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Development of maximum depth-area-duration curve for Udaipur district using Remote Sensing and GIS platform

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■ **ABSTRACT :** 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. Rainfall depth is decreases from center of the eye of the storm to its peripheries. Knowing the magnitude of this centric point rainfall is very important for water resource or water conservation engineers. Using the temporal and spatial information of the storm, maximum rainfall depth in each area and corresponding duration (1 day, consecutive 2, 3 and 4 days) can be obtained. Daily rainfall data and locations from 17 raingauge covering entire Udaipur district for the period of 41 years is collected. The isohyets maps of one to four day duration were drawn for dominant and severe most storms using Arcmap 10.3. Calculating area between two isohyet lines the average rainfall of each area (covering two isohyets) can be calculated. A curve is drawn between maximum depth of rainfall and coverage area for various durations. The curves showed that the ratio of the amount of rainfall at the center to the area of 11724 km^2 is 2.13, 1.51, 1.45 and 1.47 for the durations of 1, 2, 3 and 4 days, respectively. Areal reduction factor s are 0.687, 0.785 and 0.803 for 01, 02, 03 and 04 day, respectively.

■ **KEY WORDS :** Arcmap 10.3, Isohyets, IDW, Reclassifying

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In order to combine information of areal precipitation depths over a range of area sizes and varying durations, a technique known as a depth-area-duration (DAD) analysis is preformed. DAD results can be presented in tabular as well as graphical form (Subramnaya, 2017). The characteristics of the storm of given duration over the areas and corresponding depths of the rainfall are reflected in a plot of depths of the rainfall against areas on which the depths occurs for a given storm of different durations. In most of the design applications the maximum depth of rainfall that is likely to occur over a given area for a given duration is required. Wherever possible, the frequency of that rainfall should also be known. For example, the knowledge of maximum depth of rainfall occurring on areas of various sizes for storms of different duration is of interest in many hydrological design problems such as the design of bridges and culverts, irrigation structures etc. The storm usually has a centre, where the rainfall Po is maximum which is always larger than the average depth of rainfall P for the area as a whole. Generally, the difference between these two values (Po – P), increases with increase in area and decreases with increase in the duration. To develop quantitative relationship between Po and P, a number of storms with data obtained from raingauges have to be analyzed.

Chouhan and Mehra (1997) collected 17 years daily rainfall data from 11 raingauge station of Udaipur for the development of DAD relationship. The moving average method was used to generate isohyets. But this methodology becomes obsolete and need to be revised. Kingpaiboon and Netwong (2001) evaluated PMP from heavy storm data from 1972 to 2000, to establish the depth-area-duration relationship. Akbar *et al*. (2006) collected data and information related to 59 rainfall gauging stations in the Sirjan Kafeh Namak Watershed Iran. Two methods of Geostatistical Krigging and inverse distance with powers of 1 to 3, were evaluated to draw the isohyets maps and determination of the average rainfall. Finally DAD curves have drawn using best fit method. Kim *et al*. (2009) collected 58 monthly precipitation records covering the period 1973–2004 from the Korean network, which is under the Korean Meteorological Administration. Study involved depth–area–duration (DAD) analysis for characterizing an extreme precipitation event which provides a basis for analyzing drought events when storm depth, is replaced by an appropriate measure of drought severity (SAD Curves).

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 Udaipur district. 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.

■ METHODOLOGY

Description of study area:

Udaipur district is situated between 23^0 40’ and 25^0 30’ North latitude and 73^0 0’ and 74^0 35’ East longitude. It is located in the south eastern part of Rajasthan and lies in Aravali ranges. The district is having 11,724 Km^2 area surrounded by hills (Google map, cited on 25 May, 2019).

Collection of data:

Daily rainfall data and locations from 17 raingauge covering entire Udaipur district for the period of 41 (1973-2014) years is collected from WRD Rajasthan website.

Step followed:

– After collection of daily rainfall data, due to the high volume of data and information, the selection of dominant and maximum daily rainfall from raw data was difficult to carry out manually. The daily rainfall data were incorporated into EXCEL software and an information bank of the region’s stations were prepared. The information bank can be used easily. By using EXCEL instructions, the dominant and maximum daily rainfall for durations of one to four-days (for each duration 1 storms for a total of 4 storms) was selected.

