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ABSTRACT

In the design of engineering structures, an understanding of extreme weather conditions that may occur at the site of interest is very essential, so that the structures can be designed to withstand such situations. In this report an analysis of extreme values of meteorological parameters observed at Kakrapar Atomic Power Station site for the period 1994 – 2001 is described. The parameters considered are maximum and minimum air temperature, maximum wind speed and gust, and maximum rainfall in a month, in a day, in an hour and annual rainfall.

The extreme value analysis reveals that annual rainfall, maximum monthly rainfall, minimum air temperature & maximum wind speed at 10m obey Fisher–Tippet Type – 1 distribution whereas maximum daily rainfall, maximum hourly rainfall, maximum air temperature & maximum wind speed at 30 m obey Fisher–Tippet Type – 2 distribution function. there is no difference in correlation coefficients and fit both extreme value distribution function. Co-efficients of the distribution functions for each variable are established. Extreme values of parameters corresponding to return periods of 50 and 100 years are derived. These derived extreme values are particularly useful for arriving at suitable design basis values to ensure the safety of any civil structure in and around Kakrapar Atomic Power Station site with respect to stresses due to weather conditions

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1. *INTRODUCTION*

In any civil engineering work, knowledge of extreme weather conditions juxtaposed with that of strength of civil structures to withstand such extremities forms the basis for the design of these structures. Such study, apart from common weather variables like temperature, wind speed, rainfall and relative humidity, includes aspects like flood, earthquake, lightning etc. in the locality before actually designing the structures(1,2,3). These weather conditions are characterized by suitable parameters after subjecting the relevant data to statistical treatment. These studies provide an insight into the extreme values of the considered variable over a period, generally during the expected lifetime of the structure and help the designer to arrive at the design basis values of different parameters as regards the safety of the concerned structure.

This report presents a study on the extreme value analysis for the meteorological parameters like air temperature, wind speed and rainfall for Kakrapar Atomic Power Station (KAPS) site. A study of long-term analysis of rainfall at any place finds use in many applications like irrigation engineering, water harvesting, public health engineering, drainage system design etc. They also help in planning pre and post flood operations.

The hourly rainfall data for 8 years (1994 – 2001) forms the basic data set for the analysis. Aspects covered in this analysis are annual, monthly, daily and hourly maximum rainfall. Extreme value analysis distribution functions of each variable are established. Extreme values corresponding to 50 and 100 years return periods are derived. These values are particularly useful in arriving at design basis values to assure safety of civil structure and site with regard to stresses due to extreme weather conditions.

2 DATABASE AND ANALYSIS

Hourly temperature and relative humidity data observed form the raw data for these parameters. For extreme value analysis of wind speed, one hourly average values obtained are used. For rainfall analysis, hourly rainfall data obtained from a recording rain gauge forms the raw data.

2.1 Long Term Statistical Analysis

From the raw data of daily maximum and minimum temperature, yearly extreme values are obtained and used for extreme value analysis. From the hourly rainfall data, maximum hourly, daily and monthly rainfall and annual rainfall are obtained. The basic data set used for extreme value analysis for extreme rainfall and other meteorological parameters are shown in Table – 1 and 2 respectively.

2.2 Extreme Value Analysis

The meteorological variables chosen for this analysis are maximum and minimum air temperature, maximum wind speed, maximum rainfall in an hour, a day, a month and annual rainfall. The values are arranged in ascending order for maximum and descending order for minimum of the parameter and each data point is assigned a rank 'm'. For data with same value, though the rank is same, it is suitably designated so as to leave no gaps in the ordered data array. The probability of non-exceedence of a particular magnitude X of the data point of rank m was obtained as -

$$P(x) = m / (M+1)$$

Where 'M' is the total number of data points.

