MAUSAM, **74**, 3 (July 2023), 707-716

MAUSAM

DOI : https://doi.org/10.54302/mausam.v74i3.6302
Homepage: https://mausamjournal.imd.gov.in/index.php/MAUSAM

UDC No. 551.577.36 (540.53)

Development of rainfall intensity-duration-frequency relationships and nomographs for selected stations in Maharashtra, India

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(*Received 28 April 2020, Accepted 12 December 2022*)

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सार — जल संसाधन परियोजनाओं, जल संसाधन विकास और प्रबंधन की योजना, डिजाइनिंग, मूल्यांकन और संचालन में वर्षा तीव्रता-अवधि-आवृत्ति (IDF) संबंध एक महत्वपूर्ण भूमिका निभाता है। स्थानिक-कालिक भिन्नता के कारण वर्षा के घटकों, तीव्रता, अवधि और आवृत्ति के बीच स्थान-विशिष्ट संबंध की जांच करना आवश्यक है। इस लेख मेंहम, वर्षा की तीव्रता और उसके घटकों के बीच संबंधों की जांच और भारत के महाराष्ट्र में वाशिम, चंद्रपुर और यवतमाल जिलों के लिए नोमोग्राफ विकसित करेंगे।हमने चयनित अवधि की अधिकतम वार्षिक वर्षा तीव्रता के लिए विभिन्न स्टेशनों के वर्षा चार्ट का भी अध्ययन किया। उपरोक्त स्थानों के लिए आवृत्ति लाइनों की गणना की जाती है। नियतांक 'a' और 'b' और 'K' (Nemec 1973) के मान को निर्धारित करने के लिए एक प्रयोगसिद्ध अध्ययन किया गया। वर्षा की तीव्रता-अवधि-आवृत्ति (IDF) संबंधों (Luzzadar 1964) के लिए नोमोग्राफ भी विकसित किए गए हैं। परिणामों की पर्याप्तता का परीक्षण सांख्यिकीय सूचकांकों जैसे समाकल वर्ग त्रुटि, सहसंबंध गुणांक, प्रतिशत निरपेक्ष विचलन और मूल माध्य वर्ग त्रुटि द्वारा किया गया। नोमोग्राफिक समाधान और गणितीय समीकरणों के बीच भिन्नता 20% से कमअनुमेय सीमा के अंदर है।

ABSTRACT. The rainfall intensity-duration-frequency (IDF) relationship plays an important tool in planning, designing, evaluating and operating of water resource projects, water resources development and management.It is necessary to examine the location-specific relationship between rainfall components, intensity, duration and frequency due to their spatiotemporal variation. In this article, weinvestigate the relationship between the rainfall intensity and its components and develop nomographs for Washim, Chandrapur and Yeotmal districts in Maharashtra, India. We also studied the rainfall charts of various stations for maximum annual rainfall intensities of selected duration. The frequency lines are computed for the above locations. An empirical study is conducted to determine the value of constants 'a' and 'b' and that of 'K' (Nemec, 1973). The nomographs are also developed for the rainfall intensity-duration-frequency (IDF) relationships (Luzzadar, 1964). Adequacy of the results istested by statistical indices such as integral square error, correlation coefficient, percent absolute deviation and root mean square error. The variation between nomographic solutions and mathematical equations lies within the permissible limit, less than 20%.

Key words – IDF relationship, Nomographs, Rainfall charts, Statistical indices.

1. Introduction

The rainfall is an important component of the hydrologic cycle which governs the surface runoff as well as groundwater flow joining to streams. Adequate knowledge of rainfall characteristics such as duration, intensity and frequency is very essential in generating the hydrographs for any watersheds. The rainfall intensity-duration-frequency (IDF) relationship is a very important tool in resources engineering, which is used by hydrologists in planning, designing and operatingwater resource projects or for various engineering projects, for flood control. The study and updation of rainfall (IDF) characteristics are necessary for almost all aspects of water-related design and management, including flood control, groundwater recharge evaluation, water supply, irrigation, agricultural drainage, and energy generation (Karl *et al.*, 1995; Angel and Huff, 1997; Guo, 2006). A change in the precipitation pattern is observed due to climatic anomaly from mounting evidence of global and

TABLE 1

The study site description of Washimpur, Chandrapur and Yeotmal district, Maharashtra

