Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 3 (4) March 2014: 162-169

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.533
Universal Impact Factor 0.9804

ORIGINAL ARTICLE

Effect of Climate on Temporal Distribution Pattern of Rainfall and Comparing With Each other and Known Patterns Case Study: Ardebil Province – Iran

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ABSTRACT
Rainfall distribution pattern is one of the most important factors in simulation of runoff hydrograph and hydraulic structure design. The pattern is often different in various climates. The present study was formulated in order to determine temporal rainfall distribution pattern and comparing it with SCS, WMS, and Huff patterns in four regions (namely Haruchay, Gharasou, Meshkinchay, and Darrehroud) in Ardebil Province – Iran. For this aim, temporal rainfall distribution pattern was assigned through Huff and Pilgrim Method by use of the data related to seven rain gauge stations within the mentioned regions. Afterwards, predominant climate of each region was evaluated and compared via Do Martin Method. By using MAE, RE, RMSE, ME, and W statistics, the patterns for each region were compared with those of SCS, WMS, and Huff. The results obtained from the present study indicated that rainfall distribution patterns in different regions of Ardebil Province are different. In semi-humid climate in southern regions (i.e. Haruchay), semiarid regions (i.e. Gharasou and Meshkinchay), and arid regions (Darrehroud),the maximum rainfall rates were in the first quarter (onset of rainfall), in the third quarter (midst of rainfall), and in the fourth quarter (end of rainfall), respectively. The results acquired from comparison of the patterns obtained for the regions with those mentioned above demonstrated that relative to the regions' patterns, Huff-1st and Huff-4th patterns experienced the lowest and highest error rates, respectively. On the contrary, with regard to all statistical results, application of WMO, SCS, and Huff-3rd patterns provide more realistic estimations in Herochay and Meshkinchay, Darrehroud, and Gharasou, respectively.
Keywords: *Ardebil Province, temporal rainfall distribution, climate, SCS, Huff, WMO.*

Received 12 /01/2014 Accepted 02/03/2014

INTRODUCTION

Comprehensive management of water resources nowadays demands true and complete meteorological and hydrological data among others [8]. Simulation of runoff hydrograph and hydraulic structures design often requires rainfall characteristics such as amount, duration, and temporal rainfall distribution [20]. Temporal rainfall distribution pattern is in fact indicative of variations of rainfall intensity. Effect of rainfall characteristics, especially temporal rainfall distribution and its intensity, on simulation of runoff events are more understood [1,17]. A huge part of errors in simulation of rainfall-runoff models is due to uncertainties regarding to regions' rainfall distribution patterns [19,10,16]. Therefore, provision of rainfall distribution pattern for each region by using rainfall data for that region is very important since the pattern is varying in regions with different climates. As [15] mentioned in their study in Iran, with regard to variety of mechanisms causing rainfall events in Iran such as altitude, proximity to sea, and general circulation systems, it is impossible to consider a predominant distribution pattern for all parts of Iran. In this regard, American Soil Conservation Society [18] presented 6- and 24-hour patterns termed SCS patterns which are broadly used in Iran and other countries in order to simulate runoff and designate hydraulic structures. Other patterns have also been proposed. [6] Classified rainfalls in terms of intensity in four quarters and estimated experimental probabilities for each quarter. Furthermore, [12] provided temporal rainfall distribution pattern in Sydney by use of 50 intense rainfalls in various temporal bases related to 51 statistical years through drawing and calculating methods. Several studies have been performed on temporal rainfall distribution pattern in one region and comparison with other patterns proposed by other authors. The results obtained by some Iranian authors such as [21] in the north and Mojaradi (2010) in the west of Iran indicated that no considerable similarity exists between regional rainfall distribution pattern and SCS pattern. However, the findings of [7] in the north, south and center of Iran showed that temporal rainfall distribution pattern in these regions is not very consistent with that of [12] although it is somewhat coincided with that of [6]. On the other hand, rainfall distribution patterns are varying in different regions of Iran. In other parts of the world, several studies on temporal rainfall distribution pattern have been performed. [9] Adopted Huff's method so as to determine temporal rainfall distribution pattern in southwestern British Colombia. By comparing 6-hour temporal rainfall distribution pattern in Oman and Southern Canada, [2] contended that there is no similarity in temporal rainfall distribution patterns between arid and alpine regions and 6-hour SCS patterns. In arid regions of Saudi Arabia, [3] stated that Bell's formula and SCS rainfall distribution pattern are suitable for less than 2-hour and more than 3-hour rainfalls, respectively. By classifying rainfall events in 4 groups in Brazil, [5] claimed that type-I rainfall events are the most abundant occurring mostly in the summer. [14] showed that there is no significant coincidence between SCS pattern and Huff's pattern in the US.

