Trend analysis and formula development of extreme rainfall events: a case study of Hopa, Turkey

Sinan Jasim Hadi, and Mustafa TOMBUL

Abstract— A damaging flood happened last year in Hopa which is located in Artvin province northeast of Turkey. In this study, analysis of the event conducted through time series analysis of the extreme rainfall events. Trend using Mann-Kendall (MK) and Cox and Stuart tests, stationarity using Kwiatkowski–Phillips–Schmidt–Shin (KPSS) and Phillips–Perron (PP) tests, and homogeneity using Pettit, Alexanderson's SNHT, Buishand, and von Neumann's tests are also determined. Five distribution functions are fitted to the data: Weibull 3, Normal, Log-Normal 3, Log-Pearson 3, and Gumbel. The best fitting distribution is identified using: Chi –Square, and Kolmogorov-Smirnov which then utilized in constructing intensity - duration – frequency (IDF) curve. A formula developed based on the IDF curve. The developed formula used for calculating the return periods of the flood event observations. Extreme rainfall events for all durations are found stationary without significant trend and homogenous. The best fitting distribution found is Gumbel. The developed formula promotes high correlation 0.994 between the predicted and the observed intensities. A return period of 211 years belonging to 4 hours' storm duration is the highest calculated return period for the flood records using the developed formula. The intensity of the duration of 24 hours which causes the flood found to have a 41-year return period. Intensities of the durations ≤ 4 hours of the flood event found less than the records of the extreme events observed in 1988 while for the durations > 4 hours are higher.

Keywords— Flood, Gumbel, hopa , intensity-duration-frequenc, rainfall, stationarity, trend analysis.

I. Introduction

In the future, the intensity and the frequency of the extreme rainfall events are expected to witness a rise in the areas that already have frequent and intense events whereas areas with less frequent and intense are to witness a diminution [1]. Detecting the historical change not only in precipitation data but in any time series data can be done using trend and stationary analysis. Stationarity or non-stationarity is crucial for extreme rainfall events as it is the main assumption of the frequency analysis of the extreme rainfall events [2-4].

Management and planning of water resources includes the determination of required discharge capacity of channels, pumping station capacity and planning out the design and building of sewage and storm systems. This management can be eased by using statistical methods that use extreme rainfall data for carrying out the assessment of water resource management. These methods, particularly the Intensity – Duration – Frequency (IDF) curves which defined by [5, 6] as a diagram illustrating the intensity of the rainfall falling on a basin for a specified period of time, can play an important role in: reducing the loss of property and life by judging and assessing hazards, the damage that can occur, and the preventive methods that need to be implemented [7]. IDF is used for extracting the rainfall intensity for various storm durations and several return periods.

Based on the IDF curves, the mathematical relationship among rainfall intensity I, duration d, and return period T (also known as the frequency) can be developed [6, 8, 9]. This relationship can be used as an alternative for the IDF curve for the calculations of any of the missing variable. For example, in case of needing the intensity known as storm design this formula can be used that the intensity can be obtained by substituting any return period and duration.

Many studies have been conducted around the world for constructing the IDF curves and developing formula representing these curves. The following are some instances: [6, 7, 10-14]. Several studies have also been conducted in a number of cities around Turkey such as: [15-20]. As an example, [19] studied the area of Erzurum. The authors developed a formula for short duration rainfall i.e. 5, 10, 15, 30, and 60 minutes with the use of 2, 5, 10, 25, 50, 75 and 100 return periods. A formula was developed for all the used return periods with an exception of 100 years as a different formula developed due to its low coefficient of correlation. The authors in [16] studied the capital of Turkey (Ankara) and they used the same durations and return periods used in [19] with the exception of adding 500 years to the return periods. They developed two formulas one for return periods ≤ 10 years and another for >10 years.

The general objective of the study is to examine, and analyze the historical rainfall observations and compare them with the flood happened on 24/08/2015 in Hopa (a district of Artvin province located in the northeast of Turkey and on the eastern Turkey coast of the Black sea) caused 8 deaths, 3 missing and 17 injured. The detailed objectives are: a) Implementing trend, stationarity and homogeneity tests on the extreme rainfall

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events; b) constructing the IDF based on the best fitting distribution; c) developing a formula representing the IDF; d) comparing the flood observations and calculating their return periods.

