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Isopluvial analysis and Intensity Duration Frequency (IDF) curves for different cities in India

ASHOK KUMAR DAS*, PRAGATI SRIVASTAVA and B. P. YADAV

India Meteorological Department, MoES, Lodi Road, New Delhi – 110 003, India

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e mail : dasakimd@gmail.com

सार – विश्व स्तर पर जल संसाधन प्रबंधन प्रत्येक सरकार की प्राथमिकता बनती जा रही है। यह जनसंख्या में वृद्धि, शहरीकरण, आधुनिक जीवन शैली, कृषि गतिविधियों में वृद्धि, औद्योगीकरण आदि में अत्यधिक वृद्धि के कारण है जो दिन-प्रतिदिन पानी की मांग को बढ़ा रहा है। इस शोधपत्र में भारत के विभिन्न जलवायु क्षेत्रों में 120 **अच्छी तरह से वितरित स्वत: लेखी वर्षामापी** (SRRG) **स्टेशनों पर आधारित प्रत्यागमन काल विश्लेषण तकनीक (आइसोप्लुवियल विश्लेषण) का उपयोग करते हुए डिजाइन तूफान अध्ययन पर केंद्रित है।** 2-**वर्ष,** 5-**वर्ष,** 10-**वर्ष,** 25-**वर्ष,** 50-**वर्ष और** 100-**वर्ष के प्रत्यागमन काल के लिए** 1-**घंटे,** 3-**घंटे,** 6-**घंटे,** 12 **घंटे और** 24 **घंटे की अवधि पर आइसोप्लुवियल मानचित्र तैयार करने के लिए अत्यधिक वर्षा मान लिया जाता है। इसके अलावा, देश के** 28 **स्टेशनों के लिए स्टेशनवार तीव्रता अवधि आवृत्ति (आईडीएफ) वक्र भी तैयार किए गए हैं। इस अध्ययन में विश्लेषण के लिए अत्यधिक वर्षा श्रृंखला के लिए गंबेल वितरण तकनीक का उपयोग किया गया है। आइसोप्लुवियल मानचित्र और आईडीएफ वक्र देश में रोडवेज, पुल, हवाई अड्डे, शहरों में जल निकासी व्यवस्था, रेलवे लाइन, छोटी सिंचाई परियोजनाओं, योजना और जल संसाधन से संबंधित परियोजनाओं की डिजाइनिंग जैसे छोटे बुनियादी ढांचे के निर्माण के लिए यह डिजाइन इंजीनियरों, जलविज्ञानी और हाइड्रोलिक-परामर्शदाताओं के लिए बहुत उपयोगी पाए जाते हैं ।**

ABSTRACT. Globally water resource management is becoming a priority for every Government. This is due to tremendous increase in population growth, urbanization, modern life style, increase in agricultural activities, industrialization etc. which is increasing the water demand day by day. This paper focuses on design storms studies using return period analysis technique (Isopluvial analysis) based on 120 well distributed Self Recording Raingauge (SRRG) stations in the various climatic zones of India. The extreme rainfall values are taken for preparation of Isopluvial maps for return period of 2-year, 5- year, 10-year, 25-year, 50-year and 100-year at1-hour, 3-hour, 6-hour, 12-hour and 24-hour duration. Further, station wise Intensity Duration Frequency (IDF) curves are also prepared for 28 stations of the country. The Gumbel distribution technique for extreme rainfall series is used for analysis in this study. Isopluvial maps & IDF curves are found very useful for Design engineers, hydrologists and hydraulic-consultants for the purpose of construction of small infrastructures like roadways, bridges, airports, drainage system in the cities, railway line, small irrigation projects, planning & designing of water resources related projects in the country.

Key words – Return Period, IDF, Isopluvial Maps, Design Storm Studies, Gumbel Technique, Extreme Rainfall, Water Resource Management, Drainage System, Hydraulic Structures, hydrologists, SRRG.

1. Introduction

In the recent years, Government is approving large number of projects of the country for construction of small infrastructures related to roadways, bridges, airports, drainage system in the cities, railway line, small irrigation projects etc. For successful implementation of these projects, primary requirement is the judicial planning for construction of such structures in the country. While this type of any structure is planned to establish in any area of the country, the main concern for the design engineers is the safety of people & structure as well as economical aspects of government fund. The strength of such structure directly or indirectly hydraulic in nature should be such that any extreme rainstorm water must not damage the structure as well as life and property of people. Keeping in view of this aspect in mind, the strength is to be given to the concerned structure such that optimal fund can be utilized to meet the safety measures of the structures as well as life & property of the people