S. No.	Station	District	Location	Altitude	Annual rainfall	operator of the station	Duration	Sampling scheme
1	Manora	Washimpur	20°19′ N, 77°54′ E	600 m	1207.9 mm	NARP, Sonkhas	2002 to 2012	Automatic rain gauge chart
2	Sonkhas	Washimpur	20°40′ N, 74°70′ E	600 m	1207.9 mm	NARP, Sonkhas	2000 to 2011	Automatic rain gauge chart
3	Ajaypur	Chandrapur	19°95′ N, 79°29′ E	188 m	1420 mm	KVK Bramhapuri	1996 to 2012 (except 1997, 2000 and 2003)	Automatic rain gauge chart
4.	Bramhapuri	Chandrapur	20°56′ N, 79°85′ E	188 m	1420 mm	KVK Bramhapuri	1982 to 2011 (except 1991 to 1993, 1996 and 1998)	Automatic rain gauge chart
5.	Pusad	Yeotmal	19°88′ N, 77°55′ E	451 m	932.54 mm	ARS Pusad	2003 to 2012	Automatic rain gauge chart

regional studies (Kunkel *et al.*, 1999; Easterling *et al*., 2000; Trenberth *et al*., 2003; Goswami *et al*., 2006; Douglas and Fairbank, 2011). These changes in the rainfall characteristics with time and space suggested that IDF analysis be regularly updated and examine recent rainfall time series (Madsen *et al*., 2009).

Hershfield (1961) examined various rainfall durations and theircontour maps to establish the design rain depths for various return periods and durations. Bell (1969) proposed a formula for generalized IDF for the period of the 1 hour, 10 years rainfall depths; P_1^{10}, as an index. Koutsoyiannis *et al.* (1998) developed a mathematical relationship between the rainfall intensity-duration-return periodfor IDF curves.

In view of economic points, these relationships, *i.e*., rainfall intensity, duration, and frequency analysis is very effective. The IDF curve is an important component in characterizing a watershed rainfall pattern. The recurrence interval of various durationscan be computed from the record. For example, the size rainfall event that statistically occurs every 10 years. Typically, the Intensity-duration-frequency (IDF) curves show 2, 5, 10, 25, 50 and 100 years return periods. These IDF curves have been used in hydrologic and hydraulic design purposes with the assumption that previous rainfall statistics will continue to represent rainfall statistics in the future. Some more literature about IDF can be obtained from Shinde *et al*., 2017; Devkota *et al*.,2018; Noor *et al.*, 2018; David *et al.*, 2019.

Nomograph consists drawn for different Intensity-duration-frequencyrepresents a set of ‘n’ scales, one for each variable in an equation. It is easily determined the unknown variable from available values of n-1 variables with the help of IDF curves. The result is so obtained across the known values on the scales and by reading the unknown value from where it crosses the scale for that variable. The virtual or drawn line called *index line* or *isopleth* is created by the straightedge. Results from a nomograph are obtained very quickly and reliably by simply drawing one or more lines and the user does not even need to know the actual equation being calculated. Alternatively, a nomogram may be used to check an answer obtained from another exact calculation method.

In this paper, we attempted to derive rainfall intensity-duration-frequency relationships and nomographs for selected stations,Washim, Yeotmal and Chandrapur in Vidharbha, Maharashtrastate. To the best of our knowledge, these techniques have not previously been applied for IDF relationships at these given locations simultaneously and found novelty in research for the same.

2. Materials and methods

2.1. *Study area*

The location for the study had taken were Washimpur, Chandrapur and Yeotmal districts ofthe Vidarbha region of Maharashtra, India. The study sites consist within the given district were Washimpur district: Sonkhas and Manora, Chandrapur district: Ajaypur and Bramhapuri and Yeotmal districts: Pusadhad considered for the study area. A detailed description of the study area is given in Table 1.

