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A RE-VISIT TO PARTIAL DURATION SERIES OF SHORT DURATION RAINFALLS*

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Abstract– Uniqueness of the relationship between the return periods of the annual maximum series (AMS) and the partial duration series (PDS) are evaluated in light of the actual data. Rainfall intensities with durations of 15, 30, 60, and 360 minutes are calculated for seven stations representing a variety of climatic conditions (humid, cold, desert, and hot desert), and the corresponding AMS and PDS values are considered. PDS values are evaluated in view of annual exceedance series (AES), up to the minimum one observation (MOO). The two-parameter gamma distribution is found to be the most suitable to provide various return periods for the calculated rainfall intensities. A comparison of the results suggests that a unique relationship does not exist between return periods of AMS and PDS. Indeed, length ratio (ratio of record length of PDS series to that of AMS) should be considered as an additional independent variable. Therefore, any further attempts to extend the uniqueness of the relationship between AMS and PDS for the computation of hydrological variables such as rainfall depth are shown to be inappropriate. Finally, it is concluded that any relationship between AMS and PDS return periods is actually a function of rainfall duration as well as station location.

Keywords– Partial duration series, annual maximum series, short duration rainfalls, Iran

1. INTRODUCTION

Investigation of rainfall intensity-duration-frequency (IDF) has been suggested to be the appropriate set of hydrologic variables for probability analysis by a number of researchers [1, 2]. Furthermore, evolution of rainfall intensity in terms of a particular return period and in the context of annual maximum series (AMS) or partial duration series (PDS) has long been a common practice in hydrology. Certain types of analysis may require data arrangement in such a way that only the maximum value of each year is selected. This is commonly known as the AMS. It is possible that any particular year may contain data points that are larger than the maximum of another year. In such a case all selected data points may be chosen to be above a minimum value. This type of series is typically referred to as PDS. The selection of a minimum value (threshold), is to a large extent, by personal judgment. However, a number of researchers have defined this limit so that the number of selected data points would be equal to the record length [3-7]. In such a case the series is referred to as the annual exceedance series (AES). Other researchers have suggested that data selection should be done so that at least one data point is selected for any given year [8-12]. This series is referred to as minimum one observation (MOO). Sutcliffe [13] suggested that the application of PDS should be limited to the evaluation of mean values on flood discharge for cases with less than 10 years of data. In addition, since some degree of co-dependence may be observed between flood events, the use of PDS is more common for rainfall events [5, 6, 12, 14].

When applied to a particular problem, PDS is faced with two difficulties, i.e., the choice of threshold and the selection of criteria for retaining peak values. Rosbjerg [15] distinguished independent and dependent peak values and derived relations for computing the variance of the T-year estimate. Lang *et al*.

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[16] pointed out the problems of choice of threshold and selection of criteria for retaining flood peaks associated with the PDS approach. They further clarified three tests (mean number of over-threshold events, mean exceedance above threshold, and dispersion index) for establishing this threshold. Some researchers suggested the selection of the threshold level on the basis of a given return period. For instance return periods of 1.15 and 1.2-2 years are presented in the literature [17-19]. Based on theoretical considerations of the sampling variance of quartiles, Cunnane [20] showed that the condition length ratio>1.65 should be met when using the PDS approach instead of AMS analysis. This condition holds for the PDS model with exponentially distributed peaks. Wang [21] made a comparison of the PDS (based on Generalized Pareto distribution) and AMS (based on generalized extreme value distribution) in terms of the accuracy of T-year event estimators. However, he only considered estimation in a PDS with an average number of events equal to the number of years of the sample period. Madsen *et al*. [22] more generally, extended the work of Wang [21] and compared estimation in the AMS model with that of the PDS model using a wide range of the number of events included in the PDS. They arrived at a more complex condition that depends also on the value of the shape parameter of the PDS distribution.

The classical PDS model comprises the assumption of a Poisson distributed number of threshold exceedances and independent exponentially distributed exceedance magnitudes [23]. Alternative exceedance distributions have been proposed, including the gamma distribution [24], the Weibull distribution [25], the log-normal distribution [26], and generalized Parreto distribution [21]. Yet in previous literature one can find the experimental point plot approach on semi-logarithmic paper [6] and power function [27].

While PDS is more popularly used in flood analysis, it does have other applications as well. The PDS approach is used by Kjeldson *et al*. [28] to predict the severity of future droughts, i.e. the T-year events. Of particular interest has been the uniqueness of any type of relationship that may exist between return periods of AMS and PDS. This issue will be discussed next.

