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DERIVATION OF LOCATION-SPECIFIC INTENSITY-DEPTH-DURATION CURVES FOR VARIED FREQUENCIES OF RAINFALL IN CENTRAL GUJARAT

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ABSTRACT

This paper highlights the critical role of monsoon rainfall in Indian agriculture, impacting crop yields and food production. Farmers face challenges due to variable monsoon patterns, leading to droughts or floods. Traditional rainfed agriculture and water conservation techniques are used, alongside modern technologies and climate-smart practices to achieve sustainability. Understanding rainfall patterns is essential for informed decision-making, enabling efficient water management and erosion control. IDF curves are indispensable tools for agriculture and engineering, aiding in water management and infrastructure design. Utilizing 20 years rainfall records, region-specific IDF curves were derived, providing valuable information on rainfall aspects in 3 districts of middle Gujarat. The IDF curve is vital in hydrology and water resources engineering, assisting in rainfall intensity estimation for different durations and return periods, with applications in drainage design, flood management, and risk assessment. The study highlights the significance of rainfall knowledge for food security and sustainable development in India.

KEYWORDS: *Rainfall Analysis , IDF curves, Gamble IDF, Middle Gujarat, location specific rainfall curves.*

INTRODUCTION

Indian agriculture is heavily dependent on the monsoon rainfall, which plays a critical role in determining crop yields and overall agricultural productivity (Singh et al., 2019). The monsoon season, typically spanning from June to September, brings much-needed water for irrigating crops and replenishing groundwater reserves. However, the timing, distribution, and intensity of monsoon rains are highly variable, leading to significant challenges for farmers in managing their agricultural practices (Ghosh et al., 2018). Delayed or deficient monsoons can lead to drought conditions, adversely affecting crop growth and food production (Mall et al., 2016). On the other hand, excessive rainfall during the monsoon season can result in flooding, causing crop damage and soil erosion (Kumar et al., 2020). To address these challenges, Indian farmers have traditionally practiced rainfed agriculture and implemented various water conservation techniques, such as rainwater harvesting and constructing check dams (Pandey et al., 2017). Furthermore, with the advent of modern technologies and climate-smart agricultural practices, farmers are increasingly adopting improved irrigation methods and drought-resistant crop varieties to cope with the uncertainties of monsoon rainfall and achieve sustainable agriculture. Understanding and managing the complexities of rainfall patterns during the monsoon season are essential for ensuring food security and sustainable agricultural development in India.

The understanding of rainfall patterns in agriculture holds immense significance as it forms the foundation for informed decision-making and sustainable farming practices (Singh et al., 2020). By comprehending the frequency, intensity, and trends of rainfall events, farmers can strategically plan crop selection and planting schedules (Gupta & Sharma, 2018), effectively manage irrigation to supplement inadequate rainfall (Patel et al., 2019), and implement erosion control measures (Kumar et al., 2017). This knowledge aids in preparedness against droughts and floods, allowing for the adoption of climate-resilient agricultural practices. Moreover, it facilitates efficient water resource management, enabling farmers to balance water usage with conservation needs (Pandey et al., 2018). With climate change impacting rainfall patterns, this understanding becomes even more crucial in fostering adaptability and ensuring the long-term sustainability of agriculture, ultimately contributing to food security and environmental preservation (Singh & Devi, 2019).

IDF (Intensity-Duration-Frequency) curves play a crucial role in both agriculture and engineering, serving as indispensable tools for effective water management, infrastructure design, and flood risk assessment (Sharma et al., 2020). In agriculture, understanding IDF curves enables optimal water usage, crop selection, and erosion control, fostering sustainable productivity (Joshi & Patel, 2018). For engineering, these curves are invaluable in designing resilient stormwater drainage systems, infrastructure, and flood control measures, enhancing urban resilience and safeguarding lives and property (Choudhary et al., 2019). Moreover, in hydrology and watershed management, IDF curves facilitate informed decision-making, promoting sustainable water practices and ecological balance (Singh & Verma, 2017). As we confront the challenges of a changing climate, the accurate utilization of IDF curves empowers stakeholders to make informed choices, optimize resource allocation, and mitigate the impacts of extreme weather events, paving the way for a more sustainable and resilient future across both agriculture and engineering sectors. An attempt has been made in this paper to derive region specific IDF curves at village level to get various information on rainfall aspects.

