World Applied Sciences Journal 6 (12): 1705-1713, 2009
ISSN 1818-4952

Investigation of Depth-Area-Duration Curves for Kurdistan Province

[1]*Shirko Ebrahimi Mohammadi,* [2]*Mohammad Mahdavi*

[1]Faculty of Natural Resources, Kurdistan University, Kurdistan, Iran
[2]Faculty of Natural Resources, University of Tehran, Tehran, Iran

Abstract: Determining Depth-Area-Duration (DAD) curves in drainage basins is one of the applied researches in hydrology. DAD curves exhibit the depth and the area covered by the rainfall with a particular duration. DAD analysis is widely used in characterization of precipitation extremes for specification of so-called design storms. In this study the DAD curves for the Kurdistan province were prepared and investigated. To obtain the rainfall rate for different parts of the region for time durations of 24, 48, 72 and 96 hours, the daily rainfall data from the stations of the Ministry of Energy were studied first and the rainfall data for durations of one to four days were extracted afterward. 19 storms were then selected for the four time durations according to the rule of extensive rainfalls. The rainfall data from the interior meteorology stations and from some of the stations of the neighborhood provinces at the same occurrence time of the last storms were extracted and recorded according to their termination time. In order to determine the average of maximum rainfall depths for different durations for each storm, calculations were performed using isohyetal maps which were prepared by 'Moving Average' method. The initial DAD curves were then prepared using those calculations. Since the maximum rainfall is needed, the initial DAD curves for each duration were combined to obtain a final DAD curve, which is basically the envelope depth-area curve for the corresponding duration. This procedure was performed for all four time durations and ultimately four final DAD curves, one per each time duration, were produced.

Key words: Rainfall . Depth-Area-Duration curves . Isohyetal map . Kurdistan province

INTRODUCTION

There is a definite relation among depth, area and duration of rainfall. The longer duration rainfall covers a wider area. Short time rainfalls normally cover small areas. Rainfall rarely occurs uniformly over a large area; variations in intensity and total depth of fall occur from the centers to the peripheries of storms [1]. The further away we are from the rainfall centre, the less rainfall we observe. Knowing the parameters of rainfall is very important for engineers who design water structures such as transportation or storage constructions. Rainfall information is essential for estimations and calculations of design flows. Generally this information is summarized in tables or depicted as graphs indicating the rainfall depth in a specific area for a specific duration. Using this information, maximum rainfall depth in each area and each duration can be obtained. The purpose of preparing DAD curves is to determine maximum rainfall depth in part or all of drainage basin in different duration rainfall. Rainfall recording stations record the amount of point rainfall and this point may or may not be the centre of rainfall. Therefore the maximum rainfall is often not recorded by the stations. Design rainfall values are generally expressed in the form of point rainfall values which is the rainfall depth at a location. In order to obtain areal average values for an area, hydrologists and engineers require techniques whereby point rainfall amounts can be transformed to average rainfall amounts over a specified area [2]. For this reason DAD curves are prepared in various time durations [3]. This research aims to find the centre of various rainfalls and to determine the maximum rainfall for different time durations by analyzing the rainfall depth in different areas of the Kurdistan Province, Iran. The results will enable the estimation of the average amount of maximum rainfall for each area in the region, especially where there is not a rainfall recording station in the area. The US Weather Bureau (1985) has prepared DAD curves for duration of 0.5-24 hrs, using rain gauge station networks. It has been shown that the amount of rainfall decreases by increasing the area. Aghighi [4] made the analysis of DAD curves in Jajroud-Tehran-Karaj region and concluded that most rainfalls occur during the first three days. Ahmadi [5] performed the same analysis in Kermanshah Province. Hashemi [6] determined the DAD curves for

Corresponding Author: Shirko Ebrahimi Mohammadi, Faculty of Natural Resources, Kurdistan University, Kurdistan, Iran

Semnan Province through selecting thirteen extensive rainfalls and concluded that by increasing the area in a specific rainfall, the depth of rainfall decreases. Solaimani *et al.* [7] prepared the DAD curves of rainfalls in a semi-arid and arid region (Sirjan Kafeh Namak) using geostatistical method and showed that the ratio of the amount of rainfall at the centre over the amount of rainfall at an area of 20000 km² is 1.98, 1.74 and 1.48 for durations of 1-, 2- and 3-days, respectively. Agharazi *et al.* [8] prepared the DAD curves for Markazi Province and concluded that there is no significant difference between time durations of 3, 6 and 12 hours in small areas, whereas in large areas this event is observed. Clark *et al*. [9] based on depth-Area-Duration technique from probable maximum precipitation analysis, replaced depth with measure of drought severity S=(1-SP/t), where S=severity, SP = total percentile (soil moisture or runoff), t = duration, analyzed Severity-Area-Duration of 20^{th} century drought in the conterminous united States. Kingpaiboon S.and Netwong T. [10] evaluated PMP from heavy storm data from 1972 to 2000, then used GIS to correlate and present the results and to establish the depth-area-duration relationship.

