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Analysis of Depth Area Duration curve for Baitarani basin and Subarnarekha basin

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ABSTRACT: Storm-specific curves for a drainage basin, known as DAD curves, are one of the most effective tools in flood management. DAD curves show the depth and area covered by rainfall over a certain time period. DAD analysis is commonly used to characterize precipitation extremes and to specify so-called design storms. In the present study, two basins, viz., Subarnarekha Basin and Baitarani Basin have been considered as the study area. For both these basins, watersheds have been delineated using ArcGIS. Then, the storm which occurred during 16th June to 18th June 2008 has been considered for Depth Area Duration (DAD) curve analysis by using Thiessen polygon method.

KEYWORDS: DAD curves, Thiessen Polygon Method, Cumulative maximum precipitation, Maximum rainfall depth.

I. INTRODUCTION

There is a clear link between rainfall depth, duration, and area. Rainfall that lasts longer covers a larger region. The average rainfall is an essential factor in the construction of hydraulic structures in a watershed. Rainfall volume and intensity are also important factors in the construction of hydraulic infrastructure and watershed management. The more exact and scientifically-based the two parameters' predictions are, the more effective the structure's construction will be (Asquith et. al., 2009). Rainfall is a variable that varies in both time and space, and the intensity of a single rainfall will vary from one rainfall event to the next. Furthermore, it is uncommon for a single rainfall to be consistent across the rainy region. It is stronger in certain areas and weaker in others. The center of the rainfall in a watershed is the location receiving the most rainfall. Rainfall drops as you move away from the center. One of the key concerns in the disciplines of hydrology and meteorology is to investigate the declining tendency in the quantity of rainfall from its center. Rain gauge stations display the quantity of rainfall at specific locations within a watershed, and rainfall information is confined to these locations. The quantity of rainfall measured by rain gauge stations cannot be utilized to construct hydraulic systems. This is particularly true in arid and semiarid areas, in which the number of rain gauge stations is scarce and rainfall variability is extreme (Fulton et. al., 1998). The capacity to predict rainfall variations is crucial when designing hydraulic systems. One of the fundamental aspects in the examination of rainfall spatial variation and flood estimates is the analysis of the connection between rainfall depth-area-duration (DAD) curves. Point rainfall (measured in a rain gauge station) is converted to average rainfall over a specified region using these curves. These curves also show the geographical pattern of rainfall variations over a certain time period and area.

Rainfall data is also required for design flow predictions and computations. In most cases, this data is presented in tables or graphs that show the rainfall depth in a certain location over a specific time period. Maximum rainfall depth in each location and duration may be calculated using this data. The goal of creating DAD curves is to identify the maximum rainfall depth in a drainage basin, whether it's a portion or the entire drainage basin, for various rainfall durations.

Part 1 of Technical Paper No. 29 (TP 29) for the Ohio Valley was released by the United States Weather Bureau in 1957. (U.S. Weather Bureau 1957). For the first time, depth-area studies and a set of curves were completed and published there. For storm durations ranging from 30 minutes to 24 hours, and for regions up to 1,024 km², depth-area reduction curves were created. The data was gathered from seven intensive gauging networks in the eastern and central United States. The TP 29 Part 1 study found that storm duration and average area were the two most important factors determining depth-area reduction factors. The curves appeared to be independent of geographic location, time of year, and other characteristics, according to the researchers. Although it was recognized that the data supplied were too short to examine the probable consequences of this, it was tentatively acknowledged that storm magnitude (or return period) was not a component in the depth-area connection.



Frederick et al. (1977a) conducted a prototype research aimed at estimating geographically fixed depth-area reduction curves on the basis of digitized radar returns, noting that digitized radar data presented an essential new data source for defining depth-area curves. Because both the numerator and denominator in the depth-area reduction factor were computed using radar data, errors in the Z-R relationship used for translating radar reflectivity to rainfall rates are in part "split out." The study included a visualization of depth-area curves generated using radar data (presumably for the 100-year return period, but this is not clear). The depth-area curves published in TP 29 and later "official" publications were depicted on the same plot. Because the uncertainties in the curves were not displayed, it is unclear if the differences between the two sets of curves are statistically significant (e.g., by scatters of data points).

