T for a specified return period, T, the distribution parameters must be estimated and then plugged into the linear quantile functions (Table 3) [13].

Table (3): Quantile functions for estimating Return level (x_T):

Return level of Gumbel max. and min. (G_{max} & G_{min})	$x_T = \sim_G + \ _G Y_T$ (10)
Return level of Frechet (*F*) distribution.	$ln(x_T) = ln(\ _F) + \frac{1}{a_F}(Y_T)$ (11)
Return level of Weibull (*W*) distribution.	$ln(x_T) = ln(\ _W) + \frac{1}{a_W}(Y_T)$ (12)
Y_T for extreme maximum values (G_{max} and *F*)	$Y_T = -ln(-ln(P(X< x_T))= -ln(-ln(1-(1/T))$
Y_T for extreme minimum values (G_{min} and *W*)	$Y_T = ln(-ln(1-(P(X\geq x_T)))= ln(-ln(1-(1/T))$

Here Y_T is the reduce variate of non-exceedance probability. Substituting the values of estimators into the above equations, one can predict the return level x_T for return period of *T* years. The predicted return level is the estimated design value until next exceedance.

4. Goodness-of-Fit Tests:

Goodness of Fit tests are employed for checking the adequacy of fitting of the distribution to the recorded data. These tests calculate test-statistics, which are used in assessing whether a given distribution is suited to a set of temperature data. Two types of goodness of fit tests are used. These are Kolmogrov-Smirnov (KS) and Anderson-Darling (AD).

When the computed test statistic is less than the critical value at the chosen significance level (*alpha*), accept the null hypothesis and conclude that the sample can be described by the fitted theoretical distribution. Usually, the confidence level is taken to be 95% and thus the significance level (*alpha*) is 0.05.

4.1. Kolmogorov-Smirnov (KS):

The Kolmogorov-Smirnov (KS) goodness-of-fit test is a nonparametric test that relates to the CDF rather than the probability density function (pdf) of a continuous variable. The Kolmogorov-Smirnov *D* statistic is based on the empirical cumulative distribution function (ECDF). The KS test criterion is the maximum absolute difference between empirical CDF ($F(x)$) and theoretical CDF ($F_0(x)$), formally defined as[12]

$$D_n = \sup_x \left| F(x) - F_0(x) \right| \qquad (13)$$

4.2. Anderson Darling (AD):

The Anderson Darling (AD) goodness-of-fit test is introduced to place more weight or discriminating power at the tails of the distribution, this can be important when the tails of a selected theoretical distribution are of practical significance. Anderson and Darling showed the test statistic becomes(14)

$$A^2 = -N - \frac{1}{N}\sum_{i=1}^{N} (2i-1).\left[lnF(x_i) + ln(1-F(x_{N+1-i}))\right] \qquad (14)$$

where, $F(x)=(i-0.44)/(N+0.12)$(16) is the ECDF of x_i , $F(x)$ is evaluated CDF of x_i of the proposed distributions, N is the sample size and i is the rank assigned to the sample values arranged in ascending order (i =1, 2, ….,N) and $x_1<x_2<..<x_N$.

5. Performance Indicators (PI):

The three PI are the Mean Absolute Relative Deviation (MARD), the Root Mean Square Error (RMSE) and the Relative Mean Square Deviation (RMSD). These PI are applied to reveal which of the most optimal distribution and method of estimation of its parameters can be used to estimate the maximum and minimum temperatures.

5.1. Mean Absolute Relative Deviation (MARD)(17),

The MARD is given by Eqn 15 as follows

$$MARD = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{(x_i - x_p)}{x_i}\right| \qquad (15)$$

5.2. Root Mean Square Error (RMSE)(18),

The RMSE is given by Eqn 16 as follows

$$RMSE = \left[\frac{\sum_{i=1}^{N}(x_i - x_p)^2}{N}\right]^{1/2} \qquad (16)$$

5.3. Relative Mean Square Deviation (RMSD)(19),

The RMSD is given by Eqn 17 as follows

$$RMSD = \sum_{i=1}^{N}\left(\frac{x_i - x_p}{x_i}\right)^2 \Big/ N \qquad (17)$$

where, N is the sample size, x_i is the ascending ordered historical values of the sample and x_P is the predicted values computed from an assumed empirical probability distribution based on the sorted ranks of observed values.

RESULTS AND DISCUSSION

An attempt has been made to assess the expected monthly/annual extreme maximum (MT_{max}/AT_{max}) and monthly/annual extreme minimum temperature (MT_{min}/AT_{min}) for different return period (*T*) for Dabaa region. The series of MT_{max}/AT_{max} and MT_{min}/AT_{min} are derived from monthly temperature from years 2000 to 2013. Figures 1 and 2 show the largest average and smallest values of MT_{min}/ AT_{min} and MT_{min}/ AT_{min} recorded in Dabaa region.