Geographic and climate features of the studied area: This study uses meteorological stations from the Kurdistan province in Iran. Large parts of the Ghezel Ozan, Zarineh Rood, Karkheh, Small Zab and Sirvan drainage basins are located in this province which is situated in the west of Iran, in border with Iraq, between 34° 44′ and 36° 30′ latitudes and 45° 31′ and 45° 16′ longitudes from the Greenwich meridian. The area of this province is roughly 28,235 Km^2. The height of the highest and lowest stations from the sea level is 1,142 m (Zarineh) and 1,120 m (Palangan), repectively. The height of the region varies from a maximum of 3,390 m (Shaho mountain) to a minimum of 800 m (Sirvan river). From a climate point of view the studied area is divided by the Amberjeh system into four areas of high altitudes, semi humid-cold, semi dry-cold and dry-cold areas [11].

MATERIALS AND METHODS

Quantification of topographic maps: The first step of this study was to prepare a topographic map of the region with a scale of 1:250,000. The Kurdistan province is mapped into seven map sheets of 1:250,000 including Shahin Dej, Mahabad, Kabudar Ahang, Sanandaj, Baneh, Hamedan and Kermanshah. The maps were digitized after preparation.

Investigation of stations and selection of common observation period: After investigating the network of rainfall gauge stations in the studied area it was found that, due to missing and unreliable data, it was not possible to use the data from all the stations. Therefore 62 stations were selected among all. It was found that the stations of the Ministry of Energy were reasonably dispersed and had data from more years compared to the newly established stations. For this reason it was decided to use the data from the stations of the Ministry of Energy (only those areas located within the Kurdistan province). After specification of the final rainfall, the data from other stations in the neighborhood provinces were used. The data from the stations of the Ministry of Energy were plotted as bar graphs and those of a 26-year period 1975-2001 for which the data of all the stations were available was chosen. The data (longitude, latitude and elevation) of this period were recorded and the maximum rainfall events were extracted for the time durations of 24, 48, 72 and 96 hrs. For all the studied stations in the above-mentioned 26-year period, all one-day to four-day rainfalls with their termination date were recorded. 170 one-day (24 hours) rainfalls, 140 two-day (48 hours) rainfalls, 72 three-day (72 hours) rainfalls and 31 four-day (96 hours) rainfalls were found from the data base. Figure 1 shows a topographic map of the studied area along with its surrounding and the distribution of studied rainfall stations. The distance of the contour lines on this map is 100 m and it has a scale 1:250,000.

Reducing the number of rainfalls and selection of ultimate rainfalls of the area: In this step, it was necessary to select the extensive rainfalls among others. Extensive rainfalls are those rainfalls that are maximum in terms of scale and are in the majority of the stations. Some rainfalls should be excluded from the analysis despite being major rainfalls in some of the stations for reasons such as malfunction of the rainfall gauge station, human mistakes or loss of data. It might be possible to estimate the missing data, but in this kind of research, retrieval and estimation of missing data is not recomended. Ultimately in this study 19 rainfalls were selected and used to prepare the DAD curves. They include five rainfalls of 24 hours, four rainfalls of 48 hours, six rainfalls of 72 hours and four rainfalls of 96 hours. After this step, the data of the final rainfalls in their occurrence dates were extracted from the database of the Meteorology Organization. The data of the neighbourhood stations for the ultimate rainfalls were also extracted in this step.