Uniqueness of relationship between return periods of AMS and PDS- Relationships indicating event probabilities between AMS and annual exceedans series, AES (a particular form of PDS), were developed by Langbein [29], while the theoretical correspondence issue between AMS and AES were investigated by Chow [27, 30].

As a result of the mentioned research, the following relationship has been accepted universally to explain the inter-connection of return periods between AMS and AES [3, 9, 17, 31]

$$T_P=1/[(Ln(T_M)-Ln(T_M-1)] \quad (1)$$

where T_P and T_M are the return periods of AES and AMS, respectively, and *Ln* stands for natural logarithm. Based on Eq. (1), a distinct difference is observed for the return periods of up to 10 years, beyond which, values converge to a point of almost equality. Furthermore, the above relationship should be used for cases with the number of data points equal to the length of data. Any uniqueness that actually may exist between T_P and T_M in Eq. (1) would be a main cause for concern.

Chow [27] introduced the following relationship for a rainfall event with a return period of *T* and duration of *D*

$$R(T, D)=a' \, Log(T_P)+b' \quad (2)$$

where T_P is the return period in PDS, R(T, D) is rainfall depth as a function of return period and time duration, and a′ and b′ are regression coefficients.

For a given rainfall depth with a particular return period and duration, Chen [2] evaluated coefficients a' and b' in Eq. (2) by applying the two-point method. For this purpose he assigned values of 10 and 100, respectively, to T_P. Also, by accepting relationships (1) and (2), he suggested the following conversion factor (*CF*) to be multiplied by rainfall depth with a return period of T_P (in PDS) to get rainfall depth in AMS (*T*)

$$CF=Log[10^{2-x}Ln\{T_P/(T_P-1)\}]^{1-x}/Log[10^{2-x}T^{x-1}] \quad (3)$$

where *x* is the ratio of rainfall with a 100-year return period to that of a 10-year return period in PDS. However, Kothyari and Garde [32] showed that CF of Eq. (3) could not be directly used for some parts of India; they proposed that Eq. (3) must be multiplied by 0.77.

A review of literature indicates that there is no relationship between return periods of AMS and PDS except that of Chow. Several researchers have trusted Chow's relationship, and have extended their work accordingly. Therefore, uniqueness of such a relationship is important in engineering applications wherever analysis of frequency, either rainfall or flood, is to be considered. Any inconsistency in such a relationship could yield incorrect hydrologic values. The aim of this study is, however, to have a re-visit to this universally accepted equation under the actual data of short duration rainfall intensities of different climatic conditions in Iran. The behavior of the parameters of Eq. (2), and the behavior of x parameter are also surveyed.

2. STATION SELECTION AND DATA ANALYSIS

In order to better evaluate the uniqueness of the relationship between return periods of AMS and PDS as previously discussed, it is important to select stations with a variety of climatic conditions. Furthermore, the selected stations had to be equipped with recording raingage so that rainfall intensity values could be calculated. Table 1 shows the location and some of the important rainfall characteristics of the selected stations. These characteristics represent some of the diverse climatic conditions that are calculated based on the Embreger method. All of the selected stations are monitored by the Research Center of the Iranian Water Resources Organization (TAMAB). The geographical diversity of these stations are presented in Fig. 1. This Figure is a map of Iran with stations so included in the Embreger classification.

Table 1. Station identification and rainfall characteristics

Station	Longitude (degree)	Latitude (degree)	Altitude (m)	Mean maximum rainfall (mm) in different durations (days)				Mean maximum monthly rainfall (mm)	Mean annual rainfall (mm)	Climate
				1	2	3	4			
Baq-Malek	49.53	31.31	675	72.4	95.0	104.3	113.6	194.9	573.7	Moderately semi wet
Mohamad-Abad	54.25	31.46	1250	12.4	15.1	15.8	16.5	26.6	61.8	Cold-dry
Qaleh-Jooq	44.28	39.17	1292	30.8	37.2	41.7	44.8	88.4	352.4	Mountainous climate
Qasr-Qand	60.37	26.12	382	35.7	47.1	50.0	52.9	79.5	180.2	Severe hot-desert
Qoochan	58.31	37.03	1360	31.4	38.7	40.5	43.2	82.2	306.1	Semi cold-dry
Shahmaran	52.21	28.27	1040	30.3	43.8	52.2	54.6	73.0	171.0	Moderately hot-desert
Shilaben	48.50	37.48	99	88.8	113.7	125.8	134.2	224.2	1102.1	Highly wet