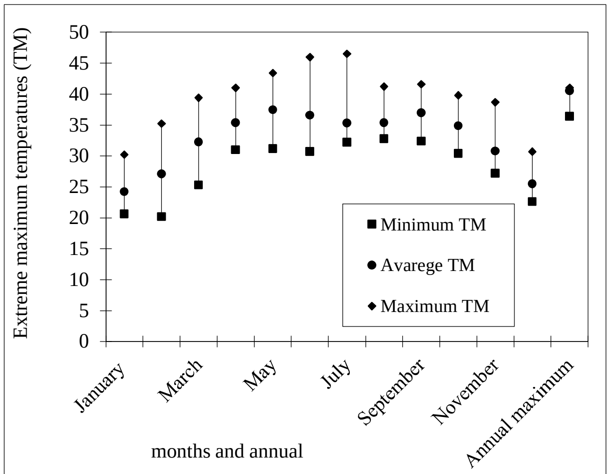

Fig. (1): The extreme maximum temperatures (largest, avarege and smallest values).

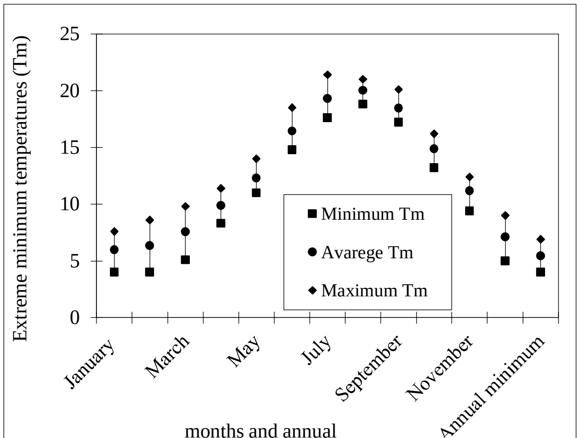

Fig. (2): The extreme minimum temperatures (largest, avarege and smallest values).

Three extreme value probability distributions are considered and compared for estimating the extreme MT_{max}/AT_{max} and MT_{min}/AT_{min}. These distributions are represented in, Gumble (G_{max})& Frechet (*F*) distributions for estimating the extreme maximum values, and Gumbel (G_{min}) & Weibull (*W*) distributions for estimating the extreme minimum values.

1- Analysis of maximum temperature:

For predicting the magnitude of an extreme event x_T (return level) for a specified return period *T*, the distribution parameters must be estimated and then plug them into the quantile functions.

Gumbel ($G_{max.}$) and Frechet *(F)* distributions are used and compared to estimate the extreme maximum values. Lieblein technique and MOM estimators are calculated for G_{max} and *F* distributions (α_G & β_G

for $G_{max.}$ distribution and β_F & λ_F for F distribution). The parameters of G_{max} and F distributions for MT_{max}/ AT_{max} are estimated using Eqns 3, 4, 6 and 7.

For a better reliability of estimates the amount of data needed should be commensurate with the need of mean recurrence interval (MRI) for which the estimates are needed. Therefore, the maximum estimated design temperatures are calculated at 100 yr return period.

MT_{max}/AT_{max} corresponding return period T of 2, 5, 10, 20, 50 and 100 years are estimated according to Eqns 10 and 11. Table 4 shows the estimation design (x_T) of $MT_{max}/AT_{max.}$

Table (4): Extreme events estimates (x_T) of MT_{max}/AT_{max} for different T using G_{max} and F distributions:

