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Rainfall Intensity-Duration-Frequency Analysis in Turkey, with the Emphasis of Eastern Black Sea Basin

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ABSTRACT

In this study, regional intensity-duration-frequency (IDF) curves for Turkey were developed using the available maximum rainfall intensity values for various durations (D=5, 15 and 30 minutes, and 1, 3, 6, 12 and 24 hours). Multi-nonlinear regression analysis was carried out by using nine kinds of IDF formulas, which were taken by using various IDF formulae in the literature and newly generated formulae. In order to test the reliability of the functions, two criteria were used: the determination coefficient and the mean relative error. IDF analysis in the Eastern Black Sea Basin of Turkey, which is the most raing basin, is also emphasized and studied in detail. It has been concluded that the reliability of the results is high enough and that this paper will motivate and open new horizons to detailed studies on IDF analysis.

Keywords: Intensity-duration-frequency analysis, LPT3 distribution, rainfall, regression analysis, Turkey.

1. INTRODUCTION

The rainfall intensity-duration-frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects, or the protection of various engineering projects against floods

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[1,2,3]. Civil infrastructure such as storm sewers, storm water management ponds, culverts and bridges are commonly designed using IDF curves, which assume that the occurrence of precipitation is in the form of rainfall and immediately available for the rainfall-runoff process [4]. The appropriately sized capacities of these civil infrastructure are so important to avoid overdesign which could lead to economic losses and/or increased property damage and possibly increased risk of loss of life. Thus, obtaining reliable estimates of IDF curves is essential [5].

The IDF relationship is a mathematical relationship between the rainfall intensity I, the duration D, and the exceedance frequency F (F=1/T, T is return period). This relation is usually obtained as curves, and each curve shows the change of intensity of rainfall with respect to a return period. These curves are generally obtained by empirical and statistical approaches [6].

The establishment of IDF relationships goes back to the 1930s [7]. Since then, different forms of relationships have been constructed for several regions of the world up to today. A general IDF relationship formula, consistent with the theoretical probabilistic foundation of the rainfall data, was provided by Koutsoyiannis et al. [8] in Greece. Okonkwo and Mbajiorgu [9] analyzed rainfall data and characteristics for locations in seven states of Southeastern Nigeria and developed IDF curves for these locations using graphical and statistical methods. Also, an application to rainfall datasets from two Mediterranean climate locations (Spain and Chile) was set up by Ayuso-Munoz et al. [10]. The regional properties of IDF relationships have been also investigated in the recent studies and maps have been developed to provide the rainfall intensities or depths for various return periods and durations [11]. There are also several studies about IDF in Turkey. Karahan et al. [12], applied a solution algorithm that solves IDF relationship by using Genetic Algorithm (GA) optimization technique to four city centers in the Southeastern Anatolia Project (GAP) region. Their results showed that the developed solution algorithm that is alternatively proposed to determine IDF relationship gives accurate results for the cities located in the GAP region. Ghiaei et al. [13], analyzed rainfall intensity-duration-return period data in the Eastern Black Sea Region by using L-moments and artificial neural networks (ANN). Based on the distribution functions, they extracted the governing equations for calculation of intensities of 2, 5, 25, 50, 100, 250, and 500 years return periods (T). Then, T values for different rainfall intensities were estimated using data quantifying maximum amount of rainfall at different times. Yavuz [14], calculated the parameters of five different potential analytical equations for the intensity-duration-return period (IDF) relationship of annual extreme rainfalls at each one of the seven geographical regions of Turkey. In the study, a single IDF equation was obtained using all the 22 stations, and by the same criteria, the most appropriate expression valid for all of Turkey has been determined.

IDF functions are used for quantifying the magnitude of rainfall events that are used in the design of a variety of civil infrastructure, especially in an urban environment. These relationships of extreme rainfall intensities are one of the most used tools in water resources engineering for planning, design, and operation of water resources projects [15]. IDF curves for a location are generally obtained by fitting a theoretical probability distribution, such as Gumbel (GM), Generalized Extreme Value (GEV), Log Pearson Type III (LPT3), Log Normal (LN), to the extreme rainfall data. These curves provide precipitation accumulation depths for various return periods and different durations, usually, 5, 10, 15, 30 min, 1, 2, 6 and 24 h. Longer durations are also used, depending on the use of IDF curves [16].

Concisely, the typical procedure involves the following: steps (i) fitting a probability distribution to the annual maximum rainfall intensity values for several rainfall durations, (ii) estimating extreme rainfall quantiles for each rainfall duration for a number of return periods, and (iii) fitting a relationship between rainfall intensity and rainfall duration, for each return period, based on the rainfall intensity quantiles estimated for each rainfall duration. The resulting relationships between rainfall intensity and rainfall duration constitute the IDF curves for the given location [5].

In Turkey, IDF analyses have been developed only for local sites and analysis with the current data encompassing the whole country is needed. In this study, maximum rainfall intensity values for various durations observed in Turkey, were analyzed and the best fit distribution for these intensities was determined. Nonlinear regression analysis was carried out by using nine types of IDF formulae, which were a combination of existing IDF formulae in literature and newly generated formulae. Then the best formula for each meteorological station was determined. In the study, IDF functions for four stations located in the Eastern Black Sea Basin (EBSB), the most raing region in Turkey, were also calculated and presented both as equations and graphics. In this study, the IDF analysis has been made for whole Turkey which is the main novelty of the paper. It is believed that this paper will motivate and will open new horizons to detailed studies on IDF analysis of Turkey, which is an important issue to optimum design of various kinds of hydraulic structures.