II. Study area and Data

The aim of this study to analyze rainfall observations that caused a flood in Hopa which led to several deaths, and injuries in addition to a vast destruction in the properties as some of the houses were almost totally covered by the water. The heavy rain caused not only flood but landslides in several parts of the area. Only one station located at the coordinates 41°24'23.55"N and 41°26'35.57"E was used. Study area is shown in fig. 1.

Data for the chosen metrological station located at hopa were collected from General Department of Meteorology - Ministry of Forest and Water Affairs of Turkey. Data from 1965 to 2015 was collected for the duration of 5, 10, 15, 30, 60, 120, 180, 240, 300, 360, 480, 720, 1080, 1440 min. The observations of 2015 which is the year the flood happened was not included in the IDF and formula calculations in order to be used for the comparison and the calculations of the return period.

III. Methodology

Detecting rise or reduction in any time series historical data is very important especially for identifying the climate change effect. In this study, two trend tests were implemented: Mann-Kendall test (MK) and Cox and Stuart test. Null hypothesis (H0) of MK and Cox and Stuart test is that no monotonic trend is present whereas the alternative hypothesis (Ha) is that Monotonic trend is present. P value for every duration was calculated and compared with the confidence level. If the P value higher than the confidence level, we fail to reject the null hypothesis and vice versa.

Trend test helps in detecting the increase or decrease in the historical data but the detected change does not provide information about nonstationarity that important in IDF constructing. Therefore, nonstationarity analysis conducted in this study using two tests: Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test and Phillips–Perron (PP) test. KPSS test's null hypothesis (H0) is that time series data are stationary and the alternative hypothesis (Ha) is that data are nonstationary while PP test has the contrast hypotheses (i.e. H0: Nonstationary, and Ha: Stationary).

Homogeneity is also important in detecting whether the time series data are homogenous or heterogeneous (i.e. a change occurs). Homogeneity in the extreme events values obtained using four test: Pettit, Alexanderson's SNHT, Buishand, and von Neumann's tests. The change year obtained using the first three of these tests due to their ability to detect the year in which the change most probably occurred. A brief of these tests mentioned in the next sections.

Generally, IDF curves are constructed through several steps [21, 22]. Initially, the historical records are fitted to one of the distribution function and that is done for every duration. In this study, five distribution functions used: Weibull 3, Normal, Log-Normal 3, Log-Pearson 3, and Gumbel. The identification of the best fitting distribution was conducted using: Chi –Square, and Kolmogorov-Smirnov (a brief of the two test later). The second step is to use the distribution functions to calculate the intensities for every duration and chosen return periods. In this study, only the best fitting distribution used for calculating the intensities using return periods: 2, 5, 10, 25, 50, 100, and 500.

An empirical IDF formula was also developed which is used for calculating the intensities as a dependent variable by substituting the storm duration and the return period which are considered as independent variables. Therefore, A power-law relation as in Eq. (1) can be used for this purpose due to the advantage of having the intensity $\mathrm{I_T}$ being dependent on the return period $\mathrm{T_r}$ and storm duration $\mathrm{t_d}$ separately.

$$\mathrm{I_T} = \frac{\mathrm{fn}\ (\mathrm{T_r})}{\mathrm{fn}\ (\mathrm{t_d})} \qquad (1)$$

The function fn(T_r), according to [7, 21, 22] can be given as:

$$\mathrm{fn}(\mathrm{T_r}) = \mathrm{a}\ (\mathrm{T_r})^{\mathrm{m}} \qquad (2)$$

According to [21, 23], the storm duration fn(t_d) can be given by:

$$\mathrm{fn}(\mathrm{t_d}) = (\mathrm{t_d} + \mathrm{b})^{\mathrm{e}} \qquad (3)$$

Eq. (1) is a formula that is used for calculating the intensity, after determining the parameters, for a specific return period and storm duration. Placing Eq. (2) and (3) in this equation, following power-law equation is obtained:

$$\mathrm{I_T} = \frac{\mathrm{a}\ (\mathrm{T_r})^{\mathrm{m}}}{(\mathrm{t_d}+\mathrm{b})^{\mathrm{e}}} \qquad (4)$$

Where I_T the intensity, T_r the return periods, t_d storm duration, and (a, m, b, and e) are the fitting parameters. In this study the b parameter was eliminated from the equation as it has no effect due to its small value. Using the statistic language R with the help of the Non- Linear Least square regression, the parameters were obtained. After obtaining the formula the correlation between the observed and the predicted values was calculated in addition to plot them for having a visual evaluation.