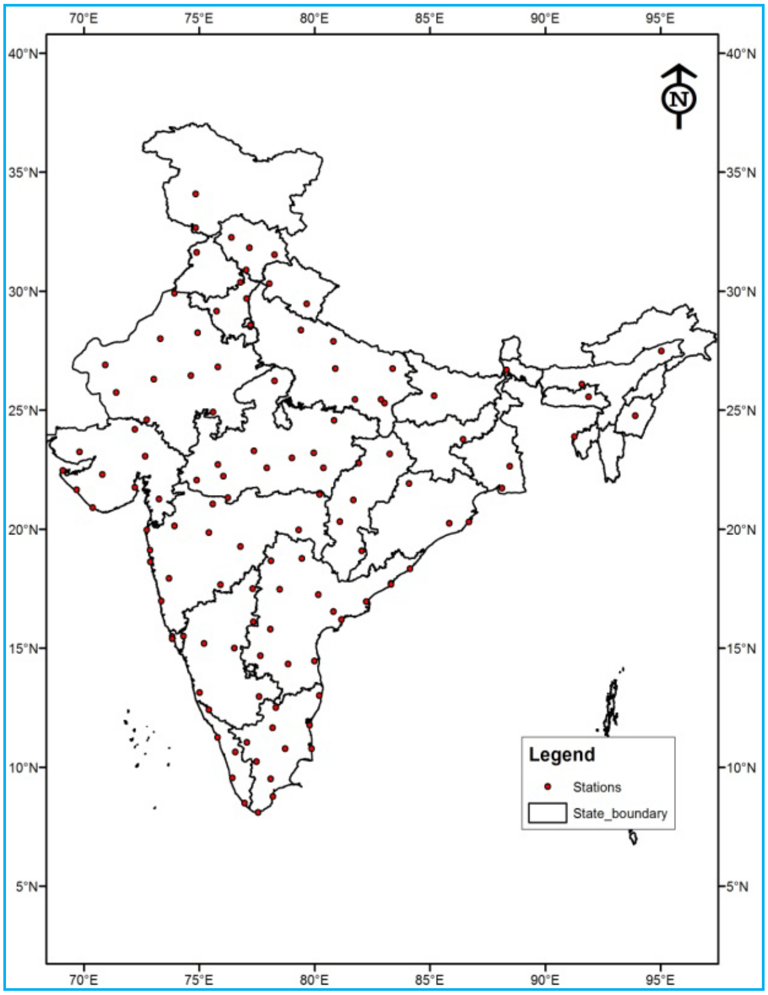


Fig. 1. Self Recording Rain Gauge (SRRG) stations used in the analysis (120 stations)

and maximum benefit can be achieved. The knowledge of maximum run-off quantitively from the rainfall is very much essential for planning and designing of such structure. Return period analysis of short duration rainfall is mostly used for the design of such structures. On the other hand, water demand is increasing day by day due to the rapid population growth, urbanization, industrialization, changing of life style, green revolution (IPCC, 2008; IMD, 2008). To meet this demand, construction of small hydraulic structures like small irrigation project, drainage system of a city etc may also be very useful and important solution which may also be the part of the development of water resources of the country.

There is also a signal of climate change which is the prime reason for increasing the frequency of heavy rainfall events and also changing the rainfall patterns (Guhathakurda *et al*., 2008; Kaur *et al*., 2017; Goswami *et al*., 2007). So, importance of short duration rainfall analysis based on extreme rainfall is required to be updated after a reasonable time of interval which may be important input for relooking the safety of existing hydraulic structures as well as construction on any new structure.

The instances of heavy or less rainfall creates havoc in the society. Too much of water leads to floods and less amount of water leads to drought. Therefore, water management is a primary requirement to tackle this changing scenario. Water resources management can be done for the purpose of use in irrigated agriculture, urbanization and industrialization. The significance of irrigated agriculture includes crop management as well as achieving the food supply rapidly which is getting decline due to water logging, soil and groundwater salinization crisis (Sule *et al*., 2016). Urban water management is effective for freezing waste water discharges and is

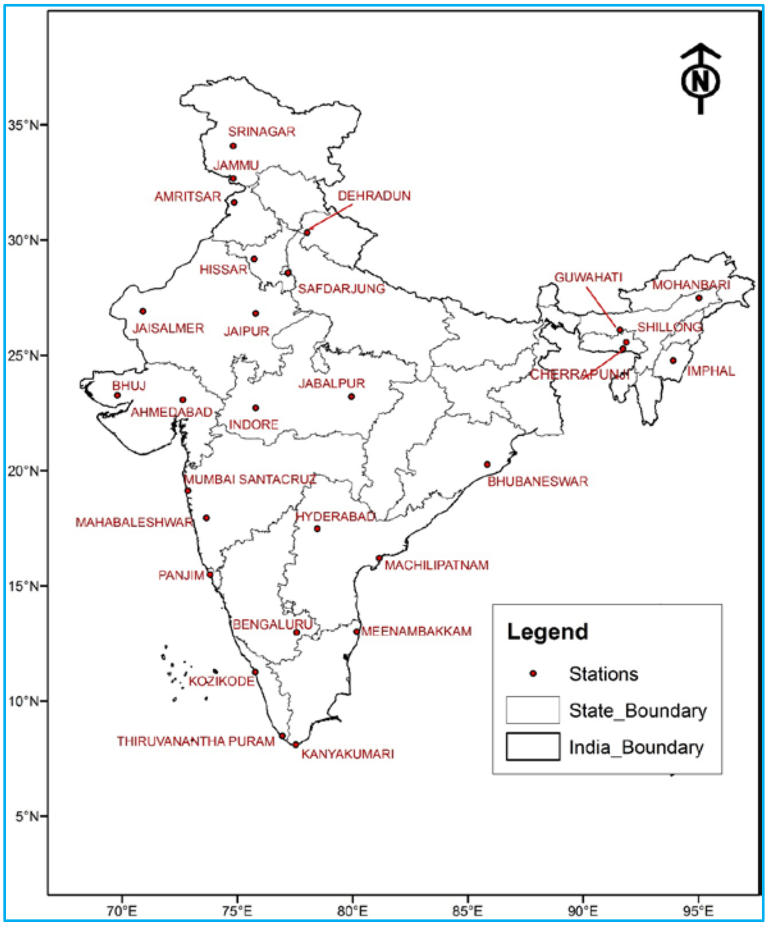


Fig. 2. SRRG stations Map for IDF curve (28 stations)

adapted by metropolitan urban area for natural drainage network. Further urbanization results in loss of runoff water management due to exponential population growth and fast paced capitals (Fernández *et al*., 2010). As water depletion crisis is increasing day by day in India due to these rapid industrialization, urbanization, population growth, agricultural activities etc., there is an urgent need for water management with the support of both meteorological and hydrological exploration.

There are various techniques used for estimation of design storms such as Normal distribution, Type-I or Gumbel distribution, Fisher and Tippett Type II and III distribution, Jenkinson's method, Pearson type III distribution and generalized extreme value of extreme rainfall series (IMD, 2010). Gumbel distribution is standard frequency approach and hence, applicable for a hydrological analysis such as flood, rainfall, temperature, evaporation, etc. to for clearly conveying information associated in rainfall pattern. Ayyar *et al*. (1971) studied the 1-hour rainfall for 2, 5, 10 and 50 years return periods for India using Gumbel's technique and prepared the isopluvial maps. Ayyar *et al*. (1971) studied the heaviest rainfall ever recorded in relation to its return period. It is concluded in the study that it is not advisable to take into account only the heaviest rainfall recorded at a particular station. There was another study by Goyal *et al*. (1984) on return period analysis of extreme rainfall events. It showed that a return period values (RPV) of an extreme event on record more than 4 to 5 times of length of the series, then Gumbel's method may be avoided.