2. STUDY AREA AND USED DATA

In Turkey, there are significant differences in climatic conditions from one region to the other because of the existence of the mountains that run parallel to the coasts and the diverse nature of the landscape. The annual average rainfall depth of Turkey is 643 mm [17]. Due to geographical location, geology and hydrological properties, Turkey has a potential risk of mainly three different types of natural disasters related to gravity flows: floods, landslides and snow avalanches. Floods are the second important natural hazards after earthquakes and destructive flood events have occurred in various river basins of Turkey, especially in The Black Sea coast, which receives the greatest amount of rainfall [21].

In last 100 years 66 extremely severe floods took place and caused great life and economic losses [21, 22]. EBSB is also the only region of Turkey that receives rainfall throughout the year. Very major and destructive floods have occurred in the EBSB of Turkey. In this basin, 51 major floods have taken place since 1955, causing 258 deaths and nearly 500 000 000 US dollars of damage [17, 23]. Thus, EBSB, the most raing basin in Turkey, is presented in detail in this paper. Total basin area of EBSB is 24 077 km^2, yielding 14.9 km^3 water, with an average 19.5 lt/sn-km^2 yield [18,19]. The annual average rainfall in the EBSB is 1 019 mm, reaching 2 300 mm near the Rize Province [17,20]. Turkey and the EBSB located on the northeastern coast of Turkey can be seen in Figure 1.

The data used in this paper are annual maximum precipitation depth values, measured at 242 meteorological stations (MS) in Turkey, which are equipped with pluviographs. Thus, by measuring precipitation depths for several time intervals it is possible to calculate rainfall intensities. These values are measured and published by Turkish State Meteorological Service (MGM, in Turkish). The observation periods of the data were between 10 to 73 years. The data were published as tables for each year, including annual maximum precipitation depths for various standard rainfall durations from 5 minutes to 24 hours. In this study, only the data of eight standard durations (D=5, 15 and 30 minutes, and 1, 3, 6, 12 and 24 hours) have been employed. The detailed information of whole Turkey data can be found in Örgün [24].

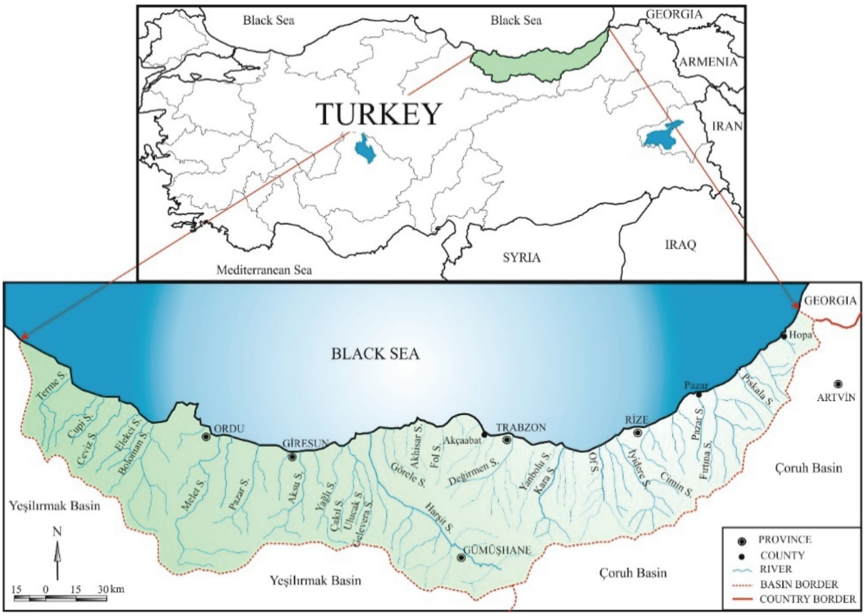

Figure 1 - Location map of the Eastern Black Sea Basin and Turkey (Ghiaei et al. 2018)

3. METHODOLOGY

3.1. Obtaining IDF Values

To obtain IDF values, the best statistical distribution for the data must be determined and by using this distribution, an intensity-frequency analysis must be carried out for the selected standard rainfall durations. There are several statistical distributions that might be suitable for rainfall intensity-frequency (or return period, T=1/F) analysis. One should select a few (say 3 to 5) distributions to test the best fit distribution. Various studies have favored the use of three suitable distributions for annual maximum precipitation (and also flood) data in Turkey: Log-Normal Distribution (LN2), Gumbel Distribution (GM) and Log-Pearson Type 3 Distribution (LPT3) [17,25]. Therefore, in this study, these three distributions were tested. In order to determine the best distribution, Chi-Square (χ^2) and Probability Plot Correlation Coefficient (PPCC) tests were applied to the data. Once the best distribution is determined, then the rainfall intensity which has a return period T=1/F is calculated as:

$$I(F) = I_{mean} + KI_{sd} \tag{1}$$

where, I_{mean} and I_{sd} are the mean and standard deviation of annual maximum intensities and K is a frequency factor, which depends both on T and the related distribution.

LN2 Distribution:

$$K_F = z = \frac{(1-F)^{0.135} - F^{0.135}}{0.1975} \tag{2}$$

GM Distribution:

$$K_F = \frac{-\ln\left[\ln\left(\frac{1/F}{1/F-1}\right)\right] - y_N}{S_N} \tag{3}$$

where Y_N and S_N are coefficients depending on number of data (N) and given in statistical tables.