The data was examined for a linear fit between the data values and probability of non - exceedence. Correlation coefficients between Y Vs X_p and ln (Y) Vs X_p for all the variables were found out in order to choose the best fit. For parameters obeying Fisher Tippet Type-1 it was found that the correlation coefficient between Y Vs. X_p range from 0.95 to 0.98 and for parameters obeying Fisher Tippet Type-2 that between ln(Y) Vs X_p range from 0.92 to 0.98 . The co-relation coefficients shows that annual rainfall, minimum air temperature & maximum wind speed at 10m obey Fisher–Tippet Type – 1 distribution function, whereas maximum daily rainfall and maximum hourly rainfall, maximum air temperature & maximum wind speed at 30m obey Fisher–Tippet Type – 2 distribution function.

Figure–1 shows the plots of extreme value distribution function for all the rainfall parameters and Figure-2 & Figure-3 present the plots for the other meteorological variables studied.

Equation for the straight line in the plot of Y vs. Xp can be written as

$$Y = \alpha + \beta_1 \; X_p \qquad \ldots \quad \ldots \quad \ldots \qquad [\,1\,]$$

Where Xp is the reduced variate corresponding to P(x), defined as –

$$X_p = -\ln [\, -\ln \{P(x)\}] \qquad \ldots \quad \ldots \quad \ldots \qquad [\,2\,]$$

Similarly the equation for the straight-line graph of ln (Y) versus X_p is –

$$\ln Y = \ln \beta_2 + \,(1 / \gamma)\, X_p \qquad \ldots \quad \ldots \quad \ldots \qquad [\,3\,]$$

Equation [1] and [3] can be easily transformed into the expressions for the two widely used extreme value distribution functions. (Fisher and Tippet, 1928)[4] Viz:

$$P(x) = \exp [\, - \exp \{\, - (Y - \alpha) / \;\beta_1 \,\}\,] \qquad \ldots \quad \ldots \quad \ldots [\,4\,]$$

Fisher – Tippet Type I[5]

$$P(x) = \exp [\, - (Y / \beta_2\,)^{-\gamma}\,] \qquad \ldots \quad \ldots \quad \ldots \qquad [\,5\,]$$

Fisher – Tippet Type II

Where,

P(x) is the probability that the value of the variable does not equal or exceed Y (also called probability of non-exceedence)

In Eq. (4) and (5), α and β_1 can be identified as location and scale parameters of the type – I distribution function; and β_2 and γ as the scale and shape parameters of the type – II distribution function. Type – I distribution can be obtained from type – II by a logarithmic transformation of the variable.

Thus from the slopes and intercepts of the straight line obtained as shown in plots in Figure – 1 to 3, the distribution parameters α and β_1 can be determined. These parameters then define P(x) completely and enable one to obtain the probability that a given value is exceeded irrespective of whether the value lies within the observed range or not.

The parameter needed for actual application is a design value of the parameter with defined probability. Contrarily, when the design value is selected the probability of exceedence of this value over a given period (say expected life time of the structure) can be worked out. For this, a Mean Recurrence Interval (MRI) or return period is defined which is related to P (x) by a relation

$$MRI = 1 / [\ 1 - P(x)\ ] \text{ years} \qquad \ldots \ \ldots \ \ldots [\ 6\ ]$$

Using the values of the distribution parameters, MRI for any value of the parameter or conversely the value of the parameter for any return period can be obtained.

3. RESULTS AND DISCUSSIONS

The distribution parameters of the extreme value distribution functions for all the parameters are summarised in Table - 3. For parameters obeying Fisher Tippet Type-1 it was found that the correlation coefficient between Y Vs. X_p range from 0.95 to 0.98 and for parameters obeying Fisher Tippet Type-2 that between ln(Y) Vs X_p range from 0.92 to 0.98 . The co-relation coefficients shows that annual rainfall, minimum air temperature & maximum wind speed at 10m obey Fisher–Tippet Type – 1 distribution function, whereas maximum daily rainfall and maximum hourly rainfall, maximum air temperature & maximum wind speed at 30m obey Fisher–Tippet Type – 2 distribution function. The table also gives the values of the extreme values of the parameters derived for the return period of 50 and 100 years. The extreme values for the return period of 50 and 100 years for all common parameters studied falls in the same range. These derived extreme values are particularly useful for arriving at suitable design basis to ensure the safety of any civil structure in and around KAPS site with respect to stresses due to weather conditions.