In this study, Gumbel distribution is used to compute the various short duration return values and isopluvial maps and Intensity-duration-frequency (IDF) curves are prepared upto 100 years return period as sufficient data length available almost in all stations in the study for computation. IDF relationship of rainfall amounts is one of the most commonly used tools in water resources engineering for planning, design and operation of water resources projects (Kotei *et al*., 2013). IDF curve gives an idea for finding the relationship between the return period of mean rainfall intensity or volume and rainfall duration or storm duration. Return period analysis of extreme rainfall series of different stations have done for preparation of IDF curves as well as isopluvial maps for the whole country for various return periods with different time durations. The present study presents the isopluvial maps of different return periods & different time durations for the whole India (Fig. 1) and also IDF curves for some selected stations in the country (Fig. 2).

The primary objective of the presented study is to provide in hand information of isopluvial analysis map and IDF curve for design engineers for the use in construction related to drainage network, roads, metro, railways, airports, small hydraulic structures for irrigation or many other purposes and also for the purpose of water management.

2. Data used

The hourly and daily rainfall data of Self-Recording Rain Gauge (SRRG) of India Meteorological department from 1969 to 2013 for 527 stations across the country is considered for the study. SRRG stations are judicially selected in such a way that they should be well distributed spatially throughout the country (Fig. 1). 120 well distributed stations are selected in this study for generation of the isopluvial maps considering its suitable location and availability of data. 83 stations having more than 30 years and 37 stations having 20 to 29 years of data have been used in this study. Also, out of 120 stations, 28 stations (Fig. 2) are selected for IDF curve.

3. Methodology

The entire rainfall record in a year is analyzed to find the maximum intensity rainfall series for various durations (1, 2, 3, 6, 9, 12, 24 hours) in respect of each station. Thus, all the storms in a given year gives one value of maximum intensity for a given duration in respect of each station and consequently annual maximum rainfall series is constructed for all the stations after scrutinizing the data. Then the Type-I or Gumbel distribution with least squares fitting technique is subjected to the annual maximum series for computing the T-year t-hour return period rainfall estimate values for T = 2, 5, 10, 25, 50, 100 years and for t = 1, 3, 6, 12 & 24 hours for all identified stations

The frequency distribution function of Gumbel's distribution is given by:

$$F(X) = e^{-e^{\frac{-(X-\mu)}{\alpha}}}$$

$-\alpha \leq X \leq \alpha$ and μ, $\alpha > 0$

Here, X represents the extreme rainfall series and μ & α are the parameters of the distribution (IMD, 2010).

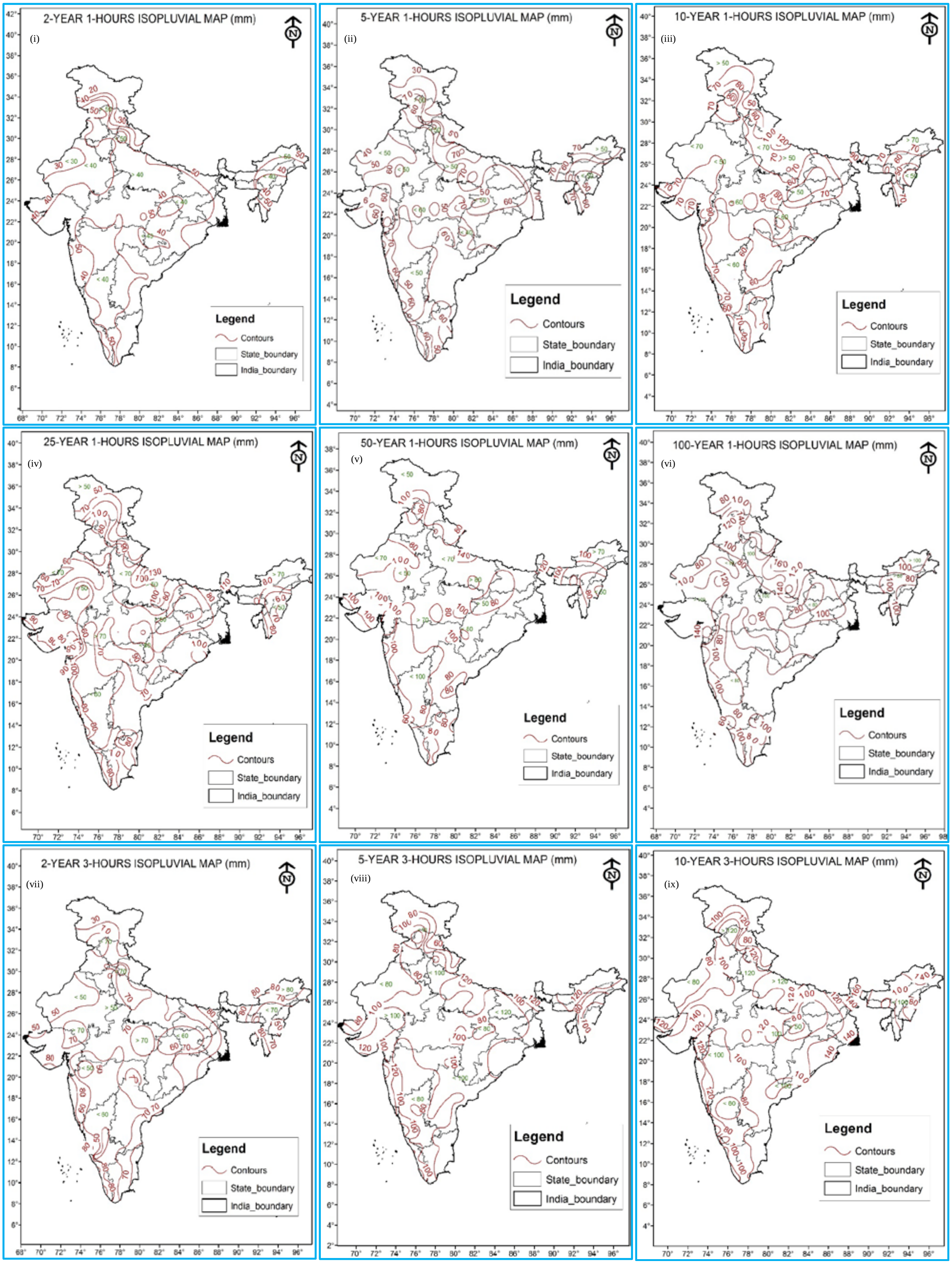
The clock-hour correction factor 1.15 is used to convert clock-hour rainfall to any 1-hour rainfall and observational-day or calendar-day amounts to corresponding 24-hour rainfall amounts for different return periods (Harihara *et al*., 1973). These return period values for each station were plotted on the India map for each T-year t-hour for isopluvial analysis. The isopluvial analysis was done by using GIS software. These isopluvial lines give fairly good estimate for T-year t-hour return period rainfall estimates.

