Rainfall Analysis in Mumbai using Gumbel’s Extreme Value Distribution Model

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ABSTRACT: Mumbai, the island city of India is becoming increasingly vulnerable to hazards related to extreme events in weather and climate related to global warming including frequent floods and water logging. Also, it has been observed that in recent years there is occurrence of exceptionally heavy rainfall events and associated flash floods in many areas of Mumbai that motivated us to study long-term changes in extreme rainfall over Mumbai region. The aim of the present study is to perform statistical analysis of rainfall for various duration and return periods, prediction of maximum probable precipitation for different return periods, and analysis of rainfall trend and intensity pattern for Mumbai region. The records of the observed annual maximum daily rainfall were analyzed statistically for different rainfall return periods (2, 3, 5, 10, 15, 20, 30, 50, 70 years) during the period 1994 to 2013 for Santacruz rain gauge station using Gumbel’s extreme value distribution model.

Keywords: Rainfall analysis, Return period, Gumbel’s Model, Probable maximum precipitation.

1. INTRODUCTION
Mumbai is a highly populated city that is located on the coast. This island city receives high intensity rainfall from monsoon and being a coastal city, due to tidal effect, even small intensity of rainfall coupled with tidal effect at the same time results in flooding. During non monsoon months, various lakes in Mumbai (modak sagar, tansa lake, vihar lake, tulsi lake, bhatsa and middle vaitarna) that are the major sources of water, becomes dry in non-monsoon season resulting in lower water availability of the huge population of Mumbai city. A large amount of the variability of rainfall is related to the occurrence of extreme rainfall events and their intensities. Therefore, there is a need to know the magnitudes of extreme rainfall events over different parts of the area under study. The study of spatial variability of extreme rainfall events help to identify zones of high and low values of extreme rainfall events. Therefore, in the context of global change, research on rainfall patterns and their variations presents a challenge to the scientific community. The main objective of this study is to analyze recent trends in precipitation in the Mumbai metropolitan area. In this article, the effect of record length on the extreme value estimates of daily rainfall at Santacruz using probabilistically appropriate probable maximum precipitation theory (PMP) and Gumbel’s distribution model has been analyzed.

2. STUDY AREA
The city of Mumbai (Greater Mumbai) consists of two administrative districts: the Island City District and the Suburban District. It extends between 18° and 19.20° N and between 72° and 73° E (OECD Report, 2010). The city extends from East to west by about 12 km, where it is broadest, and from North to South extends about 40 km. Geographically, Greater Mumbai is an island separated from the mainland by the narrow Thane Creek and a relatively wider Harbour Bay. Thus, the area of Greater Mumbai is surrounded on three sides by the seas: the Arabian Sea to the west and the south, the Harbour Bay and the Thane Creek in the east. Mumbai has a tropical wet and dry climate, and
may be best described as moderate temperatures with high level of humidity. Its coastal and tropical location ensure moderate temperature throughout the year, average of 27.2 °C and annual average precipitation of 242.2 cm (95.35 inches). The temperature of Mumbai city is on average about 30°C in summer and 18°C in winter. Mumbai has 4 distinct seasons: Winter (December–Feb); summer (March–May); Monsoon (June–Sep) and Post-Monsoon (Oct–Dec). Every year, Mumbai experiences heavy rainfall during the monsoon time as it is in the windward side of Western Ghat. Between June and September, the south west monsoon rains splurge the city. Occasionally, pre monsoon showers are received in May and north-east monsoon showering may occur in October and November. The maximum annual rainfall ever recorded was 3,452 mm (136 in) for 1954. The highest rainfall recorded in a single day was 944 mm (37 in) on 26 July 2005. The average total annual rainfall is 2,146.6 mm (85 in) for the Island City, and 2,457 mm (97 in) for the suburbs. Due to incessant rains and simultaneous high tidal waves, the overall risk to flooding is more in coastal urban areas. Mumbai is prone to flooding and experiences severe flooding almost every year, for example, 2004 and 2007, Mumbai witnessed flooding each summer. But in 2005, the city witnessed the worst flooding in its recorded history. Hence, the present study aims to develop a comprehensive estimation of IDF and DDF curves, and subsequent design rainfall estimation with substantially longer data sets, which might be essential inputs to flood modelling for this overpopulated, flood prone urban region as in [5].

3. METHODOLOGY

The daily rainfall data from (1993-2013) was collected from IMD regional office, Santacruz, Mumbai and a detailed analysis was done to check the rainfall trend and behaviour.

3.1 Rainfall Pattern Analysis

From the data obtained from IMD (Indian Metrolgical Department, Santacruz), Rainfall pattern and behaviour is been analysed on annual and monthly basis and various graphs has been plotted for years (1994-2013). Trend analysis of a time series consists of the magnitude of trend and its statistical significance. Obviously, different workers have used different methodologies for trend detection. In general, the magnitude of trend in a time series is determined either using regression analysis (parametric test) or using Sen’s estimator method (non-parametric method).

Fig 1: Location map of the study area (Source: www.mapsofindia.com)
Both these methods assume a linear trend in the time series ([6], [7]). Regression analysis is conducted with time as the independent variable and rainfall/temperature as the dependent variable. The regression analysis can be carried out directly on the time series or on the anomalies (i.e. deviation from mean).

A linear equation,

\[ y = mt + c \]  

where ,

c : the intercept trend
m : the slope,

The linear trend value represented by the slope of the simple least-square regression line provided the rate of rise/fall in the variable.