Iran's climate is generally under the effect of latitude and Alborz and Zagros alpine systems. Rainfall rates in Iran fluctuate sharply; rainfall in the north of Iran exceeds 2000 mm in the north of Iran owing to humidity of Caspian Sea and hindrance of Alborz Mountain while it is lower than 50 mm in southern and eastern regions [13]. The present study aimed at determination of temporal rainfall distribution pattern in various climates of Ardebil Province after selection of rainfall design in each region. Then, coincidence of the patterns with regional patterns was evaluated by comparing these patterns with known patterns from other parts of the world.

MATERIALS AND METHODS

2-1- Location of the area

Ardebil Province is one of mountainous provinces of Iran located in northwest with an area of 17800 km^2. It is located in Caspian Sea watershed basin (one of six grade-1 regions in Iran). Central and northern parts of Ardebil Province (i.e. Ardebil, Meshkinshahr, and Moghan) are members of Aras grade-2 region while southern parts of the province (Khalkhal) are in Sefidroud grade-2 region. Watershed basins of Ardebil, Meshkinshahr, Moghan, and Khalkhal are called Gharasou, Meshkinchay, Darrehroud, and Herochay (or Khalkhalchay), respectively. Figure 1 depicts the regions under study in northwest of Iran and Ardebil Province as well as rain gauge stations. Overall area under study is 24688 km^2, 72% of which is occupied by Ardebil Province.

2-2- Climatic characteristics of the area

Southern parts of Ardebil Province are mostly influenced by humidity of Caspian Sea and own semi-humid climate. With regard to alpine situation in central parts of the province as well as Moghan Plain in northern parts, the province experience variety of climates where aridity increases sharply as one moves from south to north of the province. Considering the fact that the most intense runoff is caused by the rainfall whose duration equals concentration time of the region as a physical parameter with varying amount for different regions, runoff moves fast in floodway in mountainous regions with smaller and steeper watershed basins [11].

Therefore, because of shorter lag time and concentration of the region, rainfall-runoff reaction time in mountainous areas is short and abrupt runoffs usually occur (4). With regard to what mentioned above, in mountainous regions of Ardebil Province, concentration time of four regions is around 6 hours and consequently, a 6-hour rainfall in this area was considered as rainfall model.

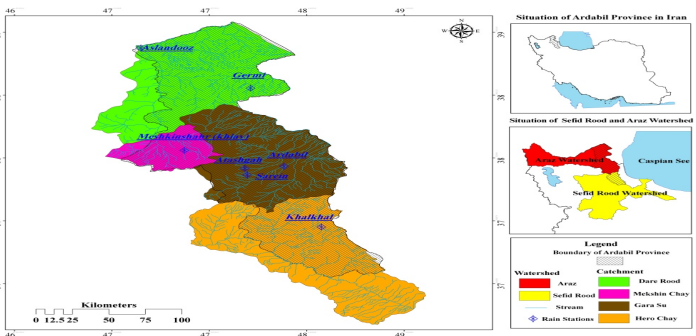

Figure 1: the area under study in Iran and Ardebil Province in addition to rain gauge stations

Research method

The present study consisted of three stages. In the first stage, temporal rainfall distribution pattern was evaluated by use of the data obtained from rain gauge stations in four watershed basins of Ardebil Province. In the second stage, Ardebil Province's climate was evaluated by use of the climatic map presented by Iranian Organization of Natural Resources and Watershedding and predominant climate for each region was assigned. In the third stage, temporal rainfall distribution pattern was specified for each stage and compared with globally-known patterns.