– One of the main steps in preparation of DAD curves is drawing isohyet maps. Several methods exist for drawing such maps such as the rainfall gradient method and complicated geostatistical methods like IDW. Although the IDW method is fast and simple.IDW command of Arcmap 10.3 requires a point file of rainguage station having depth of rainfall as a Z-coordinate. For this station with latitude and longitude were added to make the point file (Click File > Add Data > Add XY Data) Then this point file is used as an input for IDW analysis.

– In this step the area between each two isohyet lines was specified by using GIS software. The isohyet lines are drawn from higher to lower values. But area between two isohyets using this raster file is little more complicated so first the raster file is reclassified for a suitable interval using reclassifying tool so that whole data is classified in different range. Further this reclass file converted into polygon map (Arctoolbox > Conversion Tools > From Raster > Raster to polygon) for calculating area between isohyets.

– In this step the area between each two isohyet lines was evaluated using attribute data associated with reclass polygon file. The isohyet lines are drawn from higher to lower values. After determination of rainfall volume, the cumulative rainfall is obtained. Then by dividing cumulative rainfall volume by cumulative area, the average rainfall of each area is calculated. As the maximum rainfall is under consideration in the final curves, for different areas on the x-axis, the amount of rainfall is obtained from the y-axis of primary DAD curves. Same methodology was adopted for all durations.

If the maximum average rainfall depth as a function of area is divided by the maximum point rainfall depth the ratio is called the Areal Reduction Factor (ARF), which is used to convert point rainfall extremes into areal estimates. ARF (Ghnshyamdas, 2014).

$$ARF = \frac{\text{Maximum average depth}}{\text{Maximum point depth}}$$

RESULTS AND DISCUSSION

Resultant DAD curve as shown in Fig. 9 clearly indicate that the maximum depth of the rainfall decreases with the area but increases with the duration of rainfall. Same study was done by Chouhan and Mehra (1997) with different methodology, same trend of the curve was found with lesser magnitude of rainfall depth. This time more no. of raingauges were considered with greater precision using Arcgis 10.3. Such study is very essential

Table 1 : Calculation of depth of 01-day rainfall and corresponding area in each Isohyet interval

Sr. No.	Isohyet interval	Average rainfall (mm)	Incremental area (ha)	Total area (ha)	Incremental vol. (ha.mm)	Total vol. (ha.mm)	Average depth (mm)
1.	260-280	270	2285.00	2285.00	616950	616950	270.00
2.	240-260	250	3410.00	5695.00	852500	1469450	258.02
3.	220-240	230	5972.00	11667.00	1373560	2843010	243.68
4.	200-220	210	12560.00	24227.00	2637600	5480610	226.22
5.	180-200	190	43603.00	67830.00	8284570	13765180	202.94
6.	160-180	170	166084.00	233914.00	28234280	41999460	179.55
7.	140-160	150	162553.00	396467.00	24382950	66382410	167.43
8.	120-140	130	222034.00	618501.00	28864420	95246830	154.00
9.	100-120	110	245444.00	863945.00	26998840	12224567	141.50
10.	80-100	90	222758.00	1086703.0	20048220	14229389	130.94
11.	60-80	70	67640.00	1154343.0	4734800	14702869	127.37
12.	40-60	50	17137.00	1171480.0	856850	14788540	126.24

Table 2 : Calculation of depth of 02-day rainfall and corresponding area in each Isohyet interval

Sr. No.	Isohyet interval	Average rainfall (mm)	Incremental area (ha)	Total area (ha)	Incremental vol. (ha.mm)	Total vol. (ha.mm)	Average depth (mm)
1.	360-390	375	2506.40	2506.40	939900.00	939900.00	375.00
2.	330-360	345	14851.81	17358.21	5123874.45	6063774.45	349.33
3.	300-330	315	75035.33	92393.54	23636128.01	29699902.46	321.45
4.	270-300	285	265118.45	357511.99	75558758.05	105258660.51	294.42
5.	240-270	255	280211.64	637723.62	71453966.93	176712627.43	277.10
6.	210-240	225	299451.27	937174.89	67376535.84	244089163.27	260.45
7.	180-210	195	161642.82	1098817.72	31520350.54	275609513.81	250.82
8.	150-180	165	51502.60	1150320.32	8497929.00	284107442.81	246.98
9.	120-150	135	17463.40	1167783.72	2357559.00	286465001.81	245.31
10.	90-120	105	3906.66	1171690.38	410199.30	286875201.11	244.84