### 3.2 Probable Maximum Precipitation

PMP is defined as the greatest or extreme rainfall for a given duration that is physically possible over a station or basin. ([1], [2]).

\[ \text{PMP} = \bar{P} + K\sigma \]  

Where,

\( \bar{P} \) - is mean of annual maximum series,
\( \sigma \) - is standard deviation and
\( K \) - is a frequency factor which is usually taken as 15.

Later, found that the value 15 is too high for rainy areas and too low for arid areas, whereas it is too high for rain durations shorter than 24 h, so he constructed an empirical varying between 5 and 20 depending on the rainfall duration and the mean [4].

### 3.3 Gumbel's Extreme Value Distribution Model

Gumbel introduced the concept of extreme value distribution and developed a model for prediction of hydrologic event such as flood peaks, maximum rainfall, etc. ([3]). Gumbel found that the probability of occurrence of an extreme event, equal to or larger than a value is given by the following equation:

\[ P(X \geq x) = 1 - e^{-e^{-y}} \]  

Where,

\( P \) - the probability of occurrence
\( X \) - the event the hydrologic series
\( x \) - the desired value of the event
\( y \) - the reduced variate

Gumbels equations for field

The variate \( X_t \) can also be expressed as

\[ X_t = \bar{x} + K \sigma' \]  

\( \sigma' \) - standard deviation of sample

\[ \sigma' = \sqrt{\frac{(x-\bar{x})^2}{N-1}} \]  

Where,

\( K \) - frequency factor

\[ K = \frac{y_t - y_{ni}}{\sigma} \]  

\( y_t \) - the reduced variate for a given return period \( T \) and \( y_t \) is calculated by

\[ y_t = -[\ln(\ln(T/\tau)) / \sigma] \]
Where,
\[ y_n = \text{reduced mean as a function of sample size } N \]
\[ \sigma = \text{reduced standard deviation as a function of sample size } N \]

**Return period**
Return period or recurrence interval is the average interval of time within which any extreme event of given magnitude will be equalled or exceeded at least once.

\[ T = \frac{N+1}{R} \]  \hspace{1cm} (8)

Where,
- \( N \) - the total number of years of record and
- \( R \) - the rank of observed rainfall values arranged in descending order.

4. **RESULTS AND DISCUSSION**
4.1 **Rainfall pattern and Trend analysis**

As stated earlier, the rainfall pattern analysis was done using daily rainfall data for the period (1994-2013). The daily rainfall was then summed into weekly, monthly and yearly rainfall. Wide variation of annual rainfall was observed with the maximum value of 5112.5 mm and minimum of 1155.7 mm. This erratic rainfall distribution gives rise to extreme climatic conditions like floods and droughts in Mumbai region. A detailed statistical analysis of annual rainfall is shown in table 1.

**TABLE 1:** BASIC STATISTICS FOR ANNUAL DATA OF MUMBAI

<table>
<thead>
<tr>
<th>Description</th>
<th>Santacruz (1994-2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of years of observation</td>
<td>19</td>
</tr>
<tr>
<td>Minimum rainfall (mm)</td>
<td>1155.7</td>
</tr>
<tr>
<td>Maximum rainfall (mm)</td>
<td>5112.5</td>
</tr>
<tr>
<td>Mean rainfall (mm)</td>
<td>2497.15</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>857.2626</td>
</tr>
<tr>
<td>Median</td>
<td>2180.7</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.37</td>
</tr>
</tbody>
</table>

As the rainfall in Mumbai occurs mainly between June-September, a further detailed analysis of rainfall is done only for monsoon months. (Figure 2).
From the figure it is clear that there is much variation of rainfall between months and also in the same month for the entire period under observation. Hence the rainfall trend was studied for individual months for the period under observation. The figures 3, 4, showed a positive trend of rainfall in June, July and August months. However, the rainfall trend was nearly linear in September month for all the years except for the year 2005. Mumbai experienced an acute and disastrous flood hazard in this year because of this unusually high rainfall. The maximum daily rainfall in this year was 944 mm in the September month. To estimate the probability of occurrence of maximum one day rainfall in future, further analysis of rainfall was carried out.

4.2 Probable Maximum Precipitation

PMP is defined as the greatest or extreme rainfall for a given duration that is physically possible over a station or basin. Analysis of annual maximum daily rainfall series for Mumbai city for the data length from year 1994 to 2013 has been carried out. As per the results obtained, PMP for Mumbai city comes to 2250.66 mm per day. The result indicates that in near future, the daily maximum rainfall may be greater than or equal to 2250.66 mm/day.
4.3 Probability Analysis of rainfall using Gumbel’s distribution model

Analysis of rainfall trend and pattern and analysis of probable maximum precipitation indicated erratic and uneven distribution of rainfall in Mumbai region over the years. So there is a need to estimate the quantity of rainfall that may occur after 1 year and after many years. Hence the rainfall amount is estimated for different return periods using Gumbel’s extreme value model. From the analysis it was observed that the rainfall amount may be 2219.67 mm in the year 2015. The analysis indicated a positive trend in the quantity of rainfall in future. (Table. 2, Figure 5)

Fig 5: Estimation of rainfall at different return periods

5. CONCLUSION

Due to the high population growth and looming climate change, Mumbai is experiencing wide variation in spatio-temporal distribution of rainfall. Hence, rainfall trend and pattern analysis was done for Mumbai (1994-2013) through concrete analysis of daily, monthly and annual rainfall data. It was observed that relative variation in rainfall either causes flood or shortage of water supply. Also Mumbai city can expect PMP of 2250.66 mm per day at any time in future. Thus proper attention is required for storm water management of the city to avoid flooding, human and economic loss. Results obtained from detailed rainfall analysis such as rainfall estimates for different return periods for annual maximum daily as well as hourly rainfall series could be used for hydrologic modeling and for early warning systems.

REFERENCES