	January					***February***					***March***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**
2	23.8	23.7	23.9	23.8	**2**	26.3	26	26.4	26.2	**2**	31.4	31.1	31.5	31.3
5	27.4	27.4	26.9	26.6	**5**	31	31.2	30.3	29.8	**5**	36.7	36.8	35.5	35.1
10	29.7	30.2	28.9	28.7	**10**	34.2	35.2	32.8	32.5	**10**	40.2	41.2	38.2	37.9
20	32	33.1	30.8	30.8	**20**	37.2	39.4	35.3	35.2	**20**	43.6	45.9	40.8	40.7
50	34.9	37.4	33.3	33.8	**50**	41.1	45.8	38.5	39.2	**50**	48	52.8	44.1	44.8
100	37.1	40.9	35.2	36.3	**100**	44	51.2	40.9	42.5	**100**	51.3	58.6	46.6	48.1
	April					***May***					***June***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**
2	34.8	34.7	34.9	34.8	**2**	36.9	36.8	36.9	36.8	**2**	36	35.8	35.9	35.7
5	38.5	38.5	37.7	37.5	**5**	39.9	39.9	40	39.8	**5**	39.1	38.9	39.7	39.3
10	40.9	41.3	39.6	39.5	**10**	41.9	42.1	42	41.9	**10**	41.1	41.1	42.2	41.9
20	43.3	44.2	41.4	41.5	**20**	43.8	44.4	44	44	**20**	43	43.3	44.6	44.6
50	46.3	48.3	43.8	44.2	**50**	46.3	47.4	46.5	46.9	**50**	45.5	46.3	47.7	48.2
100	48.5	51.5	45.6	46.3	**100**	48.2	49.9	48.4	49.2	**100**	47.4	48.7	50	51.2
	July					***August***					***September***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**
2	34.8	34.7	34.8	34.6	**2**	34.8	34.7	34.9	34.8	**2**	36.6	36.5	36.6	36.5
5	37.4	37.2	37.9	37.7	**5**	37.4	37.3	37.5	37.3	**5**	39	39	38.7	38.6
10	39	39	40.1	39.9	**10**	39.1	39.1	39.2	39.1	**10**	40.6	40.8	40.1	40
20	40.7	40.7	42.1	42.1	**20**	40.7	41	40.9	40.9	**20**	42.1	42.6	41.4	41.4
50	42.7	43.1	44.7	45.1	**50**	42.9	43.5	43	43.3	**50**	44.1	45	43.1	43.3
100	44.3	45	46.7	47.5	**100**	44.4	45.4	44.7	45.3	**100**	45.6	46.9	44.4	44.8
	October					***November***					***December***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**	***T***	**G_{max}**	**F**	**G_{max}**	**F**
2	34.5	34.4	34.4	34.3	**2**	30.2	30	30.3	30.2	**2**	25.2	25.1	25.1	25
5	37.1	37.1	36.9	36.7	**5**	33.4	33.3	33.2	32.9	**5**	27.2	27.2	27.3	27.1
10	38.9	39.1	38.5	38.4	**10**	35.5	35.7	35.1	34.9	**10**	28.6	28.7	28.8	28.7
20	40.5	41	40.1	40.1	**20**	37.6	38.2	36.9	36.9	**20**	29.9	30.2	30.2	30.2
50	42.7	43.7	42.1	42.4	**50**	40.2	41.6	39.3	39.7	**50**	31.6	32.3	32	32.3
100	44.3	45.8	43.7	44.2	**100**	42.2	44.3	41.1	41.9	**100**	32.9	34	33.4	33.9

Annual maximum temperature				
x_T	Lieblein		MOM	
T	**G**	**F**	**G**	**F**
2	39.9	39.8	40	40
5	43	43	42.7	42.6
10	45.1	45.3	44.5	44.4
20	47.1	47.6	46.2	46.2
50	49.7	50.7	48.4	48.6
100	51.6	53.1	50	50.6

The values of KS statistics and AD statistics of G_{max} and F distributions for the series of MT_{max}/AT_{max} are computed using Eqns 13 and 14 for assessing the adequacy of these distributions and their estimators. Computed KS and AD statistics are given in Table 5.

Table (5): Computed values of KS and AD statistics of MT_{max}/AT_{max} for Dabaa region:

January	Lieblein		MOM		***February***	Lieblein		MOM	
	G_{max}	**F**	**G_{max}**	**F**		**G_{max}**	**F**	**G_{max}**	**F**
KS	0.1023	0.0942	0.1384	0.1726	KS	0.1274	0.1508	0.1055	0.1443
AD	0.3277	0.3502	0.4475	0.735	AD	0.2766	0.367	0.3546	0.8575
March	Lieblein		MOM		***April***	Lieblein		MOM	
	G_{max}	**F**	**G_{max}**	**F**		**G_{max}**	**F**	**G_{max}**	**F**
KS	0.0965	0.1129	0.1449	0.1633	KS	0.0714	0.0813	0.1149	0.136
AD	0.384	0.4119	0.4432	0.7458	AD	0.3151	0.3546	0.3728	0.5879
May	Lieblein		MOM		***June***	Lieblein		MOM	
	G_{max}	**F**	**G_{max}**	**F**		**G_{max}**	**F**	**G_{max}**	**F**
KS	0.0848	0.1023	0.0844	0.0929	KS	0.1628	0.1603	0.128	0.1518
AD	0.3425	0.4326	0.3218	0.5028	AD	0.9058	1.1384	0.2687	0.4709
July	Lieblein		MOM		***August***	Lieblein		MOM	
	G_{max}	**F**	**G_{max}**	**F**		**G_{max}**	**F**	**G_{max}**	**F**
KS	0.1583	0.1516	0.1414	0.123	KS	0.1609	0.152	0.1753	0.1717
AD	0.551	0.4532	0.75	0.6091	AD	0.6289	0.573	0.6447	0.593
September	Lieblein		MOM		***October***	Lieblein		MOM	
	G_{max}	**F**	**G_{max}**	**F**		**G_{max}**	**F**	**G_{max}**	**F**
KS	0.2027	0.2147	0.1986	0.2073	KS	0.0734	0.0712	0.0911	0.1004
AD	0.6924	0.7923	0.9374	1.2527	AD	0.1717	0.1943	0.2275	0.3517
November	Lieblein		MOM		***December***	Lieblein		MOM	
	G_{max}	**F**	**G_{max}**	**F**		**G_{max}**	**F**	**G_{max}**	**F**
KS	0.1064	0.0924	0.1296	0.1204	KS	0.0925	0.0979	0.088	0.1068
AD	0.3728	0.3427	0.3259	0.2991	AD	0.3274	0.3091	0.238	0.2854

