A Study on Consecutive Day Maximum Rainfall for Disaster Mitigation in Tiruchirapalli City, India

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ABSTRACT

In the design of irrigation and other hydraulic structures, evaluating the magnitude of extreme rainfall events is of much importance. The capacity of such structures is usually designed to cater for the prospects of incidence of extreme rainfall during the life span of the structure. In this study, an extreme value analysis of rainfall for Tiruchirapalli city in Tamil Nadu, India was carried out using 100 years of rainfall data. Weibull's plotting position formula is used in the analysis. The forecasted maximum rainfalls for the selected return periods are evaluated and the analysis will be helpful to ascertain the extreme rainfall event. The present study also aims to evaluate the consecutive days of maximum rainfalls using 100 years of daily rainfall data of Tiruchirapalli city, Tamil Nadu. This city is the fourth largest urban conglomerate of the state. From the results analysis, it is found that one day maximum rainfall for the city is obtained as 318.9 mm for 100-year return period, and that the maximum rainfall values for 2-, 3-, 4- and 5-day consecutive periods, corresponding to 100-year return period, are being obtained as 366.6 mm, 368.5 mm, 383.5 mm and 403.3 mm, respectively. Further, the study provides the rainfall amount for 10-year and 50-year return periods which will be helpful in preparing disaster mitigation and management measures in the study area.

KEYWORDS: Irrigation structures, Hydraulic structures, Rainfall, Return period, Weibull's plotting position, Disaster mitigation.

INTRODUCTION

Urbanization increases impervious area and groundwater depletion which directly affects and distorts the water cycle (Kim and Yoo, 2009). Many applications in the water resources engineering require proper evaluation of rainfall potential and its return period from available historical data.

It is clear that the water generated from urban area can be utilized effectively for improving groundwater table through several water management initiatives (Kim et al., 2002). Examples include flood estimation in watersheds, water balance studies, water management studies, rainwater harvesting, detention and retention pond design, evapotranspiration estimation, irrigation planning,… etc. Planning and development of water resources at the local or regional levels requires comprehensive and reliable information of hydrological data of the area under investigation. Assessing water availability of a region needs proper data base, the absence of which can lead to erroneous planning and design. Long period data can provide reliable water resources assessment (Bhaskar and Suribabu, 2014). The degree of uncertainty tends to be

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higher if data length is short. Mathew and Vivekanandan (2009) examined the effect of data length on water resources assessment. The results of the study indicated that the lower the data length, the higher is the likelihood of overestimating water resources availability in a region. The magnitude of rainfall with various recurrence interval, probabilities of wet spells and probability of dry spells are important from irrigation scheduling point of view. Rainfall at a particular place is also known to be influenced by the results of its local/ regional atmospheric and geomorphologic environments.

An important aspect in hydrology is to interpret the future probabilities of occurrence from past records of hydrologic events. Vivekanandan and Mathew (2010) used probabilistic modeling to fit six different distributions to annual maximum rainfall for consecutive days such as 1-day, 2-day and 3-day for Devgadhbaria region of Gujarat. Chi-square and Kolmogorov-Smirnov tests are used to judge the applicability of the distributions for modeling of the recorded rainfall data. The standard procedure for estimating the frequency of occurrence of hydrological events is frequency analysis. The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence using probability distributions.

The study of extreme rainfall events involves the selection of a sequence of the maximum observations from the respective data series. Goswami et al. (2006) examined the trend of daily heavy (R >100 mm) and very heavy (R > 150 mm) rainfall events over a relatively large region covering 1803 stations for the period 1951-2000. The findings of the study showed that there is a 10% increase per decade in the level of heavy rainfall events since the early 1950s and more than two folds increase in very heavy events. Khan et al. (2007) investigated spatial and temporal variability of daily and weekly precipitation extremes in South America. They have proposed a new measure called the precipitation extremes volatility index to measure the variability of extremes. Analysis of the study showed the increasing trend of daily maximum rain in the Amazon basin. Guhathakutra et al. (2010) carried out the frequency analysis of rain days, heavy rainfall days and one-day extreme rainfall, in order to observe the impact of climate changes on extreme weather events and flood risks in India. The report showed that the frequency of heavy rainfall events is decreasing in major parts of Central and North India; while such events are increasing in Peninsular India as well as in East and North-East India. The present study aims to evaluate rainfall magnitude for different return periods for Tiruchirapalli city in India using Weibull's plotting position method

STUDY AREA

Tiruchirappalli city, known also as Trichy, is an urbanized watershed in the Cauvery river basin. The terrain of the city is flat. The city lies at an altitude of 78 m above sea level and is traversed by the rivers Cauvery and Coleroon forming the northern boundary of Tiruchirapalli. There are few hills located within the city; with the prominent among them are: the Golden Rock, Rock Fort and the one in Thiruverumbur. There are reserve forests along Cauvery, located to the west and north-west of the city. Because of Cauvery and Coleroon rivers flowing through the city, the northern part of the city is greener than other areas. As per 2004 national census, the city has a population of 1.21 million inhabitants.