2.0 MATERIALS AND METHODS

Gujarat, the largest producer of major cash crops in India, boasts a thriving agricultural economy along with other significant crops. With over half of its land area dedicated to cultivation, the state relies heavily on animal husbandry and dairy farming to support its rural economy. Gujarat's cooperative-based dairy industry, with more than a million members, has earned it a prominent position as a global leader in milk production and processing. Additionally, the state has made remarkable strides in industrial development. Water plays a crucial role in achieving success in these sectors, especially in the context of agricultural and environmental prosperity. Rainwater, in particular, is of paramount importance, and its accurate assessment, even at micro scales of time and space, is essential for integrated water management. Climate change adds further complexity to rainfall patterns, making it imperative to understand the magnitudes, trends, and probabilities of rain occurrences. Geographically located at the extreme western end of India, with a vast sea coast, Gujarat experiences highly unusual rainfall distributions, necessitating thorough evaluation. Despite facing challenges, the state remains one of India's most prosperous regions, boasting a per-capita GDP significantly higher than the national average. Historical water resource-based infrastructure has been instrumental in supporting this growth, although it now faces imbalances across different parts of the state.

The focus of this study is on middle Gujarat, where uncertainties in natural occurrences and spatio-temporal rain distributions persist. This region experiences a semi-arid climate with medium black soils. The study concentrates on three vital districts - Anand, Kheda, and Vadodara, representing Agro-Climatic Zone-III of the state. These districts exhibit varying mean maximum and minimum temperatures throughout the year. In summary, the research seeks to understand

and quantify rainfall variabilities in middle Gujarat, considering different time scales, from annual to sub-daily, and addressing the challenges posed by changing rainfall patterns and climate uncertainties.

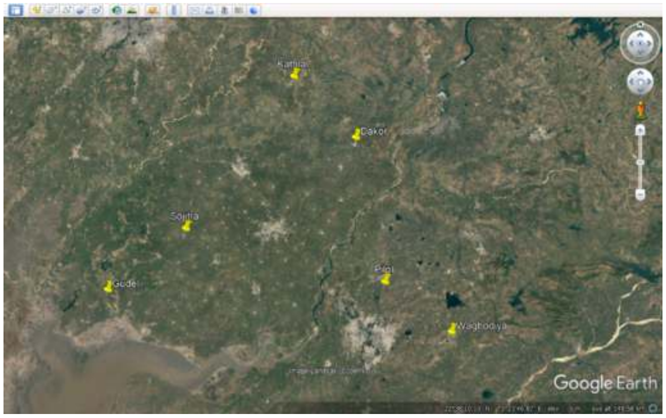

Figure 1: Google Earth snapshot showing 6 study locations of this study.

(Source: Google Earth Pro, 7.3.3.7786 (64-bit), Build Date: 21/07/2020)

2.1 Intensity Depth Duration Curves for Varied Frequency

The Theoretical Extreme Value (EV) Distribution Approach, Gumbel (Type I) distribution (Gumbel, 1941) was opted to accomplish the rainfall probability analysis. Owing to its appropriateness for modelling maxima, the Gumbel theory of distribution was considered appropriate for assessing distributions in hydrological analysis, IDF analysis as well as flood analysis. It is relatively simple and uses only extreme events (maximum values or peak rainfalls). Adopting this conceptual approach calculations were achieved for gaining 2, 5, 10, 25, 50 and 100-Year return intervals for each duration period by performing several calculations. The Gumbel Type I distribution was used as given by equation (3.1); as it was well suggested by IMD in its standard operating procedure for hydrometeorological services in India. The basic sets of mathematical parametrizations involve below given sequential formulations,

- $G\,(x,\mu,\beta) = \frac{1}{\beta} e^{\frac{x-\mu}{\beta}} e^{-e^{\frac{x-\mu}{\beta}}}$ (3.1)
- where μ is the location parameter and β is the scale parameter.
- It can be shown that the value of the random variable X_T associated with a given return period, T, may be obtained from the following expression,
- $X_T = \bar{X} + K_T S$ (3.2)
- where X is the mean of the observations (e.g., arithmetic average of the observations), and S is the standard deviation of the observations. The frequency factor associated with return period T, K_T, is given by
- $K_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\,(\ln\left(\frac{T}{T-1}\right))\right]$ (3.3)
- Equations (3.1), (3.2) and (3.3) were applied to each set of annual maxima corresponding to each duration, in below given manners,
- Computing the frequency factors associated with the desired return periods (e.g., 2, 5, 10, 25, 50, 100, 1000) using equation (3.3).

