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Isolines of location specific constants of rainfall intensity- duration- frequency for Vidarbha region

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ABSTRACT : Rainfall intensity-duration-frequency (IDF) relationship is required for design of soil and water conservation structures. Rainfall intensity-duration-frequency relation depends on the physical characteristics of rainfall occurring at a particular place. The rainfall intensity-duration-frequency relationship can be expressed as $I = (KT^a)/(t + b)^d$ in which, I is rainfall intensity (cm/h), T is return period (years), t is duration (h) and K, a, b and d are location specific constants. The location specific constants in above relationship are calculated by analyzing the rainfall data of recording type rain gauge. The values of K, a, b and d are estimated for all stations of Vidarbha region. Then isolines maps of each constant K, a, b and d for Vidarbha region have been developed. Isoline for 'a' show steeper increase in western Vidarbha with minimum in Nagpur district. The values of constant 'a' vary from 0.1544 to 0.2074 in all nine stations except Buldhana (0.2524). As far as constant 'b' is concerned the isolines show valley portion from Amravati towards Akola *i.e.* in western direction. The common range of the values of constant 'b' varies from 0.20 to 0.30. The isolinesfor'd' showed concentric circles in western Vidarbha near Akola and similar type is observed near Nagpur. The common range of constant 'd' is in between 0.6618 to 0.7668. There was no general slope for isolines of 'd'. The isoline for 'K' showed two concentric circles around Nagpur and Akola denoting two peaks and in general has slopes in North-East direction from Akola and Nagpur. The 'K' value for Vidarbha range from 3.148 to 6.680. Isolines maps developed for different parameters of intensity-duration-frequency equation of Vidarbha region are useful to designers and planners for prediction of rainfall intensity at any location of Vidarbha region for any duration up to 24 hour and return period from 10 to 100 years to design flood control, rainwater harvesting and runoff disposal structures.

Key **W**ords : Isolines, Rainfall intensity-duration-frequency (IDF) relationship, Location specific constants

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Rainfall is the most important component of hydrologic cycle and has a dominant influence on several hydrologic phenomena occurring as result of complex interaction between land and precipitation. Rainfall is varying from location to location and has different intensity and frequency. Thus, there is need to develop IDF location specific constants. District wise IDF constants can be used for the design soil and water conservation structures. Relationship between rainfall intensity-duration-frequency is location specific and mainly depends upon physical characteristics of rainfall occurring at a particular place. Hence, such relationship developed for particular station cannot be superimposed for other stations owing to different pattern of rainfall characteristics (Handa and Misra, 1968). Thus, it becomes necessary to develop such relationships for small units so that, their reliability and applicability will have greater practical importance.

The relationship between rainfall and peak runoff has been represented by many empirical formulae. The rational formula (Frevert *et al.*, 1955), which is one of the representative

of such formulae, is in use for estimating runoff to be expected from small drainage areas (up to 1300 ha). The rational formula requires rainfall intensity for duration equal to the time of concentration and for particular recurrence interval. Using rainfall intensity-duration-frequency relationship, rainfall intensity is calculated for a particular duration and recurrence interval. For understanding the rainfall characteristics of station, long period records of automatic rain gauge are required. At present, such records are available only for a limited number of stations near the HDUG (Hydrology Data Users Group) Nasik.

Nemec (1973) developed the general form of the rainfall intensity duration return period equation as :

$$I = \frac{KT^a}{(t+b)^d} \quad \text{.....(1)}$$

where,

I = Maximum rainfall intensity (cm/h)

T = Return period (year)

t = Duration (h)

K, a, b and n = Location specific constants sample calculation for developed IDF equation of Gondia is presented. Adopting the same procedure IDF equation for other nine stations of Vidarbha region were developed and used for drawing the Isolines which is useful to find out the intensity of rainfall for different durations and recurrence intervals at any location of Vidarbha region.