Annual maximum	Lieblein		MOM	
	G_m	**F**	**G_m**	**F**
KS	0.0908	0.0999	0.1	0.1109
AD	0.2855	0.2763	0.22	0.2271

From Table 5, it may be noted that the computed value of KS and AD statistics given by Gumbel and Frechet distributions with Lieblein and MOM estimators are less than the critical value at 0.05 significance level ($KS_{14,0.05}$=0.3489 and $AD_{14,0.05}$= 2.5018). The results indicate that the two distributions and both methods of estimating their parameters are found to be suitable for modeling MT_{max}/AT_{max} for Dabaa region.

Comparison between G_{max} , F distributions and the methods of their estimators is made to select the best distribution and estimation method. The Comparison is constructed on the basis of the smallest values of MARD, RMSE and RMSD which are calculated from Eqns 15-17. Table 6 shows the indices of MARD, RMSE and RMSD of MT_{max}/AT_{max} for Dabaa region.

Table (6): Indices of MARD, RMSE and RMSD of MT_{max}/AT_{max} for Dabaa region:

January	Lieblein		MOM		***February***	Lieblein		MOM	
	G_{maxc}	F	G_{max}	F		G_{max}	F	G_{max}	F
MARD	*2.5238	2.8015	2.78184	3.1933	MARD	2.66113	3.63179	*2.41147	3.48729
RMSE	0.90736	1.20072	*0.79674	0.93979	RMSE	1.05631	1.74145	*0.81786	1.09216
RMSD	0.00124	0.00183	*0.001	0.00135	RMSD	0.00126	0.00284	*0.00096	0.00179
March	Lieblein		MOM		***April***	Lieblein		MOM	
	G_{maxc}	F	G_{max}	F		G_{max}	F	G_{max}	F
MARD	3.41843	3.81758	*2.7292	3.348	MARD	1.98472	2.21219	*1.4351	1.71734
RMSE	1.76625	2.4677	*1.26686	1.50157	RMSE	1.00173	1.27866	*0.7101	0.81049
RMSD	0.00231	0.00418	*0.00127	0.00188	RMSD	0.00069	0.00106	*0.00037	0.0005
May	Lieblein		MOM		***June***	Lieblein		MOM	
	G_{maxc}	F	G_{max}	F		G_{max}	F	G_{max}	F
MARD	1.65613	1.80265	*1.6412	1.80415	MARD	2.65207	2.85503	*1.3058	1.85397
RMSE	0.79108	0.88441	*0.7772	0.89785	RMSE	1.12062	1.12807	*0.60198	0.74573
RMSD	0.00045	0.00055	*0.000432	0.00059	RMSD	0.00095	0.00099	*0.00028	0.00045
July	Lieblein		MOM		***August***	Lieblein		MOM	
	G_{maxc}	F	G_{max}	F		G_{max}	F	G_{max}	F
MARD	2.16119	*1.9254	2.83887	2.392	MARD	1.75672	*1.6734	1.81113	1.69534
RMSE	1.56012	1.49329	1.45735	*1.3260	RMSE	0.87397	0.83554	0.85797	*0.8308
RMSD	0.00127	0.00114	0.00137	*0.0011	RMSD	0.00056	0.0005	0.00055	*0.0005
September	Lieblein		MOM		***October***	Lieblein		MOM	
	G_{maxc}	F	G_{max}	F		G_{max}	F	G_{max}	F
MARD	1.78758	2.00319	*1.6923	1.85312	MARD	*0.9919	1.10895	1.13997	1.38072
RMSE	0.76275	0.87608	*0.70608	0.75544	RMSE	*0.4973	0.62683	0.51218	0.61174
RMSD	0.00043	0.00054	*0.000403	0.00047	RMSD	*0.00018	0.00027	0.0002	0.00029
November	Lieblein		MOM		***December***	Lieblein		MOM	
	G_{maxc}	F	G_{max}	F		G_{max}	F	G_{max}	F
MARD	1.64992	1.47136	1.56999	*1.42911	MARD	1.53456	1.36369	*1.32854	1.33243
RMSE	0.60741	0.5328	0.58612	*0.54151	RMSE	0.48476	0.44754	*0.42144	0.45042
RMSD	0.00045	0.00034	0.00035	*0.00028	RMSD	0.00033	0.00028	*0.00025	0.00028