For Victoria, Australia, Siriwardena and Weinmann (1996) investigated depth-area connections. Relationships were constructed for recurrence intervals of 2 to 100 years and durations of 1 to 3 days for regions up to 8,000 km². The connections varied slightly depending on where you were in Victoria, and the reduction factors were substantially smaller than those discovered in Australian Rainfall and Runoff (Institution of Engineers of Australia 1987).

For Austin, Dallas, and Houston, Texas, Asquith and Famiglietti (2000) created annual-maxima centred depth-area correlations. As previously stated, the geographical distribution of precipitation coincident with and surrounding a point yearly maximum is considered in this technique to developing depth area connections. In the sense that the recurrence interval linked with the areal rainfall is not stated or known, it is fundamentally distinct from other forms of geographically fixed connections. It is possible to determine the recurrence interval for a single location in a rainfall region. The lack of information of the return duration associated with the regionally averaged rainfall depth may restrict its practical implementation, despite the fact that the technique is fascinating and less computationally intensive than alternatives.

Myers and Zehr (1980) provide a method for developing depth-area curves that emphasises station-pair data. Data from an extensive gauging network in the Chicago metropolitan region was used to create and test the model. The impacts of the return duration on the depth area reduction variables were clearly displayed in the study's figures. Long return period events, in particular, were found to have lower depth-area reduction factors than short return period events for a given storm duration and average area. The changes seemed to be minimal for practical purposes during storm durations of 24 hours or greater.

II. STUDY AREA

The study area includes Baitarani basins and Subarnarekha basin. Baitarani basin has a total catchment area of 10,982 km². The basin is roughly located between 85°10' and 87°03' east longitudes and 20°35' and 22°15' north latitudes. The Subarnarekha basin has a total catchment area of 29,196 km². It is located between the longitudes of 85°8' and 87°32' east and the latitudes of 21°15' and 23°34' north.

III. METHODOLOGY

This section of the paper includes the watershed delineation using ArcGIS software followed by preparation of Depth Area Duration (DAD) curve for Baitarani and Subarnarekha basins.

A. DEPTH AREA DURATION (DAD) CURVES

The goal of creating DAD curves is to establish the maximum rainfall depth in a drainage basin for various rainfall periods. Rainfall recording stations keep track of the quantity of point rainfall, which may or may not represent the center of the storm. As a result, the maximum rainfall is frequently missed by weather stations. In most cases, design rainfall values are given as point rainfall values. Hydrologists and engineers need strategies to convert point rainfall levels to average rainfall amounts across a specific region in order to acquire areal-average values for an area. As a result, DAD curves are created in a variety of time periods. DAD analysis is a technique that determines the maximum rainfalls for various durations across a wide range of locations. Any reasonable technique for predicting average rainfall, such as the Thiessen polygon approach, can be used to create a DAD curve.

B. THIESSEN POLYGON METHOD

The daily precipitation data for the storm that occurred during 16th – 18th June 2008 in Subarnarekha and Baitarani Basin have been collected from Natural calamities, Special Relief, Government of Orissa, Annual Report 2008-09 as shown in Tables 1 and 2 for a total of 5 rain gauge stations and 10 rain gauge stations for Baitarani basin and Subarnarekha basin, respectively.

Table 1. Daily precipitation (mm) data for Baitarani Basin

Rain Gauge Station	16/06/2008	17/06/2008	18/06/2008
Champua	0.2	80.2	160.2
Ghatagaon	23.4	82.8	123.2
Jhumpura	0.0	67.2	173.5
Joshiapur	0.0	172.0	191.2
Karanjia	0.0	106.0	192.0

Table 2. Daily precipitation (mm) data for Subarnarekha Basin

Rain Gauge Station	16/06/2008	17/06/2008	18/06/2008
Bhograi	48.0	185.0	115.0
Fekoghat	125.0	93.4	597.8
Jaleswar	38.0	249.0	288.0
Rajghat	76.4	248.6	280.6
Rairangpur	0.0	0.0	319.0
Balasore	107.4	213.6	132.8
Balimundali	90.4	116.4	145.4
Baripada	111.2	136.0	245.2
Jaypur	119.6	119.8	101.4
NH5, Govindpur	146.2	138.0	94.4