Table 3 : Calculation of depth of 03-day rainfall and corresponding area in each Isohyet interval

Sr. No.	Isohyet interval	Average rainfall (mm)	Incremental area (ha)	Total area (ha)	Incremental vol. (ha.mm)	Total vol. (ha.mm)	Average depth (mm)
1.	360-390	375	112.88	112.88	42331.125	42331.125	375.00
2.	330-360	345	17453.66	17566.54	6021512.769	6063843.894	345.19
3.	300-330	315	88732.82	106299.36	27950838.55	34014682.45	319.99
4.	270-300	285	346492.08	452791.44	98750242.57	132764925	293.21
5.	240-270	255	372940.11	825731.55	95099726.8	227864651.8	275.95
6.	210-240	225	262972.20	1088703.74	59168743.88	287033395.7	263.65
7.	180-210	195	60677.89	1149381.63	11832188.84	298865584.5	260.02
8.	150-180	165	17484.60	1166866.23	2884959	301750543.5	258.60
9.	120-150	135	4940.38	1171806.61	666951.3	302417494.8	258.08

for watershed and water resource projects and need to be revised after 1997.

Conclusion:

Depth area duration curves are the representation of combined temporal and spatial variation of rainfall storm in the region. These curves are very helpful and essential to convert average depth of rainfall into maximum point rainfall which is likely to be occurred at or near the center of the storms based on historic data

Table 4 : Calculation of depth of 04-day rainfall and corresponding area in each Isohyet interval

Sr. No.	Isohyet interval	Average rainfall (mm)	Incremental area (ha)	Total area (ha)	Incremental vol. (ha.mm)	Total vol. (ha.mm)	Average depth (mm)
1.	420-440	430	4997.00	4997.00	2148710	2148710	430.00
2.	400-420	410	31959.00	36956.00	13103190	15251900	412.70
3.	380-400	390	36456.00	73412.00	14217840	29469740	401.43
4.	360-380	370	52551.00	125963.00	19443870	48913610	388.32
5.	340-360	350	100543.00	226506.00	35190050	84103660	371.31
6.	320-340	330	158486.00	384992.00	52300380	136404040	354.30
7.	300-320	310	93823.00	478815.00	29085130	165489170	345.62
8.	280-300	290	105599.00	584414.00	30623710	196112880	335.57
9.	260-280	270	168960.00	753374.00	45619200	241732080	320.87
10.	240-260	250	257411.00	1010785.00	64352750	306084830	302.82
11.	220-240	230	102607.00	1113392.00	23599610	329684440	296.11
12.	200-220	210	35637.00	1149029.00	7483770	337168210	293.44
13.	180-200	190	13685.00	1162714.00	2600150	339768360	292.22
14.	160-180	170	8759.00	1171473.00	1489030	341257390	291.31