TABLE 2

The highest rainfall intensities (mm/h) for different stations of Washimpur, Chandrapur and Yeotmal district, Maharashtra

Duration (hours, h)	Intensities (mm/h)				
	Washimpur		Chandrapur		Yeotmal
	Sonkhas	Manora	Ajaypur	Bramhapuri	Pusad
0.08 h	192	240	170	122	184
0.16 h	168	180	148	122	145
0.25 h	120	144	142	120	114
0.5 h	120	120	114	92	72
1 h	90	90	68	76	46
2 h	60	65	50	48	41
3 h	42	59	39	33	27
6 h	29	30	17.33	20	21.33
12 h	16	15.21	17	20	14.17
24 h	8	9	16	20	9.33

2.2. *Data acquisition*

The rainfall data for different given study locations of different duration, the operator of the station and the sampling scheme is also been presented in Table 1. The rainfall data of the Manora and Sonkhas stations of the Washimpur district were taken for 10 years and 12 years. Likewise, Ajaypur and Bramhapuri of Chandrapur district were taken of duration 14 years and 25 years. Meanwhile, 10 years of data were considered for the study at Pusad station of Yeotmal district. The different durations of rainfall data were taken based on the availability of the data from the different stations.

2.3. *Data analysis*

In the present study, autographic rainfall records data of given stations at Washim, Chandrapur and Yeotmal districts of Vidarbha region of Maharashtra, India wasused for analysis in the form of annual maximum series of various durations, *viz*., 5, 10, 15, 30 min, 1, 2, 3, 6, 12 and 24 h. The rainstorms of peak intensities were considered for the analysis as the goal is to obtain the annual maximum intensity of rainfall. The maximum depth of rainfall for various durations was worked out by using the Original trace method. A detailed study for the method can be obtained from the literature Babu *et al*., 2001.

2.4. *Plotting Positions for Development of Frequency Lines*

The plotting positions for analysis were obtained by using the Computing method, as suggested by Ogrosky and Mockus (1957). Therefore, the detailed description can access through Ogrosky and Mockus (1957).

2.5. *Development of Frequency Lines*

The lognormal paper was used for plotting rainfall intensities. The plotting is such that the rainfall intensities were plotted on a logarithmic scale while the percent chance of occurrence is on the probability scale. A frequency line of rainfall intensity passing through three points is considered as a straight line that extended to the ordinates. The ten frequency lines of rainfall intensities were drawn for ten durations which are designated as $I_{0.08}$, $I_{0.16,}$ $I_{0.25,}$ $I_{0.50,}$ $I_{1,}$ $I_{2,}$ $I_{3,}$ $I_{6,}$ I_{12} and I_{24} for 0.08, 0.16, 0.25, 0.50, 1, 2, 3, 6, 12 and 24 h duration respectively.A detailed description of the method can be obtained from Nemec 1973 and Babu *et al.*, 1979.

2.6. *Estimation of constant b*

A line representing the geometric mean slope was drawn at the base of the graph of frequency distribution lines passing through origin. The solid lines parallel to this geometric mean slope line were drawn against the dotted lines for different durations, the values at Y-axis represent rainfall intensities for different durations and a one-year return period.A detailed description can be obtained from the literature Shinde *et al.*, 2017.

2.7. *Estimation of K and d*

The constants K and d were determined by the least square method. A detailed description can be obtained from the literature Shinde *et al*., 2017.

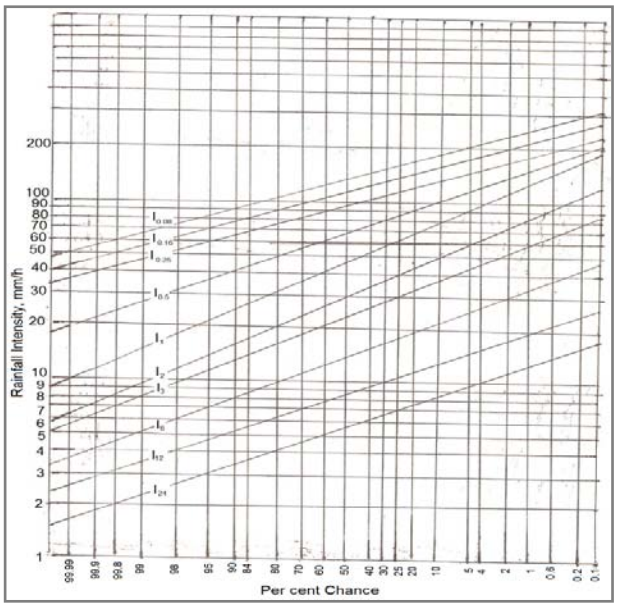

Fig. 1. Frequency distribution of rainfall intensities for various durations at Washim district