Drawing of isohyetal lines: It was found in this study that isohyetal lines of the Kurdistan province prepared using the information of rainfall gauge stations and correlations between these findings and elevations in the region were not correct. Therefore by

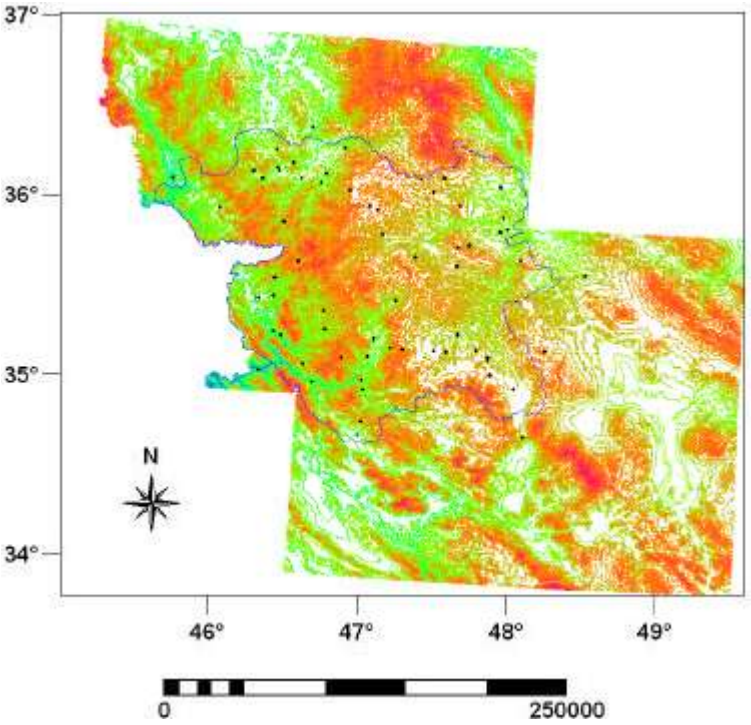

Fig. 1: The topographic map of the studied are and the distribution of studied rainfall stations

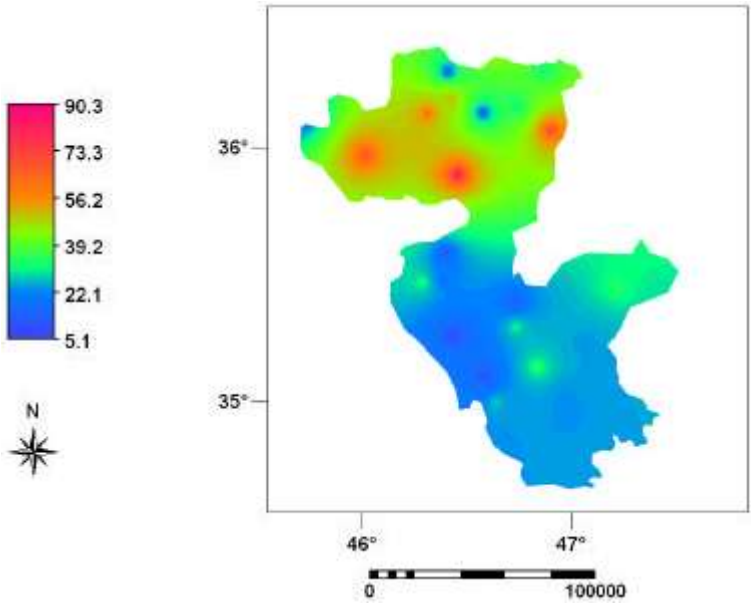

Fig. 2: Isohyetal map of the 24 hour rainfall on 2/11/1993 in the western section of the province

using interpolation methods and by comparing them with one another, the method of 'Moving Average' was used to draw the isohyetal lines.

Stein, A. and J.W White [12] compared interpolation techniques and concluded that Moving Average is the best for quick interpolation from sparse data on regular grid or irregularly spaced samples. The calculations were performed using the software Ilwis and Arcview. In the first step the Kurdistan province was divided into two sections of eastern and western, based on the major crests of Zagros mountain chain. The isohyetal lines were then drawn in each section and isohyetal maps were prepared for all studied rainfalls.