Probabilistic Method

Probability distributions are widely used to understand the rainfall pattern and compute probabilities. In the present study, the probability of exceedence of rainfall T = m/(N+1), where m is the descending order and N is the total number of events, was computed using the Weibull’s plotting position formula applied to the observed daily rainfall data.

Analysis of Data

The study of temporal distribution of rainfall requires continuous historical data. The present study uses 100-year daily rainfall data, obtained from IMD, Pune. The maximum 1-, 2-, 3-, 4- and 5-day rainfall days were analyzed as per procedure detailed above. Fig. 1 presents the results. The 1-day maximum rainfall for the city is computed to be 318.9 mm for 100-year return period. The maximum rainfall values for 2-, 3-, 4- and 5-day consecutive periods, corresponding to 100-year return period, are obtained to be 366.6 mm, 368.5 mm, 383.5 mm and 403.3 mm respectively. The 1-day maximum rainfall corresponding to 10-year return period is obtained as 152.4 mm.

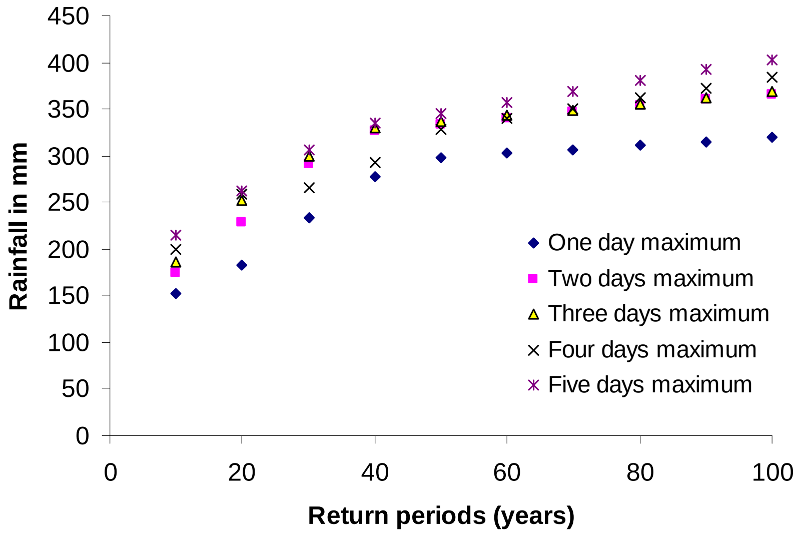

Figure (1): Maximum rainfall for various return periods

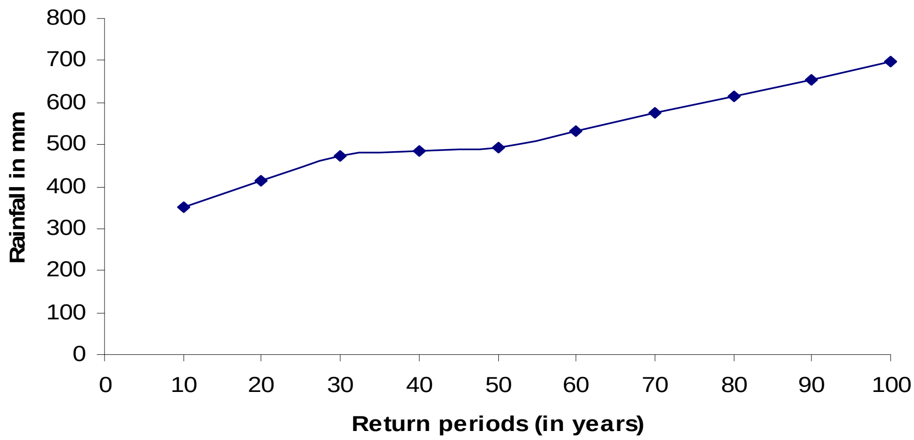

Figure (2): Maximum monthly rainfall for various return periods

It may be noted from Fig. 1 that when an imaginary vertical ordinate is drawn between one-day and five-day rainfall, the height of the ordinate is uniform. In case of four-and five-day cases, the significant variation is attributed to the increased size of return periods. In most of the return periods, the four-day and five-day maximum rainfall values are found to be close to each other. Hence, it is concluded that in the case studied, the consideration of either four or five consecutive day rainfall makes neither an overestimation nor an underestimation if any of the data is used for the design of a hydraulic structure.

Table 1 shows the maximum rainfall amount for 10-year, 50-year and 100-year return periods for one-day to five-day consecutive rainfalls. The average difference in rainfall amount between 10-year and 50-year return periods is 142 mm, whereas between 100-year and 50-year return periods, the average difference is 40 mm.