- Compute the sample mean and sample standard deviations of the series of annual maxima, (X_1, X_m) For each duration (e.g., 5-min, 10-min, …etc.),
- $\bar{X} = \frac{1}{m}\sum_{i=1}^{m} x_i$ (3.4)
- $S^2 = \frac{1}{m-1}\sum_{i=1}^{m}(x_i - \bar{X})^2$ (3.5)
- Using equation (3.2) to compute the precipitation intensity associated with each return period.
- Plotting the results which in fact remain the actual IDF curves of particular duration and associated frequency.

3.0 RESULTS AND DISCUSSION

The vast original rainfall data was visualized for whole year-based dispersals in average daily rains considering a span of 21 years. The characteristics of average daily rains in this regard are reflected in tables 4.2, 4.3 and 4.4. Among these the first table depicts above variabilities for two different stations falling under the Kheda district of Gujarat. The spectrum of maximum daily rains, average daily rains and standard deviation in regards to Dakor and Kathlal are well portrait herein (table 4.2), whose numerical values remained as 336, 15, 40 and 274, 15, 38 respectively. Similar information was generated in regards to Gudel and Sojitra for Anand district as well as Pilol and Waghodiya for Vadoadara district. The sets of three numerical values for pair of stations in Anand district (table 4.3) remain as 288, 14, 33 and 265, 15 and 38 respectively; while in case of Vadodara district Pilol and Waghodiya stations reflects sets of these values as 399, 15, 46 and 400, 14, 38 respectively (table 4.4). It altogether establishes the prevailing dispersal ranges across individual station/location; which could be of utmost utilities and importance hydrologists, planners, R&D experts and agricultural or water policy experts; to devise tailor made plans towards rainwater harvesting and utilization for gaining better water productivities in the region

Table 1: Maximum and average values of daily rains along with standard deviation for two stations located in Kheda district (during rainy season)

Year	Dakor			Kathlal		
	Max (mm)	Avg (mm)	SD	Max (mm)	Avg (mm)	SD
2000	120.8	3.5	12.6	129.8	3.7	13.5
2001	81.7	5.0	11.1	90.5	5.0	12.2
2002	143.3	4.5	15.2	57.5	4.0	10.2
2003	173.9	9.6	25.2	203.0	8.8	25.5
2004	86.0	7.7	15.4	117.0	7.4	16.2
2005	271.1	12.2	34.7	221.2	11.4	32.7
2006	335.7	15.0	40.4	274.0	14.6	38.1
2007	220.9	12.2	30.3	142.1	10.3	24.7
2008	181.4	7.5	23.6	136.8	6.5	19.4
2009	177.9	5.8	19.8	130.3	5.7	18.1
2010	102.4	9.6	20.1	122.8	9.4	20.2
2011	87.3	6.2	14.3	129.6	6.7	18.2
2012	126.0	6.8	18.3	118.1	7.4	20.5
2013	130.3	10.4	24.2	93.9	8.8	18.0
2014	259.1	9.2	28.8	197.7	8.0	23.7
2015	79.5	5.4	15.8	99.2	5.5	16.8
2016	80.7	5.5	12.4	70.2	4.9	10.4
2017	97.5	7.7	16.4	149.1	7.5	18.2
2018	174.8	7.8	23.0	168.9	6.5	20.2

2019	133.4	9.9	21.9	68.7	8.6	15.4
2020	106.6	8.6	17.2	90.8	8.3	17.3

Table 2: Maximum and average values of daily rains along with standard deviation for two stations located in Anand district (during rainy season)

Year	Gudel			Sojitra		
	Max (mm)	Avg (mm)	SD	Max (mm)	Avg (mm)	SD
2000	202.5	3.8	19.1	163.2	3.7	16.1
2001	89.4	5.7	13.0	107.9	5.4	12.8
2002	126.4	4.4	16.3	102.8	4.3	14.0
2003	236.3	8.9	26.1	247.9	10.1	28.3
2004	106.8	7.5	17.2	113.4	8.4	18.0
2005	198.2	14.2	33.4	265.5	14.8	37.5
2006	287.6	11.8	32.9	196.7	13.3	33.2
2007	231.4	12.2	32.0	180.7	11.2	25.5
2008	170.6	8.6	25.0	200.9	9.4	27.0
2009	163.8	6.0	20.7	115.1	5.8	18.3
2010	246.7	10.4	28.5	99.2	10.5	20.2
2011	156.6	7.3	19.5	89.4	7.4	16.4
2012	121.0	7.0	19.1	105.6	7.3	20.5
2013	89.5	9.6	18.0	93.1	10.4	19.8
2014	279.7	9.5	31.3	245.8	9.4	29.6
2015	83.0	5.2	13.8	81.4	5.3	15.0
2016	49.5	4.7	9.7	49.1	4.8	9.4
2017	84.1	7.3	13.9	102.9	7.6	15.4
2018	97.5	6.1	15.6	133.5	6.9	19.2
2019	126.8	8.8	18.8	144.3	9.4	19.9
2020	97.2	9.4	16.6	76.4	8.8	16.0