The intensity-duration–frequency (IDF) curves for extreme rainfall which are the graphical representation of rainfall intensity distribution T-year t-hour return period rainfall estimated values for T=2, 5, 10, 25, 50, 100 years and for t = 1, 3, 6, 12 & 24 hours for each identified 15 stations.

4. Results and discussion

The isopluvial maps and IDF curves are utilized mainly for assessing rainfall events, classifying climatic regimes, assisting in designing urban drainage systems, highways, railways, airports etc. The deriving procedure for preparation of isopluvial maps and IDF curves requires long-term historical short duration rainfall observations, whereas lack of short duration rainfall records (hourly) often results in less reliable isopluvial maps and also IDF curves. Isopluvial maps were drawn for different return periods with different durations for T-year t-hour rainfall estimates T = 2, 5, 10, 25, 50, 100 years and t = 1, 3, 6, 12 and 24 hours using the output as computed by using the Gumbel extreme value distribution function.

The maps of isopluvial contour lines based on different return periods with different durations is very useful in order to obtain fairly reliable estimates of the rainfall intensity at a particular point or nearby smaller area. The spatial distribution of return period rainfall values for T-year t-hour rainfall estimates T = 2, 5, 10, 25, 50, 100 years and t = 1, 3, 6, 12 and 24 hours rainfall is shown in Figs. 3(i)-(xxxii). All the isopluvial maps are broadly similar in nature for a t-hour rainfall L for different T-year return periods. The intensity of a particular t-hour rainfall should increase with the increase in T year return periods which is revealed in the figures. The intense rainfall occurred for low return periods mainly due to frequently occurring short period synoptic situations. In the other case, these systems become less marked in case of higher return periods due to the occurrence of long term various combined synoptic features (Ayyar *et al*., 1971).