Fig. 1. Relative locations of stations under study

For four typical rainfall durations of 15, 30, 60, and 360 minutes, intensity values were calculated and the corresponding AMS values were selected. The same process was undertaken for the PDS values. First, the number of data points was chosen to be equal to the length of data, referred to as AES. Then, by allowing a gradual increase in the number of data points, more analysis was conducted. In this research, the ratio of the number of data points to the length of data at each stage of evolution is referred to as the length ratio (LR). The process of gradually increasing the number of data points was increased up to a point where at least one data point was selected for every year with allowable data (MOO).

For the purpose of selecting an appropriate probability distribution function, one of the common procedures as outlined in most hydrological literature may be applied [33]. In this case the two-parameter gamma distribution function was found to best fit the rainfall intensity statistics as they relate to the corresponding return periods. Then, based on the recommended procedures [34], regression relationships were developed between the return periods of AMS and PDS with different LR values.

3. RESULTS AND DISCUSSION

a) Simultaneous return periods of AMS and PDS

The non-linear multiple regression approach was used and the following expression was found to be the most appropriate

$$Y = a\, X_1^{\,b} X_2^{\,c} \qquad (4)$$

where Y and X_1 are return periods for AMS and PDS, respectively, X_2 is the length ratio (ratio of length of PDS series to that of AMS), and a, b, and *c* are regression coefficients. Since return periods of less than two-years may have different applications as compared to those greater than two-years, results were classified to show such differences. Table 2 shows the results for the Qaleh-Jooq station (results for other stations are reported in Ghahraman [35]). The *F* value (for F-test example see Haan [8]) of Ln(a) is for testing the significance of this coefficient with *K* and *N-K* degrees of freedom for the nominator and the denominator, respectively (*N*= total number of observations, *K*= sum of dependent and independent variables). F values of b and c coefficients are for testing the significance of introducing independent variables of X_1 and X_2, Eq. (4), respectively. Degrees of freedom for the nominator and the denominator in this case are 1 and N-K, respectively (for more details refer to Dropper and Smith [36]). High *F* and R^2 values support the structure selected for Eq. (4). Although the F value for c (testing for LR independent variable) is much lower than the F value for b, its value is highly significant since it validates the incorporation of LR in the model. It implies that a unique relationship does not exist between the return periods of AMS and PDS. Meanwhile, variation of coefficients among different time durations (Table 2) and also for different stations (data not shown) is noticeable, indicating that a global relationship may not be developed.

Table 3 shows the results for the case of MOO. The computed coefficients in this table also show some degree of variations among time durations, and therefore support a non-global relationship. Similar types of analysis were also performed for the other six stations [35]. Figure 2 shows the results of regression analysis between the return periods of PDS (dependent variable) and the return periods of AMS and LR (independent variables) as compared with Eq. (1). This figure is a re-statement of Table 2 in part, and shows that the return period of PDS does not only depend on the return period of AMS (as Eq. (1) indicates), but also on length ratio. The high deviation of the results from Chow's relationship Eq. (1) for all stations are clearly shown. The highest LR in each sub-plot represents the MOO case of the PDS series. This LR is different for different stations due to the nature of data. This indicates that Chow's relationship may not be a universal equation. One may easily come to the conclusion that there is a remarkable deviation between Chow's relationship with our results. On average, this difference increases as the return period of AMS increases without bounds, and Chow overestimates the return period of PDS in all cases. On the other hand, at a lower part of the return period of AMS, Chow's relationship greatly underestimates the return period of PDS.

Although the return period of the PDS is highly dependent on the return period of the AMS (curves are highly sloped), the dependency to LR is not so high (curves are so close to each other). This point can also be drawn from F-values indicated in Table 2. Other rainfall durations produced similar results [35].

All available data for LR=1 (AES case of PDS) were considered, and at a constant return period of AMS and rainfall time duration, the values of the return period of the PDS were averaged over all seven stations. Figure 3 shows the mean and CV (coefficient of variation) values of the return period of PDS as a function of the return period of AMS. It is interesting to note the convergence of the return period of PDS values for different rainfall durations, indicating the possibility of a unique relationship for an AES case of the PDS series. In addition, variations in CV values are not high for small return periods (Fig. 3). In general, as return period increases, the CV value increases accordingly. However, the variations of mean of the return periods of AMS are not monotonic, showing a pseudo-sinuidonal form. The minimum CV values for all rainfall time durations occurred around 5 years of the return period, where CV value increases just negligibly for smaller return periods. On average, the 1 hr series depicts the lowest CV values, while the highest *CV* values are attributed to the 6 hr series.