Table 3: Maximum and average values of daily rains along with standard deviation for two stations located in Vadodara district (during rainy season)

Year	Pilol			Waghodiya		
	Max (mm)	Avg (mm)	SD	Max (mm)	Avg (mm)	SD
2000	72.2	3.9	10.3	108.6	4.0	11.7
2001	54.4	5.3	10.6	92.7	5.9	13.4
2002	115.0	4.9	15.8	124.1	5.5	16.8
2003	136.4	9.8	24.1	182.2	10.7	25.7
2004	144.8	9.9	22.4	107.2	10.2	20.9
2005	398.9	15.2	45.6	282.7	13.6	38.7
2006	192.5	12.2	28.6	184.1	12.5	31.1
2007	113.8	10.5	22.6	143.1	10.9	25.1
2008	384.5	10.0	37.9	374.0	9.6	36.0
2009	90.8	6.1	16.3	106.1	6.5	16.9
2010	264.7	11.4	30.8	400.0	12.4	41.7
2011	102.7	8.0	17.2	105.7	8.3	18.1
2012	188.3	7.6	22.1	266.3	9.2	28.5
2013	239.4	13.5	33.2	129.9	11.2	22.1
2014	196.0	10.1	28.1	214.6	9.7	27.2
2015	68.4	4.8	12.9	71.9	4.8	11.8
2016	93.1	5.8	12.5	67.9	6.1	13.0
2017	81.9	8.1	15.6	80.5	8.3	16.5
2018	124.8	7.8	19.6	141.8	8.9	22.4
2019	140.4	10.5	21.0	137.2	11.1	22.3

2020	113.7	9.3	19.1	122.5	10.0	19.8

3.1 Derivation of Location Specific Theoretical IDF Curves

Attempts were made towards seeking derivation of stochastic IDF curves using popular approach like Theoretical Extreme Value (EV) Distribution Approach, Gumbel (Type I) distribution. This method was applied to perform the rainfall probability scrutiny with regards to Intensity-Duration and Frequency analysis. As the Gumbel theory of distribution happens to be most widely used distribution approach in hydrological, IDF, or even the flood analysis; owing to its appropriateness for modelling maxima The Gumbel Type distribution is suggested as one of the best options by IMD in its standard operating procedure for hydro meteorological services in India. Being relatively simple it uses only extreme events (maximum values or peak rainfalls), and remains capable to synthesise values for 2, 5, 10, 25, 50 and 100 year return intervals for each duration period with least calculations.

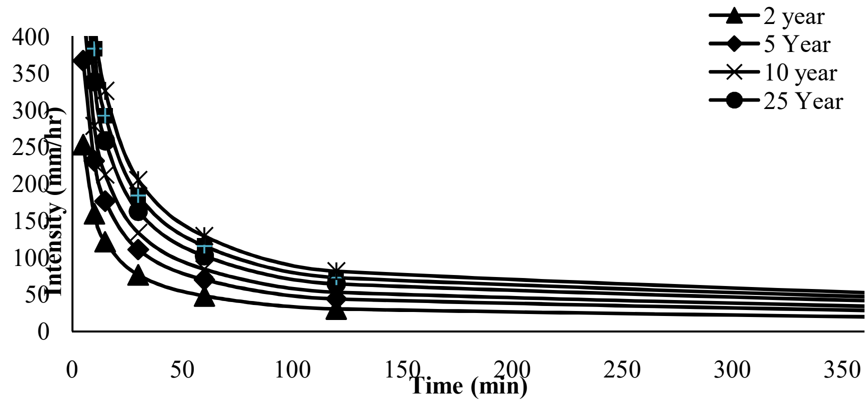

Figure 2: Theoritically Derived IDF Curve for Dakor.