4. *CONCLUSION*

Based on the degree of correlation between Xp and Y (or ln (Y)), it is seen that annual rainfall, maximum monthly rainfall, minimum air temperature and maximum wind speed at 10m obey Fisher–Tippet Type – 1 distribution function, whereas maximum daily rainfall and maximum hourly rainfall, maximum air temperature & maximum wind speed at 30 m obey Fisher–Tippet Type – 2 distribution function. Extreme value distribution function parameters have been established for all the meteorological variables recorded at ESL KAPS for the return period of 50 and 100 years. These values are useful in arriving at the design basis values to ensure safety of civil structures in and around KAPS site. The results of the maximum rainfall analysis may be used for the future plans in the water harvesting, irrigation and drainage design in the area.

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Table – 1

YEARWISE RAINFALL (mm) PARAMETERS AT ESL KAPS

Year	Annual Rainfall (mm)	Maximum Rainfall (mm)		
		Monthly	Daily	Hourly
1994	1941.1	761.5	411.3	90.0
1995	1066.2	737.3	133.2	45.5
1996	1387.9	489.5	272.6	62.0
1997	1480.3	468.5	137.2	33.2
1998	1454.3	549.8	246.2	59.0
1999	771.7	327.3	80.7	41.9
2000	793.5	456.0	154.9	48.7
2001	1384.9	487.0	149.0	53.0

Table – 2

YEARWISE EXTREME METEOROLOGICAL PARAMETERS AT ESL KAPS

Year	Max. Temperature °C	Min. Temperature °C	Max. Wind speed (km/h) 10 m level	Max. Wind speed (km/h) 30 m level
1994	42.0	9.0	36.0	36.0
1995	42.5	8.9	34.2	39.6
1996	42.6	7.8	32.4	48.6
1997	42.0	6.6	28.8	36.0
1998	43.8	4.5	36.0	50.4
1999	42.8	7.0	25.2	36.0
2000	41.8	7.5	28.8	39.6
2001	43.0	6.5	28.8	36.0

Table –3

DISTRIBUTION PARAMETERS FOR EXTREME VALUE PROBABILITY FUNCTIONS AND 50 & 100 YEARS RETURN PERIOD VALUES FOR DIFFERENT METEOROLOGICAL PARAMETERS AT ESL KAPS

Parameters	No.of years	Observed Variate form used	Function Type #	α	β	R	Return period (years)	
							50	100
Annual Rainfall (mm)	8	Linear	FT-1	1097.9	386.22	0.95	2604.91	2874.57
Maximum Monthly Rainfall (mm)	8	Linear	FT-1	464.55	144.67	0.95	1029.04	1130.05
Maximum Daily Rainfall (mm)	8	Linear	FT-2	4.92	0.51	0.97	1002.24	1430.92
Maximum Rainfall in Hour (mm)	8	Linear	FT-2	3.80	0.30	0.98	144.11	177.69
Maximum Air Temp.°C	8	Linear	FT-2	3.74	0.16	0.98	44.81	46.15
Minimum Air Temp.°C	8	Linear	FT-1	7.93	-1.46	0.98	2.21	1.19
Maximum Wind Speed 10m (km/hr)	8	Linear	FT-1	29.39	3.88	0.95	44.53	47.24
Maximum Wind Speed 30m (km/hr)	8	Linear	FT-2	3.62	0.13	0.92	62.01	67.90

: (1) FT – I means Fisher – Tippet type – I distribution function of the form
$P(x) = \exp[-\exp\{-(Y-\alpha) / \beta_1\}]$ or $Y = \alpha + \beta_1 X_p$ with $X_p = [-\ln\{-\ln P(x)\}]$ &
$P(x) = m(x)/(M+1)$ where $m(x)$ is rank of variate X and M is the total no. of data points

(2) FT – II means Fisher – Tippet type – II distribution function of the form
$P(x) = \exp\{-(Y/\beta_2)^{-\gamma}\}$ or $Y = \beta_2 \exp(X_p/\gamma)$ with $X_p=[-\ln(-\ln P(x))]$ & $P(x) = m(x)/(M+1)$