RESEARCH PROCEDURE

Location of study area :

The study was carried out for Vidarbha region of Maharashtra state. The geographical data and average annual rainfall of study area is given in Table 1. The automatic rain gauge charts of 20 to 30 years were used for analysis. The adequacy of rain gauge charts was tested before analysis.

Determination of constants of IDF relationship :

The values of rainfall intensities for all durations were plotted on Y- axis and values of return period on X- axis on log-log paper. All these points were connected by a thin dotted line giving more weightage to points from 10 year to 100 years return period. The dotted line was extended to cut the Y axis against 1-year return period. The slope of the individual dotted lines for each duration was determined. The geometric mean slope ($\overline{m}$) for the entire set of lines was given in Table 2 for Gondia district. The geometric mean slope of the lines represents the exponent 'a' in the equation. The values of rainfall intensities for different durations and one year return period were plotted on Y axis against selected duration on X-axis on log-log paper. The points plotted in such that they do not fall in a straight line. Marked all these points which, fall in one straight line and suitable constant 'b' is to be added to all the values of durations by trial and error method. After adding this constant in the values of durations the points were aligned into a straight line.

The constants 'K' and 'd' were solved by least square method. In this method by using the values of one year rainfall intensities for selected durations and Table 3, the values of 'K' and 'd' were determined by solving the equation (2) and (3).

$$\text{Log K} = \frac{\sum \text{Log} \mid \sum [\text{Log}(t+b)]^2 - \sum [\text{Log 1} \times \text{Log}(t+b)] \times \sum \text{Log}(t+b)}{N \sum [\text{Log}(t=b)]^2 - [\sum \text{Log}(t+b)]^2} \quad \text{....(2)}$$

$$d = \frac{\sum \text{Log} \mid \sum [\text{Log}(t+b)] - N \sum \text{Log} \mid \times \text{Log}(t+b)}{N \sum [\text{Log}(t+b)]^2 - [\sum \text{Log}(t+b)]^2} \quad \text{.... (3)}$$

where,

K, b and d = Location specific constants

I =One year rainfall intensity (mm/h)

t = Duration (h)

N = Number of selected durations

IDF constants for Vidarbha region:

Bhamre (2010) developed the IDF relationship for Akola, Amravati and Buldhana districts, Shinde (2011) developed for Wardha, Yavatmal and Bhandara districts and Kothawale (2012)

Table 1 : Geographical and climatological data for Vidarbha region

Sr. No.	Name of district	Altitude, m	Latitude	Longitude	Avg. Annual Rainfall, mm
1.	Buldhana	639	19°98'N	76°51'E	946
2.	Akola	282	20°7'N	77°07' E	850
3.	Amravati	1000	20°32' N	76°37'E	800
4.	Yavatmal	451	20°23' N	78°59'E	1029.0
5.	Wardha	287	20°83'N	78°60' E	1062.5
6.	Nagpur	312	21°7' N	79°7' E	1082.1
7.	Chandrapur	188	19°57' N	79°18 ' E	1305.4
8.	Bhandara	244	21°09'N	79°40'E	1470.6
9.	Gadchiroli	217	20°10' N	80°00' E	1428.5
10.	Gondia	346	21°28' N	80°12' E	1377.9

Table 2 : Determination of geometric mean slope of frequency lines (value of 'a') for Gondia

Frequency lines of different duration, h	Scale distance (cm) From X-axis		Difference (col 2 - col 3)/ length of slope line AB= Slope	Logarithmic values of col 4
	B_1	A_1		
1	2	3	4	5
0.08	14.9	13.2	0.134	-0.8734
0.16	14	12.2	0.142	-0.8485
0.25	13.6	11.9	0.133	-0.8768
0.50	13.1	11.2	0.148	-0.8285
1	12.5	10.3	0.172	-0.7648
2	11.2	9	0.172	-0.7648
3	10.8	8.3	0.195	-0.7093
6	9.9	7.2	0.211	-0.6758
12	8.6	5.6	0.231	-0.6368
24	7.2	4.6	0.202	-0.6956
	Sum			-7.6742
	Mean			-0.7674
	Antilog(-0.8113)			0.1708
	Geometric mean slope			0.1708
	Hence, frequency factor 'a'			0.1708