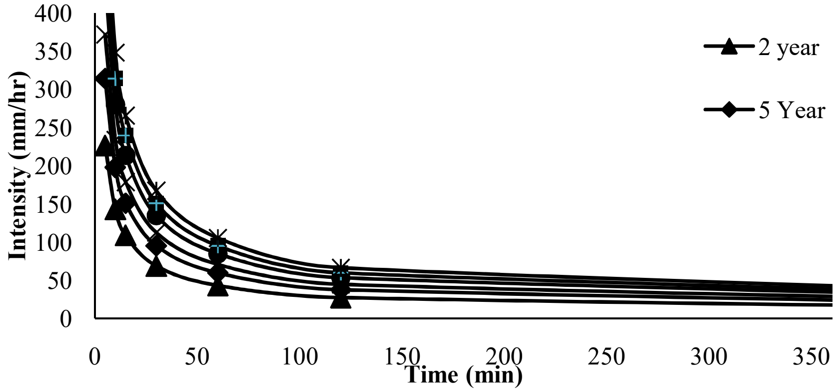

Figure 3: Theoritically Derived IDF Curve for Dakor.

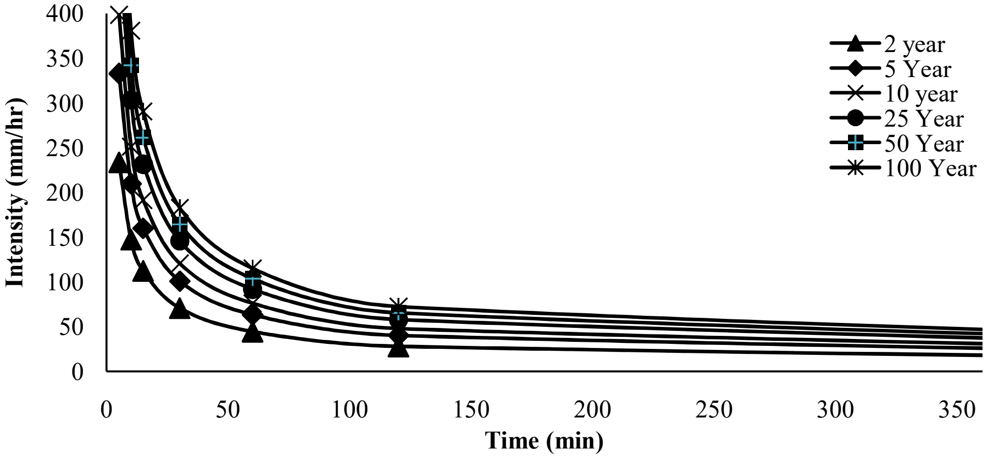

Figure 4: Theoritically Derived IDF Curve for Gudel.

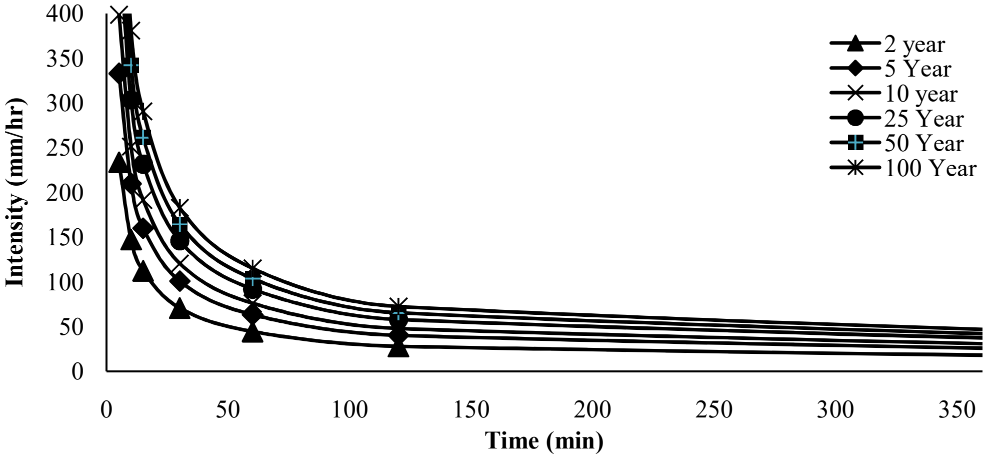

Figure 5: Theoritically Derived IDF Curve for Sojitra.