2-3-1- Determination of temporal rainfall distribution pattern

In order to assign rainfall distribution in seven rain gauge stations of Ardebil Province (namely Ardebil, Sarein, Atashgah, Khalkhal, Meshkinshahr, Germi, and Aslandooz), dimensionless distribution and quarters of 6-hour rainfall were assigned through (6) and (12) methods after deriving 6-hour lasting rainfall. Generally, Iranian rain gauge stations' data are for short terms; thereby, in the present study, the terms used in the stations were almost 5 years except for Khalkhal Station whose data were for 29 years. Overall, 37 five-hour rainfall events were obtained from all stations with the most events acquired from Khalkhal Station.

Determination of Ardebil Province's climate

As mentioned above, the map presented by Iranian Organization of Natural Resources and Watershedding was adopted in order to determine climate. In the map, Ardebil Province's climate has been divided into arid, semiarid, semi-humid, humid, very humid, and Mediterranean via Do Martin Method. In this stage, predominant climate in each region was assigned according to the highest area covered by a given climate in each sub-region.

Effect of climate on rainfall distribution pattern

In order to determine temporal rainfall distribution pattern in each stage, rainfall distribution pattern in Ardebil, Sarein, and Atashgah stations, the one in Khalkhal Station, that in Germi and Aslandooz stations, and finally the one in Meshkinshahr Station were considered for Gharesou, Haruchay, Darrehroud, and Meshkinchay regions, respectively. Finally, the difference of each rainfall distribution pattern in the regions was evaluated with regard to the region's climate.

Evaluation statistics

Dimensionless distribution patterns in the stations werecompared with those of WMO, SCS, and Huff considering rainfall types of the stations. For this, MAE, RE, RMSE, and ME were adopted; the criteria are calculated as follows:

$$RE = \left|\frac{\text{Qi - Qm}}{\text{Qi}}\right| \times 100 \qquad (1)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\text{Qi - Qm}\right| \qquad (2)$$

$$ME = \frac{\sum_{i=1}^{n}(\text{Qi - Qm})}{\text{n}} \qquad (3)$$

$$\text{RMSE} = \sqrt{\frac{\sum_1^n(\text{Qi}-\text{Qm})^2}{\text{n}}} \qquad (4)$$

Where Q_i, Q_m, and n stand for observed amount, predicted amount, and number of observed data, respectively.

RE amounts closer to zero indicate that maximum percentage of regional rainfall is more consistent with the pattern under evaluation. Positive and negative amounts of ME show that temporal rainfall distribution pattern is overestimated and underestimated relative to the regional pattern's amount, respectively. MAE and ME differ in that the error caused by rounded estimation error in various patterns are not introduced into models evaluation process and the amount is not affected by positive and negative estimated error. RMSE was always positive whose amount closer to zero indicates icreased distribution performance. In fact, RMSE points to estimated error all over the dimensionless curve of rainfall distribution.

Another index for evaluation of rainfall distribution patterns is Willmott Index (W) (22). The index ranges between zero and one where one indicates identical regional and compared distribution patterns. W is obtained as follows:

$$W = 1 - \frac{\sum_{i=1}^{n}(Qm - \text{Qi})^2}{\sum_{i=1}^{n}\left[\left|Qi - \overline{\text{Qi}}\right| + \left|Qm - \overline{\text{Qi}}\right|\right]^2} \qquad (5)$$

Where $\overline{\text{Qi}}$ stands for mean percentage of regional rainfall pattern.