Annual	Lieblein		MOM	
	G_{maxc}	F	G_{max}	F
MARD	1.32638	1.32871	*0.86394	0.93249
RMSE	0.65509	0.71456	*0.56954	0.60032
RMSD	0.00024	0.00027	*0.00017	0.00019

* is the performance indicators which give the smallest values of MARD, RMSE and RMSD.

It is obvious from Table 6 that the Gumbel distribution combined with MOM gave the highest fit, most reliable and accurate predictions for estimation of MT_{max}/AT_{max} except July, August, October and November months. The Frechet distribution with MOM is the most accurate for estimating the extreme maximum temperatures in July, August and November. The Gumbel distribution and Lieblein technique is the best for October month. Consequently, the estimated MT_{max} at 100-yr return period from January to December are 35.2, 40.9, 46.6, 45.6, 48.4, 50, 47.5, 45.3, 44.4, 44.3, 41.9 and 33.4 ^{o} C, respectively. The estimated AT_{max} at 100-yr return period is 50 ^{o} C.

2- Analysis of minimum temperature:

Gumbel *(G_{min})* and Weibull (*W)* distributions are compared to estimate the extreme minimum values. Lieblein technique and MOM are calculated for G_{min} and *W* distributions to estimate their parameters (α_G & β_G for $G_{min.}$ distribution and β_W & λ_W for *W* distribution). The parameters of G_{min} and *W* distributions for MT_{min}/ AT_{min} are estimated using Eqns 3, 5, 8 and 9. Extreme MT_{min}/AT_{min} estimates (x_T) for different return periods (*T*) using G_{min} and *W* distributions are calculated. Table 7 shows the return level (x_T) of MT_{min}/AT_{min} according to Eqns 10 and 12.

Table (7): Extreme events estimates (x_T) of MT_{min}/AT_{min} for different T using G_{min} and W distributions:

	January					***February***					***March***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**
2	5.2	5.1	6.2	6.1	**2**	5.4	5.3	6.6	6.4	**2**	6.1	6	7.8	7.7
5	4.1	4.2	5.2	5.1	**5**	4.3	4.4	5.4	5.3	**5**	4.4	4.7	6.4	6.2
10	3.4	3.8	4.6	4.6	**10**	3.5	3.9	4.6	4.6	**10**	3.2	3.9	5.4	5.4
20	2.8	3.3	4.1	4.1	**20**	2.8	3.4	3.9	4	**20**	2	3.4	4.5	4.7
50	1.9	2.9	3.3	3.6	**50**	1.9	2.9	2.9	3.4	**50**	0.6	2.7	3.271	3.9
100	1.3	2.6	2.7	3.3	**100**	1.2	2.6	2.2	3	**100**	-0.5	2.3	2.4	3.4

	April					***May***					***June***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**
2	9.1	9.1	10	10	**2**	11.7	11.7	12.5	12.4	**2**	15.6	15.6	16.6	16.6
5	8	8.1	9.2	9.2	**5**	11	11	11.6	11.6	**5**	14.6	14.7	15.7	15.7
10	7.3	7.6	8.7	8.7	**10**	10.6	10.6	11	11	**10**	14	14.1	15.1	15.1
20	6.7	7	8.2	8.3	**20**	10.1	10.2	10.5	10.5	**20**	13.3	13.6	14.6	14.6
50	5.8	6.4	7.6	7.7	**50**	9.6	9.8	9.8	9.9	**50**	12.5	12.9	13.8	13.9
100	5.2	6	7.1	7.3	**100**	9.1	9.4	9.2	9.5	**100**	11.9	12.4	13.3	13.5