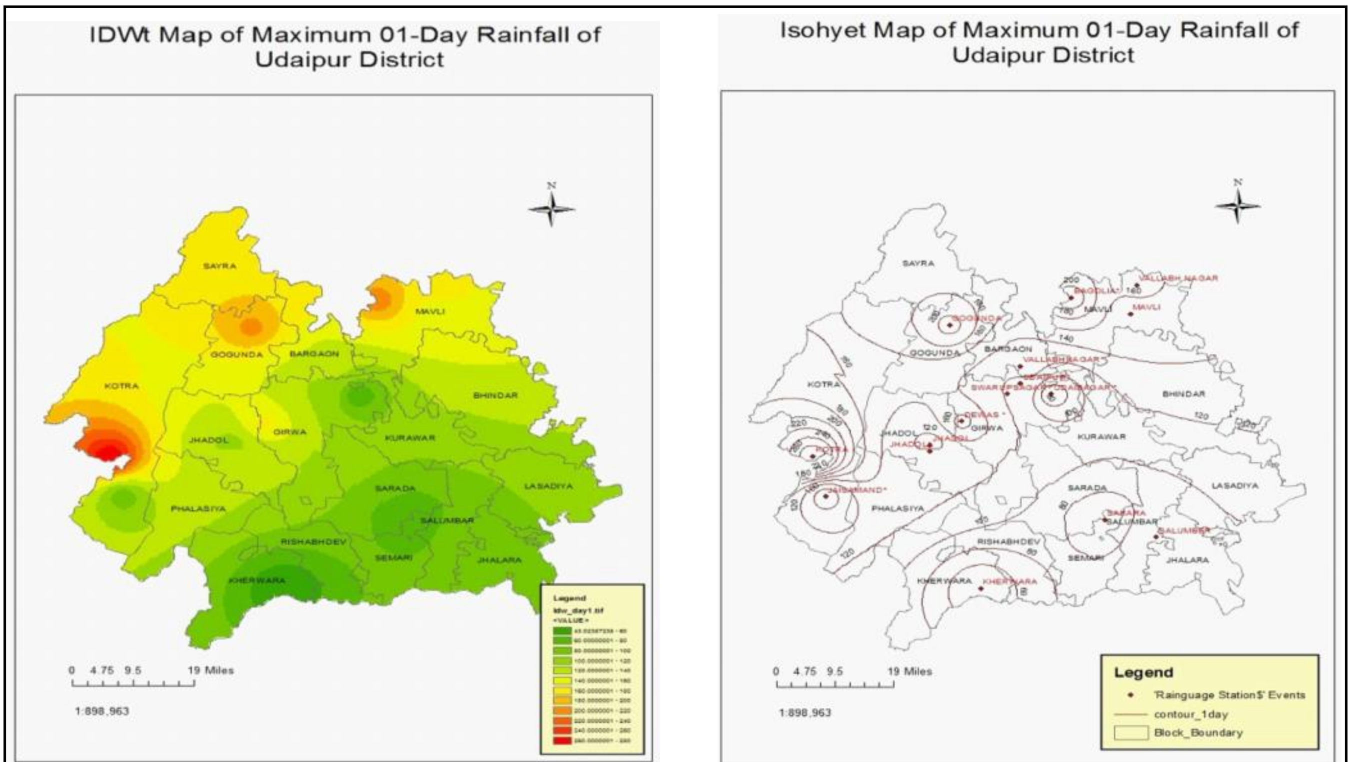


Fig. 1 and 2 : IDW (interpolated) and Isohyetal map of maximum 01-day rainfall