LPT3 Distribution:

$$K_F = \frac{2}{C_s}\left(1 + \frac{zC_s}{6} - \frac{C_s^{\,2}}{36}\right)^3 - \frac{2}{C_s} \tag{4}$$

where z is calculated by Eq. (2) and C_s is skewness coefficient.

Since LN and LPT3 distributions are related the logarithmic values of data (y=lnx), for these distributions, the mean and standard deviations of logarithmic values are used, and the real intensity values are calculated by inverse logarithm as follows:

$$\ln[I(1/F)] = (\ln I)_{mean} + K(\ln(I)_{sd} \tag{5}$$

$$I(1/F) = Exp\left[\ln I(1/F)\right] \tag{6}$$

where Exp(x) is the exponential function of x.

3.2. The Used IDF Functions

There are several formulae to determine IDF relationship. In general, return period is used instead of frequency. General structure of these formulae is as follows [24].:

$$I(D,F) = \frac{A(F)}{B(D)} \tag{7}$$

where I (D, F) is rainfall intensity (mm/hour) as a function of frequency (F=1/T, year^{-1}) and rainfall duration (D, hour). Several functions have been given in the literature for the A (F) and B (D) functions [26, 27, 28, 29, 30]. A list of these is presented in Table 1. By combining these functions, nine IDF functions are obtained and they are given in Table 2. In Table 1 and 2; a, b, c and d are regression coefficients to be calculated by non-linear regression analysis. By using calculated I, D and F values, the related non-linear functions are transformed to linear ones by using appropriate transformations and then both the regression coefficients (a, b, c, and d) and determination coefficients (R^2) are calculated.

Table 1 - Functions for A(F) and B(D)

	No	Function	References
A(T)	1	$a*(1/F)^b$	Sherman, 1931; Koutsoyionnis et al.,1998
	2	$a+b*\ln(1/F)$	Koutsoyionnis et al., 1998; Aşıkoğlu, 2005
	3	$a+b*\ln(\ln(1/F))$	Minh Nhat et al, 2007
B(D)	4	D^c	Sherman, 1931; Bernard, 1932
	5	D^c+d	Minh Nhat et al. 2006
	6	$(D+d)^c$	Koutsoyionnis et al., 1998; Benzeden and Hacısüleyman,2003

Table 2 - Used IDF Functions

Combination	Funtion	Equation no
1 and 4	$I(D,F)=\frac{a*(1/F)^b}{D^c}$	8
1 and 5	$I(D,F)=\frac{a*(1/F)^b}{D^c+d}$	9
1 and 6	$I(D,F)=\frac{a*(1/F)^b}{(D+d)^c}$	10
2 and 4	$I(D,F)=\frac{a+b*\ln(1/F)}{D^c}$	11
2 and 5	$I(D,F)=\frac{a+b*\ln(1/F)}{D^c+d}$	12
2 and 6	$I(D,F)=\frac{a+b*\ln(1/F)}{(D+d)^c}$	13
3 and 4	$I(D,F)=\frac{a+b*\ln(\ln(1/F))}{D^c}$	14
3 and 5	$I(D,F)=\frac{a+b*\ln(\ln(1/F))}{D^c+d}$	15
3 and 6	$I(D,F)=\frac{a+b*\ln(\ln(1/F))}{(D+d)^c}$	16

4. RESULTS

4.1. The Best Distribution

In the study, the data of 242 meteorological stations (MS), with eight different durations (D, hours) have been used, thus there are totally 242*8=1936 models available. The results of the best distribution show that no data fit LN distribution. Totally 191 data (9.87%) fit GM and 1745 data (90.13%) fit LPT3. It is obvious that LPT3 is the best distribution. Especially, as the duration increases, the data tend to fit LPT3. Results of the analysis are given in Table 3, which shows the percentage of the best distribution depending on rainfall duration. After determining the best distribution, IDF values were found by using Eq. (1 and 3) for GM and Eq. (4, 5 and 6) for LPT3 distributions.

Table 3 - The Percentage of the Best Distribution

Dist.	Overall	Rainfall Duration (Hours)							
		0.08	0.25	0.5	1	3	6	12	24
LPT3	90.13	78.93	78.93	82.64	88.84	96.69	98.35	98.76	97.93
GM	9.87	21.07	21.07	17.36	11.16	3.31	1.65	1.24	2.07

4.2. IDF Functions

By using SPSS program, regression coefficients were calculated and IDF functions, with Eq. 8 to 16, were obtained for 242 MS. Then, in order to test the reliability of the functions, two criteria were used. The first criterion is the determination coefficient (R^2, square of correlation coefficient, R) and the second one is the mean relative error (RE, %) among the calculated IDF values both by the best distribution and by SPSS program. RE is calculated by:

$$RE = \frac{1}{N}\sum\left(\frac{IDF_1 - IDF_2}{IDF_1}\right)*100 \tag{17}$$

where, IDF_1 and IDF_2 are calculated IDF values for the best distribution by SPSS program, and N is the number of data. RE value should be as low as possible. A summary of R^2 and RE values for 242 MS are given in Table 4.