Thiessen polygons were prepared for each basin using rainfall data from different rain gauge stations in ArcGIS and area corresponding to each zone was obtained. Then average rainfalls for the progressively accumulated areas have been worked out and tabulated. Here the weights were used in proportion to the areas of the zones as shown in Eq. 1.

$$\text{Average Rainfall} = \frac{(A_1P_1 + A_2P_2 + \dots \dots \dots A_nP_n)}{(A_1 + A_2 + \dots \dots \dots A_n)} \tag{1}$$

Where, P_1, P_2, \dots, P_n are rainfall magnitudes recorded by rain gauge stations 1, 2, ..., n respectively and A_1, A_2, \dots, A_n are the respective areas enclosed by Thiessen polygons. Then maximum average depths corresponding to cumulative area for Thiessen polygon has been plotted on a graph paper. This is the depth-area curve of the maximum rainfall for the selected time period. Similarly, DAD curves were prepared for other time periods.

IV. RESULTS AND DISCUSSION

A. WATERSHED DELINEATION

Figure 1 shows the delineated Baitarani Basin and Subarnarekha Basin along with coastline using ArcGIS software.

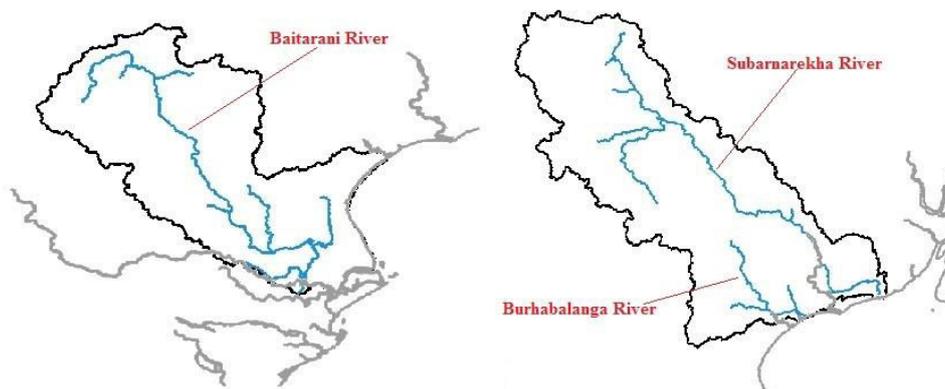


Fig. 1. Baitarani Basin and Subarnarekha Basin along with coastline

B. THIESSEN POLYGON METHOD

Table 3 and 4 shows the cumulative maximum precipitation for Baitarani and Subarnarekha basin, respectively. Using rain gauge stations coordinate in ArcGIS, Thiessen polygons were prepared. Thiessen polygons for Baitarani basin and Subarnarekha basin along with rain gauge stations are shown in Figs. 2 and 3, respectively. Then cumulative average rainfalls for the progressively accumulated areas were calculated using cumulative maximum precipitation and area enclosed by Thiessen polygons for all durations. Here the weights were used in proportion to the areas of the different rain gauge stations. Tables 5 and 6 shows the area enclosed by Thiessen polygons for Baitarani basin and Subarnarekha basin, respectively. Cumulative average rainfalls for 1-day, 2-days and 3-days for Baitarani Basin are shown in Tables 7, 8 and 9, respectively. Cumulative average rainfalls for 1-day, 2-days and 3-days for Subarnarekha basin are shown in Tables 10, 11 and 12, respectively. Then DAD curves were plotted between maximum average depth of rainfall and cumulative area for all durations. DAD curve for Baitarani basin and Subarnarekha basin are shown in Figs. 4 and 5, respectively.

Table 3. Cumulative maximum precipitation (mm) for Baitarani Basin

Rain Gauge Station	1-Day Maximum Precipitation	2-Days Maximum Precipitation	3-Days Maximum Precipitation
Champua	160.2	240.4	240.6
Ghatagaon	123.2	206.0	229.4
Jhumpura	173.5	240.7	240.7
Joshiapur	191.2	363.2	363.2
Karanjia	192.0	298.0	298.0