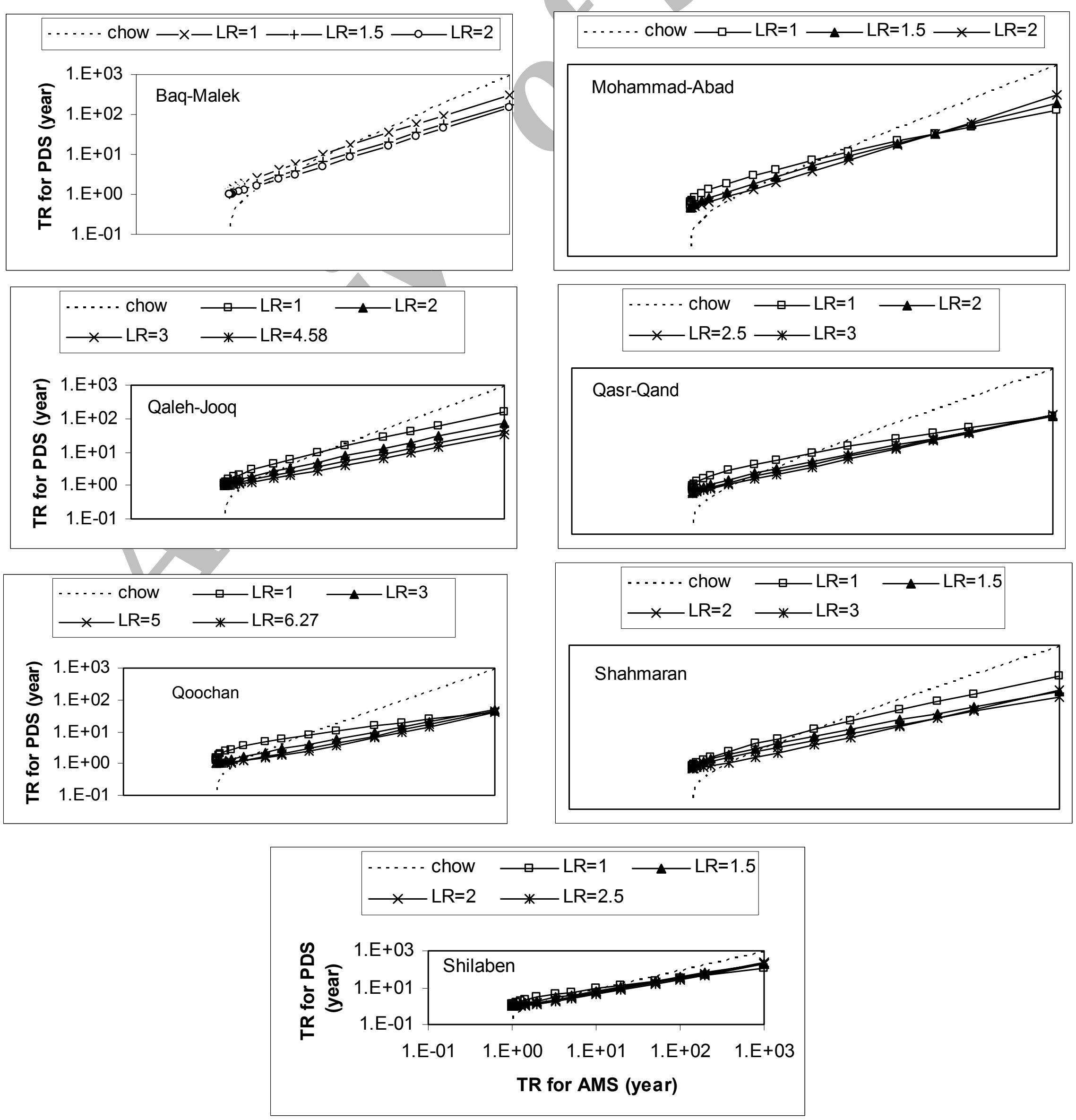

Fig. 2. The relationship between return periods (TR) of AMS and PDS series of 1-hr rainfall duration for stations under study