4.3. Success Rating of the Functions

Determination of the best IDF function is of importance and is also among the outcomes of this paper. Out of nine analyzed functions, the best is the one with greatest R^2 and smallest RE. Considering these criteria and taking into account the data given in Table 4, it is obvious that Eqs. 12 and 13 have relatively high R^2 and low RE values. Determination of success rating out of these two functions is not an easy task, due to fact that the average values of both R^2 and RE values are close to each other. However, Eq. 13 has minute greater average R^2 and less RE. Moreover, both minimum R^2 value is greater and maximum RE is less than those of Eq. 12. Therefore, Eq. 13 is chosen as the best and Eq. 12 is the second good IDF function. Similarly, Eqs. 9 and 10 exhibit closer results, however similar considerations lead that Eq. 9 is better than Eq. 10. Eqs. 15 and 16 also have both great R^2 and small RE values and they are considered as sixth and fifth good functions, respectively. These six functions may be acceptable for IDF functions. The other three functions, Eqs. 8, 11 and 14 have smaller R^2 and rather greater RE values, which means that they are not suitable for IDF functions. Finally, success rating of the functions (from 1, the best to 9, the worst) is given as the last column of Table 4.

Table 4 - Summary of R^2, RE and Success Ratings for the Equations

Eq. No	R^2			RE			Success Rating
	Min.	Max.	Mean	Min.	Max.	Mean	
8	0.921	0.988	0.967	9.87	151.59	52.31	8
9	0.978	0.996	0.985	6.62	45.76	17.25	3
10	0.972	0.997	0.984	6.97	48.55	17.55	4
11	0.911	0.998	0.973	6.74	142.94	49.15	7
12	0.950	0.998	0.987	3.76	87.56	16.04	2
13	0.973	0.999	0.989	3.65	54.61	15.39	1
14	0.832	0.979	0.952	9.18	142.19	52.80	9
15	0.917	0.997	0.969	4.13	59.26	20.76	6
16	0.860	0.996	0.966	3.63	63.69	20.08	5

4.4. Analysis of Numerators and Denominators of the Used Functions

As was stated in Chapter 3.2., general structure of IDF functions is given in Eq. 7. By analyzing the success rating of the IDF functions, the following analysis has been made for the reliability of numerator A(F) and denominator B(D). Numerator A(F): Eqs. 12 and 13 are the best two functions. Both have numerator as A(F)=a+b*Ln(1/F). This finding recommends and encourages the use of this function as a numerator. However, as can be seen in Table 4, Eq. 11, which has the same numerator but a different denominator, is not a good suggestion. The cause of this is the function of denominator $B(D)=D^c$, as will be emphasized in the following, it is not a good function. Eqs. 9 and 10, both of which numerator is $A(F)=a*(1/F)^b$ have the 3rd and 4th ratings. Similarly, Eq.8, which has the same numerator but a different denominator, $B(D)=D^c$ is the 8th good function. Comparison of Eq. 15 with 9 and 12, and Eq. 16 with 10 and 13, all of which have the same denominators, has yielded that the numerator of both Eqs. 15 and 16, A(F)=a+b*ln(ln(1/F)) is not a good proposal. Mutual comparison of Equations (9 and 12) and (10 and 13) makes it clear that a numerator as

A(F)=a+b*ln(1/F) is a little better than $A(F)=a*(1/F)^b$. Denominator B(D): For B(D), two functions have resulted in similar findings: D^c+d and $(D+d)^c$. Mutual comparison of Equations (9 and 10), (12 and 13) and (15 and 16) has concluded that is a little better than $B(D)=D^c+d$. A value of $B(D)=D^c$ has resulted in both small R^2 and great RE values, which means that this kind of a function is not appropriate.

By summarizing the above considerations, out of nine functions for IDF analysis, for the numerator, both A(F)=a+b*ln(1/F) and $A(F)=a*(1/F)^b$ may be used. A conclusion on which function is better depends greatly on the MS. The results of some MS have favored the use of one, some have favored use of the other one and there is no significant difference between their reliabilities. The use of a function of A(F)=a+b*ln(ln(1/F)) is not recommended, due to both low R^2 and high RE values. Similarly, for the denominator, both $B(D)=(D+d)^c$ and $B(D)=D^c+d$ may be used. A conclusion on which function is better depends greatly on the meteorological station. The results of some MS have favored the use of one, some have favored use of the other one and there is no significant difference between their reliabilities. The use of a function of $B(D)=D^c$ is not recommended, due to both low R^2 and high RE values.

4.5. Reliability of the Functions

As can be seen in Table 4, the calculated mean determination coefficients, for the best six functions (Eqs. 13, 12, 9, 10, 16 and 15) are between 0.966 and 0.989. Taking into consideration the fact that minimum number of the used data is 10 years, these R^2 values are high enough and they can be used with reliability for prediction of IDF values. Yet, the calculated RE values, which are between 15.39 and 20.76, are relatively high and their reliability is questionable. However, these values are calculated as average values for all the MS. When these values are calculated for individual stations, RE values are lower and their reliabilities are higher.

4.6. Results and Analysis of IDF Functions in the EBSB

The R^2 and RE values for IDF functions (equations), which were given in Table 2, of the meteorological stations in the EBSB are presented in Table 5. In this table, the best three equations are also given in parenthesis as (1, 2 and 3).