2-YEAR 1-HOURS ISOPLUVIAL MAP (mm)
(i)
5-YEAR 1-HOURS ISOPLUVIAL MAP (mm)
(ii)
10-YEAR 1-HOURS ISOPLUVIAL MAP (mm)
(iii)
25-YEAR 1-HOURS ISOPLUVIAL MAP (mm)
(iv)
50-YEAR 1-HOURS ISOPLUVIAL MAP (mm)
(v)
100-YEAR 1-HOURS ISOPLUVIAL MAP (mm)
(vi)
2-YEAR 3-HOURS ISOPLUVIAL MAP (mm)
(vii)
5-YEAR 3-HOURS ISOPLUVIAL MAP (mm)
(viii)
10-YEAR 3-HOURS ISOPLUVIAL MAP (mm)
(ix)
Legend
Contours
State_boundary
India_boundary
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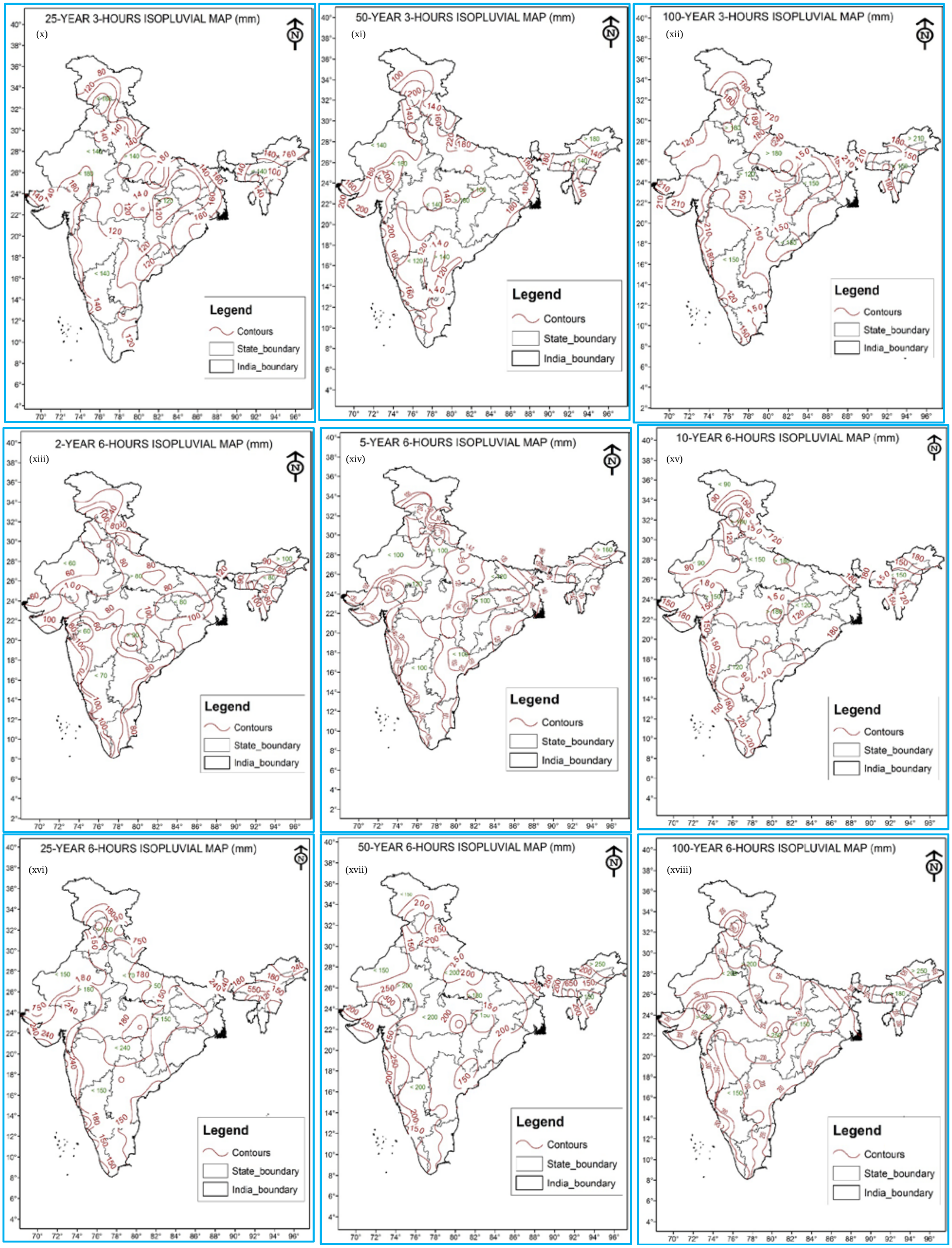
25-YEAR 3-HOURS ISOPLUVIAL MAP (mm)
(x)
50-YEAR 3-HOURS ISOPLUVIAL MAP (mm)
(xi)
100-YEAR 3-HOURS ISOPLUVIAL MAP (mm)
(xii)
2-YEAR 6-HOURS ISOPLUVIAL MAP (mm)
(xiii)
5-YEAR 6-HOURS ISOPLUVIAL MAP (mm)
(xiv)
10-YEAR 6-HOURS ISOPLUVIAL MAP (mm)
(xv)
25-YEAR 6-HOURS ISOPLUVIAL MAP (mm)
(xvi)
50-YEAR 6-HOURS ISOPLUVIAL MAP (mm)
(xvii)
100-YEAR 6-HOURS ISOPLUVIAL MAP (mm)
(xviii)
Legend
Contours
State_boundary
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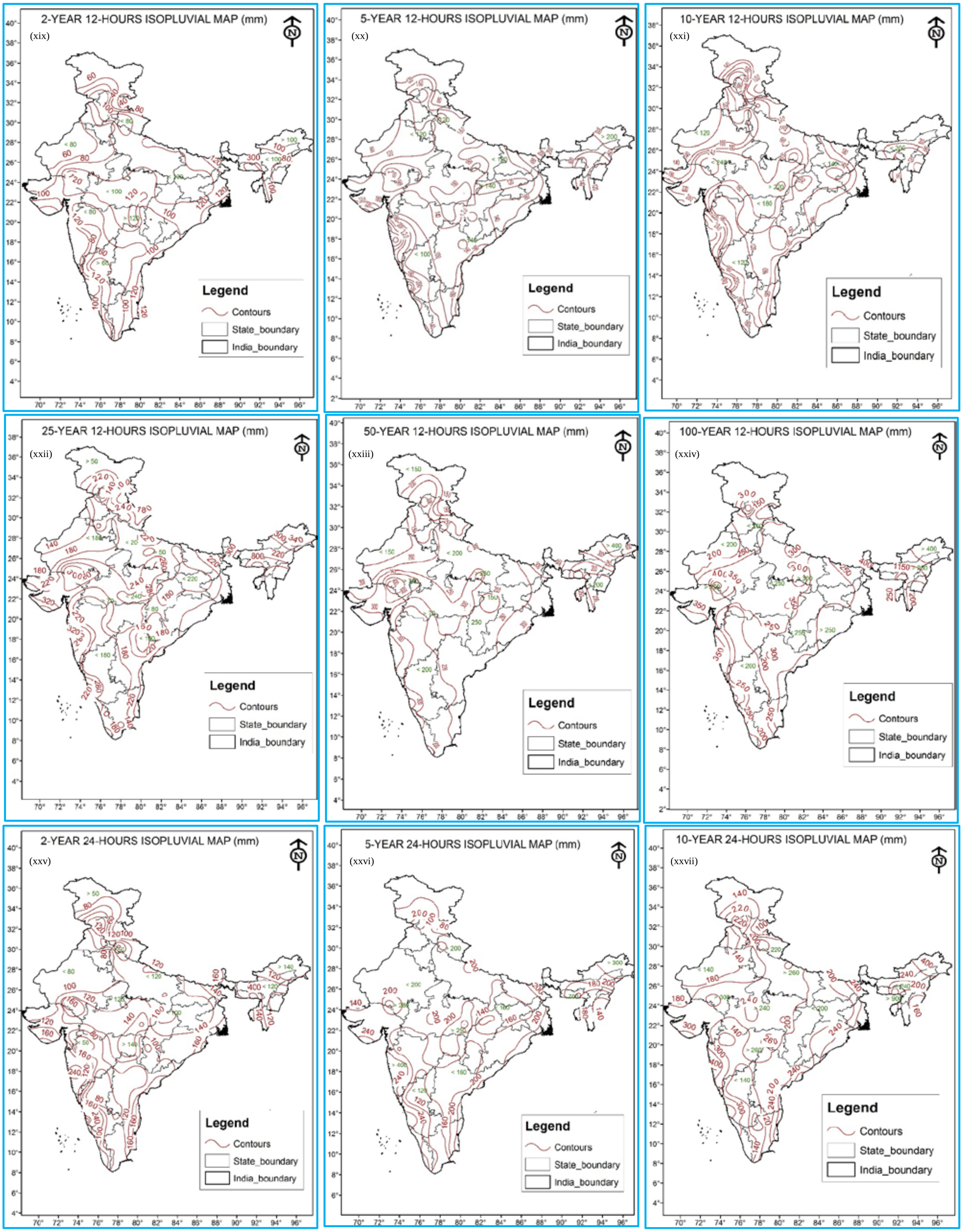
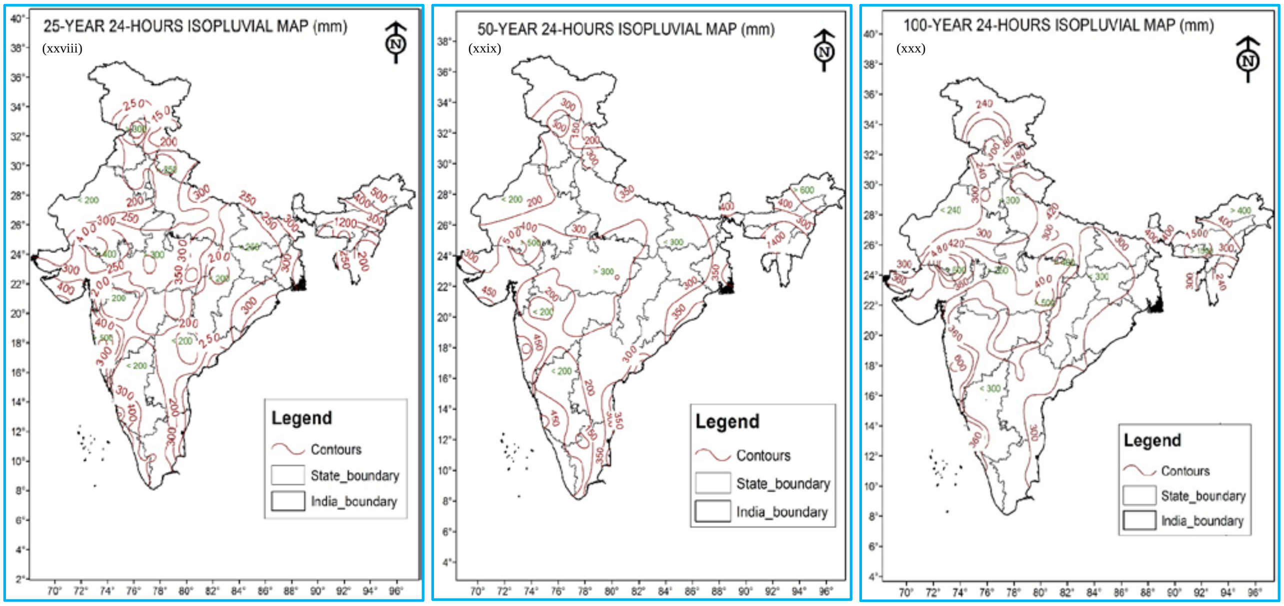