With regard to what mentioned, the pattern with lower RE, ME, and RMSE and higher W is more consistent with regional distribution pattern. If regional distribution pattern is not available in the studies relative to water resources, the pattern will be more efficient.

RESULTS

As it can be seen in Table 1, the first quarter experienced the highest 6-hour temporal rainfall distribution pattern where 18 out of 37 derived events occurred in this quarter; 12 out of the 18 events were for Khalkhal rain gauge station.

Table 1- Number of events in temporal rainfall distribution pattern in each rain gauge station in the quarters

Rain gauge stations	Count events	1st Quarter	2ndQuarter	3rd Quarter	4thQuarter
Ardabil	2	1	-	1	-
Meshkinshahr	3	-	1	2	-
Khalkhal	15	12	-	2	1
Germi	3	-	2	-	1
Sarein	2	-	1	1	-
Aslandooz	8	3	-	3	2
Atashgah	3	-	2	-	1
Total	37	18	6	9	4

According to Figure 2, the highest 6-hour rainfall rates in Herochay, Gharasou, Meshkinchay, and Darrehroud regions occurred in the first, third, third, and second & fourth quarters with 42, 32, 30, and 26 percent of overall rainfall. Therefore, rainfall variations in Darrehroud and Herochay regions are more than those in Gharasou and Darrehroud regions. Figure 3 shows average temporal rainfall distribution curves for each region.