4.7. Comparison of the Results of Turkey and EBSB

By comparing the results given in Table 4 and 5, it is obvious that, they are similar. For example, Eq. 13 is the best one both for all of Turkey and EBSB. Although Eq. 12 is the second good one in Turkey, it is suitable only for Ordu MS. Eq. 9 is convenient for Giresun, Trabzon and Rize MS, and Eq. 10 is proper for Trabzon and Rize. Eq. 16, which has 5th success rating in Turkey, has also 5th rating in EBSB. The most surprising result is that Eq.15, which is the 6th good one for Turkey, has yielded very unreliable estimations for EBSB. Of course, similar analyses should be made for various sub basins in Turkey. By making these analyses, general conclusions, about which kind of functions may be advisable in which kinds of basins and stations, may be attained. By obtaining these kind of conclusions, more practical decisions about IDF functions may be achieved.

Table 5 - Summary of IDF Functions in the EBSB

Eq. No	Ordu		Giresun		Trabzon		Rize	
	R^2	RE	R^2	RE	R^2	RE	R^2	RE
8	0.924	63.64	0.952	64.01	0.966	59.58	0.980	42.35
9	0.978	15.24	0.979	21.76 (3)	0.986	12.22 (2)	0.991	18.04 (2)
10	0.978	14.81	0.977	22.10	0.986	12.77 (3)	0.989	20.27 (3)
11	0.932	60.53	0.959	60.51	0.971	55.67	0.983	40.28
12	0.986	12.71 (2)	0.141	271.91	0.883	118.81	0.126	244.16
13	0.986	11.99 (1)	0.994	19.10 (1)	0.991	10.61(1)	0.993	17.79 (1)
14	0.923	59.62	0.945	60.98	0.950	57.62	0.962	42.93
15	0.136	242.42	0.123	272.65	0.140	324.05	0.107	245.72
16	0.977	13.40 (3)	0.970	20.56 (2)	0.969	17.69	0.972	21.85

4.8. The Best Functions and Relative Errors

As was explained, Eq. 13 was the best function for all the four stations in the EBSB and they were presented as follows. Equations of 17, 18, 19, 20 are for Ordu, Giresun, Trabzon and Rize MS, respectively. In these equations, the dimensions were as: I (D, F): mm/minute, F: year^{-1}, and D: minute. The results of these equations are presented in Tables 6, 7, 8 and 9 for the related stations. In these tables, the rainfall intensities calculated by best equations (17, 18, 19, 20) are given together with relative errors. In the last column of each row, mean RE values for each duration and in the last row mean RE values for each duration are also presented. As can be seen, mean RE values tend to increase as duration goes up. However, there is no significant relation between mean RE values and return period. The graphical presentation of the rainfall intensity values is given in Figs 2, 3, 4 and 5 as considered equation (EQ) values

$$I(D,F) = \frac{30.268 + 12.054 * \ln(1/F)}{(D + 35.114)^{0.932}} \quad (17)$$

$$I(D,F) = \frac{12.349 + 5.620 * \ln(1/F)}{(D + 19.229)^{0.737}} \quad (18)$$

$$I(D,F) = \frac{9.236 + 5.680 * \ln(1/F)}{(D + 14.026)^{0.819}} \quad (19)$$

$$I(D,F) = \frac{6.459 + 12.948 * \ln(1/F)}{(D + 7.377)^{0.606}} \quad (20)$$

Table 6 - Rainfall Intensity Values of Ordu MS Calculated by LPT3 Distribution and Equation 17

t	F = 1/2 $year^{-1}$			F = 1/5 $year^{-1}$			F = 1/10 $year^{-1}$			F = 1/25 $year^{-1}$			F = 1/50 $year^{-1}$			F = 1/100 $year^{-1}$			F = 1/500 $year^{-1}$			MEAN RE
	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	
(hour)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	
0.083	80.0	74.2	7.3	107	95.3	11.2	123	110.5	9.1	139	133	4.7	150	149	0.7	159	165	3.6	177	202	14.4	7.3
0.250	52.3	60.2	15.1	77.2	77.5	0.5	93.5	90.5	3.2	114	108	5.5	129	121	6.3	143	134	6.7	175	164	6.3	6.2
0.500	35.9	47.2	31.6	53.4	60.7	13.7	65.3	70.9	8.6	80.5	84.4	4.8	91.9	94.6	3.0	103	105	1.7	128	129	0.1	9.1
1.000	22.9	33.2	44.6	35.3	42.7	20.9	44.2	49.8	12.5	56.5	59.3	5.0	66.0	66.5	0.6	76.0	73.6	3.1	100	90.3	9.6	13.8
3.000	10.5	15.5	47.4	15.8	19.9	26.5	19.7	23.3	18.3	25.1	27.7	10.2	29.5	31.1	5.1	34.2	34.4	0.6	45.9	42.2	8.1	16.6
6.000	6.42	8.76	37.3	9.30	11.3	21.9	11.5	13.2	14.5	14.9	15.7	5.8	17.7	17.6	0.3	20.8	19.5	6.0	29.1	23.9	17.8	14.8
12.00	3.94	4.80	22.2	5.57	6.18	10.8	6.84	7.20	5.6	8.64	8.58	0.6	10.1	9.66	5.1	29.1	11.9	17.8	16.1	13.1	18.6	11.5
24.00	2.66	2.58	3.4	3.68	3.30	10.0	4.47	3.84	13.5	5.62	4.62	18.1	6.60	5.16	21.7	16.1	6.1	18.6	10.5	7.0	33.1	16.9
	MEAN RE: 26.1			MEAN RE: 14.4			MEAN RE: 10.7			MEAN RE: 6.8			MEAN RE: 5.4			MEAN RE: 7.3			MEAN RE: 13.4			