	July					***August***					***September***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**
2	18.5	18.5	19.5	19.4	**2**	19.4	19.4	20.1	20.1	**2**	17.8	17.8	18.6	18.6
5	17.5	17.5	18.6	18.6	**5**	18.6	18.6	19.5	19.5	**5**	16.9	17	17.8	17.7
10	16.8	16.9	18.1	18	**10**	18	18.1	19.1	19.1	**10**	16.4	16.5	17.2	17.2
20	16.2	16.4	17.5	17.5	**20**	17.5	17.6	18.7	18.7	**20**	15.8	16	16.7	16.7
50	15.4	15.7	16.8	16.9	**50**	16.9	17	18.2	18.2	**50**	15.2	15.4	16	16
100	14.8	15.2	16.3	16.4	**100**	16.4	16.6	17.8	17.9	**100**	14.6	15	15.4	15.6

	October					***November***					***December***			
x_T	Lieblein		MOM		x_T	Lieblein		MOM		x_T	Lieblein		MOM	
T	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**	***T***	**G_{min}**	**W**	**G_{min}**	**W**
2	14.2	13.3	15	15	**2**	10.4	10.4	11.3	11.3	**2**	6.1	6.1	7.3	7.2
5	13.4	12.5	14.3	14.3	**5**	9.4	9.4	10.5	10.4	**5**	5	5.1	6.3	6.2
10	12.9	12.1	13.8	13.8	**10**	8.8	8.9	9.9	9.9	**10**	4.2	4.6	5.6	5.6
20	12.4	11.7	13.3	13.3	**20**	8.1	8.4	9.3	9.4	**20**	3.4	4.1	5	5.1
50	11.7	11.2	12.7	12.8	**50**	7.3	7.8	8.6	8.8	**50**	2.5	3.6	4.1	4.5
100	11.2	10.8	12.3	12.4	**100**	6.7	7.3	8.1	8.3	**100**	1.7	3.2	3.5	4.1

Annual minimum temperature				
x_T	Lieblein		MOM	
T	**G_{min}**	**W**	**G_{min}**	**W**
2	4.8	4.7	5.6	5.5
5	3.9	4	4.8	4.7
10	3.3	3.5	4.2	4.2
20	2.7	3.2	3.7	3.7
50	2	2.7	3	3.2
100	1.4	2.5	2.4	2.9

The values of KS and AD statistics of G_{min} and W distributions for the series of MT_{min}/AT_{min} are computed for checking the adequacy of distributions fitting and their estimators to the recorded data. Computed KS and AD statistics are given in Table 8.

Table (8): Computed values of KS and AD statistics of MT_{min}/AT_{min} for Dabaa region:

January	Lieblein		MOM		***February***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
KS	NF	NF	0.1577	0.1270	KS	NF	NF	0.1104	0.0807
AD	NF	NF	0.6293	0.3549	AD	NF	NF	0.6769	0.4026
March	Lieblein		MOM		***April***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
KS	NF	NF	0.0911	0.0848	KS	NF	NF	0.1444	0.1249
AD	NF	NF	0.2253	0.2015	AD	NF	NF	0.4365	0.3143
May	Lieblein		MOM		***June***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
KS	NF	NF	0.2138	0.1990	KS	NF	NF	0.1376	0.1360
AD	NF	NF	1.1441	0.8701	AD	NF	NF	0.5814	0.4645
July	Lieblein		MOM		***August***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
KS	NF	NF	0.1475	0.1368	KS	NF	NF	0.1471	0.1503
AD	NF	NF	0.7859	0.6333	AD	NF	NF	0.4955	0.4965
September	Lieblein		MOM		***October***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
KS	0.2582	0.2679	0.2006	0.1895	KS	NF	NF	0.0899	0.0871
AD	NF	NF	1.3095	1.0725	AD	NF	NF	0.3196	0.2672
November	Lieblein		MOM		***December***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
KS	NF	NF	0.1279	0.1187	KS	NF	NF	0.1433	0.1078
AD	NF	NF	0.4075	0.3231	AD	NF	NF	0.6198	0.2909

Annual	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**
KS	NF	NF	0.11	0.0902
AD	NF	NF	0.36	0.2522

NF: Modeling the MT_{min}/AT_{min} using Gumbel min. and Weibull distributions with Lieblein estimators are not feasible due to the non-convergence of the data series while determining the distributional parameters.