2-YEAR 12-HOURS ISOPLUVIAL MAP (mm)
(xix)
5-YEAR 12-HOURS ISOPLUVIAL MAP (mm)
(xx)
10-YEAR 12-HOURS ISOPLUVIAL MAP (mm)
(xxi)
25-YEAR 12-HOURS ISOPLUVIAL MAP (mm)
(xxii)
50-YEAR 12-HOURS ISOPLUVIAL MAP (mm)
(xxiii)
100-YEAR 12-HOURS ISOPLUVIAL MAP (mm)
(xxiv)
2-YEAR 24-HOURS ISOPLUVIAL MAP (mm)
(xxv)
5-YEAR 24-HOURS ISOPLUVIAL MAP (mm)
(xxvi)
10-YEAR 24-HOURS ISOPLUVIAL MAP (mm)
(xxvii)
Legend
Contours
State_boundary
India_boundary
N



Figs. 3.(i-xxxii). Isopluvial map for T-year t-hour return period rainfall

TABLE 1

Variation of T-year t-hour estimated return period rainfall values

Return periods T = 2, 5, 10, 25, 50, 100 years for duration t hour	RPV (cm) for the region						
	West region	West Coast region	Peninsula region	Gangetic Plain	North-West region	NE region	Central region
t = 1 hour	3-8	5-14	4-10	4-16	6-14	4-10	5-8
t = 3 hour	5-12	8-18	5-15	7-14	7-24	5-21	7-21
t = 6 hour	6-20	10-30	6-20	8-25	10-30	6-30	10-30
t = 12 hour	6-20	12-35	7-30	12-30	10-30	8-115	12-35
t = 24 hour	8-24	24-60	8-30	12-42	14-36	12-150	14-40

The RPV estimates are discussed for the following seven broad regions of the country; (*i*) West region, (*ii*) West Coast, (*iii*) Peninsula region, (*iv*) Gangetic Plains, (*v*) North-West region, (*vi*) North-East region, (*vii*) Central region. The spatial variation of T-year t-hour return period rainfall estimated values [Figs. 3(i)-(xxxii)] for T = 2, 5, 10, 25, 50, 100 years and for t = 1, 3, 6, 12 & 24 hours are summarized (Table 1) below:

i. West region : The RPV estimate for t==1, 3, 6, 12 & 24 hours and T = 2, 5, 10, 25, 50, 100 years varies from 3 cm to 24 cm over West region.

ii. West Coast region : The RPV estimate for t==1, 3, 6, 12 & 24 hours and T = 2, 5, 10, 25, 50, 100 years varies from 5 cm to 60 cm over West Coast region.