Table 7 - Rainfall Intensity Values of Giresun MS Calculated by LPT3 Distribution and Equation 18

t	F = 1/2 $year^{-1}$			F = 1/5 $year^{-1}$			F = 1/10 $year^{-1}$			F = 1/25 $year^{-1}$			F = 1/50 $year^{-1}$			F = 1/100 $year^{-1}$			F = 1/500 $year^{-1}$			MEAN RE
	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	
(hour)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	
0.083	100	92.9	7.5	138	122	11.3	161	145	10.0	187	174	6.9	205	196	4.3	222	219	1.5	256	270	5.6	6.7
0.250	62.6	72.0	15.1	87.0	94.9	7.9	105	112	7.2	126	135	7.5	141	152	8.0	156	169	8.7	190	210	10.6	9.3
0.500	45.6	55.1	20.9	67.2	72.5	7.9	82.7	85.7	3.7	103	103	0.3	120	116	2.8	136	130	5.0	176	160	9.2	7.1
1.000	30.0	38.8	28.8	45.5	51.1	12.3	57.2	60.4	5.5	73.9	72.7	1.7	87.7	82.0	6.5	102	91.3	10.9	140	113	19.6	12.2
3.000	14.6	19.6	34.6	21.7	25.9	18.9	27.3	30.6	12.1	35.2	36.8	4.6	41.8	41.5	0.6	48.9	46.3	5.4	67.4	57.2	15.1	13.0
6.000	8.48	12.2	44.2	12.3	16.1	31.3	15.1	19.0	26.1	19.1	22.9	20.1	22.3	25.9	15.8	25.7	28.7	11.7	34.5	35.6	3.1	21.8
12.00	4.89	7.50	52.9	6.78	9.84	45.1	8.21	11.6	41.7	10.2	14.0	36.9	11.9	15.8	32.8	13.7	17.6	28.6	18.3	21.7	19.0	36.7
24.00	2.99	4.50	51.1	3.93	5.94	51.5	4.66	7.02	51.3	5.70	8.46	48.8	6.56	9.54	45.7	7.51	10.6	41.8	10.0	13.1	31.7	46.0
	MEAN RE: 31.9			MEAN RE: 23.3			MEAN RE: 19.7			MEAN RE: 15.9			MEAN RE: 14.6			MEAN RE: 14.2			MEAN RE: 14.2			

Table 8 - Rainfall Intensity Values of Trabzon MS Calculated by LPT3 Distribution and Equation 19

t	F = 1/2 year^{-1}			F = 1/5 year^{-1}			F = 1/10 year^{-1}			F = 1/25 year^{-1}			F = 1/50 year^{-1}			F = 1/100 year^{-1}			F = 1/500 year^{-1}			MEAN RE
	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	
(hour)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	
0.083	79.1	70.8	10.5	110	98.8	10.3	130	120	7.8	155	148	4.3	172	169	1.9	189	190	0.5	227	239	5.6	5.8
0.250	44.7	50.1	12.1	64.4	69.8	8.5	78.8	84.8	7.7	98.4	105	6.4	114	120	5.0	130	135	3.4	170	169	0.5	6.2
0.500	29.3	35.6	21.6	43.3	49.7	14.6	54.3	60.3	11.0	70.3	74.3	5.7	83.8	85.0	1.4	98.5	95.6	3.0	138	120	12.6	10.0
1.000	19.1	23.3	21.9	27.8	32.5	16.5	35.0	39.4	12.6	45.8	48.6	6.1	55.2	55.6	0.5	65.9	62.5	5.2	95.6	78.6	17.8	11.5
3.000	9.00	10.6	17.8	12.6	14.8	17.4	15.4	17.9	16.1	19.7	22.1	12.1	23.3	25.2	8.1	27.4	28.4	3.5	38.6	35.7	7.6	11.8
6.000	5.35	6.18	15.2	7.18	8.58	19.8	8.63	10.4	21.0	10.8	12.9	19.6	12.6	14.8	16.8	14.6	16.6	13.2	20.2	20.9	3.5	15.6
12.00	3.36	3.54	5.6	4.42	4.98	12.0	5.21	6.00	15.5	6.29	7.44	17.9	7.17	8.46	18.3	8.10	9.54	17.8	10.5	12.0	14.8	14.6
24.00	2.25	2.04	9.9	2.85	2.82	0.8	3.28	3.42	4.7	3.86	4.26	9.7	4.32	4.86	12.2	4.80	5.46	13.7	5.97	6.84	14.9	9.4
	MEAN RE: 14.3			MEAN RE: 12.5			MEAN RE: 12.1			MEAN RE: 10.2			MEAN RE: 8.0			MEAN RE: 7.5			MEAN RE: 9.7			