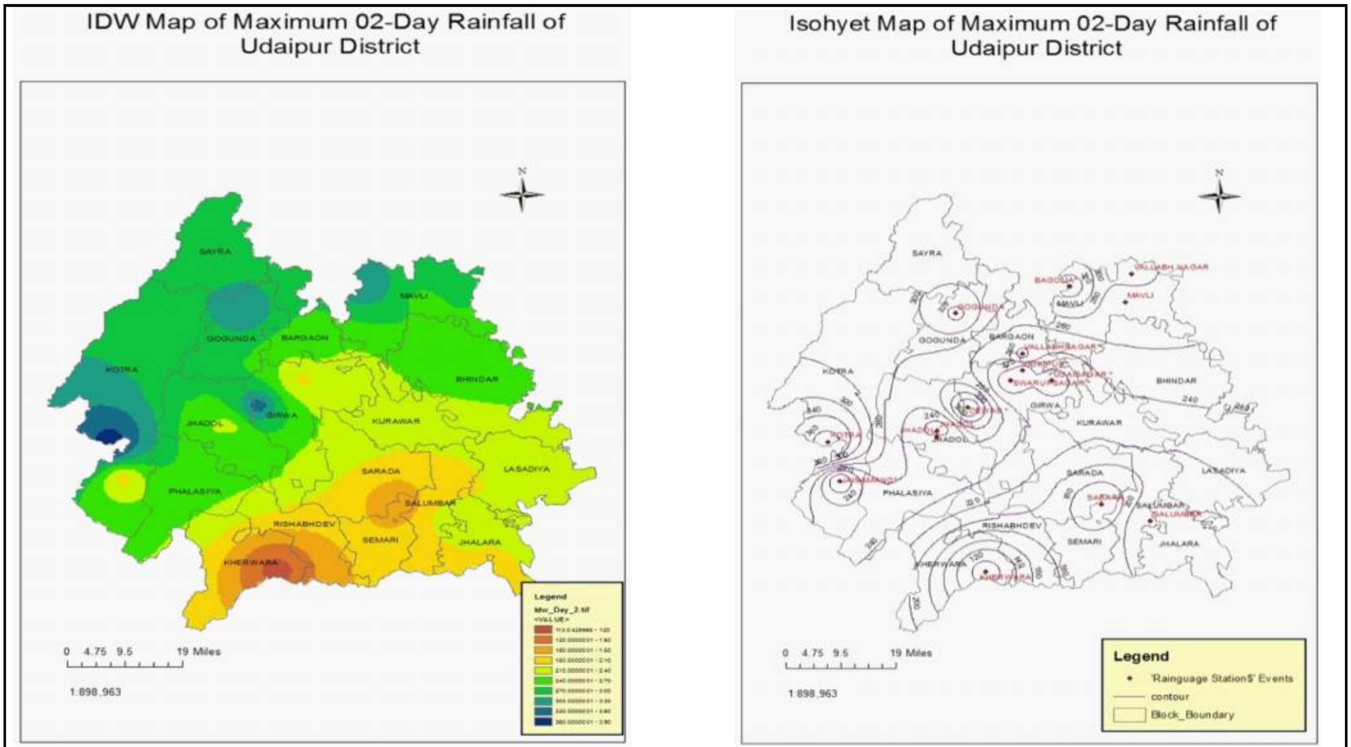


Fig. 3 and 4 : IDW (interpolated) and Isohyetal map of