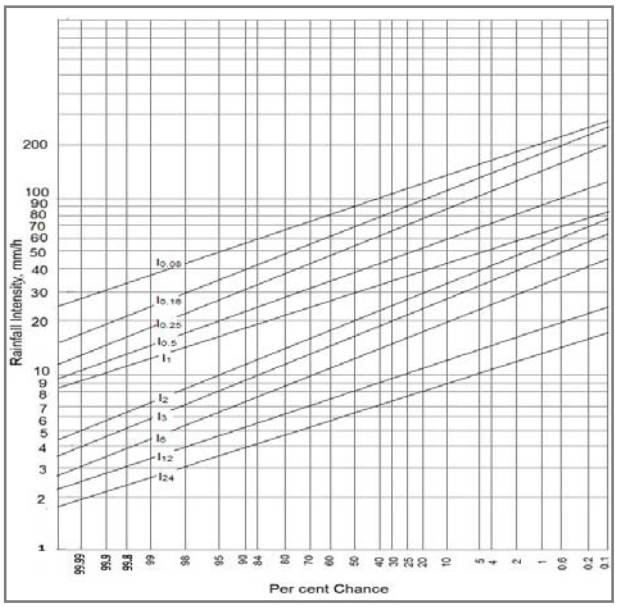

Fig. 3. Frequency distribution of rainfall intensities for various durations at Yeotmal district

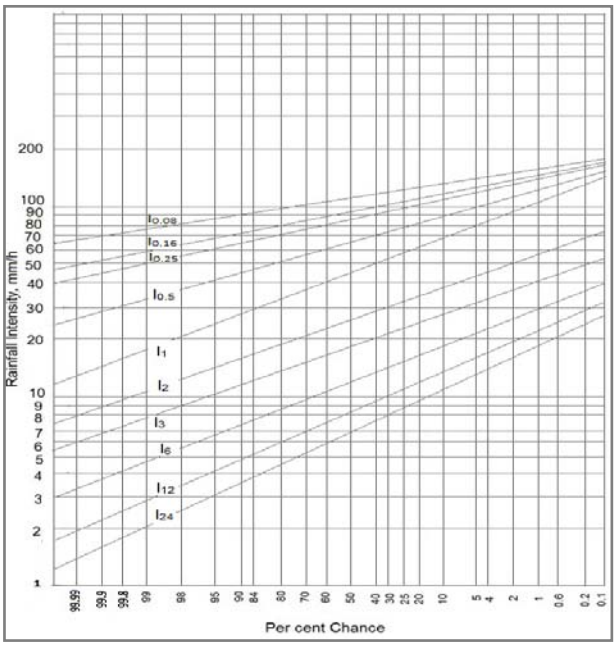

Fig. 2. Frequency distribution of rainfall intensities for various durations at Chandrapur district

2.8. *Development of Nomograph*

A nomograph is an alignment chart consisting of a set of suitably graduated parallel scales. Luzzadar (1964) suggested procedure for development of nomographs and one can obtained the detailed description form the same literature.

2.9. *Statistical analysis*

The statistical analysis for testing the goodness of fit between observed and computed values has been done by Integral square error (ISE), correlation coefficient (r), percent absolute deviation (PAD) and root mean square error (RMSE) (Diskin *et al*., 1978; Kumar *et al*., 2020).

3. Results and discussion

The present study was conducted to develop a rainfall intensity-duration-frequency relationship and nomographs of selected stations in Maharastra. This chapter deals with the development of nomographs and comparisons with corresponding computed values.

3.1. *Rainfall intensity-duration-frequency (IDF) relationship*

The intensity-duration-frequency (IDF) relationships for Sonkhas and Manora stations of Washim district, Ajaypur and Bramhapuri stations of Chandrapur district and Pusad station of Yeotmal were developed. (Table 2). The Computing method was used to evaluate plotting positions. Then, the graph was plotted on the lognormal probability paper with rainfall intensities on a log scale as ordinate and percent chance of occurrence of rainfall intensity on probability scale on abscissa as presented in Fig. 1, Fig. 2 and Fig. 3 respectively for Washim, Chandrapur and Yeotmal districts. A straight line passing through all the three points extended on