Table 2. Regression analysis for Qaleh-Jooq station (case of PDS)

Duration (min)	Return period (year)	Number of observations (N)	Coefficient of determination (R^2)	Regression parameter	Value of regression coefficient	F^+	SD
15	TR≤100	240	0.99	Ln(a)	-0.604280	8464.5	0.02785
				b	1.466344	16858.5	0.01129
				c	0.770840	270.3	0.04688
	2≤TR≤100	112	1.00	Ln(a)	-1.215867	19269.0	0.02371
				b	1.666900	38194.0	0.00853
				c	1.151248	1658.6	0.02827
	TR<2	128	0.89	Ln(a)	-0.156216	486.2	0.01121
				b	0.668842	964.8	0.02153
				c	0.255059	225.6	0.01698
30	TR≤100	420	0.99	Ln(a)	-0.612504	18347.1	0.02006
				b	1.450105	36606.8	0.00758
				c	0.729783	1004.3	0.02303
	2≤TR≤100	196	1.00	Ln(a)	-1.077880	57262.0	0.01382
				b	1.529005	113939.6	0.00453
				c	1.174006	9532.6	0.01202
	TR<2	224	0.76	Ln(a)	-0.151300	341.1	0.01320
				b	0.777585	679.1	0.02984
				c	0.211325	219.0	0.01428
60	TR≤100	660	0.97	Ln(a)	-0.763762	11739.0	0.02667
				b	1.648130	23442.0	0.01076
				c	0.740292	1030.0	0.740292
	2≤TR≤100	308	0.99	Ln(a)	-1.495059	19674.0	0.02579
				b	1.750371	39220.0	0.00884
				c	1.358253	6301.0	0.01711
	TR<2	352	0.76	Ln(a)	-0.142239	561.7	0.01045
				b	0.929779	1120.3	0.02778
				c	0.151752	307.4	0.00865
360	TR≤100	615	0.98	Ln(a)	-0.909352	17157.8	0.02236
				b	1.647920	34259.7	0.00890
				c	0.774104	1526.9	0.01981
	2≤TR≤100	287	1.00	Ln(a)	-1.647578	65486.2	0.01443
				b	1.828150	130516.1	0.00506
				c	1.224703	16545.4	0.00952
	TR<2	328	0.76	Ln(a)	-0.212560	521.5	0.01238
					0.711949	1039.9	0.02208
					0.209740	420.2	0.01023

+ All F values are significant at 0.005 level of significance

Jayasuriya and Mein [37] fitted a log-Pearson type III to three series of flood (AMS and PDS with different length ratios) for Canberra, Australia. We digitized their data and prepared Fig. 4 to show the dependency of AMS series-return period to both PDS series-return period and LR, to show support for our results. Chow's relationship shows a good comparison with the case of LR=1 (AES of PDS). However, for other return periods, the two curves (that of Chow and that for LR=1) diverge. Figure 4 shows that as the LR increases, the results deviate even more from Chow's relationship. Henson [38] analyzed the bankfull depth from small watersheds in the Appalachian Mountains. He reported recurrence intervals for both AMS and PDS. We used Eq. (1) to calculate return periods of PDS based on his return periods of AMS. Henson's data produced an average 62% underestimation over Chow's relationship. This finding also supports our work on the deficiency of Chow's. Henson's data covers the return period of AMS between 1.03 and 3.77 years.

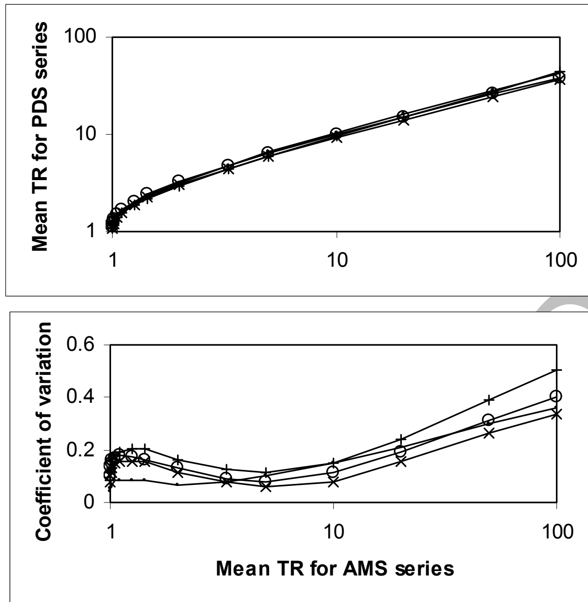

Fig. 3. Mean and CV for return periods of PDS series among all seven stations for different rainfall time durations: ., 15 min; o, 30 min; x, 1 hour; and +, 6 hour