(3) R = Correlation coefficient between parameter studied and probability of non exceedence

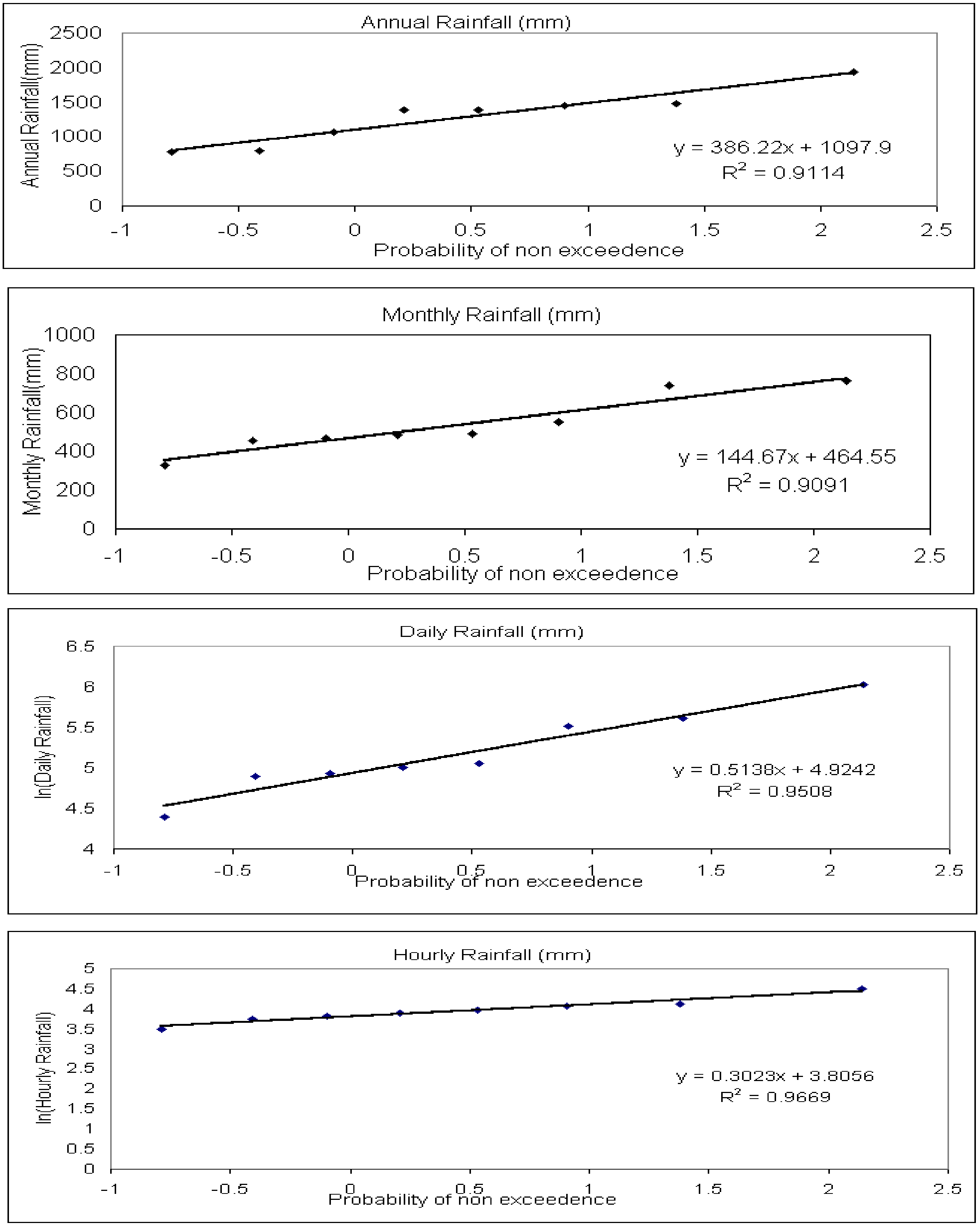

Fig-1 : TYPICAL PLOTS OF EXTREME VALUE DISTRIBUTION OF RAINFALL PARAMETERS AT ESL, KAPS