The observations of 2015 that represent the extreme rainfall values which all recorded on the day of the flood, were removed from the IDF and formula calculations for using them for the comparison. The observations which collected as the depth of the rainfall were converted to intensities. These intensities along with the storm duration were substituted in the obtained formula for calculating the expected return periods. The observations of 1988 are the highest records in the studied period. Therefore, they were chosen for the comparison.

A. Goodness of Fit: Chi-Square and Kolmogorov – Smirnov Tests

Estimation of the maximum rainfall intensity for varying return periods and storm duration has been carried out in this study using five distribution functions: Weibull 3, Normal, Log-Normal 3, Log-Pearson 3, and Gumbel. Tests need to be carried out on the functions to evaluate the function that best fits the data. The most popularly used test for this is the Chi-Square test. This test helps to determine the degree of fitness between the sample frequencies (i.e. rainfall records in this study) and the frequencies calculated using the five distribution methods. Eq. (5) gives the Chi-Square test:

$$X^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i \quad (5)$$

In the above equation, O_i depicts the observed frequencies, i represents the class interval of the histogram, E_i are the expected values, X^2 is used to represent the test value, and k shows the number of class intervals. A better fit for the data will have smaller value of X^2 which means the expected and observed frequencies will be closer and if the value of X^2 is large then the function does not have a good fit [24]. In this study, P values were calculated and compared.

Another test that is used for determining the best fit distribution for the data is the Kolmogorov – Smirnov test. Empirical Cumulative Distribution Function (ECDF) is the basis for carrying out this test. The test can be implemented using the following equation:

$$F_n(x) = \frac{1}{n} . [\text{Number of Observations} \leq x] \quad (6)$$

In this equation $x_1, x_2, x_3, \ldots \ldots, x_n$ are the random samples obtained from continuous distribution with CDF F(x). The largest vertical difference between F(x) and $F_n(x)$ is used for determining the statistics of the test. This can be represented as:

$$D_n = \mathrm{Sup}_x |F_n(x) - F(x)| \quad (7)$$

Smaller the value obtained from the Kolmogorov- Smirnov test, the better is the fitting of the distribution and vice versa.

B. Homogeneity: Pettit, Alexanderson's SNHT, Buishand, von Neumann's tests

Homogeneity tests are used for determining if there is a change occurs in time series data or not. In case no change detected the series considered as homogenous whereas if a significant change occurs the series considered as heterogeneous.

In this study four tests used: Pettit, Alexanderson's SNHT, Buishand, and von Neumann's tests. Pettit test was developed and discussed by [25]. Pettit test requires no assumption about the distribution as it is non parametric test. This test focuses on the case of two-tailed test but cases of one-side tailed tests are also possible. The null hypothesis (H_0) of Pettitt test is that T variable (i.e. the length of the time series) follow one or more distributions but having the same location parameters while the alternative hypothesis (H_a) with two-tailed test is that a change point occurs and the alternative hypothesis (H_a) with one-side test is that there is a time t exists from which the variables location parameters reduced or augmented.

Alexanderson's SNHT (Standard Normal Homogeneity Test) developed by [26, 27]. The test was initially developed for detecting a change in a series of rainfall data. The test is applied to a series of ratios which compare the observations of a certain station with the average of several stations. These ratios are then standardized and they are notated here as Xi. The null hypothesis (H_0) of this test is that T variables Xi has a normal distribution with the parameters N (0,1). the alternative hypothesis (H_a) is that variables between 1 and n has an N (μ1,1) distribution and variables between n + 1 and T has an N (μ2,1) distribution.