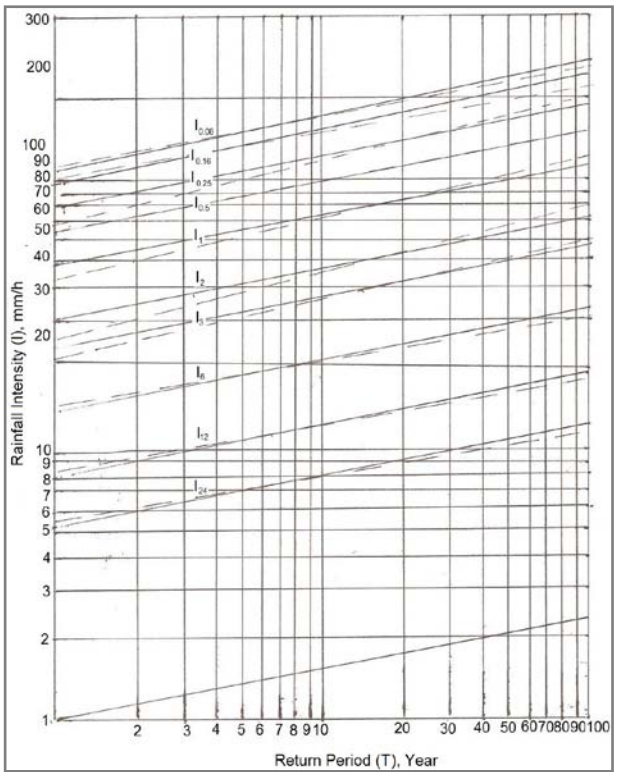

Fig. 4. Rainfall intensities for selected durations and return periods at Washim District

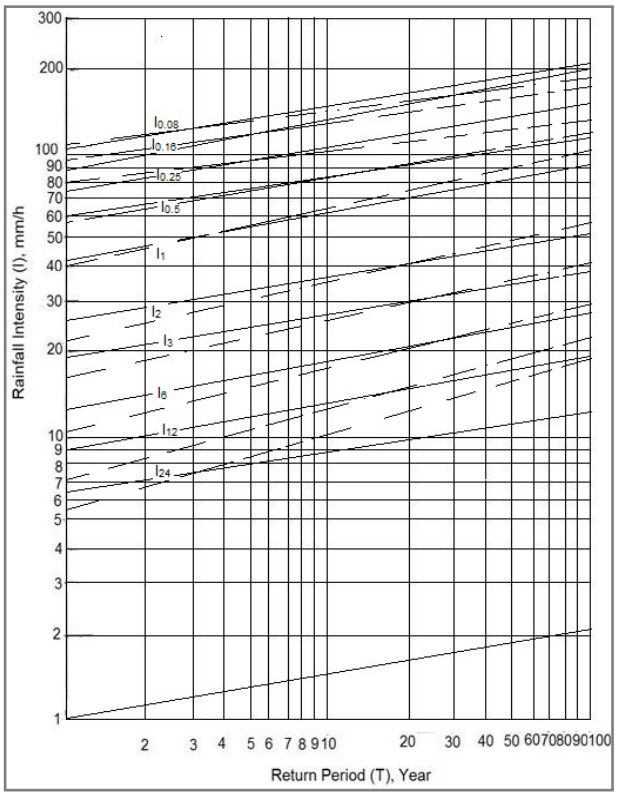

Fig. 5. Rainfall intensities for selected durations and return periods at Chandrapur district