Table 1: Calculations of the 24-hours rainfall of 2/11/1993

Limit of isohyetal lines	Average of isohyetal (mm)	Area /Km^2	Cumulative area /Km^2	Volume of the rainfall mm Km^2	Volume of the cumulative rainfall /mmKm^2	Average of maximum rainfall mm
90-100	95	0.02	0.02	1.90	1.90	95.00
80-90	85	3.88	3.90	329.80	331.70	85.05
70-80	75	21.10	25.00	1582.50	1914.20	76.56
60-70	65	149.66	174.66	9727.90	11642.10	66.65
50-60	55	1184.18	1358.84	65129.90	76772.00	56.49
40-50	45	3175.47	4534.31	142896.15	219668.15	48.44
30-40	35	3221.91	7756.22	112766.85	332435.00	42.86
20-30	25	10676.70	18432.92	266917.50	599352.50	32.51
10-20	15	9731.51	28164.43	145972.65	745325.10	26.46
0-10	5	73.57	28238.00	367.85	745693.00	26.40

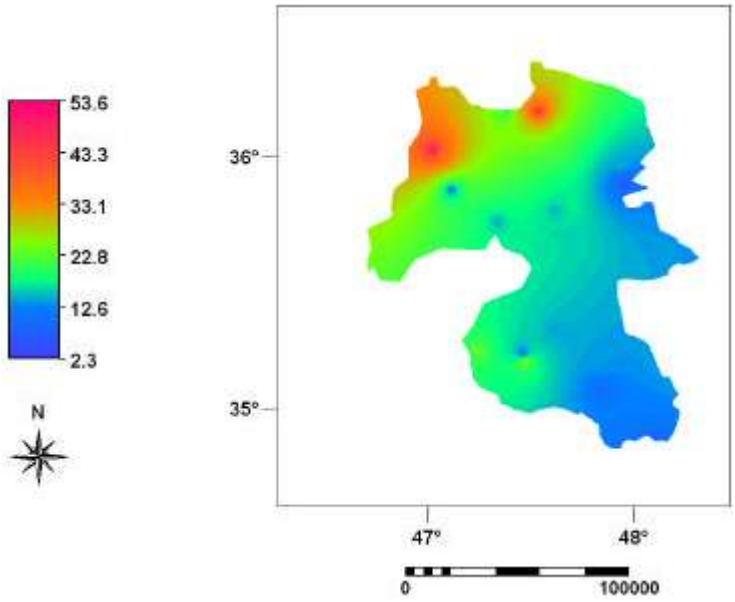

Fig. 3: Isohyetal map of the 24 hours rainfall on 2/11/1993 in the eastern section of the province

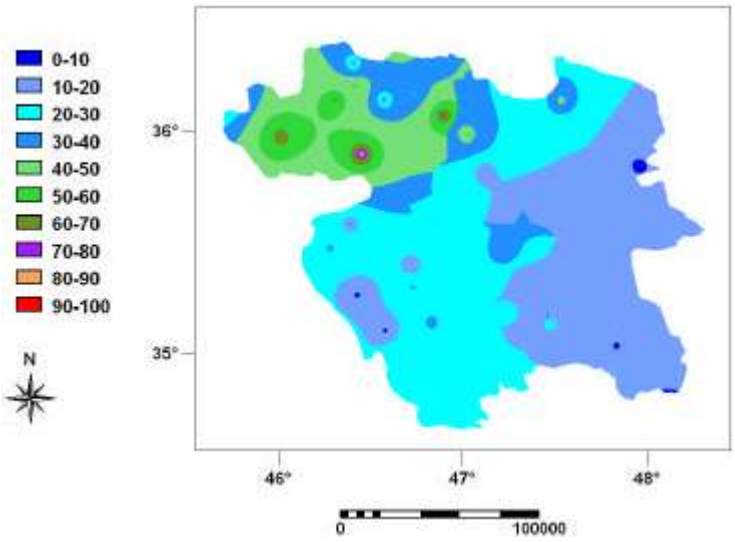

Fig. 4: Isohyetal map of the 24 hours rainfall on 2/211/1993 in Kurdistan province