maximum 02-day rainfall

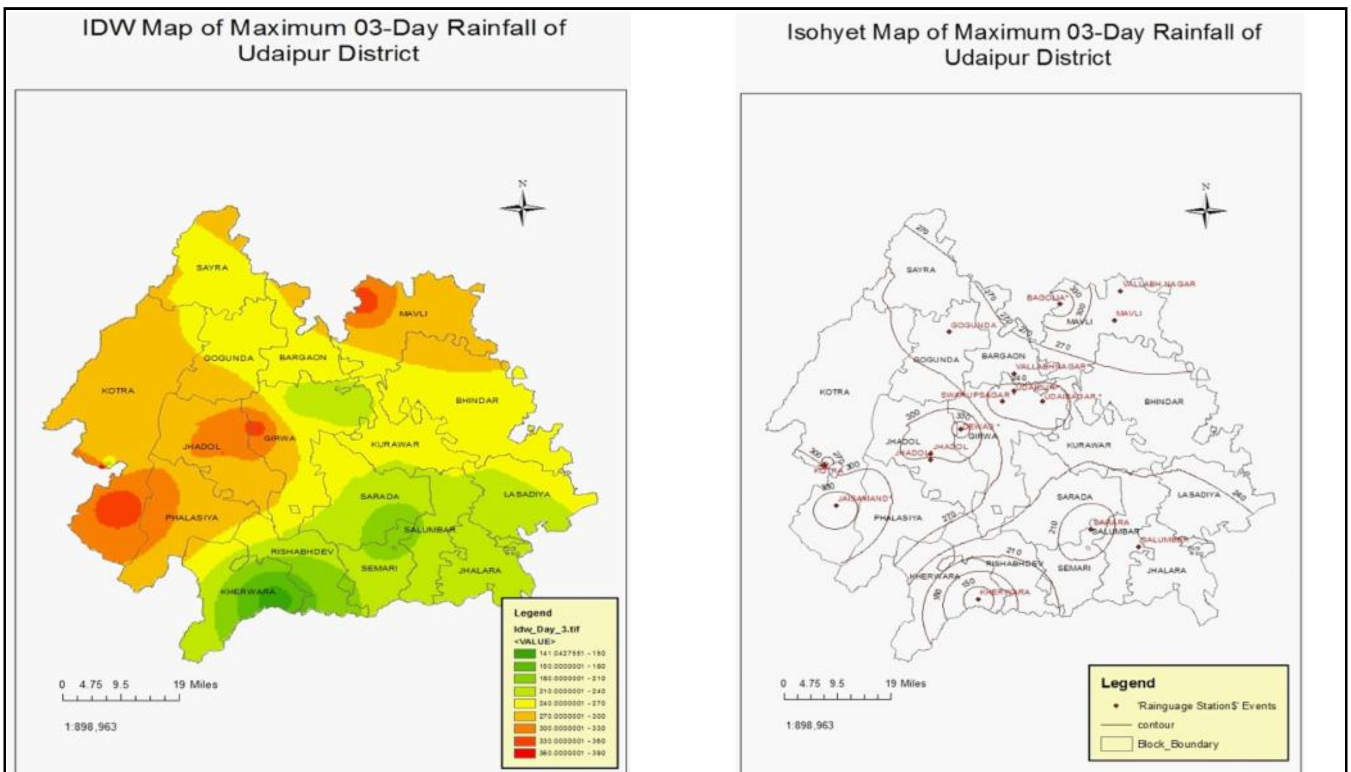
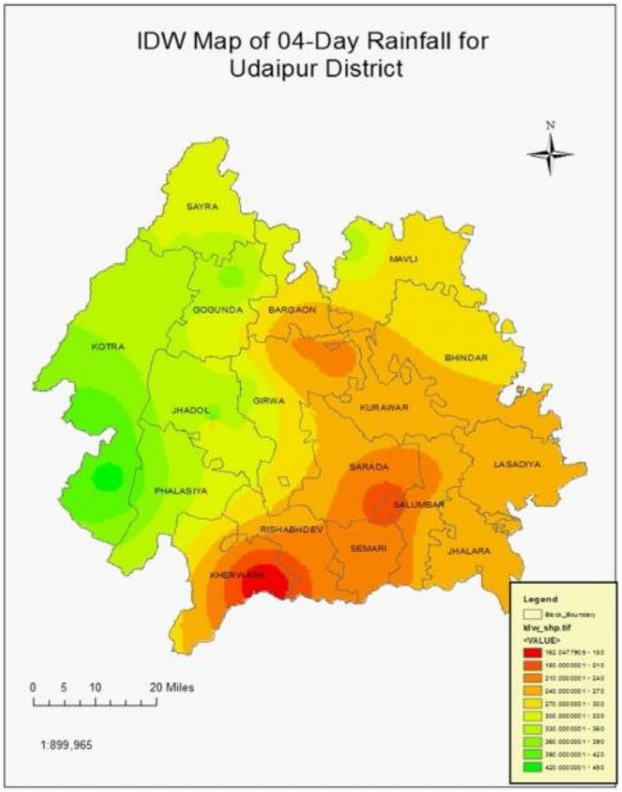