Buishand test [28] can be used regardless the distribution that the variables follow but it was especially studied for the normal case. Alike the Pettit test, this test is used with three cases: one with two-tailed test and two cases with the left-tailed test. The null hypothesis (H_0) of this test is that the T variables has one or more distribution with the same mean. the alternative hypothesis (H_a) with two-tailed test is that there is a time t in which the variables change of mean and the alternative hypothesis with one-side test is that there is a time t exists from which the variables mean reduced or augmented.

Finally, von Neumann's test is also a powerful test but it does not provide the time in which the change happened on the contrast of the three afore mentioned test which allow detecting the time of the change. Its null hypothesis (H_0) and alternative hypothesis (H_a) are that data are homogenous and data are not homogenous respectively. Mathematics of the tests can be found in [25-30].

IV. Result and discussion

The time series data shown in fig.2. illustrates that trend cannot easily deduced due to the high number of local fluctuation. Therefore, linear fitting used for having a line that can be used for deduction of change during studied period.

The fitted lines illustrate that the extremes rainfall events of the durations ≤ 1 hour, in general, has almost no change. Starting with 5 minutes' duration with slightly decreasing trend moving to no change in the modest duration ending with the 1-hour duration with a very slight increase.

The durations > 1 hour demonstrate a slight increasing trend in all durations without the ability to identify which duration has increased more than others or which duration has a significant trend.

Trend analysis is conducted in this study using two tests Mann-Kendall test (MK) and Cox and Stuart test. The P values of these two tests for all storm durations are shown in table 1. All the values for the two tests higher than the three significance levels; 0.1, 0.05, 0.01, which means that the null hypothesis is failed to be rejected in all durations and that leads to making a decision that the time series data has no trend.

The result of the nonstationarity two tests Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test and Phillips–Perron (PP) test are shown in table 2. KPSS test is two-sided test and the test statistics of all storm durations are less than the critical values of all significance levels leading to the conclusion that data are stationary. On the other hand, PP test is left sided taking into account that the null hypothesis is that data are nonstationary. Test values of all durations are less than the critical values leading to the result that null hypothesis rejected, thus, data are stationary.

one hour and less while 2007 obtained in the middle durtions and long durations.

The results of Chi-Square and Kolmogorov – Smirnov tests used for identifying the best fitting distribution are listed in table 4. The higher the score (P values) in Chi-Square test the better fitting the data. Therefore, Gumbel can be deducted as the best fitting according to this test as it has the highest values in all durations. On the contrast, in Kolmogorov – Smirnov test

Table 1. Test statistics values for each duration of two Trend analysis tests: Mann-Kendall (MK) and Cox and Stuart

Test	5 min	10 min	15 min	30 min	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr	8 hr	12 hr	18 hr	24 hr
MK Test	0.17	0.14	0.13	0.23	0.38	0.32	0.27	0.16	0.29	0.39	0.17	0.19	0.51	0.94
Cox and Stuart	0.99	0.97	0.99	0.97	0.78	0.88	0.5	0.88	0.78	0.78	0.78	0.78	0.5	0.22
Confidence levels for MK and Cox and Stuart test are: 0.1, 0.05, 0.01														

Table 2. Test statistics values for each duration of two Nonstationarity analysis tests: Kwiatkowski–Phillips–Schmidt–Shin (KPSS) and Phillips–Perron (PP).

Test	5 min	10 min	15 min	30 min	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr	8 hr	12 hr	18 hr	24 hr
KPSS Test	0.247	0.314	0.318	0.2	0.088	0.061	0.092	0.054	0.049	0.039	0.03	0.03	0.04	0.092
PP Test	-5.983	-6.978	-6.723	-6.999	-7.41	-7.746	-7.51	-8.134	-7.93	-7.916	-7.171	-7.107	-7.846	-7.061
Confidence Level	KPSS	0.1	0.05	0.01	PP Test	0.1	0.05	0.01						
Critical value		0.347	0.463	0.739		-3.176	-3.495	-4.138						

Table 3. Most probable change year and homogeneity identification by Pettit, Alexanderson's SNHT, Buishand, and von Neumann's.