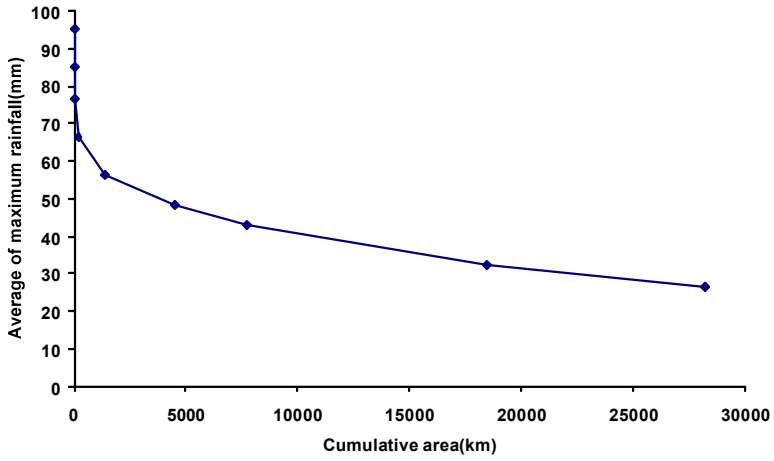

Fig. 5: DAD curve of the 24-hours rainfall of 2/11/1993

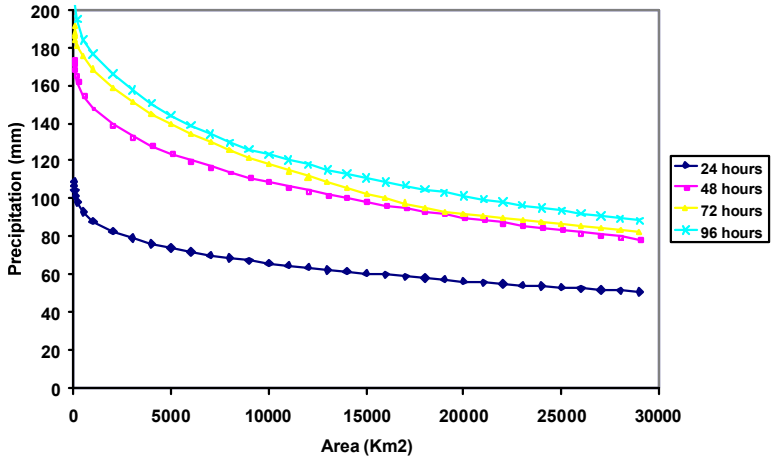

Fig. 6: Final DAD curves of Kurdistan Province

Figure 2 shows the isohyetal map of 24 hours rainfalls on 2/11/1993 in the western section of the Kurdistan province. Figure 3 shows the isohyetal map of the same rainfall in the eastern section of the province and finally Fig. 4 shows the isohyetal map of this rainfall in the entire province. In these maps the distance of the isohyetal maps are 10 mm and they have a scale 1:250,000.

Initial DAD curves: In this step for each rainfall with durations of 24-, 48-, 72- and 96-hour, calculations such as those given in Table 1 were performed and then the initial DAD curves were plotted (it is called initial because in later steps these curves should be combined). To plot these curves the data of the column 'cumulative area' were shown on the X axis and those of the column 'average of maximum rainfall' on the Y axis. Table 1 shows the calculations for the 24-hours rainfall on 2/11/1993 and Fig. 5 depicts the initial DAD curve for this rainfall.

RESULTS AND DISCUSSION

Combining DAD curves with identical time duration and preparation of final DAD curves: The DAD curves for different rainfalls with identical time duration were combined in this step. Previous steps were performed for different rainfalls in the four time durations and a DAD curve was determined for each rainfall. Since the maximum value of the rainfall is needed in this case, for each area (X axis), the corresponding amount of the rainfall (Y axis) with the same duration can be inferred from the initial DAD curves. For example if five curves of 24-hours rainfall are to be combined, the corresponding rainfall (Y) of each particular area (X) needs to be found and then for each area, the maximum rainfall should be selected. This amount of the rainfall is the required value for preparing the final DAD curve for 24 hours time duration (Table 2). This process should be repeated for the four 48-hours rainfalls initial DAD curves, the six

