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"Research Note"

THE ESTIMATION OF ONE DAY DURATION PROBABLE MAXIMUM PRECIPITATION OVER ATRAK WATERSHED IN IRAN*

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Abstract– The probable maximum precipitation (PMP) for many stations in Iran and other places using the Hershfield formula is routinely estimated as the mean plus 15 standard deviations processed from one-day yearly maximum rainfall values. However, the value of 15 may not be suitable for all stations with different climatic specifications. In this paper, yearly maximum one day rainfall data of 20-36 years for 30 stations in the Atrak watershed region in the northeast of Iran were analyzed in an attempt to estimate PMP for a one day duration based on an appropriate frequency factor. Based on the actual maximum daily rainfall data of these stations, the highest value of these frequency factors was found to be 9.63 for a one day duration. This frequency factor was subsequently used to estimate one day PMP values. Using these PMP estimates, a generalized pattern for the spatial distribution of one day PMP was demonstrated. It was found that one day PMP over the Atrak watershed ranges from 97 to 295 mm, and the mean ratio of PMP to the highest observed one day rainfall was about 2.51. The PMP maps are considered important tools to determine reliable and consistent estimates for any location in the Atrak watershed for large hydraulic structure designs.

Keywords– PMP, precipitation, Atrak watershed, Iran, frequency

1. INTRODUCTION

The need for the development of water resources has become of considerable importance in the Atrak watershed with a view to ensuring sufficient potable and industrial water supplies, providing irrigation for food production and flood control. As a result, large amounts of money are invested each year for the construction of different water resources projects such as dams, storage reservoirs, etc. Probable maximum precipitation (PMP) is a common way to synthesize corresponding probable maximum floods in short-data cases.

The PMP is defined as the greatest depth of precipitation for a given duration that is meteorologically possible over a given station or a specified area [1]. There are two main methods including hydro-meteorological and statistical approaches for calculating PMP. Due to the shortage of data for applying the first method, there is a great tendency to adopt the second one. Hershfield [2, 3] was a pioneer who developed a statistical method for estimating PMP values for small areas around the world. Required in this method are a series of maximum annual daily rainfall at an observation point, yet the partial duration series [4] may be an alternative. The use of the Hershfield method has shown that the PMP estimates obtained by this method are closely comparable to those obtained by the elaborate physical method. Having this in mind, several researchers have employed Hershfield's statistical techniques extensively for estimating PMP for stations having a long period of rainfall records [5, 6]. The purpose of this research is to carryout a study on the estimation of PMP for a 24-h duration using the Hershfield technique for stations in the Atrak watershed with sufficient daily rainfall data.

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2. STUDY AREA AND DATA USED

The Atrak watershed, with a higher than 25627 km^2 area, is located between Khorasan and Golestan provinces which are located in the northeast of Iran. This watershed is bordered in the north by Torkamanestan, to the west by the Caspian Sea and to the east and south by Kashafrood and Gorganrood watersheds. Its watershed is bounded from the west by the Caspian Sea with a marine climate and is located in the vicinity of the Qaraqum Salt desert in Torkamanestan, with a desert climate. Thus, these two diverse climates cause variable climate changes for Atrak. During the course of a year, Atrak watershed experiences one major rainy season (winter; winter is nominal, in some years it also may cover autumn and/or spring) associated with mostly Mediterranean originated air masses.

The station names and their record lengths are given in Table 1. The data length ranges from 20 to 36 years with a mean of 28.7 years.

Table 1. List of stations within the Atrak watershed[+]

Station Number	Station Name	Data Length (years)	Annual Rainfall (mm)	Station Number	Station Name	Data Length (years)	Annual Rainfall (mm)
11001	Tabarak Abad	36	261	11028	Qaleh Jiq	27	368
11003	Hey Hey	27	284	11029	Hesseh Gah	20	316
11006	Se Yek Ab	32	252	11031	Darkesh	31	464
11007	Jahan Abad	23	309	11033	Shir Abad	32	421
11008	Ali Mohammad	31	321	11035	Dar Band	31	308
11011	Barezoo	32	235	11039	Aghmazar	31	230
11013	Reza Abad	20	210	11044	Asadli	17	324
11014	Barbar Qaleh	35	237	11045	Qazanqayeh	29	253
11016	Chaman Bid	31	284	11047	Maraveh Tappeh	35	353
11018	Incheh Olya	26	225	11053	Qareh Qanloo	20	267
11020	Khartoot	31	266	11057	Torshakli	27	329
11021	Baba Aman	31	278	11073	Hootan	31	310
11023	Qezelqan	26	256	11086	Abiari Bojnord	23	205
11026	Incheh Boroon	27	340	11204	Garmkhan	30	291
11027	Qatlish	32	211	11206	Farooj	29	271