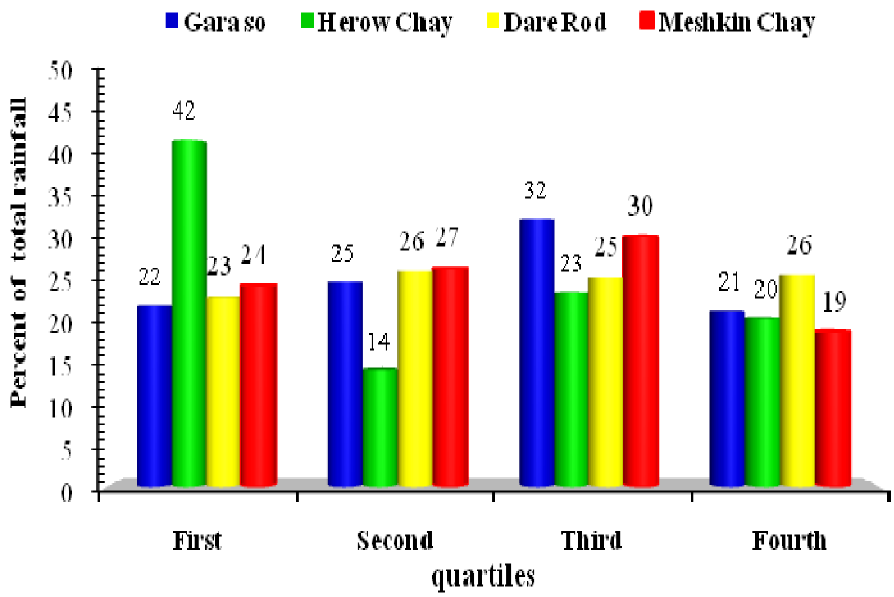

Figure 2- Rainfall quarters in each region

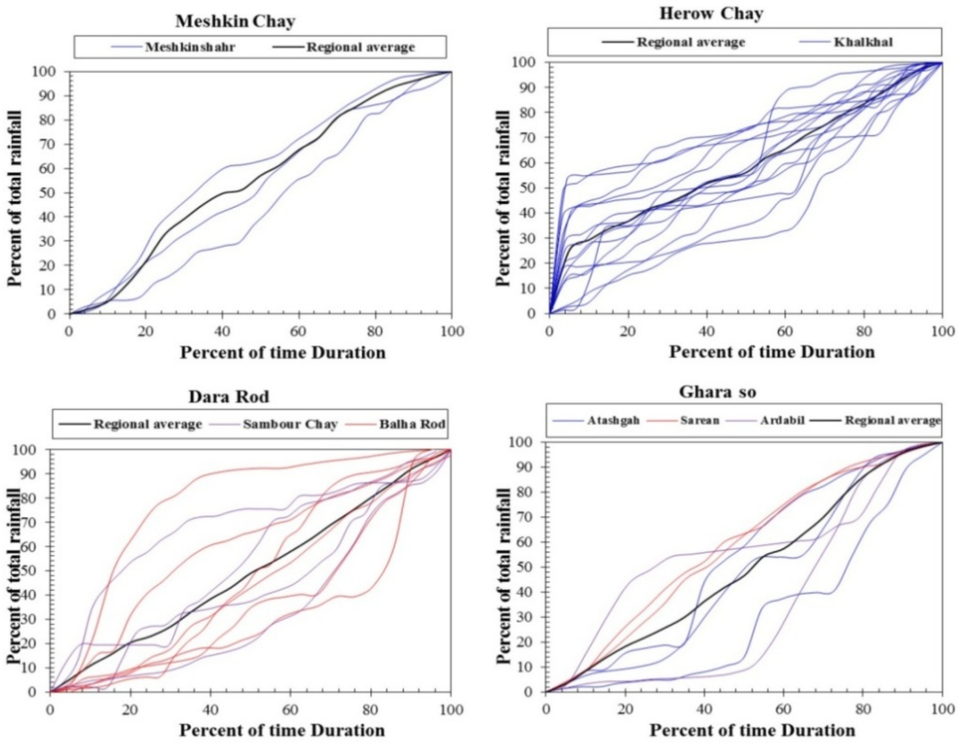

Figure 3- Temporal rainfall distribution curves for the regions

The results obtained from determination of the climate of the area under this study according to climatic map (based upon Do Martin method) presented by Iranian Organization of Natural Resources and Watershedding showed that semiarid region among others was the predominant climate with 53.4% of all the area. Ardebil, Meshkinshahr, and Moghan regions' prevailing climate is semiarid while Khalkhal has semi-humid climate. Figure 4 shows climatic map of the area under study and Table 2 depicts the information on area, predominant climate, and area percentage covered by the climate in each region.

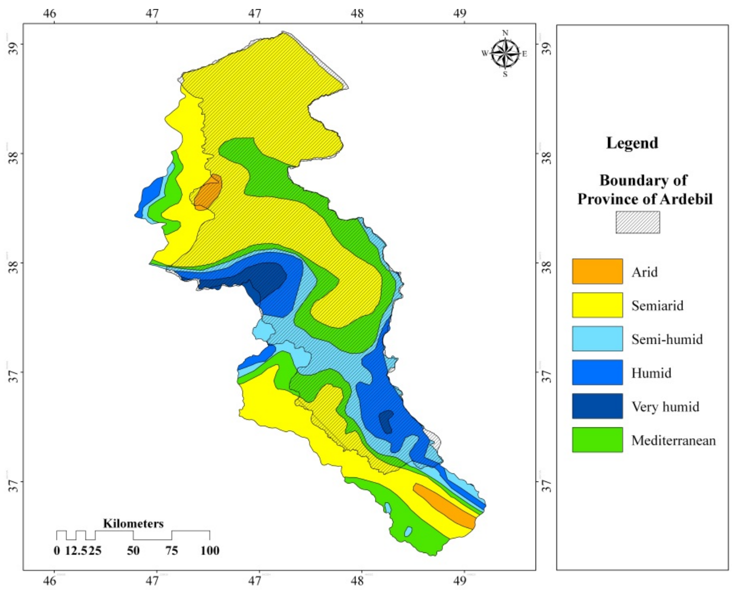

Figure 4- climatic map of Ardebil Province

Table 2- Area, predominant climate, and area percentage covered by the climate in each region