Table 4. Cumulative maximum precipitation (mm) for Subarnarekha Basin

Rain Gauge Station	1-Day Maximum Precipitation	2-Days Maximum Precipitation	3-Days Maximum Precipitation
Bhograi	115	300	348
Fekoghat	597.8	691.2	816.2
Jaleswar	288	537	575
Rajghat	280.6	529.2	605.6
Rairangpur	319	319	319
Balasore	132.8	346.4	453.8
Balimundali	145.4	261.8	352.2
Baripada	245.2	381.2	492.4
Jaypur	101.4	221.2	340.8
NH5, Govindpur	94.4	232.4	378.6

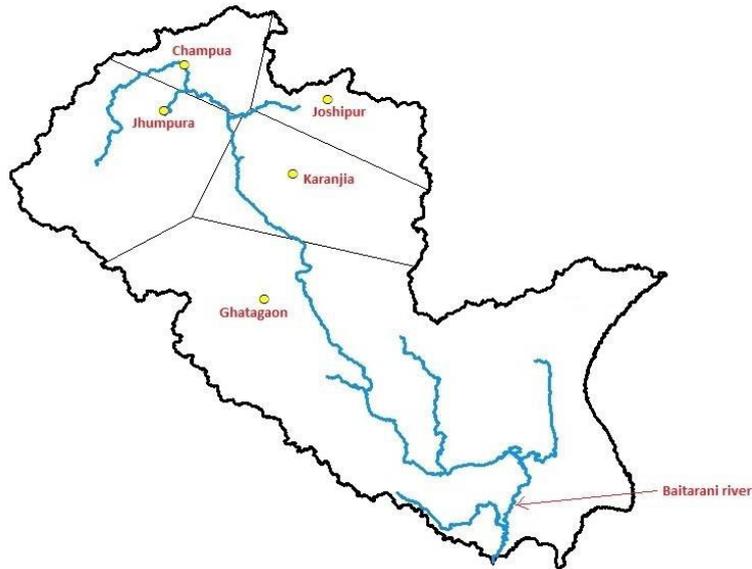


Fig. 2. Thiessen polygon for Baitarani Basin

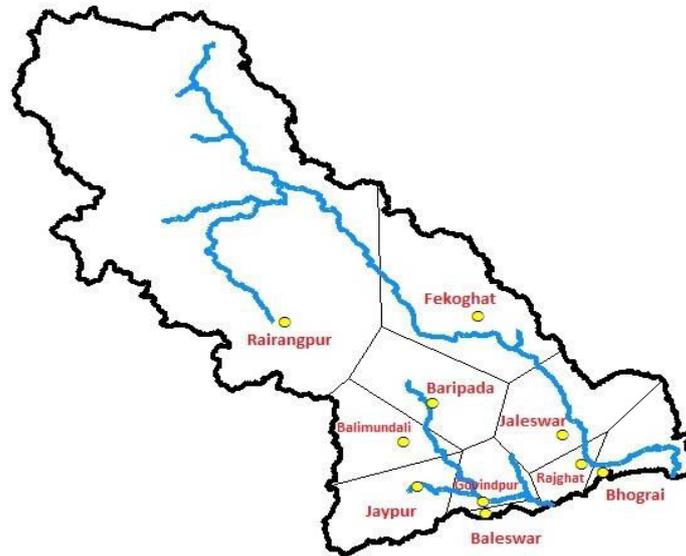


Fig. 3. Thiessen polygon for Subarnarekha Basin

Table 5. Area enclosed by Thiessen polygons for Baitarani Basin

Rain Gauge Station	Area (km ²)
Champua	645.6
Ghatagaon	6061.9
Jhumpura	1833.2
Joshipur	895.6
Karanjia	1515.7

Table 6. Area enclosed by Thiessen polygons for Subarnarekha Basin

Rain Gauge Stations	Area (km ²)
Bhograi	1100.1
Fekoghat	3321.6
Jaleswar	1986.4
Rajghat	501.5
Rairangpur	16335.6
Balasore	125.7
Balimundali	1362.4
Baripada	1956.1
Jaypur	1594.7
NH5, Govindpur	818.6

Table 7. Cumulative average rainfalls for 1-day for Baitarani Basin

S. No.	Maximum R/f (mm)	Area (km ²)	Cumulative area (km ²)	Average R/f (mm)
1	192.0	1515.7	1515.7	192.0
2	191.2	895.6	2411.4	191.7
3	173.5	1833.2	4244.6	183.8
4	160.2	645.6	4890.3	180.7
5	123.2	6061.9	10952.2	148.8