Table 3. Regression analysis for Qaleh-Jooq station (case of MOO)
(Coefficient of determinations are 1 for all regressions)

Duration (min)	Return peruid (year)	Number of observations (N)	Regression parameters	Value of regression coefficient	F+	SD
15	TR≤100	15	Ln(a)	-0.063167	13534.0	0.01747
			b	1.551204	12632.0	0.01380
	2≤TR≤100	7	Ln(a)	-0.180569	64555.0	0.01263
			b	1.608454	55333.0	0.00684
	TR<2	8	Ln(a)	-0.013811	1401.0	0.00467
			b	1.225693	1225.5	0.03501
30	TR≤100	15	Ln(a)	0.081542	3966.8	0.03076
			b	1.669715	3702.3	0.02744
	2≤TR≤100	7	Ln(a)	0.272162	4493.6	0.04148
			b	1.570110	3851.6	0.02530
	TR<2	8	Ln(a)	0.009308	1720.7	0.00384
			b	2.445621	1505.6	0.06303
60	TR≤100	15	Ln(a)	0.078620	4139.4	0.03014
			b	2.095372	3863.5	0.03371
	2≤TR≤100	7	Ln(a)	0.266851	5239.6	0.03848
			b	1.971994	4491.1	0.02943
	TR<2	8	Ln(a)	0.005892	7082.2	0.00192
			b	3.074431	6196.9	0.03906
360	TR≤100	15	Ln(a)	0.053014	7467.2	0.02264
			b	1.857885	6969.3	0.02225
	2≤TR≤100	7	Ln(a)	0.194025	6019.8	0.03677
			b	1.776028	5159.8	0.02472
	TR<2	8	Ln(a)	0.002662	5875.2	0.00213
			b	2.127826	6015.3	0.02998

+ All F values are significant at 0.005 level of significance

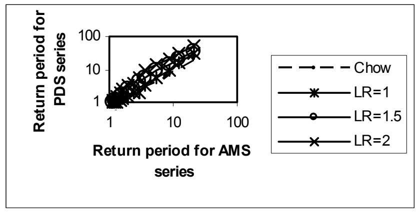

Fig. 4. The relationship between return periods of AMS and PDS series for floods of Canberra River, Australia (after Jayasuria and Mein, 1985)

b) Universality of Equation 2

For Eq. (2), Chen [2] suggested that 100-year and 10-year return periods may be used to arrive at coefficients a' and b'. To test the uniqueness of these values, alternative return periods were used, and also the best coefficients were calculated through semi-logarithmic regression. Our results indicated that b' was very sensitive to choice on TP1 and TP2, while a′ just showed some minor fluctuations. Therefore, regression analysis seems more accurate than Chen's method. His method showed a +2.6 and –42.0% difference from regression lines on average for all data points. Table 4 shows the best values for a′ and b′, including determination coefficients for regression lines of length ratios of 15-minute and 1-hr time durations and stations. We did not report the results for 30-minute and 6-hr, due to space limitations. The following results show some systematic trends:

1. a′ increases with either time duration or length ratio.
2. b′ has a random fluctuation and does not depend on time duration or LR.
3. determination coefficient increases with length ratio and decreases with time duration.
4. for three different vast climates of cold, humid, and desert, the average of R^2 is highest for humid and is lowest for desert climate, where for cold climate is in between. As desert climate becomes more severe (from Shahmaran to Qasr-e-Qand), the average R^2 decreases in amount.