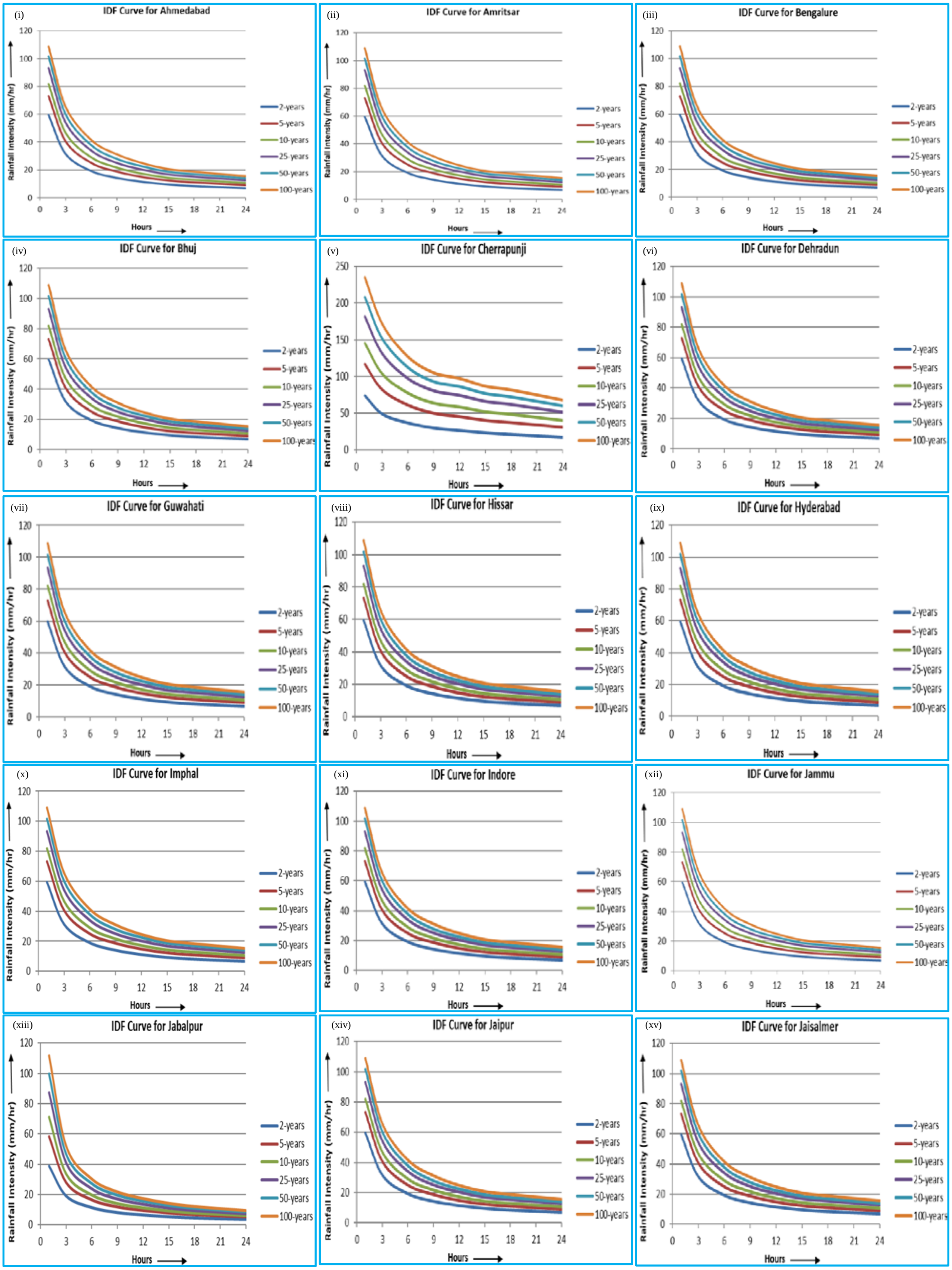
iii. Peninsula region : The RPV estimate for t==1, 3, 6, 12 & 24 hours and T = 2, 5, 10, 25, 50, 100 years varies from 4 cm to 30 cm over Peninsula region.

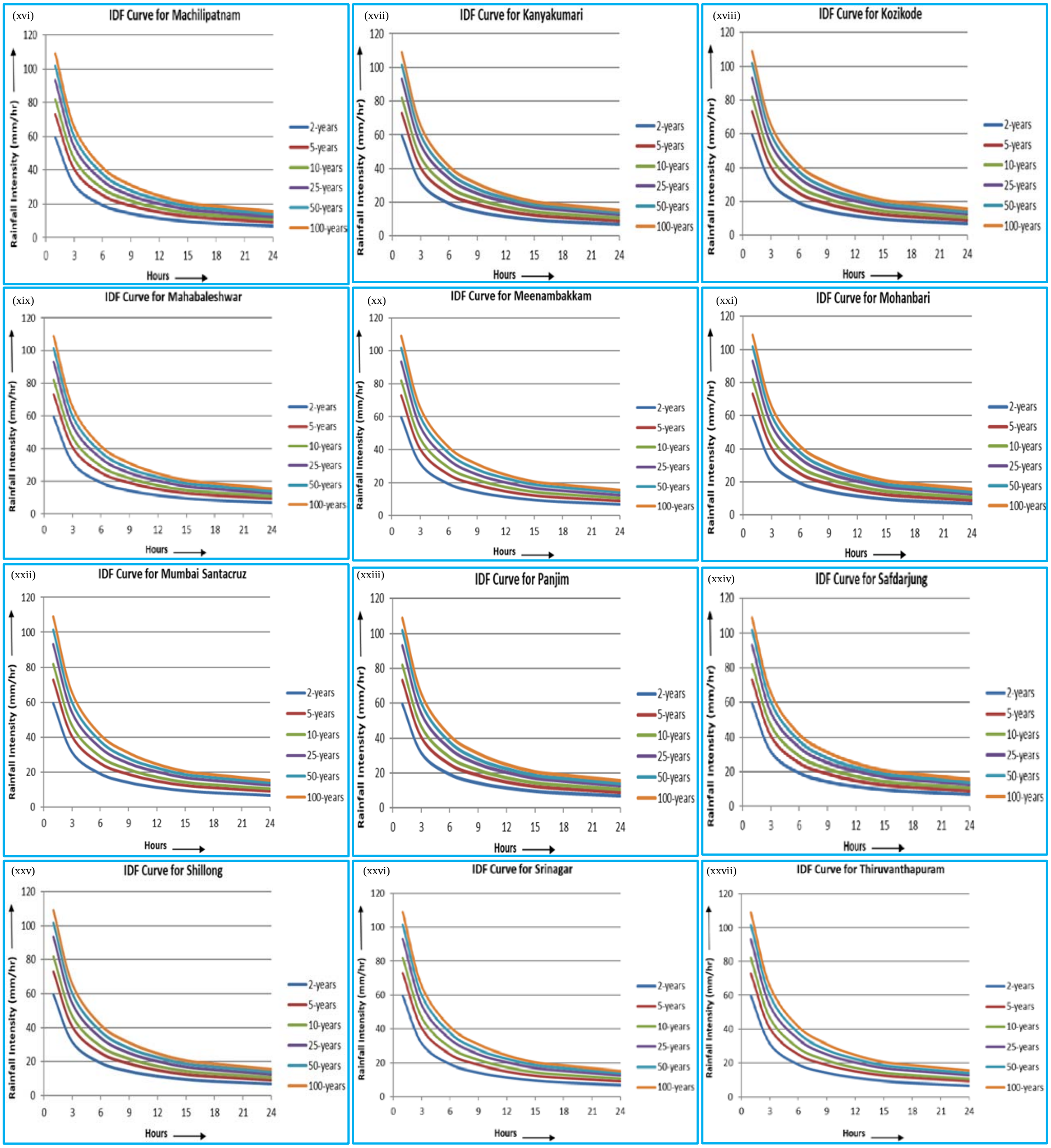
iv. Gangetic Plain : The RPV estimate for t==1, 3, 6, 12 & 24 hours and T = 2, 5, 10, 25, 50, 100 years varies from 4 cm to 42 cm over Gangetic plain region.