Test Name	Pettit		SNHT		Buishand		von Neumann
Duration	Year	Hypothesis	Year	Hypothesis	Year	Hypothesis	Hypothesis
5 Minutes	1992	Ho	1992	Ho	1992	Ho	Ho
10 Minutes	1977	Ho	1977	Ho	1977	Ho	Ho
15 Minutes	1977	Ho	1977	Ho	1977	Ho	Ho
30 Minutes	2007	Ho	1968	Ho	1977	Ho	Ho
1 Hours	2007	Ho	1977	Ho	1977	Ho	Ho
2 Hours	2007	Ho	2007	Ho	1988	Ho	Ho
3 Hours	2007	Ho	2007	Ho	2007	Ho	Ho
4 Hours	1986	Ho	2007	Ho	2007	Ho	Ho
5 Hours	1993	Ho*	2007	Ho*	2007	Ho	Ho
6 Hours	1993	Ho*	2007	Ho*	2006	Ho	Ho
8 Hours	1995	Ho*	2012	Ho*	1995	Ho	Ho
12 Hours	1993	Ho	2007	Ho*	1995	Ho	Ho
18 Hours	2000	Ho	2012	Ho	2007	Ho	Ho
24 Hours	2007	Ho	2012	Ho	2007	Ho	Ho
*** Significant at 0.05 only**							

Homogeneity tests are also important for determining if time series data are homogeneous or a change has occurred. The results of homogeneity tests listed in table 3 show that all duration of the time series data are homogenous in the four tests. In four durtions;5, 6, 8, and 12 hours, Pettit and SNHT tests are significant in the level of significance 0.05 while insignificant in the level of 0.01 which is considered in general as insignificant and the null hypothesis outweighed.

Pettit, SNHT, and Buishand test were used not only for testing the homogeneity of the data but for identifying the most probable change year also. Generaly, the results show no specific change year detected but 1977 and 2007 are the most obtained years.

The year of 1977 moslty obtained in the small durations i.e.

the lower the score (test statistic) the better the fitting. Gumbel also can be identified as the best fitting as it has the lowest values in most of the duration with the exceptions of 2, 3, 4, 5, 12, and 24 hours. According to the result of the two test Gumbel is determined as the best fitting and as consequences used for IDF development.