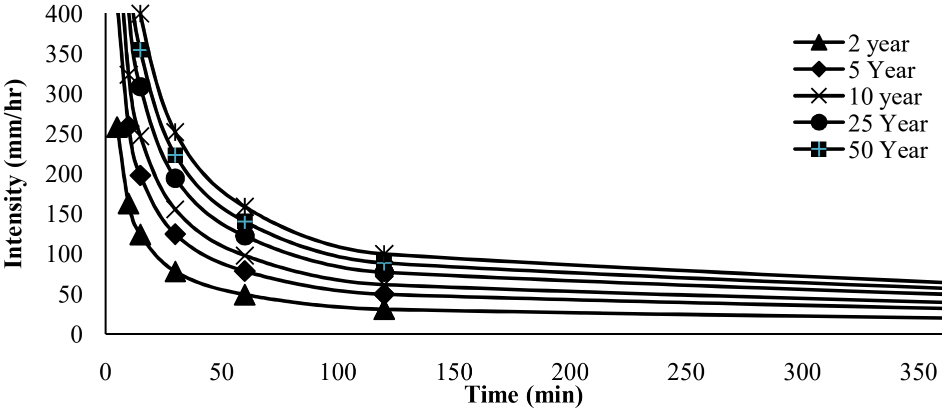

Figure 6: Theoritically Derived IDF Curve for Pilol.

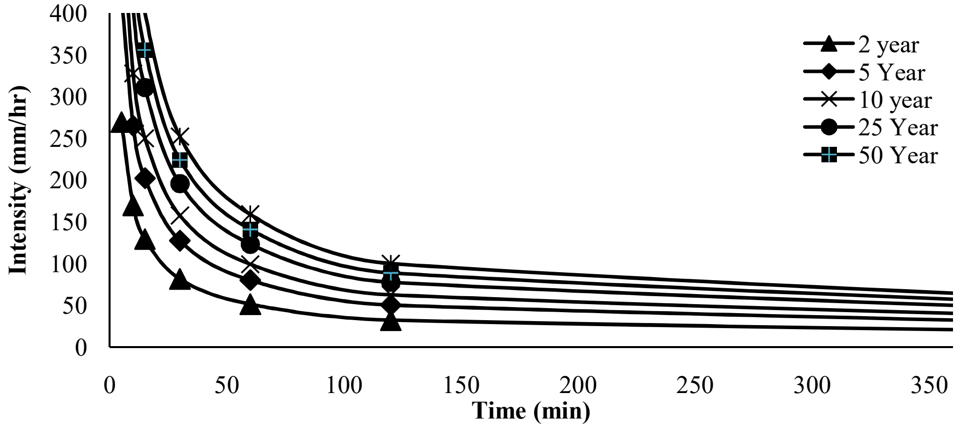

Figure 7: Theoritically Derived IDF Curve for Pilol.

The results obtained from the exercise are graphically depicted in Figure 2 to Figure 7, representing data from six study locations. The curves were developed based on the essential characteristics of each study location and synthesized following standard methodological protocols. These type curves serve multiple purposes in various areas, including soil conservation structure design, water resource modeling, and rainfall runoff modeling. The significance of these curves lies in their applicability as ready-made inputs for decision-makers dealing with diverse scenarios. They can be readily used in situations where data may be limited or unavailable, making them valuable tools in the study region.

Table 4 provides the values of probable intensities for different time steps/durations ranging from 5 minutes to 12 hours, corresponding to various reoccurrence intervals for each study location. These values hold particular importance for scenarios in the study region where no gauge data is available. Moreover, they play a crucial role in designing various soil and water conservation structures and formulating relevant plans for land and water development in the area. Given their wide-ranging utilities, these type curves and intensity values contribute significantly to informed decision-making and planning processes, particularly in the context of soil and water conservation efforts.

Table 4: Probable maximum intensity at various time STEP for the 2, 5, 10, 25, 50 and 100 years return period at study locations.