The study area	Ardabil	Khalkhal	Moghan	Meshkinshahr	Total study area
Area(km^2)	5655	5860	3767	6189	24628
Dominant climate	Semi arid	Semi-humid	Semi-arid	Semi-arid	Semi-arid
Percent of Dominant climate area	40.7	45.05	84.47	67.57	53.41

Determination of rainfall distribution pattern in regions of Ardebil Province showed that the patterns are different in various climates of Ardebil Province; according to Figure 5, as mentioned before, the maximum rainfall in Herochay (semi-humid), Gharasou & Meshkinchay (semiarid), and Darrehroud (arid) occurred in the first, third, and second & fourth quarters, respectively. Moreover, on the basis of dimensionless rainfall distribution pattern depicted in Figure 6, rainfall percentage in Herochay region in the southern part of Ardebil Province peaked in the onset of rainfall o that 25% of total rainfall took place in the first 5% of 6-hour rainfall. However, as one moves from southern to northern parts of the province, the maximum 6-hour rainfall occurred in the last parts of rainfall so that the maximum rainfall in Darrehroud region in the northern part of the province with arid climate occurred in the middle and last parts of rainfall. Also, in middle part of Ardebil Province, i.e. Meshkinshahr and Gharasou regions with semiarid climate, the maximum rainfall occurred in the middle parts of rainfall.