Table 8. Cumulative average rainfalls for 2-days for Baitarani Basin

S. No.	Maximum R/f (mm)	Area (km ²)	Cumulative area (km ²)	Average R/f (mm)
1	363.2	895.6	895.6	363.2
2	298.0	1515.7	2411.4	322.2
3	240.7	1833.2	4244.6	287.0
4	240.4	645.6	4890.3	280.8
5	206.0	6061.9	10952.3	239.4

Table 9. Cumulative average rainfalls for 3-days for Baitarani Basin

S. No.	Maximum R/f (mm)	Area (km ²)	Cumulative area (km ²)	Average R/f (mm)
1	363.2	895.6	895.6	363.2
2	298.0	1515.7	2411.4	322.2
3	240.7	1833.2	4244.6	287.0
4	240.6	645.6	4890.3	280.8
5	229.4	6061.9	10952.2	252.3



Table 10. Cumulative average rainfalls for 1-day for Subarnarekha Basin

S. No.	Maximum R/f (mm)	Area (km ²)	Cumulative area (km ²)	Average R/f (mm)
1	597.8	1100.1	1100.1	597.8
2	319.0	3321.6	4421.7	388.4
3	288.0	1986.4	6408.2	357.3
4	280.6	501.5	6909.7	351.7
5	245.2	16335.6	23245.3	276.9
6	145.4	125.7	23371.0	276.1
7	132.8	1362.4	24733.4	268.3
8	115.0	1956.1	26689.5	257.0
9	101.4	1594.7	28284.2	248.2
10	94.4	818.6	29102.8	243.9

Table 11. Cumulative average rainfalls for 2-days for Subarnarekha Basin

S. No.	Maximum R/f (mm)	Area (km ²)	Cumulative area (km ²)	Average R/f (mm)
1	691.2	1100.1	1100.1	691.2
2	537.0	3321.6	4421.7	575.4
3	529.2	1986.4	6408.2	561.1
4	381.2	501.5	6909.7	548.0
5	346.4	16335.6	23245.3	406.3
6	319.0	125.7	23371.0	405.9
7	300.0	1362.4	24733.4	400.0
8	261.8	1956.1	26689.5	389.9
9	232.4	1594.7	28284.2	381.0
10	221.2	818.6	29102.8	376.5

Table 12. Cumulative average rainfalls for 3-days for Subarnarekha Basin

S. No.	Maximum R/f (mm)	Area (km ²)	Cumulative area (km ²)	Average R/f (mm)
1	816.2	1100.1	1100.1	816.2
2	605.6	3321.6	4421.7	658.0
3	575.0	1986.4	6408.2	632.3
4	492.4	501.5	6909.7	622.1
5	453.8	16335.6	23245.3	503.8
6	378.6	125.7	23371.0	503.2
7	352.2	1362.4	24733.4	494.8
8	348.0	1956.1	26689.5	484.1
9	340.8	1594.7	28284.2	476.0
10	319.0	818.6	29102.8	471.6