v. North-West region : The RPV estimate for t==1, 3, 6, 12 & 24 hours and T = 2, 5, 10, 25, 50, 100 years varies from 6 cm to 36 cm over North-West region.

vi. North-East region : The RPV estimate for t==1, 3, 6, 12 & 24 hours and T = 2, 5, 10, 25, 50, 100 years varies from 4 cm to 160 cm over NE region which includes the world's highest ever recorded rainfall station Cherrapunji.

vii. Central region : The RPV estimate for t==1, 3, 6, 12 & 24 hours and T = 2, 5, 10, 25, 50, 100 years varies from 5 cm to 40 cm over Central region.


(i) IDF Curve for Ahmedabad
(ii) IDF Curve for Amritsar
(iii) IDF Curve for Bengalure
(iv) IDF Curve for Bhuj
(v) IDF Curve for Cherrapunji
(vi) IDF Curve for Dehradun
(vii) IDF Curve for Guwahati
(viii) IDF Curve for Hissar
(ix) IDF Curve for Hyderabad
(x) IDF Curve for Imphal
(xi) IDF Curve for Indore
(xii) IDF Curve for Jammu
(xiii) IDF Curve for Jabalpur
(xiv) IDF Curve for Jaipur
(xv) IDF Curve for Jaisalmer
Rainfall Intensity (mm/hr)
Hours
2-years
5-years
10-years
25-years
50-years
100-years



Figs. 4(i-xxvii). Intensity Duration Frequency (IDF) Curves for some selected cities

West coast region shows the higher values of RPV of rainfall (5-60 cm) for all return periods of any durations, which may be due to the various synoptic features at local level, *e.g*, periodic shifts and pulsations in the easterly jet streams (Koteswaram *et al*., 1958), cyclonic micro-vortices near Maharashtra and Saurashtra coasts, offshore trough and vortices during monsoon season (George *et al*., 1956) and also the role of orography whereas West Region can receive the lower side of estimated rainfall (3-24 cm). Gangetic plains and central India show nearly similar variation in the minimum and maximum amount of rainfall for any return periods and durations in the regions. The areas near to Cherrapunji station in the North-East region can receive maximum rainfall (4-150 cm) as compared to all other regions of the country for all RPVs. However, the higher values are within the nearby periphery of Cherrapunji station and then sharply decreases away for the station in the region.

The North-East region including the areas near to Cherrapunji can receive rainfall (4-160cm).

The rainfall IDF curves for extreme rainfall play a vital role for design engineers, hydrologists and hydraulic-consultants of different public & private sector organizations for the purpose of planning & designing of water resources related projects, *viz*., construction of small hydraulic structures, planning of irrigation & drainage purposes, airports, power plants, railways, metro rail, road bridges, National Highways, culverts etc. A short duration high intensity rainfall may cause disastrous consequences in an area, if proper drainage system will not be available. To take future course of action for construction of drainage system and also planning for the water management, this study of IDF curves will play a very useful tool. The IDF curves for 27 stations are prepared and shown in Figs. 4(i)-(xxvii). The intensity of rainfall should decrease with the increase in duration of t hour for a T year return period which is revealed in all figures.

These results may fulfill the requirements of construction of larger structures like bridges, railways, metro rail, airports and also small hydraulic structures such as irrigation tanks, culverts etc. For any design purposes, in the first case, estimated rainfall values of higher return periods will be required whereas in second case, values of low return periods are generally used. So, these IDF curves are very much useful for the purpose of establishment of any structure which is hydraulic in nature as well as water management.

5. Conclusion

This study will be very useful for design engineers, hydrologists and hydraulic-consultants of different public & private sector organizations for the purpose of planning & designing of water resources related projects viz., construction of small hydraulic structures, planning of irrigation & drainage purposes, metro, railways and road bridges, National Highways, culverts etc. IDF Curves are more vital for studying for the flood hydrograph. It is observed that the return period rainfall value increases with increasing return period and also with increasing duration. It is observed from the study that rainfall intensity increases with the increase in return period and *vice versa*. The maximum estimated rainfall for any return periods and durations, West coast region can receive the higher rainfall values (5-60 cm) and West region can receive the lower side of rainfall (3-24 cm). Gangetic plains and central region can receive lesser and nearly similar estimated rainfall (4-40 cm) for any return periods and durations. The areas in the North-East region including the areas near to Cherrapunji can receive rainfall (4-160 cm). However, the higher values are within the nearby periphery of Chherapunji station and then sharply decreases away for the station in the region.

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