Table 3 : Determination of constants 'K' and'd' for Gondia

Duration, t (h)	One hour intensity, I (mm/h)	(t+b) = (t+ 0.21)	Log I	Log (t+b)	$[Log(t+b)]^2$	Log I x log(t+b)
0.08	138	0.29	2.139	-0.5376	0.2890	-1.1504
0.16	96	0.37	1.982	-0.4318	0.1864	-0.8559
0.25	80	0.46	1.903	-0.3372	0.1137	-0.6418
0.5	66	0.71	1.819	-0.1487	0.0221	-0.2706
1	48	1.21	1.681	0.0828	0.0069	0.1392
2	31	2.21	1.491	0.3444	0.1186	0.5136
3	24	3.21	1.380	0.5065	0.2565	0.6991
6	16.3	6.21	1.212	0.7931	0.6290	0.9614
12	10.2	12.21	1.008	1.0867	1.1810	1.0961
24	6.1	24.21	0.785	1.3840	1.9154	1.0869
n=10		sum	15.403	2.7421	4.7187	1.5774

Table 4 : District wise specific IDF constants of Vidarbha region

Sr. No.	Name of district	Constant 'a'	Constant 'b'	Constant 'd'	Constant 'K'
1.	Buldhana	0.2524	0.30	0.7564	3.981
2.	Akola	0.1985	0.50	0.8591	6.615
3.	Amravati	0.1764	0.20	0.6412	4.573
4.	Yavatmal	0.2074	0.12	0.5574	3.148
5.	Wardha	0.1832	0.28	0.7356	5.370
6.	Nagpur	0.1544	0.23	0.7668	6.680
7.	Chandrapur	0.1914	0.30	0.7473	5.861
8.	Bhandara	0.1611	0.24	0.6618	4.884
9.	Gadchiroli	0.1861	0.27	0.7529	5.767
10.	Gondia	0.1708	0.21	0.6671	5.284

developed for Nagpur, Chandrapur, Gadchiroli and Gondia districts of Vidarbha region. These all values of location specific constant a, b, d and K of IDF equations are presented in Table 4.

Development of isolines :

Isolines maps of each constant a, b, d and K for Vidarbha region has been developed from district wise specific IDF constants given in Table 4.

RESEARCH ANALYSIS AND REASONING

The results obtained from the present investigation as well as relevant discussion have been summarized under the following heads :

IDF location specific constants of Gondia district :

For Gondia district, the geometric mean slope of the line, represents the exponent 'a', was observed as 0.1708 given in Table 2. The value of constant 'b' was estimated as 0.21 and the values of K and d were calculated as 5.2844 and 0.6671, respectively with equation (2) and (3). The details are given in Table 3.

Isoline map of intensity-duration- frequency constants of Vidarbha region :

Isoline maps developed for different parameters of rainfall intensity-duration-frequency equation for Vidarbha region is useful for prediction of maximum rainfall intensity at any location of Vidarbha region. Fig. 1 shows the map of Vidarbha region.