Table 9 - Rainfall Intensity Values of Rize MS Calculated by LPT3 Distribution and Equation 20

t	F = 1/2 year^{-1}			F = 1/5 year^{-1}			F = 1/10 year^{-1}			F = 1/25 year^{-1}			F = 1/50 year^{-1}			F = 1/100 year^{-1}			F = 1/500 year^{-1}			MEAN RE
	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	I (mm/h)		RE	
(hour)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	LP	EQ	(%)	
0.083	115	111	3.6	151	146	3.0	176	173	1.7	210	208	0.6	236	235	0.4	263	262	0.4	328	324	1.4	1.6
0.250	75.3	77.5	3.0	99.9	102	2.3	116	121	3.8	138	145	5.6	154	164	6.6	170	183	7.4	207	226	8.8	5.4
0.500	55.9	56.8	1.6	76.2	74.9	1.7	90.3	88.5	2.0	109	107	2.2	123	120	2.5	138	134	3.0	173	166	4.3	2.5
1.000	38.7	39.7	2.8	53.8	52.4	2.7	64.8	61.9	4.4	79.7	74.6	6.5	91.6	84.1	8.2	104	93.7	9.9	135	116	13.9	6.9
3.000	18.1	21.4	17.8	25.4	28.2	10.7	31.3	33.3	6.6	39.9	40.0	0.6	47.2	45.2	4.2	55.4	50.4	9.1	77.8	62.3	19.9	9.8
6.000	11.7	14.2	21.8	15.6	18.7	20.1	18.5	22.1	20.1	22.4	26.6	19.1	25.5	30.0	17.8	28.9	33.5	16.1	37.2	41.5	11.5	18.1
12.00	6.89	9.42	36.2	8.98	12.4	37.9	10.5	14.6	39.6	12.6	17.6	40.4	14.2	19.9	40.0	15.9	22.1	38.9	20.3	27.4	35.0	38.3
24.00	4.36	6.18	41.9	5.45	8.16	49.8	6.19	9.66	55.9	7.15	11.6	62.4	7.89	13.1	66.1	8.64	14.6	68.9	10.4	18.1	73.4	59.8
	MEAN RE: 16.1			MEAN RE:16.0			MEAN RE: 16.8			MEAN RE: 17.2			MEAN RE: 18.1			MEAN RE: 19.2			MEAN RE: 21.0			