Table 4. The coefficients of Eq. (2) obtained by regression procedure for stations under study

Length Ratio	a′	b′	R^{2+}	Length Ratio	a′	b′	R^{2+}
Baq-Malek							
15 minute				1-hr			
1	3.096	14.185	0.987	1	6.963	12.763	0.979
1.5	5.111	14.498	0.980	1.5	11.502	15.940	0.984
2	5.837	13.959	0.992	2	15.141	12.563	0.988
2.5	6.089	13.067	0.990				
3	6.215	12.252	0.994				
Mohammad-Abad							
15 minute				1-hr			
1	1.338	6.130	0.931	1	3.009	5.515	0.887
1.5	2.208	6.265	0.932	1.5	4.970	6.890	0.936
2	2.522	6.032	0.941	2	5.679	5.429	0.940
2.5	2.631	5.646	0.946				
3	2.732	5.317	0.950				
Qaleh-Jooq							
15 minute				1-hr			
1	1.404	6.434	0.937	1	3.158	5.789	0.891
1.5	2.318	6.576	0.939	1.5	5.217	7.232	0.941
2	2.648	6.332	0.945	2	5.960	5.698	0.942
2.5	2.762	5.926	0.949	2.5	6.208	6.523	0.903
				3	7.140	6.912	0.905
				3.5	7.524	7.324	0.905
				4	8.098	7.548	0.907
				4.5	8.345	7.790	0.909

Table 4 Continued.

Qasr-h-Qand							
15 minute				1-hr			
1	1.334	6.113	0.781	1	3.000	5.500	0.780
1.5	2.202	6.247	0.785	1.5	4.956	6.870	0.785
2	2.515	6.015	0.790	2	5.663	5.414	0.788
2.5	2.624	5.630	0.793	2.5	5.898	6.197	0.792
3	2.700	5.513	0.797	3	5.975	5.981	0.793
Qoochan							
15 minute				1-hr			
1	1.662	7.614	0.937	1	3.738	6.851	0.891
1.5	2.743	7.782	0.939	1.5	6.174	8.558	0.941
2	3.133	7.493	0.945	2	7.054	6.744	0.942
2.5	3.268	7.014	0.949	2.5	7.348	7.720	0.943
3	3.579	7.095	0.953	3	8.061	8.001	0.945
3.5	3.889	7.138	0.954	3.5	8.783	8.502	0.905
4	4.253	7.246	0.957	4	9.528	8.014	0.907
				4.5	9.997	7.506	0.909
				5	10.781	8.171	0.912
Shahmaran							
15 minute				1-hr			
1	1.160	5.313	0.880	1	2.608	4.78	0.880
1.5	1.914	5.430	0.883	1.5	4.308	5.972	0.886
2	2.186	5.228	0.890	2	4.922	4.705	0.886
2.5	2.281	4.894	0.893	2.5	5.127	5.386	0.892
3	2.510	4.889	0.895	3	5.155	6.150	0.893
				3.4	5.245	5.416	0.893
Shilaben							
15 minute				1-hr			
1	3.562	16.318	0.982	1	8.010	14.682	0.981
1.5	5.879	16.677	0.984	1.5	13.231	18.341	0.986
2	6.715	16.058	0.990	2	15.117	14.452	0.987
2.5	7.004	15.031	0.994	2.5	15.746	16.543	0.993

+ Coefficient of determination

c) Analysis of x ratio

Chen [2] assumed that *x*-value (ratio of 100-year rainfall to that of 10-year, used in Eq. (3) is only a function of geographical location of raingage, yet its variations in different stations are not remarkable. Figure 5 shows that *x* is not only highly dependent on the location of raingage, but also on rainfall duration and length ratio. Also at a specific length ratio, the variation of *x* with rainfall duration is not monotonic, but for specific rainfall duration, *x* directly increases with length ratio. Therefore, a constant value for *x* can not be considered, which may explain the necessary coefficient of 0.77 in Kothyari and Garde's study [32] for certain parts of India. Dependency of *x* on rainfall duration at a constant length ratio and for a specific raingage is quite similar to the findings of Ghahraman [39] for 126 recorded raingages of Iran using the AMS series. This author has shown that x is in fact a function of rainfall duration. Such ratio for selected rainfall durations used in this study (15, 30 minutes, 1, 6 hours) can be read as 1.606, 1.603, 1.579, and 1.528, respectively, [39] which are in the order of this research just for LR=1 (Fig. 5).

4. CONCLUSION

The universally accepted relationship between AMS and PDS, as originally proposed by Chow [27, 30] has been widely used by researchers and practitioners. However, the underlying assumption of uniqueness for the above relationship requires further investigation in light of local data. This is rather important since if uniqueness is not established, any resulting estimated value for a particular return period of interest would be questionable.

In this paper we have investigated the uniqueness of the relationship between return periods of AMS and PDS, utilizing actual data from a variety of climatic sites in Iran. PDS values are investigated in terms of AES and MOO values.