Table 2: The amount of 24 hours rainfall in mm for different areas

Area/Km^2	2/11/1993	23/11/1994	13/4/1996	17/3/1997	18/3/1997	Maximum rainfall
10	81.30	46.20	109.20	95.72	72.70	109.20
20	78.80	45.99	107.27	95.19	70.22	107.27
50	75.05	45.58	104.20	94.18	66.65	104.20
100	71.84	45.13	101.42	93.08	63.72	101.42
200	68.20	44.49	98.15	91.58	60.58	98.15
500	62.78	43.23	92.95	88.73	56.12	92.95
1000	58.14	41.83	88.23	85.65	52.51	88.23
2000	52.98	39.90	82.68	81.48	48.69	82.68
3000	49.70	38.45	79.01	78.38	46.37	79.01
4000	47.25	37.24	76.19	75.84	44.69	76.19
5000	45.28	36.19	73.87	73.65	43.36	73.87
6000	43.62	35.26	71.88	71.69	42.26	71.88
7000	42.20	34.41	70.14	69.92	41.32	70.14
8000	40.90	33.63	68.58	68.29	40.50	68.58
9000	39.76	32.90	67.16	66.78	39.77	67.16
10000	38.72	32.21	65.85	65.37	39.12	65.85
11000	37.77	31.57	64.65	64.04	38.52	64.65
12000	36.89	30.96	63.52	62.77	37.97	63.52
13000	36.07	30.38	62.47	61.57	37.47	62.47
14000	35.30	29.82	61.48	60.42	37.00	61.48
15000	34.58	29.29	60.54	59.33	36.56	60.54
16000	33.89	28.78	59.65	58.27	36.15	59.65
17000	33.25	28.29	58.80	57.25	35.76	58.80
18000	32.63	27.82	57.99	56.27	35.39	57.98
19000	32.05	27.36	57.21	55.33	35.04	57.21
20000	31.49	26.91	56.46	54.41	34.71	56.46
21000	30.95	26.48	55.74	53.52	34.40	55.74
22000	30.44	26.06	55.05	52.66	34.09	55.05
23000	29.94	25.66	54.38	51.82	33.81	54.38
24000	29.46	25.26	53.73	51.00	33.53	53.73
25000	29.00	24.88	53.10	50.20	33.26	53.10
26000	28.56	24.50	52.49	49.43	33.01	52.50
27000	28.13	24.13	51.90	48.67	32.76	51.90
28000	27.71	23.77	51.33	47.93	32.52	51.33
29000	27.31	23.43	50.77	47.20	32.29	50.77

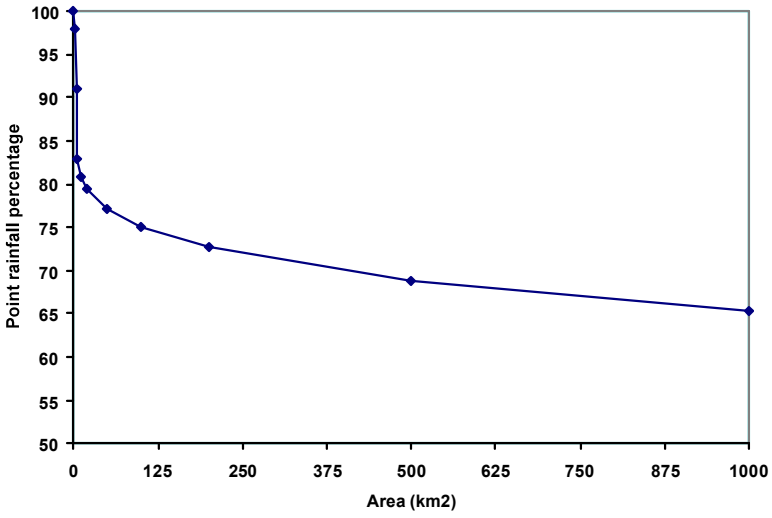

Fig. 7: Plot for the conversion of the point rainfall to the average rainfall of the Kurdistan province for 24 hours rainfalls duration

Table 3: The maximum rainfall for different areas and time durations

Area/Km^2	24-hours	48-hours	72-hours	96-hours
10	109.20	173.50	191.70	217.07
20	107.27	171.78	187.74	213.39
50	104.20	168.74	185.79	207.36
100	101.42	165.66	183.97	201.72
200	98.15	161.73	181.23	194.97
500	92.95	154.80	175.45	183.95
1000	88.23	147.86	168.63	176.55
2000	82.68	139.07	158.76	166.15
3000	79.01	132.88	151.14	157.60
4000	76.19	127.96	144.76	150.39
5000	73.87	123.81	139.20	144.20
6000	71.88	120.19	134.22	138.80
7000	70.14	116.95	129.70	134.04
8000	68.58	114.02	125.55	129.80
9000	67.16	111.33	121.70	126.25
10000	65.85	108.83	118.10	123.25
11000	64.65	106.51	114.72	120.48
12000	63.52	104.32	111.53	117.89
13000	62.47	102.25	108.51	115.45
14000	61.48	100.30	105.63	113.16
15000	60.54	98.43	102.89	110.98
16000	59.65	96.65	100.27	108.91
17000	58.80	94.95	97.76	106.94
18000	57.98	93.32	95.35	105.05
19000	57.21	91.74	93.42	103.25
20000	56.46	90.23	92.17	101.51
21000	55.74	88.76	90.98	99.84
22000	55.05	87.35	89.83	98.22
23000	54.38	85.98	88.73	96.66
24000	53.73	84.65	87.66	95.16
25000	53.10	83.36	86.63	93.69
26000	52.50	82.10	85.64	92.28
27000	51.90	80.88	84.68	90.90
28000	51.33	79.69	83.75	89.56
29000	50.77	78.53	82.85	88.26

72-hours rainfalls initial DAD curves and the four 96-hours rainfalls initial DAD curves. Then to draw the final DAD curves, the values of the maximum rainfalls are plotted against their corresponding area (area and the maximum amount of rainfalls being the X and Y axes, respectively).