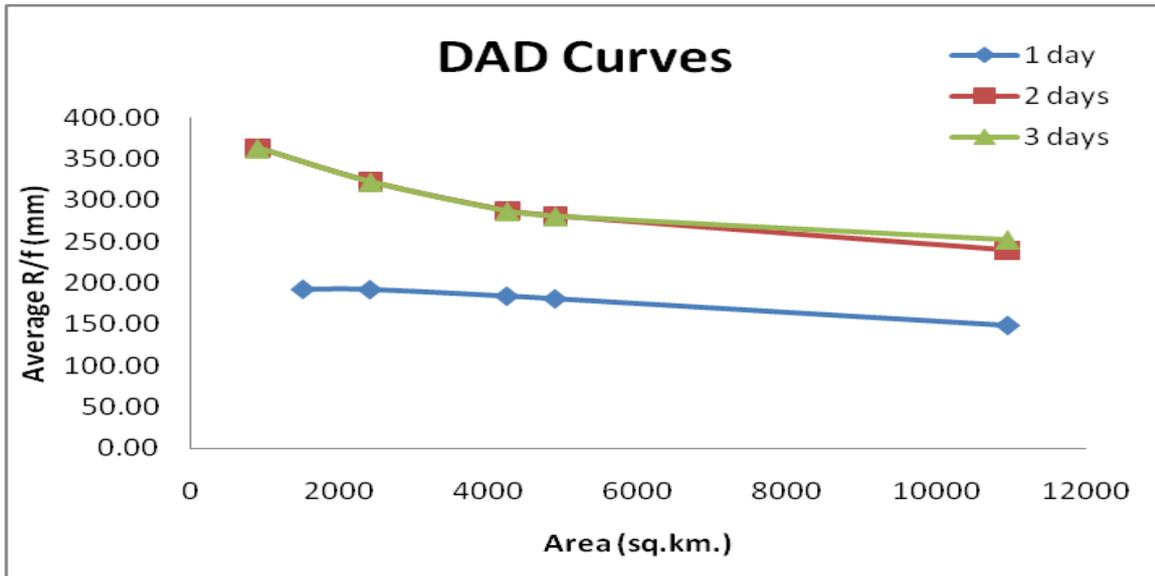


Fig. 4. DAD curves for Baitarani Basin

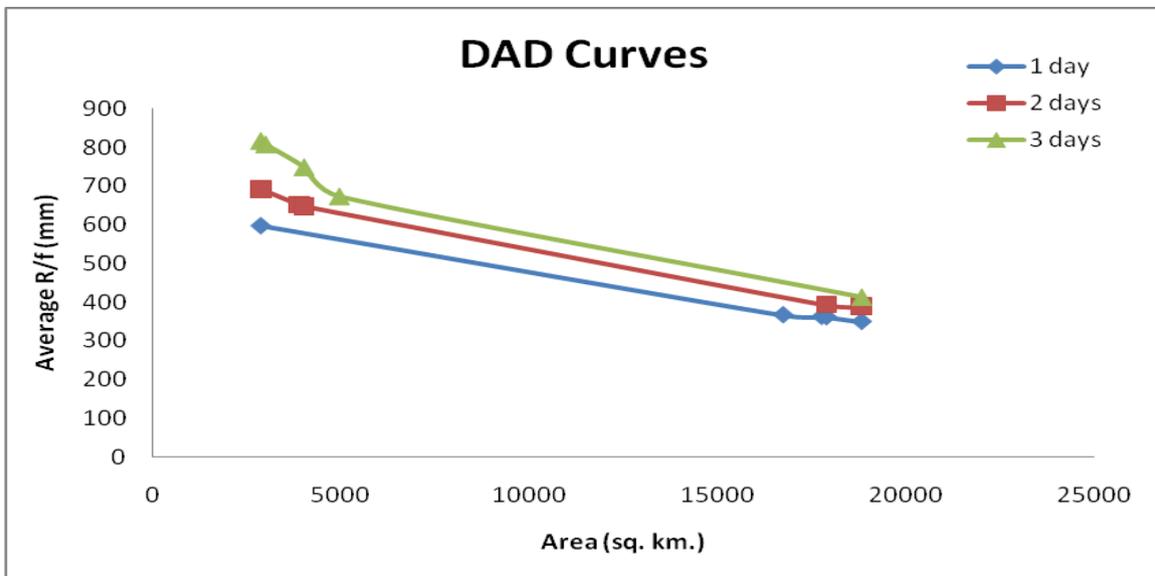


Fig. 5. DAD curves for Subarnarekha Basin

V. CONCLUSIONS

In the present work, two watersheds have been delineated using ArcGIS followed by preparation of Thiessen polygons. Then DAD curves were prepared for the storm which occurred during 16th to 18th June 2008 in two basins.

Based on the work done, following conclusions are drawn. There is a negligible difference among the actual basin area, the maximum cumulative area obtained after watershed delineation in ArcGIS and the sum of the areas of Thiessen polygons. The point rainfall may be converted to average rainfall for a region using these DAD curves. For study and planning reasons, the curves could be used to calculate the average rainfall of the watershed. The dominating and maximum rainfall with a length of four days does not occur in this watershed. This suggests that all rain will fall within the first three days. In data-poor settings, the Thiessen polygon approach can be used to create DAD-specific curves. The technical viability of the Inter basin water transfer concept may be reevaluated using the DAD curves with the goal of flood mitigation.

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