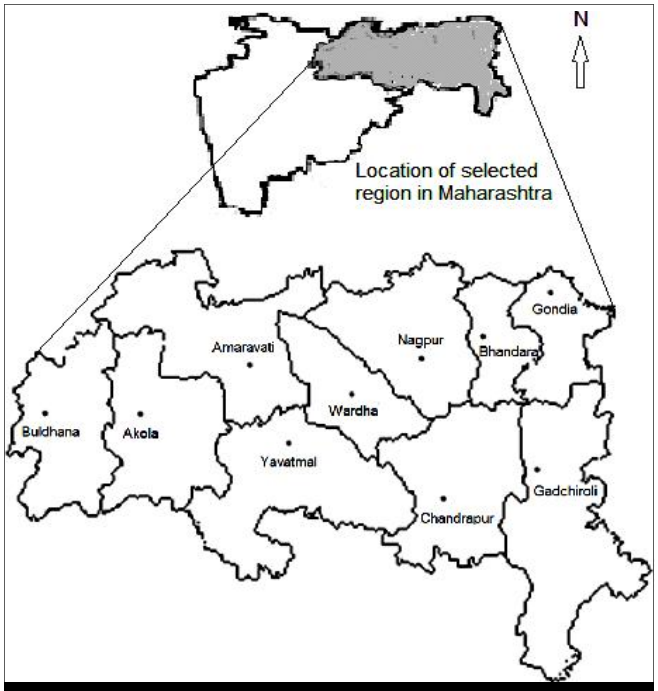

Fig. 1 : District map of Vidarbha region

Isoline map of constant 'a' :

It is revealed from Fig. 2 and Table 4, the values of constant 'a' is lowest for Nagpur (0.1544) and highest for Buldhana (0.2524). The values of constant 'a' vary from 0.1544 to 0.2074 in all nine stations except Buldhana (0.2524). Isolines indicates that magnitude of constant 'a' increases in all the direction from Nagpur, however the increasing trend is low up to Amravati and later on it increases at faster rate. As the value 'a' increases for given recurrence interval the maximum rainfall intensity also increases.

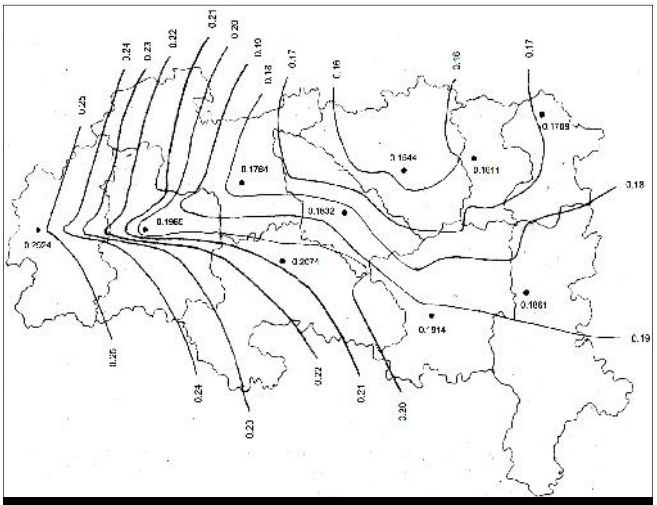

Fig. 2 : Isolines of constant 'a' for Vidarbha region

Isoline map of constant 'b' :

Maximum rainfall intensity is inversely proportional to the value of constant 'b'. The common range of the values of constant 'b' varies from 0.20 to 0.30 for Vidarbha region. It is observed from Fig. 3, the values of constant 'b' increase from North to South of Vidarbha region. Value of 'b' changes at

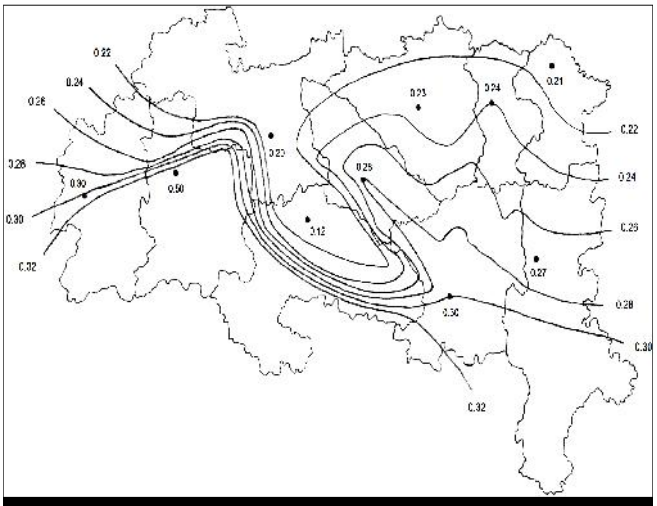

Fig. 3 : Isolines of constant 'b' for Vidarbha region

faster rate at Yavatmal, Amravati and Akola as compared to all other stations of Vidarbha region. Lowest and highest value of 'b' is 0.12 and 0.50 for Yavatmal and Akola station, respectively.