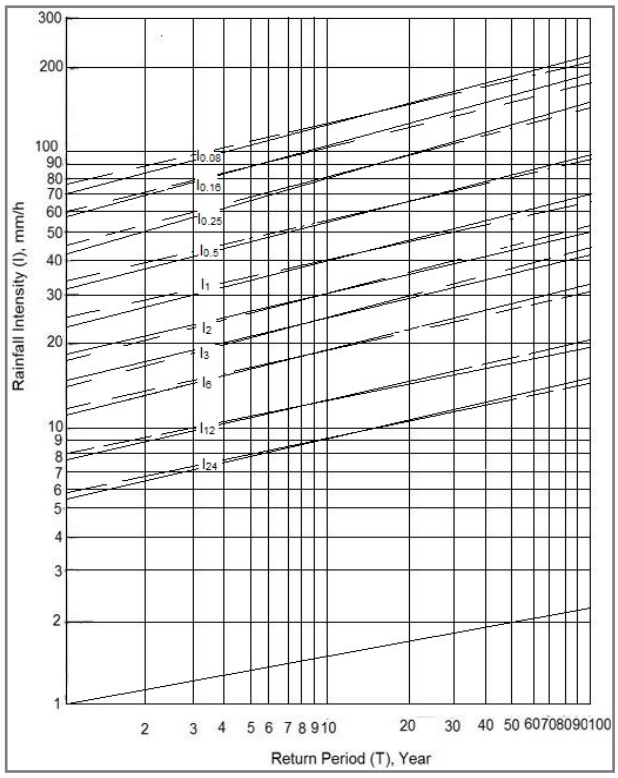

Fig. 6. Rainfall intensities for selected durations and return periods at Yeotmal district

TABLE 3

The values of constants a, b, K and d for Washimpur, Chandrapur and Yeotmal district, Maharashtra

Parameters	Washimpur	Chandrapur	Yeotmal
a	0.216	0.204	0.234
b	0.32	0.32	0.12
K	2.754	5.176	2.824
d	0.614	0.696	0.527

either side was obtained which is the frequency line of rainfall intensity for a selected duration.

The geometric mean slope of the line represents the exponent a was calculated as 0.216 for Washim district, 0.204 for Chandrapur district and 0.234 for Yeotmal district. The details are explained in the graph areshown in Fig. 4, Fig. 5 and Fig. 6 respectively for Washim district, Chandrapur district and Yeotmal district.

The rainfall intensity of the one-year return period wasused for estimation of constant ‘b’.The values of constants K and d were determined using the least square

TABLE 4

Comparison between computed and observed intensities of rainfall for Washim district

Duration (min.)	$I_{computed}$ (cm/h)			$I_{observed}$ (cm/h)			Per cent deviation		
	10 yr	25 yr	50 yr	10 yr	25 yr	50 yr	10 yr	25 yr	50 yr
15	6.39	7.79	9.05	6.10	7.60	8.80	-4.54	-2.44	-2.76
30	5.11	6.23	7.24	4.90	5.91	7.01	-4.11	-5.14	-3.18
60	3.82	4.65	5.40	3.91	4.90	5.71	2.36	5.38	5.70
180	2.17	2.64	3.07	2.37	2.82	3.21	9.22	6.82	4.56
360	1.46	1.78	2.07	1.52	1.90	2.26	4.11	6.74	9.18