Table 1. Maximum rainfall for one, two, three, four and five consecutive days using plotting position method

Return period (year)	One-day rainfall (mm)	Two-day rainfall (mm)	Three-day rainfall (mm)	Four-day rainfall (mm)	Five-day rainfall (mm)
10	152.4	174.8	185.7	199.4	214.4
50	297.96	333	336.2	328.7	345.5
100	318.9	366.2	368.5	383.5	403.3
X_{50}-X_{10}	145.56	158.2	150.5	129.3	131.1
X_{100}-X_{50}	20.94	33.2	32.2	54.8	57.8

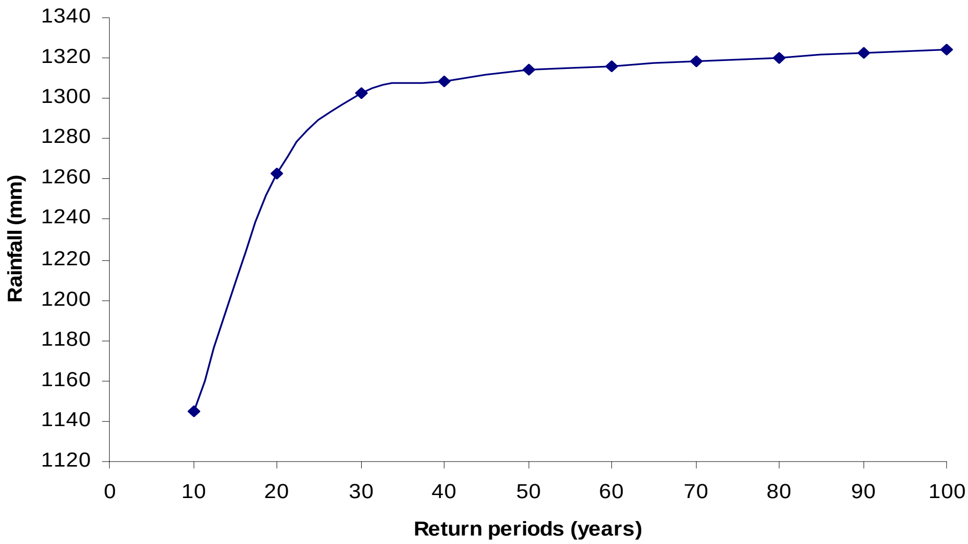

Figure (3): Annual rainfall for various return periods

The hydraulic system designed based on 10-year and 50-year return periods will have distinct dimensions of the components. Designs based on 50-year and 100-year return periods will have small differences in the dimensions of the components.

Fig. 2 shows the maximum monthly rainfall for various return periods. The variation of maximum monthly rainfall between 10-year and 50-year return periods is obtained as 141.5 mm, whereas between 50-year and 100-year return periods it is 204.9 mm. The maximum monthly rainfall of the study area occurs during Oct.-Dec., the north-east monsoon period. From Fig. 2, it is seen that the slope of the curve between 30-year and 50-year return periods is flatter than the other portion of the curve. There is a steep increase in the amount of maximum rainfall from 50-year return period onwards.

In the case of annual rainfall, the shape of the curve shown in Fig. 3 is flat from 30-year return period onwards. The annual rainfall figures for 10-year, 30-year and 100-year return periods are 1144.6 mm, 1302.8 mm and 1324.5 mm, respectively. As per plotting position, the difference in rainfall amount between 50-year and 100-year return periods is 21.7 mm. This indicates that 30- year return period is good for planning in case that annual rainfall is required for specific analysis.

For the design of drainage system for any urban area, a vital but tricky consideration is the return period of the "extreme" rainfall events. Generally, a best value will lie between overestimating and underestimating the risks involved and a major deciding factor is the cost. When design is done based on 10-year return period, the risk involved will be higher, whereas if 100-year return period is considered, the risk probability will be less. Hence, selection of appropriate design value is becoming crucial. It is very important that selection of probability distribution for a particular data set should not provide an underestimate design value. The data corresponding to 50-year return period can be used in the study area as it falls within the underestimating and overestimating design value. In particular, the design estimate presented here would be beneficial, and valuable guidelines during the construction of new drainage system and rehabilitation of existing drains in the study area have been provided, as poor drainage has been identified as one of the major factors causing flooding in the area.

CONCLUSIONS

Extreme rainfall events pose threat to thickly populated areas. The increase in the impervious area in an urban conglomerate can result in large flooding during extreme rainfall events. An accurate estimation of frequency and distribution of such events can significantly aid in policy planning and observation system design. Two important aspects have been investigated in this study; namely (i) maximum daily rainfall and (ii) consecutive days of maximum rainfalls using 100 years of daily rainfall of Tiruchirapalli city, Tamil Nadu. From the analysis of 100 years of daily rainfall, it is found that there is a significant difference in rainfall amount between 10-year and 50-year return periods for one-day to five-day consecutive rainfall. The difference in rainfall amount for one to five consecutive day rainfall estimates between 50-year and 100-year return periods is insignificant. Hence, the hydraulic design based on 50-year return period holds good even for 100-year return period rainfall for the study area.

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