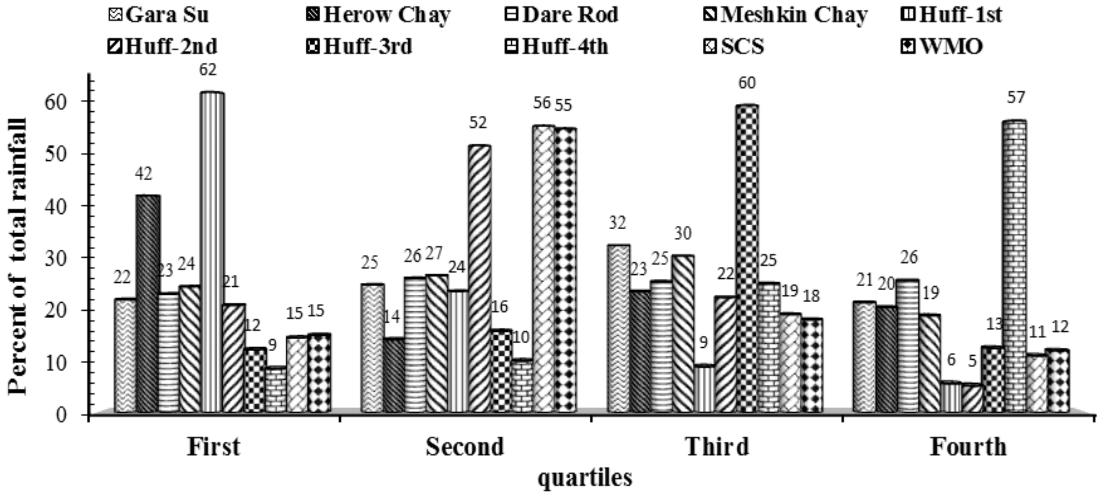

Figure 5- Rainfall quarters with varying patterns in each region

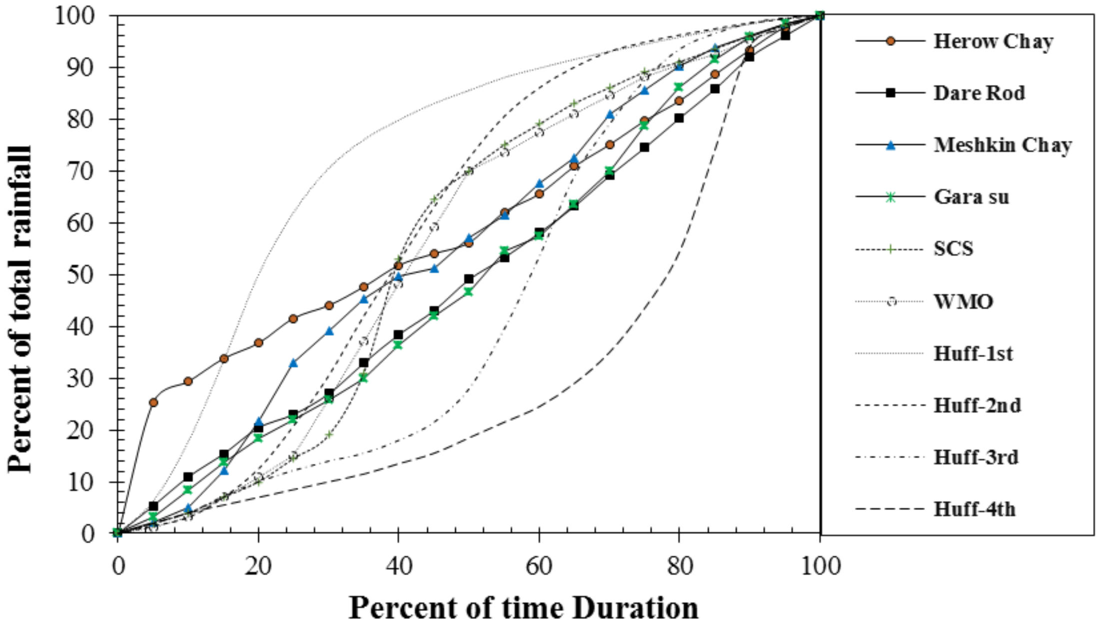

Figure 6- Average dimensionless 6-hour rainfall curve in different regions and patterns

The results obtained by comparison of evaluation statistics were shown in Table 3. According to the results, the lowest and highest RE were for comparison of Meshkinchay pattern with Huff 4th (18%) and Darrehroud pattern with Huff 4th(120%), respectively. Generally, the lowest RE rates were for Herochay and Darrehroud related to Huff 2nd and Meshkinchay and Gharasou related to Huff 4th. The results acquired from determination of ME statistics indicated that SCS, WMO, Huff 1st, and Huff 2nd presented underestimation while Huff 3rd and Huff 4th presented overestimation. Also, the lowest ME statistics in Darrehroud and Gharasou regions, Herochay region, and Meshkinchay region were for Huff 3rd, Huff 2nd, and SCS patterns, respectively. In addition, RMSE statistics showed that Herochay and Meshkinshahr regions, Darrehroud region, and Gharasou region are more consistent with WMO, SCS, and Huff 3rd patterns, respectively. Finally, comparison of regional patterns with W pattern showed that in Herochay, Darrehroud, and Meshkinchay regions, Huff 4th pattern presented a more realistic estimation relative to regional pattern while in Gharasouregion, it was Huff 1st pattern that had closer estimation to regional pattern.

Table 3- Error rates in WMO, SCS, and Huff patterns relative to regional patterns