Period (Years) Time (Min)	2 years	5 years	10 years	25 years	50 years	100 years
	Dakor					
5	253.1	367.0	442.4	537.7	608.4	678.6
10	159.5	231.2	278.7	338.7	383.3	427.5
15	121.7	176.5	212.7	258.5	292.5	326.2
30	76.7	111.2	134.0	162.8	184.3	205.5
60	48.3	70.0	84.4	102.6	116.1	129.5
120	30.4	44.1	53.2	64.6	73.1	81.6
720	9.2	13.4	16.1	19.6	22.1	24.7
1440	5.9	8.6	10.4	12.6	14.2	15.9
	Kathlal					
5	227.0	314.3	372.1	445.1	499.3	553.0
10	143.0	198.0	234.4	280.4	314.5	348.4
15	109.1	151.1	178.9	214.0	240.0	265.9
30	68.7	95.2	112.7	134.8	151.2	167.5
60	43.3	60.0	71.0	84.9	95.3	105.5
120	27.3	37.8	44.7	53.5	60.0	66.5

720	8.3	11.4	13.5	16.2	18.2	20.1
1440	5.3	7.4	8.7	10.4	11.7	13.0
	Gudel					
5	259.6	373.3	448.6	543.7	614.2	684.3
10	163.6	235.2	282.6	342.5	386.9	431.1
15	124.8	179.5	215.7	261.4	295.3	329.0
30	78.6	113.1	135.9	164.7	186.0	207.2
60	49.5	71.2	85.6	103.7	117.2	130.5
120	31.2	44.9	53.9	65.3	73.8	82.2
720	9.5	13.6	16.3	19.8	22.4	24.9
1440	6.1	8.7	10.5	12.7	14.4	16.0
	Sojitra					
5	233.8	333.0	398.6	481.6	543.2	604.3
10	147.3	209.8	251.1	303.4	342.2	380.7
15	112.4	160.1	191.6	231.5	261.1	290.5
30	70.8	100.8	120.7	145.9	164.5	183.0
60	44.6	63.5	76.1	91.9	103.6	115.3
120	28.1	40.0	47.9	57.9	65.3	72.6
720	8.5	12.1	14.5	17.5	19.8	22.0
1440	5.5	7.8	9.3	11.3	12.7	14.2
	Pilol					
5	258.5	411.9	513.5	641.9	737.1	831.7
10	162.8	259.5	323.5	404.4	464.4	523.9
15	124.3	198.0	246.9	308.6	354.4	399.8
30	78.3	124.8	155.5	194.4	223.2	251.9
60	49.3	78.6	98.0	122.5	140.6	158.7
120	31.1	49.5	61.7	77.1	88.6	100.0
720	9.4	15.0	18.7	23.4	26.8	30.3
1440	6.1	9.6	12.0	15.0	17.3	19.5
	Waghodiya					
5	269.9	420.8	520.8	647.1	740.8	833.8
10	170.0	265.1	328.1	407.7	466.7	525.3
15	129.7	202.3	250.4	311.1	356.1	400.9
30	81.7	127.5	157.7	196.0	224.4	252.5
60	51.5	80.3	99.4	123.5	141.3	159.1
120	32.4	50.6	62.6	77.8	89.0	100.2
720	9.8	15.3	19.0	23.6	27.0	30.4
1440	6.3	9.9	12.2	15.2	17.3	19.5

4.0 CONCLUSIONS

A vast amount of rainfall data spanning 21 years of continuous daily and sub-daily records was collected from multiple sources. Standard protocols were strictly followed during the data retrieval, generation, processing, and utilization stages. Managing such massive volumes of data and performing intricate computerization and mathematical manipulations required an advanced platform, and the "R" programming language proved to be the ideal choice. Significant efforts and time were invested in leveraging the power of "R" to produce comprehensive and valuable results by analyzing the data in various ways. Specialized R packages were employed and customized to extract the desired information from the extensive time series data. Sets of mass curves for varied storm durations were considered valuable for retrieving real relations among depths, durations and intensities of rains for different recurrence intervals (5, 10, or 20 years). For this purpose, maximum rainfall intensities were derived for each rainstorm, which remained varied for their durations and occurrences of such intensities at varied point of time across whole time span of rain storm events in different categories of storm depths. Standard theoretical IDF curves were generated by adopting popular Gumble distribution / approach. Location specific relationships among depth & durations; intensity & duration and other combinations in terms of 3 specific recurring interval period (5, 10, 20 years) was accomplished for all 6 statins as adopted in present study. The IDF (Intensity-Duration-Frequency) curve serves as a crucial tool in hydrology and water resources engineering, enabling the estimation of rainfall intensity for different durations and return periods. Its applications are diverse and essential in various areas, including urban drainage design, floodplain management, water supply systems, erosion and sediment control, stormwater management, infrastructure design, and risk assessment for insurance purposes.

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