Based on observations and analysis reported in this paper, it is concluded that a unique relationship does not exist between return periods of AMS and PDS. Furthermore, any relationship is a function of LR, and also the derived relationships are a function of station location, as well as rainfall duration.

It is clearly shown that a unique relationship between return periods of AMS and PDS of short rainfall series can not be developed for Iran, since the length ratio should also be considered as another independent variable. In general, for a given return period of AMS, the return period of PDS increases with LR. For AES series (i.e., LR=1), the average of the return periods of PDS for a specific return period of AMS, and rainfall time duration over all seven stations showed a CV value of less than 0.2. The average of *CV* over all return periods were 0.123, 0.171, 0.142, and 0.198 for rainfall time durations of 15, 30, 60, and 360 minutes, respectively. On the other hand, rainfall duration had a negligible effect on the results (Fig. 3), as far as AES series is concerned. Based on our results for AES series of rainfall, Chow's relationship is not found to be appropriate. However, the results of Jayasuriya and Mein [37] for one flood AES data series, and also that of Henson [38], support our work. Finally, x-ratio (ratio of 100-years rainfall to 10-years) also showed some degrees of sensitivity to geographical location, rainfall time duration, and length ratio (Fig. 5).

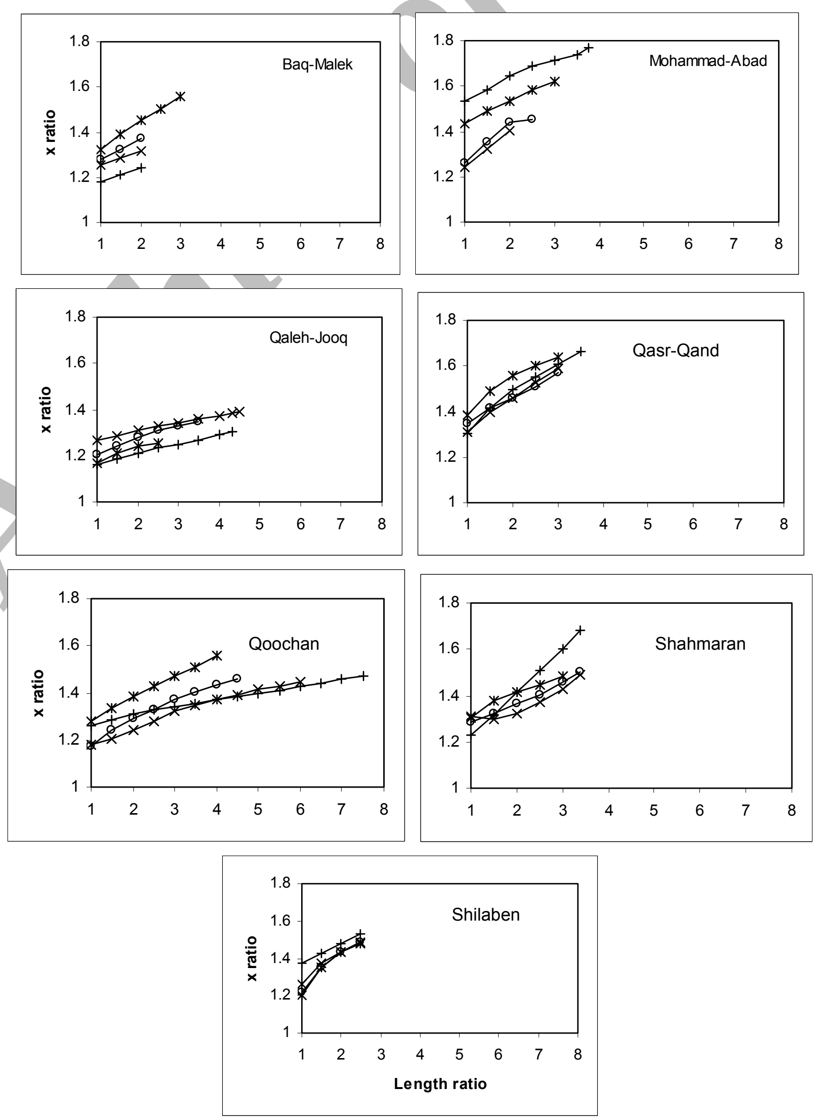

Fig. 5. Variation of x ratio with LR and rainfall time duration (*, 15 min; 0, 30 min; x, 1 hr; and +, 6 hr) for stations under study

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