[+] Daily rainfall data of 30 stations within Atrak watershed obtained from rainfall archives of Water Affairs of Khorasan and Golestan provinces were used in this study.

3. METHODOLOGY

The Hershfield [2, 3] technique for estimating PMP is an adapted version of Chow [7] for the frequency analysis of rainfall. Hershfield [2, 3] considered that for PMP estimation, there is a value of frequency factor which will not exceed, say K_m. He then modified Chow's equation as:

$$K_{PMP} = \overline{X}_n + K_{m\sigma n} \tag{1}$$

where X_{PMP} is PMP for a given set of data, $\overline{X}_n$ and σ_n are the mean and standard deviation of annual maximum, respectively. The K_m factor is calculated using the following equation:

$$K_m = (X_1 - \overline{X}_{n-1}) / \sigma_{n-1} \tag{2}$$

where X_1 is the highest observed annual maximum rainfall in the series, and $\overline{X}_{n-1}$ and σ_{n-1} are the mean and standard deviation of the annual maximum, respectively, when the highest value is excluded in calculating the parameters.

Rainfall data were thoroughly checked and any doubtful observations were discarded. For each station, the annual maximum series of a one day maximum amount of rainfall was selected and an array of annual maximum values of rainfall was formed. The homogeneity of all 30 series was checked by a non-parametric Mann-Kendall rank test [8]. The statistic is computed from $\tau = \frac{4\sum n_i}{N(N-1)} - 1$, ($n_i$ is the number of values larger than i^{th} value in the series subsequent to its position in the series of N values). Its expected value in a random series is 0 and its standard deviation (σ_τ) is given by $\sigma_\tau = \sqrt{\{(4N+10)/[9N(N-1)]\}}$. The ratio of τ to σ_τ, is considered an indication of a possible trend in the data. For no trend in the data series this value lies within the limits of ±1.96 at the 5% level significance. Afterwards K_m value and the corresponding one day PMP value were determined using Eqs. 2 and 1, respectively, for all 30 stations. An average factor of 1.13 (e.g. Tomlinson [9]) was used to convert one day PMP estimates into 24-h PMP.

4. STATISTICAL ESTIMATES OF PMP

One day annual maximum rainfall values of 30 stations were analyzed to extract the station-based PMP estimate. The values of $\overline{x}$, $\overline{X}_{n-1}$, σ_n and σ_{n-1} and the coefficient of variability ($CV=\sigma_n/\overline{X}_n$) were also calculated. The frequency factor (K_m) was determined for each station using Eq. (2). The results are summarized in Table 2. As indicated, the values are mostly less than 5. Only 5 values (~16.5%) were found between 5.31 and 9.63, with the latter being the upper limit of the estimated K_m. As PMP deals with unusual rainfall values, the corresponding frequency factor must also be chosen from the extremely high values. For the case of the Atrak watershed, K_m would be 9.63. Yet it may be acknowledged that K_m is highly dependent on the climatic conditions of the study area. One support for the K_m value of 9.63 could be found in Desa et al [10]. These authors derived K_m=8.7 as an upper limit for a humid region of Malaysia. Desa et al [10] used 33 stations with 30-60 years of data each. Since the Atrak watershed is drier than that in Malaysia, our entry (K_m=9.63) seems to be reasonable. This implies that, considering K_m=15, [2] gives an overestimated value for PMP in the Atrak watershed.