Isoline map of constant 'd' :

As the value of 'd' increases, rainfall intensity decreases. It is observed from Fig. 4, the common range of constant 'd' is in between 0.6618 to 0.7668 and lowest for Yavatmal *i.e.* 0.5544 and highest for Akola *i.e.* 0.8591. The variation of value of constant'd' of IDF equation in the eastern part of Vidarbha is low as compared to western part of Vidarbha.

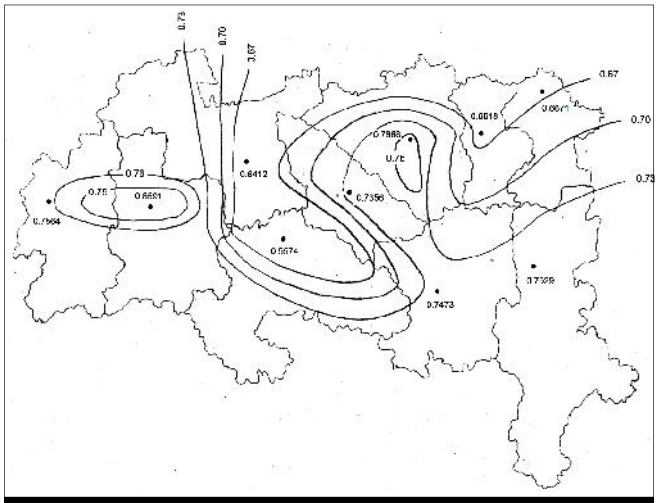

Fig. 4 : Isolines of constant 'd' for Vidarbha region

Isoline map of constant 'K' :

The value of constant 'K' is directly proportional to the maximum rainfall intensity. The 'K' value for Vidarbha range from 3.148 to 6.680. Highest value 6.680 is at Nagpur followed by Akola 6.615 whereas lowest value is at Yavatmal *i.e.* 3.148. For all other seven stations value rangebetween 3.981 to 5.861 as shown in Fig. 5.

Conclusion :

Isolines maps developed for different parameters of rainfall intensity- duration – frequency equation of Vidarbha region is useful for prediction of maximum rainfall intensity at any location of Vidarbha region for any duration up to 24 hour and a return period from 10 to 100 years to design flood control, rainwater harvesting and runoff disposal structures.

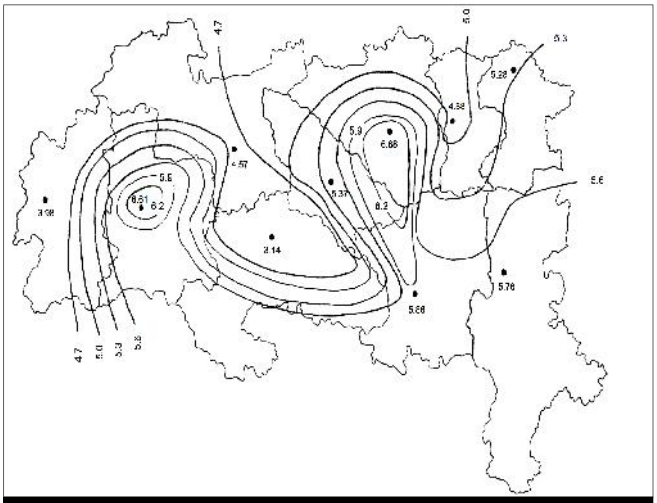

Fig. 5 : Isolines of constant 'K' for Vidarbha region

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