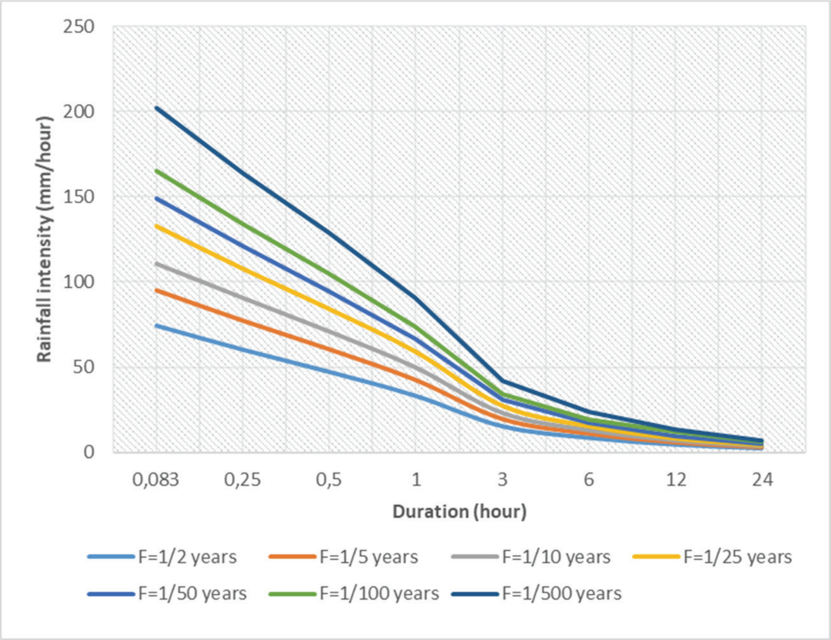

Figure 2 - IDF relationship for Ordu

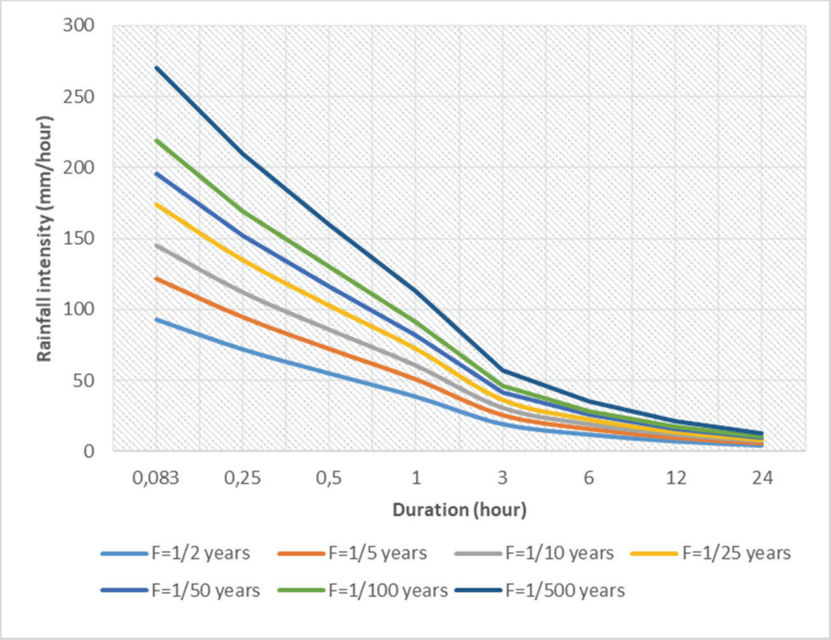

Figure 3 - IDF relationship for Giresun

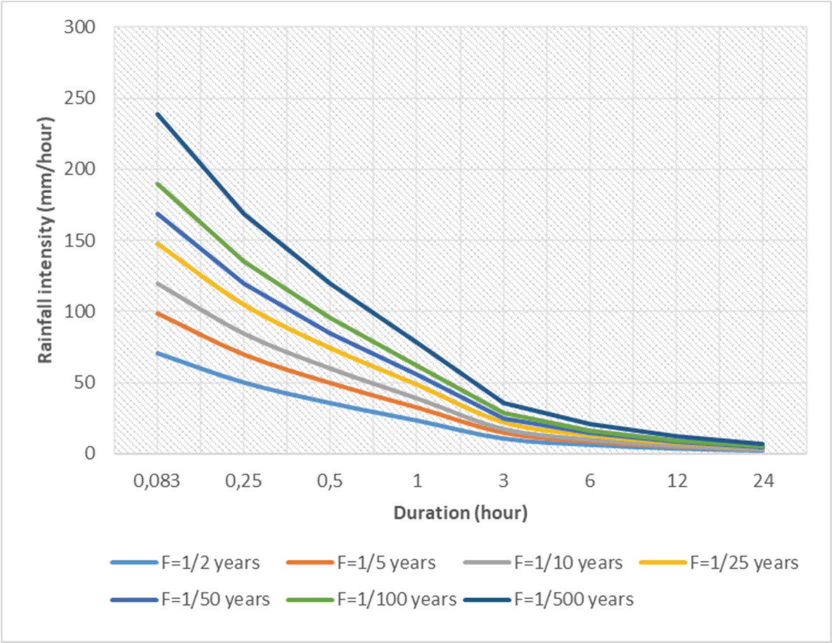

Figure 4 - IDF relationship for Trabzon

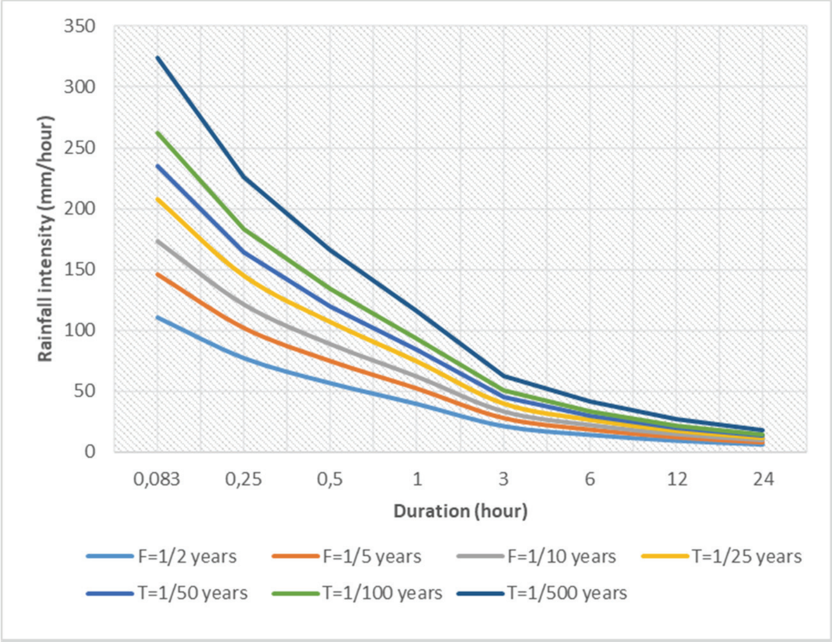

Figure 5 - IDF relationship for Rize

5. CONCLUSIONS

In this study, by using the annual maximum rainfall depth values in 242 MS in Turkey, maximum intensity values for various durations are calculated and analyzed, and the best fit distribution for these intensities are determined as LPT3, by employing Chi-Square and PPCC tests. Rainfall intensity (I) values are estimated for various rainfall duration (D) and frequency (F) values according to the LPT3 distribution. Multi-nonlinear regression analysis has been carried out by using nine kinds of IDF formulas and various regression coefficients are obtained. The best formula for each MS is determined depending on R^2 and RE between intensity values, calculated by both the best statistical distribution and by multi non-linear regression. The best formula has been determined as one with maximum R^2 and the minimum RE. The mean R^2 and RE values have varied between 0.952 and 0.989 and between 15.39 and 52.80 %, respectively. The studied 9 functions are analyzed in detail. In this context, the numerator A(F) and denominator functions of Equation 7, have been evaluated in the context of their reliabilities in predicting rainfall intensities. A success rating list of nine functions is presented. Then, it has been determined that 6 functions, out of 9 proposed functions, to have great R^2 and small RE values, are proposed as to be suitable to estimate IDF values in Turkey.

In the final phase of the study, IDF functions for four stations, located in the EBSB, the most raing region in Turkey, are presented both as equations and graphics. Also, the results of the whole Turkey and EBSB have been compared and similar trends about the best functions are detected. Although RE values are great for all of Turkey, they are relatively small when they have been calculated for each MS. Therefore, it has been concluded that the reliability of the results is high enough and that this paper will motivate and open new horizons to detailed studies on IDF analysis.

Most of the previous IDF analysis in Turkey are the local studies [12,13] Nevertheless, this study covers all Turkey. As for the EBSB, in their study Ghiaei et al. [13] applied homogeneity measure to the seven stations and they concluded the EBSB to be homogeneous according to the Hosking's discordancy and heterogeneity measures. In this study the homogeneity test was not applied to the data but there was no significant heterogeneity observed in the previous studies [13,14]. Nevertheless, homogeneity tests and other methods such as L-moments [13], GA optimization technique [12] etc. should be applied for whole Turkey in future studies.

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