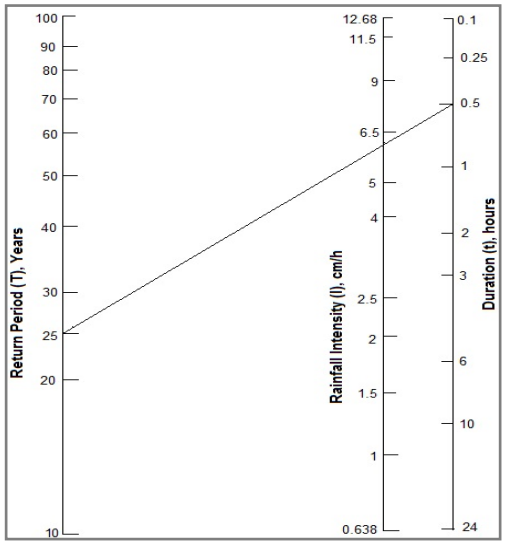

Fig. 7. Nomograph for Washim district

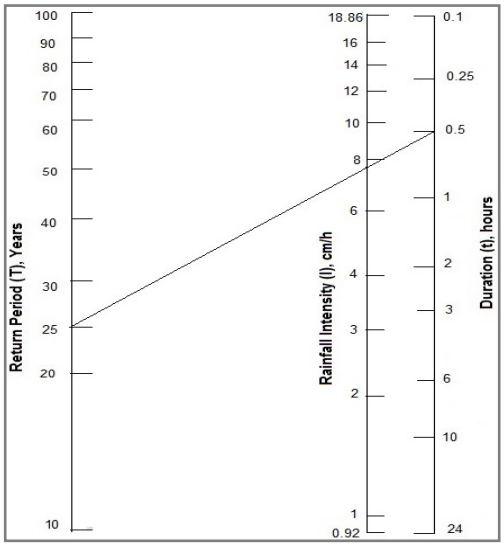

Fig. 9. Nomograph for Yeotmal district

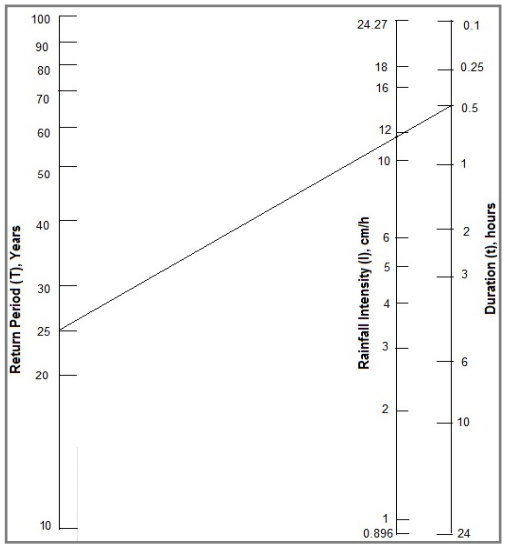

Fig. 8. Nomograph for Chandrapur district

method. The values of constants a, b, K and d for Washimpur, Chandrapur and Yeotmal district, Maharashtra are presented in Table 3.

The rainfall intensity-duration-frequency (IDF) relationship is expressed as (Bernard, 1932; Chow 1964; Kothyari and Grade, 1992),

$$I_W = \frac{2.754T^{0.216}}{(t+0.32)^{0.614}} \tag{3.1}$$

$$I_C = \frac{5.167T^{0.204}}{(t+0.32)^{0.696}} \tag{3.2}$$

$$I_Y = \frac{2.824T^{0.234}}{(t+0.12)^{0.527}} \tag{3.3}$$

TABLE 5

Comparison between computed and observed intensities of Rainfall for Chandrapur district

Duration (min.)	$I_{computed}$ (cm/h)			$I_{observed}$ (cm/h)			Per cent deviation		
	10 yr	25 yr	50 yr	10 yr	25 yr	50 yr	10 yr	25 yr	50 yr
15	12.22	14.73	16.97	12.62	14.64	16.43	3.27	-0.62	-3.18
30	9.49	11.44	13.18	9.67	11.62	13.23	1.89	1.57	0.38
60	6.81	8.21	9.46	7.01	8.43	9.60	2.94	2.68	1.48
180	3.58	4.32	4.98	3.25	3.85	4.40	-9.22	-10.87	-11.64
360	2.29	2.76	3.18	2.38	2.71	3.22	3.93	-1.81	1.26

TABLE 6

Comparison between computed and observed intensities of rainfall for Yeotmal district

Duration (min.)	$I_{computed}$ (cm/h)			$I_{observed}$ (cm/h)			Per cent deviation		
	10 yr	25 yr	50 yr	10 yr	25 yr	50 yr	10 yr	25 yr	50 yr
15	8.27	10.29	12.15	8.52	10.61	12.32	2.93	3.06	1.40
30	6.30	7.84	9.26	7.02	11.62	9.08	11.41	3.90	-1.91
60	4.61	5.74	6.78	5.08	6.3	7.23	10.14	9.72	6.69
180	2.69	3.35	3.95	2.94	3.62	4.43	9.37	8.18	12.17
360	1.88	2.35	2.77	1.97	2.41	2.82	4.53	2.72	1.84

TABLE 7

Performance evaluation of computed and observed values for Washim district

Return period (yr)	ISE	r	PAD	RMSE
10	0.022	0.999	4.36	0.036
25	0.021	0.996	3.76	0.050
50	0.019	0.998	3.59	0.053

where, $I_{w,}$ I_C and I_Y are the rainfall intensity for Washim, Chandrapur and Yeotmaldistrict (cm/h), T is the return period (yr) and t is the duration (h).