From Table 8, it can be noted that the computed value of KS and AD statistics given by Gumbel G_{min}) and Weibull (W) distributions with MOM estimators are less than the critical value at 0.05 significance level ($KS_{14,0.05}$=0.3489 and $AD_{14,0.05}$= 2.5018). The results indicate that both distributions with the MOM parameters estimation are acceptable for assessing the MT_{min}/AT_{min} for Dabaa region. The G_{min} and W distributions with Lieblein estimators are greater than the critical value at 0.05 significance level. Thus, both distributions with Lieblein technique are not suitable in a set of minimum temperature data. This is attributed to the fact that the MT_{min}/AT_{min} using Gumbel minimum and Weibull distributions with Lieblein estimators are not feasible due to the non-convergence of the data series while determining the distributional parameters(18).

Comparison between G_{min} , W distributions with the MOM estimators is made to reveal the most optimal distribution that can be used to estimate the minimum temperature. Table 9 shows the indices of MARD, RMSE and RMSD of MT_{min}/AT_{min} for Dabaa region. Table 9 shows that the Weibull distribution combined with MOM estimators gave the highest fit, most reliable and accurate predictions for estimating MT_{min}/AT_{min}. Therefore, the estimated MT_{min} at 100-yr return period from January to December are 3.3, 3, 3.4, 7.3, 9.5, 13.5, 16.4, 17.9, 15.6, 12.4, 8.3 and 4.1 ^{o} C, respectively. The estimated AT_{min} at 100-yr return period is 2.9 ^{o} C.

Table (9): Indices of MARD, RMSE and RMSD of minimum temperature for Dabaa region:

January	Lieblein		MOM		***February***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
MARD	NF	NF	3.4102	*2.698	MARD	NF	NF	4.2518	*2.8181
RMSE	NF	NF	0.2501	*0.206	RMSE	NF	NF	0.3029	*0.2135
RMSD	NF	NF	0.0018	*0.0012	RMSD	NF	NF	0.0023	*0.0011
March	Lieblein		MOM		***April***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
MARD	NF	NF	3.241	*2.8292	MARD	NF	NF	1.7607	*1.5472
RMSE	NF	NF	0.2735	*0.2513	RMSE	NF	NF	0.1952	*0.1693
RMSD	NF	NF	0.0022	*0.0013	RMSD	NF	NF	0.0004	*0.0003
May	Lieblein		MOM		***June***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
MARD	NF	NF	2.827	*2.581	MARD	NF	NF	1.3074	*1.238
RMSE	NF	NF	0.385	*0.352	RMSE	NF	NF	0.2791	*0.2596
RMSD	NF	NF	0.0011	*0.00088	RMSD	NF	NF	0.0003	*0.0002
July	Lieblein		MOM		***August***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
MARD	NF	NF	1.1295	*1.0651	MARD	NF	NF	0.7255	*0.7042
RMSE	NF	NF	0.2893	*0.2731	RMSE	NF	NF	0.1848	*0.1828
RMSD	NF	NF	0.0002	*0.00018	RMSD	NF	NF	9E-05	0.00009
September	Lieblein		MOM		***October***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
MARD	4.3532	4.278	1.782	*1.66576	MARD	NF	NF	0.8858	*0.8124
RMSE	0.8875	0.869	0.3691	*0.34837	RMSE	NF	NF	0.1608	*0.1524
RMSD	0.0023	0.0022	0.00041	*0.00036	RMSD	NF	NF	0.0001	0.0001
November	Lieblein		MOM		***December***	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**		**G_{min}**	**W**	**G_{min}**	**W**
MARD	NF	NF	1.63827	*1.4538	MARD	NF	NF	3.2129	*2.2816
RMSE	NF	NF	0.20285	*0.1858	RMSE	NF	NF	0.2683	*0.1949
RMSD	NF	NF	0.00036	*0.00029	RMSD	NF	NF	0.0014	*0.0007

Annual min	Lieblein		MOM	
	G_{min}	**W**	**G_{min}**	**W**
MARD	NF	NF	4.1519	*3.1621
RMSE	NF	NF	0.2481	*0.1889
RMSD	NF	NF	0.003	*0.0017

The relationship between different return period and estimated maximum and minimum temperature (annual and monthly) are shown in Figs 3 and 4, respectively. Figure 3 shows that the maximum temperature tends to increase with the increase in the return period (directly proportional). Figure 4, however, shows that the minimum temperature tends to decrease with the increase in the return period (inversely proportional).