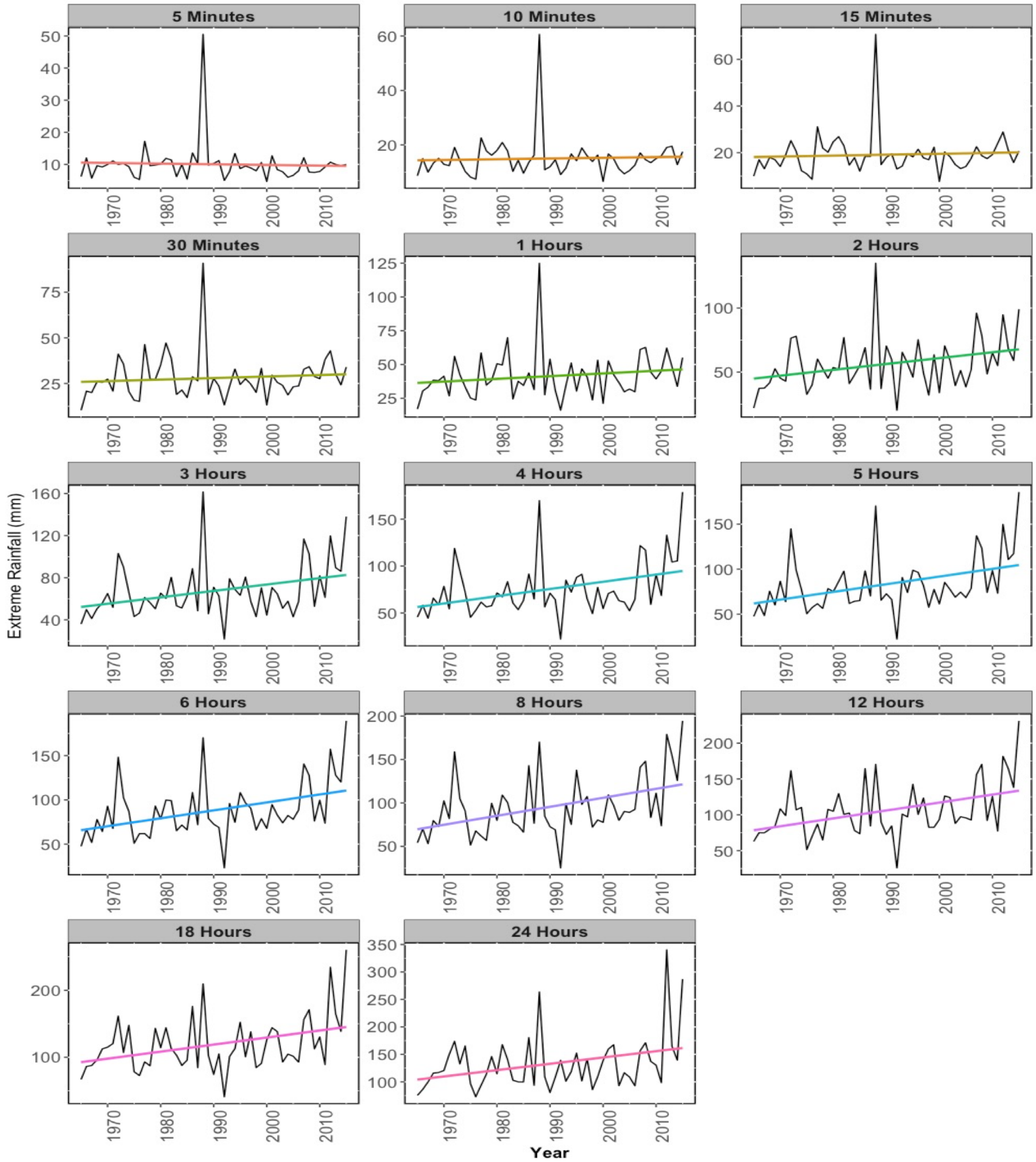

Fig. 2 Time series plot for all durations of the extreme rainfall events of Hopa station.

Table 5 shows the calculated intensities using frequency factor method of the Gumbel distribution including the calculation of the frequency factor KT for every return period. Using these result an IDF curve plotted in fig.3. Based on this IDF curve, intensity decreases as the storm duration increases for any return period while it increases as the return period increases for any storm duration.

In order to ease the extraction of any of the variables included in the IDF curve; intensity, return period, and storm duration, a formula developed according to the relation between them. The parameters obtained for the formula shown in equation (1) are substituted in the formula to have a formula can calculate any of the missing variables having the other two. The result of developing this formula shown in table 6 reveals high correlation 0.994. A visual comparison between the observed intensities that obtained from the fitting of Gumbel function and the predicted intensities shown in fig.4 illustrating tight agreement.

Table 4. Calculation of frequency intensity I_T (mm/hr) values for different durations t_d (minutes and hours) and return periods *Tr* (years) using Gumbel method.