Table 3 shows the maximum rainfall in different time duration for different areas and Fig. 6 shows the final DAD curves. If the amount of rainfall is shown as percentage, DAD curves can be presented as plots for converting the point rainfall to the average rainfall of the region. Figure 7 shows the conversion graph of the point rainfall into the average rainfall of the Kurdistan province for 24 hours rainfalls.

Using this information it can be concluded that:

- The depth-area-duration relationship for 1 to 4 days duration of the rainfalls in the studied area is shown in Fig. 6. The point rainfall can be converted to an average rainfall for an area of up to 29,000 Km². The curves can be used to determine average rainfall of the province for research and designing purposes.
- The ratio of point rainfall to average rainfall in an area of 29,000 Km² in durations of 1 to 4 days are 2.15, 2.2, 2.32 and 2.46 respectively. This means that by increasing the duration from 1 day to 4 days, this ratio increases.
- The amount of 2-, 3- and 4-days rainfalls are closed to each other, but there is a big gap between the 1-day and 2-day duration rainfalls.
- There is no significant difference between the time durations 2-, 3- and 4-day in large areas. However, significant differences are seen in small areas. For example in an area of 29,000 Km² and in the time durations 2-, 3- and 4-day, the amount of precipitation are 78.53, 82.85 and 88.26, respectively.
- By increasing the area, the amounts of rainfall for 1-day and 2-day durations are closed to one another. For example in an area of 1000 Km^2 the difference is 60 mm and in an area of 29,000 Km^2 it is 28 mm.
- The difference between 3- and 4-day rainfalls remains constant around 5 mm for up to an area of 10,000 Km^2. From this to 19,000 Km^2 the difference increases. For example at 19,000 Km^2 this difference reaches 10 mm. However the difference decreases from 19,000 to 29,000 Km^2 until it becomes 5 mm again.
- Rainfalls with duration of two or more days are indicative of stable climatic systems that always produce more rainfall. In Kurdistan province there are 72- and 96-hr rainfalls and a considerable portion of the rainfalls are discharged in the first 48 hours. 24-hours rainfalls are more abundant, albeit with less amounts of rainfall. According to the reports of the Iranian Meteorology Organization, 15-days rainfalls have also been seen in the Kurdistan province [15].
- The relationship between rainfall and elevation is not statistically significant, so it can not be used for calculation of the average rainfall.
- Examination of isohyetal maps indicates that the amount of rainfall in the Kurdistan province decreases significantly from west to east and this factor has caused several distinct regions in terms of climate.

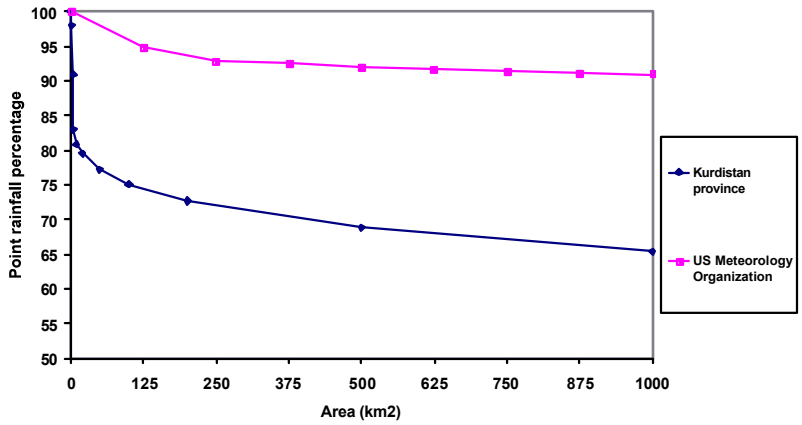

Fig. 8: Comparison of 24-hour point rainfall conversion curves of the US and Kurdistan province

In addition using Geographic Information System (GIS) it is possible to show isohyets maps of the entire province. These data can be applied by experts for planning and making decision about developing water resources.