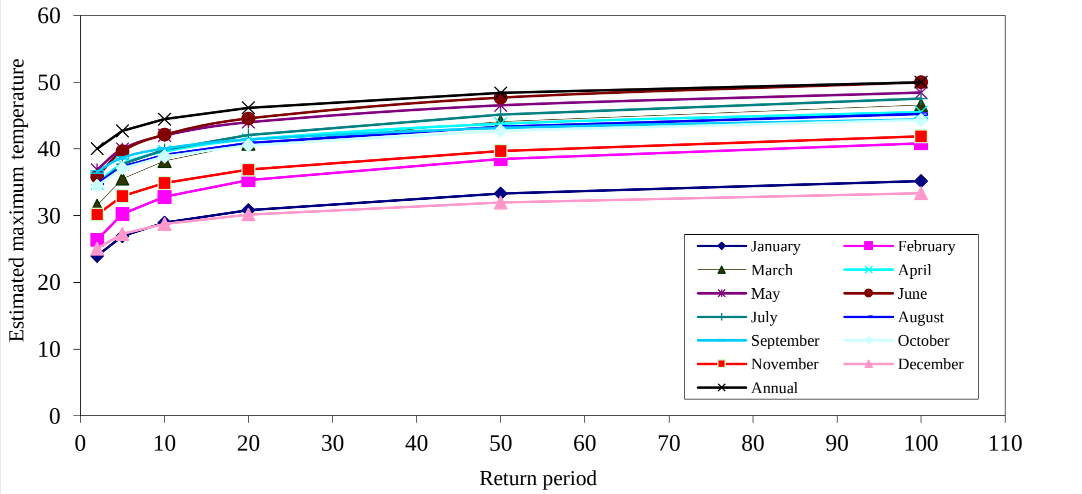

Fig. (3): The relationship between the return period and maximum temperature.

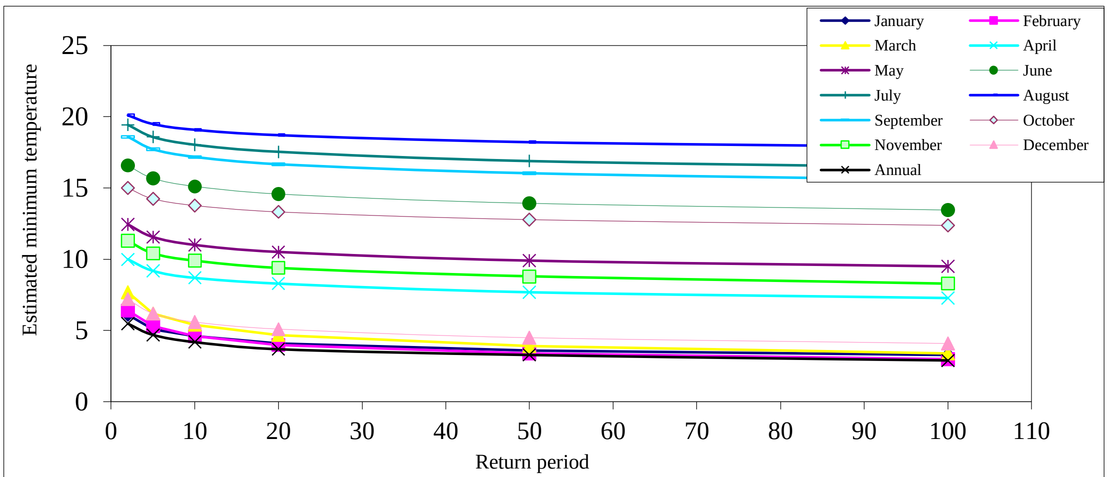

Fig. (4): The relationship between the return period and minimum temperature.

CONCLUSIONS

This paper presents a study on assessing adequacy of extreme value probability distributions represented in Gumbel (*G*), Ftechet (*F*) and Weibull (*W*) for estimating design maximum and minimum temperature (annual and monthly) in Dabaa region. The recommendations of IAEA (International Atomic Energy Agency) were taken into our consideration.

The following conclusions can be reached:

(1) The results of KS and AD tests confirmed that:

-The G_{max} and *F* distributions with both methods of estimation of their parameters (Lieblein and MOM)

are found to be suitable for modeling MT_{max}/AT_{max} for Dabaa region.

-The G_{min} and *W* distributions with the MOM estimators are acceptable for modeling the MT_{min}/AT_{min}.

(2) According to the smallest values of MARD, RMSE and RMSD, the results showed that:

-The G_{max} distribution combined with MOM estimators gave the highest fit, most reliable and accurate predictions for estimation MT_{max}/AT_{max} at different return period for the region under study; except July, August, October and November months. The *F* distribution and MOM estimators is the most accurate for estimating the extreme maximum temperature in July, August and November. The G_{max} and Lieblein technique is the best for October month.

-The *W* distribution combined with MOM estimators gave the highest fit and accurate predictions for estimating the extreme minimum temperature MT_{min}/AT_{min}.

(3)The study showed that the estimated 100-yr return period AT_{max} and AT_{min} are 50^o C and 2.9^o C, respectively.

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