	5 Minute		10 Minute		15 Minute		30 Minute		1 Hour	
Distribution	**CHS**	**KS**	**CHS**	**KS**	**CHS**	**KS**	**CHS**	**KS**	**CHS**	**KS**
Weibull3	0.000	0.266	0.003	0.146	0.002	0.150	0.055	0.118	0.550	0.107
Normal	0.000	0.272	0.000	0.211	0.000	0.190	0.017	0.168	0.303	0.108
Log-normal3	0.001	0.141	0.064	0.103	0.080	0.135	0.329	0.090	0.870	0.073
Log-Pearson 3	0.002	0.142	0.073	0.098	0.089	0.139	0.339	0.095	0.855	0.075
Gumbel	**0.022**	**0.118**	**0.218**	**0.097**	**0.215**	**0.116**	**0.549**	**0.086**	**0.964**	**0.059**
	2 Hour		**3 Hour**		**4 Hour**		**5 Hour**		**6 Hour**	
Weibull3	0.168	0.085	0.023	0.123	0.004	0.146	0.002	0.144	0.043	0.119
Normal	0.103	0.107	0.013	0.161	0.003	0.183	0.004	0.176	0.071	0.137
Log-normal3	0.348	**0.058**	0.156	0.096	0.084	0.118	0.042	0.127	0.243	0.100
Log-Pearson 3	0.366	0.073	0.191	**0.083**	0.105	**0.107**	0.044	**0.104**	0.257	0.112
Gumbel	**0.501**	0.063	**0.307**	0.089	**0.185**	0.115	**0.095**	0.115	**0.402**	**0.100**
	8 Hour		**12 Hour**		**18 Hour**		**24 Hour**			
Weibull3	0.004	0.105	0.017	0.131	0.002	0.120	0.188	0.101		
Normal	0.003	0.128	0.031	0.142	0.001	0.151	0.007	0.139		
Log-normal3	0.021	0.087	0.123	**0.091**	0.012	0.091	0.212	0.095		
Log-Pearson 3	0.049	0.097	0.114	0.101	0.014	0.092	0.474	**0.078**		
Gumbel	**0.082**	**0.083**	**0.196**	0.093	**0.027**	**0.088**	**0.485**	0.085		

- CHS = Chi –Square Test (P value)
- KS = Kolmogorov-Smirnov test (Statistic)
- Bold numbers representing the best result

Table 5. Calculation of frequency intensity I_T (mm/hr) values for different durations t_d (minutes and hours) and return periods *Tr* (years) using Gumbel method.

t_d		5 min	10 min	15 min	30 min	1 hr	2 hr	3 hr
Tr	K_T				I_T			
2	-0.16	108.07	82.40	70.63	51.62	38.24	26.08	20.68
5	0.72	175.34	122.23	102.07	73.37	53.60	35.02	27.87
10	1.30	219.88	148.61	122.88	87.77	63.77	40.94	32.62
25	2.04	276.16	181.93	149.18	105.96	76.62	48.42	38.63
50	2.59	317.91	206.64	168.69	119.45	86.15	53.97	43.09
100	3.14	359.35	231.18	188.06	132.85	95.61	59.48	47.51
500	4.39	455.11	287.88	232.81	163.81	117.48	72.21	57.74
t_d		4 hr	5 hr	6 hr	8 hr	12 hr	18 hr	24 hr
Tr	K_T				I_T			
2	-0.16	17.30	15.32	13.58	11.03	8.17	6.11	5.09
5	0.72	23.05	20.25	17.80	14.63	10.65	7.91	6.79
10	1.30	26.86	23.51	20.59	17.01	12.29	9.10	7.92
25	2.04	31.68	27.63	24.12	20.03	14.36	10.60	9.35
50	2.59	35.25	30.69	26.74	22.26	15.90	11.71	10.41
100	3.14	38.79	33.73	29.34	24.48	17.43	12.82	11.46
500	4.39	46.98	40.74	35.35	29.61	20.96	15.38	13.89

Table 6. Parameters of the developed formula and correlation.

Distribution	a	e	m	Derived Equation	Correlation
Gumbel	34.5	0.56	0.19	$I_T = \frac{34.5\,(T_r)^{0.19}}{(t_d)^{0.56}}$	0.994

Finally, the obtained formula used for calculating the return periods of the observation of 2015 which are recorded on the day of the flood event. The intensities converted from the collected depth and the calculated return periods for all storm durations shown in table 7. In the same table, the observations of 1988 the year that observed values are the highest among the years of the studied period are shown for the reason of comparison. The return period of the 24 hour is 41 years which means the intensity which is 12 mm/hr already recoded in the collected data. In 1988, the recorded intensity was 11 mm/hr which is close to that value. The highest return period is 211 years belongs to the duration 4 hours with an intensity 44.7 mm/hr and the value recorded in 1988 is 42.5 mm/hr.