Errors	Rainfall pattern	Gara Su	MeshkinChay	Dare Rood	HerowChay
RMSE	Huff-1st	27.8	20.4	11.5	19.0
	Huff-2nd	15.1	9.8	15.7	16.2
	Huff-3rd	10.2	16.3	12.0	21.1
	Huff-4th	21.9	29.1	21.6	30.7
	SCS	12.5	9.6	8.5	16.0
	WMO	11.1	7.8	11.5	14.8
MAE	SCS	9.22	6.96	10.64	12.90
	WMO	8.28	5.70	9.39	11.62
	Huff-1st	22.37	16.60	22.61	16.06
	Huff-2nd	11.44	7.64	12.60	13.64
	Huff-3rd	8.18	11.30	10.60	17.18
	Huff-4th	17.72	23.49	17.82	27.04
ME	SCS	-5.89	-0.13	-6.13	3.36
	WMO	-5.49	0.27	-5.73	3.76
	Huff-1st	-22.37	-16.60	-22.61	-13.11
	Huff-2nd	-9.49	-3.72	-9.73	-0.23
	Huff-3rd	4.41	10.18	4.17	13.67
	Huff-4th	17.72	23.49	17.48	26.98
W	SCS	0.968	0.98	0.963	0.934
	WMO	0.973	0.987	0.97	0.941
	Huff-1st	0.835	0.905	0.831	0.893
	Huff-2nd	0.953	0.98	0.947	0.933
	Huff-3rd	0.978	0.946	0.969	0.893
	Huff-4th	0.893	0.823	0.823	0.775
RE%	SCS	41	37	57	65
	WMO	44	41	53	64
	Huff-1st	73	71	78	48
	Huff-2nd	31	26	80	50
	Huff-3rd	84	96	51	71
	Huff-4th	23	18	121	64

DISCUSSION AND CONCLUSION

The results obtained from the present study showed that climate play a pivotal role in rainfall distribution pattern of Ardebil Province. Although there is a considerable difference between semiarid climate in northern parts and semi-humid climate in southern parts such as Darrehroud and Herochay, no difference is seen between climates in central parts of Ardebil Province (i.e. Gharasou and Meshkinchay) and Darrehroud region. Aridity in northern parts is more than central parts which may be attributed to topographic situation of Moghan Plain in northern part of Ardebil Province. Existence of this plain leads to the fact that distribution pattern of this region is different from that of central semiarid regions despite its more pronounced semiarid climate compared to central parts. If the maximum rainfall occurs in the last parts of 6-hour rainfall, it will be very considerable event in studies on runoff simulation. Because if the maximum precipitation occurs in the onset of rainfall, overall loss will be low due to dryness of soil and lack of interception; however, with continued rainfall and reduced soil capacity as well as saturation of soil and reduction of interception capacity, overall loss skyrockets. Therefore, adoption of regional distribution pattern of Darrehroud region compared to that of Hero hay will produce more runoff owing to maximum rainfall in last parts of rainfall. As a result, in addition to insufficient vegetation, rainfall distribution pattern also leads to increased volumetric flow rate of runoff. Comparison of 6-hour rainfall distribution pattern with those of the present study revealed that differences exist between the patterns. This is somewhat consistent with the results obtained by (21) in Iran and other authors, namely (2) in arid climates of Oman and Australia and (3) in arid regions of Saudi Arabia. The results obtained from comparison of regional patterns with the mentioned ones indicated that adoption of Huff-1st and Huff 4th patterns in runoff simulation lead to under- and overestimation compared to regional pattern, respectively. On the contrary, with regard to overall results obtained from evaluation statisticsin order to simulate runoff hydrograph, adoption of WMO, SCS, and Huff 3rd patterns will present more realistic estimation in Herochay& Meshkinchay regions, Darrehroud region, and Gharasou region, respectively. Since data related to rain gauge stations are sketchy in many parts of the world, especially in Iran, it is inevitable to make use of patterns of other regions. Of course, consistency of regional patterns with other ones can be evaluated by conducting such studies as the present one in order to provide a suitable pattern for other areas. The results obtained from the present study showed in agreement with those acquired by [15] that adoption of a single pattern cannot provide an accurate estimation of rainfall distribution pattern in various regions of Ardebil Province.

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How to cite this article:
Ali G, Sajad M, Yadollah M, Majid R, Maryam M. Effect of Climate on Temporal Distribution Pattern of Rainfall and Comparing With Each other and Known Patterns Case Study: Ardebil Province – Iran. Bull. Env. Pharmacol. Life Sci. 3 (4) 2014: 162-169