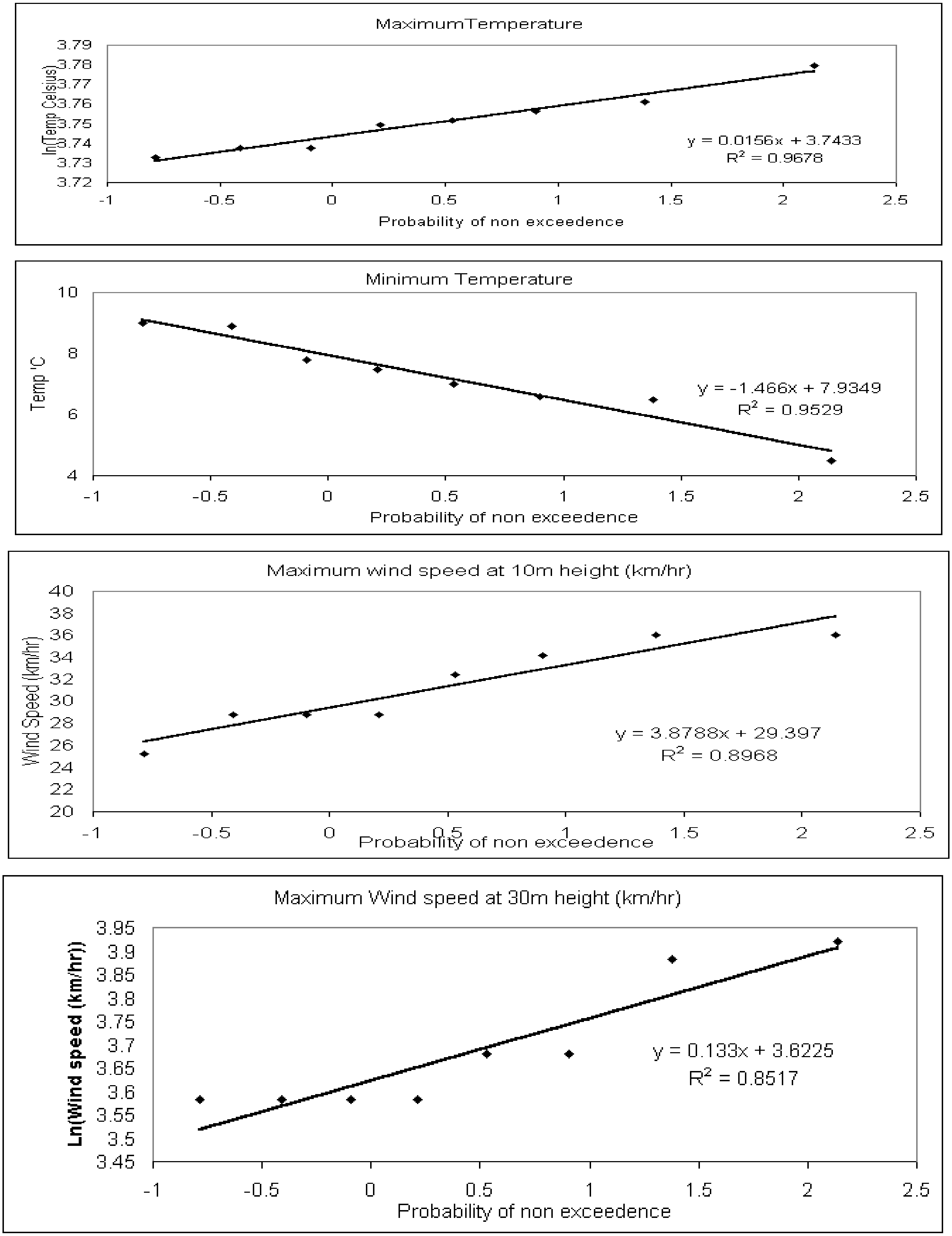

Fig-2 : TYPICAL PLOTS OF EXTREME VALUE DISTRIBUTION OF MAXIMUM & MINIMUM TEMPERATURE & MAXIMUM WIND SPEEDS AT 10 & 30 m AT ESL, KAPS