Table 2. Frequency distribution of K_m values

K_m(mm)	<3	3-5	5-7	7-9	>9
Number	7	18	3	1	1

Using K_m of 9.63, the mean ($\overline{X}$) and standard deviation (σ_n) for each station, PMP values for a one day duration for all stations were computed using Eq. (1). An average factor of 1.13 (e.g. Tomlinson [9]) was used to convert one day PMP estimates into 24-h PMP. The values of the mean, the standard deviation and the corresponding PMP for all 30 stations are given in Table 3. The observed one day highest rainfall, as well as the ratio of estimated PMP to these rainfall values, are shown to facilitate comparisons. For different stations in the Atrak watershed, this ratio varies between 1.95 and 3.01. Such variation may originate from: (a) stations with different microclimates, and (b) a different record length of the stations. Desa et al. [10] reported similar values ranging from 1.5 to 2.7 which are lower than those obtained in this study. One possible reason may be due to the dryness of the Atrak watershed which may produce more severe rainfall and also more variability of rainfall among different years (it also is supported by higher K_m values of Atrak, as compared with Malaysia [10]).

The 24-h PMP estimates for all stations were plotted on a map of the Atrak watershed and isolines were drawn by standard routines available in GIS software. The resulting isohyets are not shown here due to space limitation. The distribution of 24-h PMP has exhibited patterns with high and low PMP values in certain areas. The isohyets of the 24-h PMP over the Atrak watershed range from 97.6 to about 295 mm. The high values generally can be seen along a narrow part in the east. There are three regions of relatively high PMP (>200 mm). One is in the west part which could be due to the presence of the Caspian Sea, and the other two are located in the east and in the middle of the watershed. These two zones have an arid climate. No constant PMP value was found in the region, however, there is a marked gradient in PMP all over the watershed. The average ratio of 24-h PMP to the highest observed one day rainfall was found to be about 2.51 (CV=0.11).

5. CONCLUSION

The main purpose of this study was to introduce a simple standardized method of PMP computation. Statistical estimates of 24-h PMP rainfall for 30 stations in the Atrak watershed, Iran, were made using an appropriate frequency factor of 9.63. Based on these PMP estimates, a generalized map could be prepared showing the spatial distribution of 24-h PMP. The PMP ranges from 97 mm over the south to 295 mm on the south-east of the Atrak watershed. The point PMP rainfall estimates can be converted into areal PMP estimates by using a depth-area relationship. This method could be recommended for other regions, however, future records may be needed to verify the ensuing results of PMP and the corresponding resulted PMF values.

Table 3. One-day highest observed and 24-hr PMP for stations in Atrak watershed

Station number	One-day highest observed range (mm)	Mean (mm)	Coefficient of variation	24-h PMP (mm)	24-h PMP/ highest observation
11001	9-120	33.2	0.71	295.29	2.46
11003	15-70	28.2	0.48	178.21	2.55
11006	15.46	24.6	0.35	121.59	2.64
11007	12.50	26.4	0.33	124.16	2.48
11008	15.62	27.9	0.38	147.25	2.38
11011	6-50	23.1	0.42	132.74	2.65
11013	14.40	21.4	0.32	97.61	2.44
11014	10-50	24.0	0.40	115.77	2.32
11016	16-60	25.3	0.34	121.68	2.03
11018	6-46	18.6	0.41	104.42	2.27
11020	19-51	29.1	0.25	112.56	2.21
11021	12-39	24.7	0.32	112.37	2.88
11023	12.5-61.5	25.6	0.50	167.12	2.72
11026	10-46	20.8	0.44	122.06	2.65
11027	11-45	21.0	0.40	115.47	2.57
11028	15-79	41.0	0.42	232.45	2.94
11029	13-45.5	26.4	0.28	109.28	2.40
11031	21-94	34.9	0.38	182.94	1.95
11033	17-104	35.0	0.49	226.71	2.18
11035	13-100	26.1	0.61	201.20	2.01
11039	11-50	25.3	0.37	131.2	2.62
11045	9-40	22.3	0.39	120.29	3.01
11047	16.5-60	23.4	0.33	152.11	2.54
11053	9.5-40	24.2	0.35	120.31	3.01
11057	13.5-53	25.3	0.41	140.52	2.65
11067	18-62	31.8	0.30	137.72	2.22
11073	15.5-49	26.1	0.32	122.12	2.49
11086	13-55	23.1	0.49	150.11	2.73
11204	15-45	27.9	0.29	119.88	2.66
11206	10-40	21.0	0.35	103.7	2.59

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