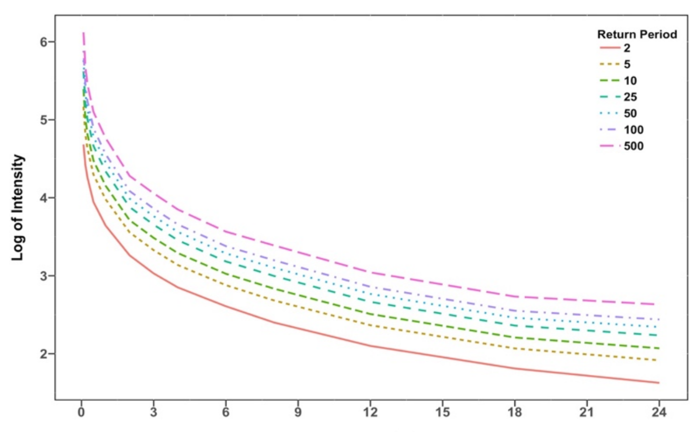

Fig.3 Fitted Intensity- Duration – Frequency (IDF) Curve of Gumbel function using extreme rainfall events for 14 durations storm and 6 return periods.

Table 7. intensities of year 2015, and 1988 and the calculated return periods.

Duration	Return period (Years)	Intensity (mm/hr) (2015)	Intensity (mm/hr) (1988)
5 min	1	120	606
10 min	2	105	363.6
15 min	2	82.8	282.8
30 min	4	68.0	181.8
1 hr	11	55.1	125
2 hr	48	49.6	67.5
3 hr	106	46.0	53.8
4 hr	211	44.7	42.5
5 hr	153	37.1	34.0
6 hr	112	31.6	28.4
8 hr	67	24.3	21.3
12 hr	65	19.3	14.2
18 hr	48	14.5	11.6
24 hr	41	12.0	11.0

In general, the intensities recorded in 1988 are higher than those recorded in 2015 in the duration ≤ 4 hours, while for the durations > 4 hours the 2015 intensities are higher.

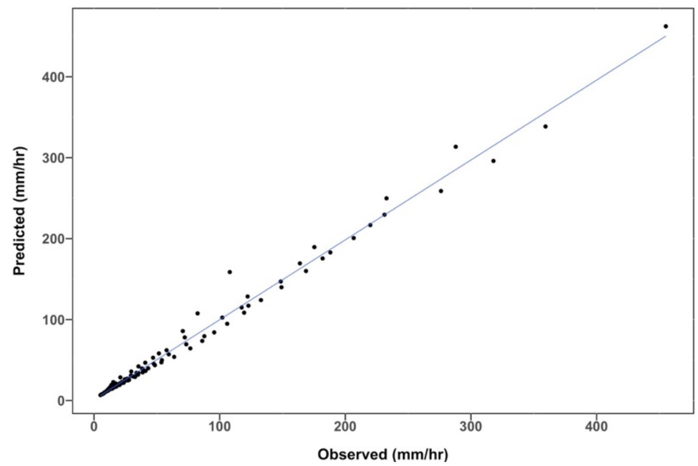

Fig.4 The observed values (i.e. obtained from the fitting of

V. Conclusion

The main aim of this study is to analyse the historical rainfall time series data of Hopa and the observations recorded on the day of the flood and compare them to have a broad idea about the event. The rainfall data proved as a stationary data and have no significant trend for the studied period 1965 – 2014. The observations recorded on the event day 23-24/08/2015 found as very close to the observations recorded in 1988 especially in the storm duration > 4 hours while for the durations ≤ 4 hours the event records are smaller. Although, the return period of 4 hours is found 211 years but the intensity recorded in the event 44.7 mm/hr is very close to the intensity 42.5 mm/hr which is recorded in 1988. The return periods 24 and 18 hours' duration are 41 and 48 years respectively which considered as not high values.

The calculation of the return periods and the comparison with the observations recorded in the studied period proved that the recorded intensities are expected to return with in the near future. the intensities recorded 28 years ago did not cause a flood and landslides like the one happened on the events day.

This study has not shown the reason of the flood. So, there is a shortcoming in this study that the analyses implemented based on one station records and that could be not enough to have a full image of the event. Therefore, there are two highly recommended points: spatial analysis of the event covering the entire area that the rainfall fell on, hydrologic modelling of the rainfall and flooded area with including the topography and the existing infrastructure.

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