Fig. 5 and 6 : IDW (interpolated) and Isohyetal map of maximum 03-day rainfall



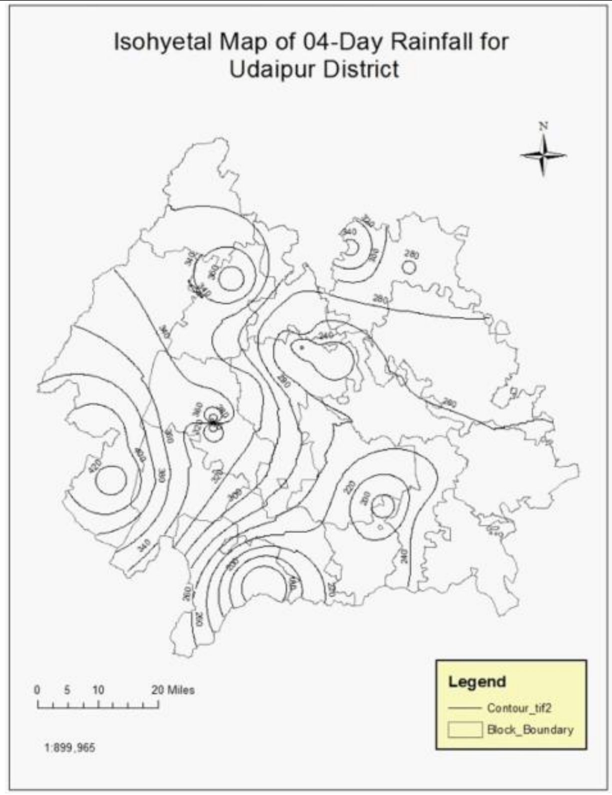


Fig. 7 and 8 : IDW (interpolated) and Isohyetal map of maximum 04-day rainfall

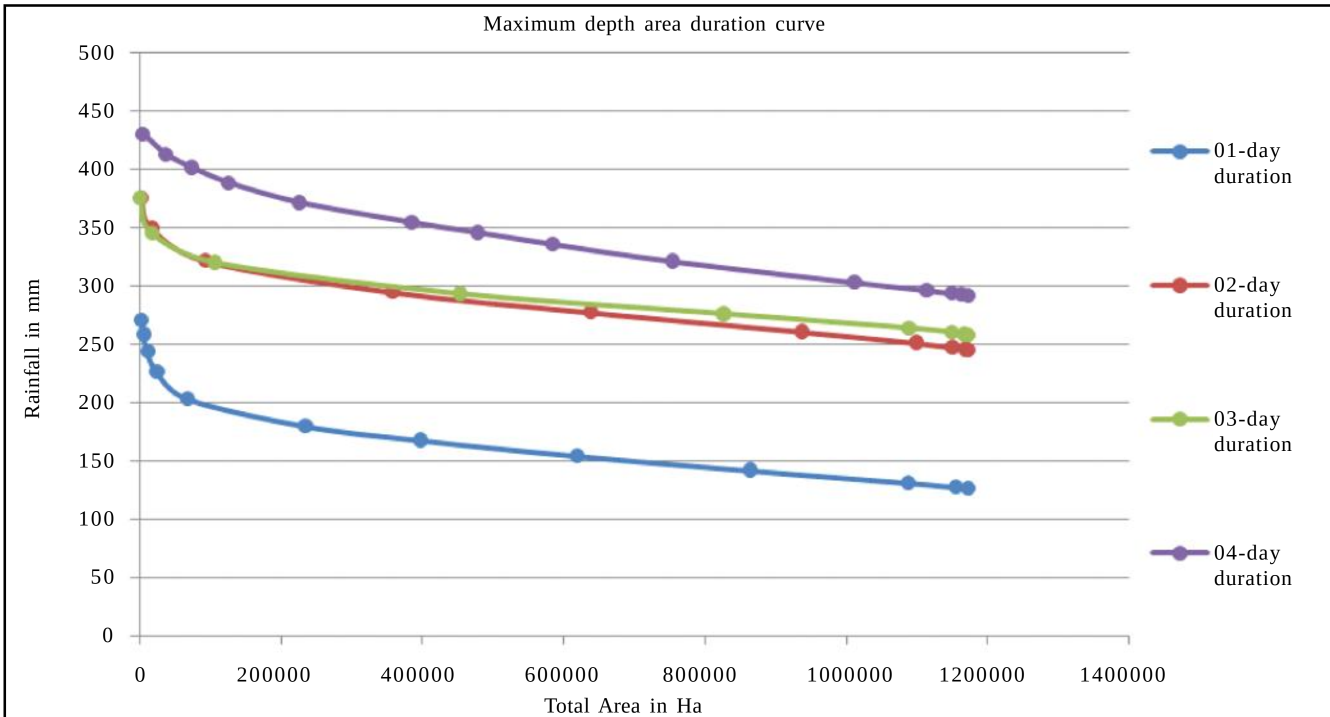


Fig. 9 : Maximum depth-area duration curve for various durations

using ARF's. for developing depth area duration curve, isohyet maps were prepared after collection of data from rain gauge stations installed in Udaipur district. The dominant and severe storms for durations of one to four days were selected. Inverse distance with power 01 to 03 was evaluated to draw isohyet maps in Arcmap 10.3 software. The depth area duration curves were drawn after calculating average depth of rainfall increment with isohyet expansion. The ratio of rainfall at the center to the amount of rainfall at an area of 11724 km^2 is found to be 2.13, 1.51, 1.45 and 1.47 for the durations of 1, 2, 3, and 4 days, respectively. Areal reduction factor is calculated which can be used to convert maximum average depth of rainfall into maximum point rainfall. ARF's are 0.687, 0.764, 0.785 and 0.803 for 01, 02, 03 and 04 day, respectively.

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