Comparison of the curves of point rainfall conversion to average rainfall for 24-hour time duration of the US and Kurdistan province using Hershfield method: Probable maximum precipitation (PMP) can be estimated by Hershfield Method [13]. In this method, the maximum rainfall for a given time duration (e.g. 6, 12 or 24 hrs) in each year is selected and the mean (P) and standard deviation (S.D.) are calculated. After extracting the value of the coefficient K from the graph, the amount of PMP is calculated by using the following equation.

$$PMP = P + K \times S.D. \quad (1)$$

It is recommended that the amount of PMP multiplied by a reducer coefficient for basins with an area of more than 25 Km^2. For this purpose we used the curves for conversion of point rainfall to average rainfall [14]. The US Weather Bureau has prepared such curves for 1.5, 3, 6, 12 and 24 hours durations. In Fig. 8 we compare the 24-hour curve of the US Weather Bureau with that of the Kurdistan province. It can be seen that in the plot of the US Weather Bureau, the amount of rainfall is reduced by 5% by moving away from the centre of the rainfall to an area of 125 Km^2. From this area up to 1000 Km^2, the amount of rainfall has been reduced by 4%. It means that there is 9% decrease from the centre of the rainfall to an area of 1000 Km^2 around it. On the other hand in the Kurdistan curve the amount of rainfall has been reduced by 35% by moving away from the centre of the rainfall to an are of 1000 Km^2 around it. This implies that we cannot generalize the DAD curves of a given region and use it for other places. This is because the DAD curves are determined based on the real rainfall data of each area. Also, this shows that the rainfall in Kurdistan province has complex characteristics and therefore, we recommend that the DAD curves in each sub-basin of the Kurdistan province to be used to estimate the PMP using Hershfield method.

REFERENCES

1. Raghunath, H.M., 2006. Hydrology Principles, Analysis and Design, Rivised Second Edition, New Age International Publication, pp: 33.
2. Gill, T.D., 2005. Transformation of point rainfall to areal rainfall estimating areal reduction factors, using radar DAT, Master of science thesis, Texas A&M University.
3. World Meteorological Organization (WMO), 1961. Manual of Depth-Area-Duration Analysis of Storm Precipitation. No. 237.
4. Aqhiqhi, M., 1995. Analysis of Depth-Area-Duration curves of Karaj-Tehran-Jajrood region. Maters thesis, Tehran University, Iran.
5. Ahmadi *et al*., 2003. Depth-Area-Duration (DAD) relationships in Kermanshah province, Final report of research project. Research Center of Soil Conservation and Watershed Management.
6. Hashemi *et al*., 2001. Analysis of Depth-Area-Duration (DAD) relationships in Semnan province, Final report of research project, Research center of soil conservation and watershed management.
7. Solaimani, K. and A. Abkar, 2006. Analysis of depth-area-duration curves of Rainfall in semi-arid and arid region Using Geostatistical methods (Case Study: Sirjan Kafeh Namak Watershed). Pakistan Journal of Biological Sciences, 9 (9): 1764-1768.

8. Agharazi, H. and A. Telvari, 2007. Preparation of Depth-area-duration curves as important factors for flood estimation in Basins. Pajouhesh and Sazandegi Journal, N74: 94-100.
9. Clark, E.A. *et al.,* 2004. Severity-area-duration analysis of 20th century drought in the conterminous United Stated. NOAA 29th Annual Climate Diagnostics and Prediction Workshop, Madison, Wisconsin.
10. Kingpaiboon S.and Netwong T., August 9-13, 2004. Relation of Probable Maximum Precipitation Depth-Area-Duration Using GIS, 24th Annual ESRI International User Conference.
11. Hamoon Study Group, 1996. Weather and climatology, Comprehensive study of social and economical improvement of Kurdistan province, Iran.
12. Stein, A. and J.W White, Interpolation Techniques for Climate Variables. NRG-GIS series 99-01, Mexico.D.F.CIMMYT.
13. Hershfiled, D.M., 1961. Estimating the Probable Maximum Precipitation. Journal of Hydraulics Division ASCE Proceedings, pp: 99-116.
14. Mahdavi, M., 1999. Applied hydrology, Tehran University Press, Tehran.
15. Nivar engineering company, 1997. project technical report of wind, rainfall, temperature, sub-zero weather, Kurdistan province weather patterns due to weather map preparation, Kurdistan province Weather Bureau.