Three variables, *i.e.*, rainfall intensity, duration and return period are so graduated on three parallel scales of an alignment chart, that a line joins values on any two

TABLE 8

Performance evaluation of computed and observed values for Chandrapur district

Time period (yr)	ISE	r	PAD	RMSE
10	0.017	0.989	4.75	0.070
25	0.013	0.998	5.14	0.062
50	0.016	0.988	4.86	0.130

TABLE 9

Performance evaluation of computed and observed values for Yeotmal district

Time period (yr)	ISE	r	PAD	RMSE
10	0.025	0.996	7.10	0.077
25	0.023	0.938	10.88	0.099
50	0.019	0.987	4.44	0.099

scales intersects the third scale at a point that satisfies the given relationship. The procedure adopted for the development of the Nomograph as suggested by Luzzadar (1964) was adopted. The nomograph for Washim district, Chandrapur district, and Yeotmal district is depicted in Fig. 7, Fig. 8 and Fig. 9 respectively.

3.2. *Comparision of mathematical and nomographic solutions*

The values of percent deviation between rainfall intensity determined from nomographs and the values obtained from corresponding mathematical equations for various durations and return periods are shown in Table 4, Table 5 and Table 6 respectively for Washim district, Chandrapur district and Yeotmal district. It is observed from the Tables that deviations between the nomographic solutions (observed) and computed values of rainfall intensity vary from -5.14 to 9.22 percent for Washim district, from -11.64 to 3.93 percent for Chandrapur district and from -1.91 to 12.17 percent in case of Yeotmal district. Thus, the variation lies within the accepted limit, *i.e.*, less than 20% [Babu *et al*., 2001(a); Babu *et al*., 2001(b)]. Looking into simplicity in use, quickness and precision in results, nomograph is appeared to be the handiest tool for field workers.

3.3. *Statistical analysis*

The statistical results for Integral square error (ISE), Correlation coefficient (r), Percent absolute deviation (PAD) and Root mean square error (RMSE) are given in Table 7, Table 8 and Table 9 respectively for the Washim district, Chandrapur district and Yeotmal district.

The present study had also compared with the research analyzed for Arni station of Yeotmal district(Shinde *et al.*, 2017). The study developed nomograph of rainfall intensity-duration-frequency relationship for the given study area. The maximum deviation in the values of intensity obtained from the mathematical relationship of IDF and corresponding nomograph was in the range of -5.54 to 2.98 percent, which was well within the accepted range. The integral square error was tested for goodness of fit between observed and computed values. ISE values for Arni of 10, 25 and 50 years duration are (0.004, 0.001, 0.010), respectively, which are nearly to zero and it is satisfactory.

Similarly, the nomograph study for rainfall intensity-duration-frequency relationship at Washim district, Chandrapur district and Yeotmal districtwas found satisfactory. Thus, the nomograph study can be used satisfactorily for obtaining the solution of the rainfall intensity-duration-frequency relationship.

4. Conclusions

This study investigated thedevelopment of rainfall intensity-duration-frequency relationshipsand nomographs for Washim district, Chandrapur district and Yeotmal district in Maharashtra, India. The rainfall intensity-duration-frequency (IDF) relationship play an important tool in proper development and management of water resource project. The study analyzing rainfall charts ofvarious stations for maximum annual rainfall intensities of selected duration. The Computed method was used for the development of frequency lines. The graphical method was used to determine the value of constants 'a' and 'b' and that of 'K' was determined by the least-square technique method.The nomographs were also developed for the rainfall intensity-duration-frequency (IDF) relationships by method suggested by Luzzadar (1964). The values of constants K, a, b and d are obtained for Washim district as 2.754, 0.216, 0.32 and 0.614, for Chandrapur district as 5.167, 0.204, 0.28 and 0.696 and Yeotmal district as 2.824, 0.239, 0.12 and 0.527 respectively. The nomograph is also developed for all three stations for obtaining quick solution of rainfall intensity-duration-frequency (IDF) relationships. The deviations between the nomographic solutions (observed) and computed values of rainfall intensity vary from -5.14 to 9.22 percent for Washim district, from -11.64 to 3.93 percent for Chandrapur district and from -1.91 to 12.17 percent in case of Yeotmal district. Thus, the variation lies within the accepted limit, *i.e*., less than 20% [Babu*et al.*, 2001(a); Babu *et al*., 2001(b)]. The results had also compared with Shinde*et al.*, 2017 and were found satisfactory for nomograph study. The study concluded thatthe nomographs provide engineers with fast graphical calculations of complicated formulae to a practical precision.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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