FLOOD RESILIENCE STUDY FOR MITHI RIVER CATCHMENT IN MUMBAI, INDIA

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ABSTRACT

Mumbai, an island city having a population of 12.43 million in an area of 437.71 km² (average population density is 27,209 persons per km²) is located on the Western coast of India. The city has been formed due to merger of eight islands and reclamation from the sea. The city is susceptible to frequent flooding and witnesses disruptions on an average twice a year. Mumbai was severely flooded on 26th July, 2005 due to the 944 mm rainfall in 24 hours resulting in the overflow of the Mithi River. Hence the Mithi River catchment has been selected as the case study. One of the main objectives of the Mumbai case study in the context of CORFU project was to provide simulation of the flooding for various rainfall intensities and impact assessment for various scenarios in the Mithi River catchment. The hydraulic simulations have been carried out and water depths have been computed for various rainfall intensities corresponding to the return period of 1 in 1, 1 in 10 and 1 in 100 years. Subsequently, depth damage curves have been developed based on site visits and interviews with people living in the flood prone areas. These curves have been developed for different types of land-use/ building typology. With the development of depth-damage curves for the case study area, damage assessment has been carried out for these scenarios. Flood spread and damage maps allow identifying such areas in which special focus should be put in order to be prepared to the possible flood events that may occur. The detailed analysis carried out in this study has enabled the formulation of a methodology to determine the water levels, flood spread and depth, depth damage curve, vulnerability and flood damage.

KEYWORDS
Urban flooding; damage assessment; flood resilience; depth damage curve; Mumbai.

1. INTRODUCTION

Mumbai, an island city having a population of 12.43 million in an area of 437.71 km² (average population density is 27,209 persons per km²) is located on the Western coast of India. The city has been formed due to the merger of eight islands and reclamation from the sea. The city elevation at some locations is just one meter above mean sea level and at some locations 1.5 meter below the high tide level (MCGM, 2011). Mumbai receives an average annual rainfall of 2430 mm, of which 95% falls during the monsoon months from June to September. 70% of the average annual rainfall occurs in July and August and 50% of this occurs in just two or three events with over 100 mm in a day on an average twice in a year (Gupta 2007).

Mumbai was severely flooded on 26 July, 2005 due to the 944 mm rainfall in 24 hours resulting in the overflow of the Mithi River. Hence the Mithi River catchment has been selected as case study (Figure 1). The longitudinal profile of Mithi River has been shown in Figure 2.
Figure 1. Location of Mumbai, Mithi River and study area

Figure 2. Longitudinal profile of Mithi River (Government of Maharashtra, 2006)
2. DESCRIPTION OF CASE STUDY

2.1 Description of catchment

The Mithi River with a catchment area of 7,295 ha and total length of 17.84 km originates from the overflow of Vihar lake at an altitude of 42.5 m above mean sea level. The overflow from Powai lake into Mithi River occurs after 2.65 km from Vihar Lake. The river carries stormwater during June to September and sewage and effluents from slums and small scale industries throughout the year.

2.2 History of flooding

Flooding has been a regular feature during the monsoon and several committees of enquiry have identified the main causes of the flooding in Mumbai and these are summarised in Table 1.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>City area</th>
<th>Suburban areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low ground levels</td>
<td>Low ground levels</td>
</tr>
<tr>
<td>2</td>
<td>Low Level of outfalls</td>
<td>Siltation of drains/ nallas</td>
</tr>
<tr>
<td>3</td>
<td>Dilapidated drain</td>
<td>Obstructions of utilities</td>
</tr>
<tr>
<td>4</td>
<td>Obstructions of utilities</td>
<td>Encroachment along nallas</td>
</tr>
<tr>
<td>5</td>
<td>Siltation of drains/ nallas</td>
<td>Slums along outfalls</td>
</tr>
<tr>
<td>6</td>
<td>Urbanisation and loss of holding ponds</td>
<td>Garbage dumping in SWD mainly in slums</td>
</tr>
<tr>
<td>7</td>
<td>Increase in runoff coefficient</td>
<td>No access for desilting</td>
</tr>
</tbody>
</table>

The Mithi River catchment area is highly susceptible to frequent flooding and witnesses severe disruptions annually. On 26th July 2005 Mumbai received 944 mm rainfall in 24 hours ending 08:30 am on 27th July 2006. Heavy rainfall started at 14:30 with 481.2 mm falling in just four hours between 14:30 to 18:30 and hourly rainfall exceeding 190 mm/h during 14:30 to 15:30. The extremely high rainfall resulted in overflows from the already inadequate drainage system and it was unable to drain out to the sea because of the maximum high tide level of 4.48 m at 15:50.

Following the 26th July 2005 flooding various measures, structural and non-structural, have been taken by the government. Major steps were initiated to enhance the carrying capacity of Mithi by widening and deepening its course. Mithi river has been widened from 7 m to 20 m in upstream, 20 m to 35 m in middle stream, 35 m to 60-100 m in downstream and 6 m height flood wall has been constructed for 7.5 km u/s portion of river. Two weirs have been constructed on the Mithi River to detain flows during high intensity rainfall events.

2.3 Main problems and challenges, state of the art in flood management at the beginning of CORFU

Encroachments and habitat in flood plains of Mithi River are main problem and removal of encroachment is a major challenge. Various measures, structural and non-structural, have been taken by the government and as a result, considerable protection has been provided to the people.
3. PLANNED OBJECTIVES WITHIN CORFU PROJECT

One of the main objectives of the Mumbai case study in the context of CORFU project was to provide simulation of the flooding for various rainfall intensities and impact assessment for various scenarios. Hydraulic simulations have been carried out using MIKE 11. Three storm events were selected for calibration process, while another one was selected for verification. Water depths have been computed for various rainfall intensities corresponding to the return period of 1 in 1, 1 in 10 and 1 in 100 years.

4. ACTIVITIES/DEVELOPMENTS/RESEARCH CARRIED OUT DURING CORFU

4.1 Development of scenarios

Various flooding scenarios for different stages of development and climate change have been formulated in this study and these are shown in Figure 3.

![Combined scenarios for the Mithi River catchment.](image)

Three population forecast scenarios representing business as usual, optimistic and pessimistic growth and two climate situations: business as usual and climate change with 1.20 uplift factor have been considered in this study as shown in Figure 3. Business as usual scenario provides the baseline for comparison with the other future scenarios. It is assumed that no new measures are implemented until 2050 and thus the level of adaptive capacity in 2050 is the same as in 2013. Three rainfall scenarios corresponding return period of 1, 10 and 100 years have been considered.

The population of Mumbai has increased from 0.92 million in 1901 to 12.45 million in 2011, but the decadal growth has varied. However, the annual compound growth rate showed a reduction from 3.28 percent during 1971-81 to 0.43 percent in 2001-11. Based on the projections, population of Mumbai by 2031 is about 14.69 (optimistic) and 16.31 million (pessimistic) (CDP, 2006). This data has been extrapolated to 2031 for development of pessimistic, business as usual (BAU) and optimistic scenarios.
as shown in Table 2 and Figure 4. Total development is not likely to vary from 2031 to 2051, hence projections beyond 2031 are not considered.

Table 2. Pessimistic, BAU and optimistic population growth scenarios from 2031 to 2031

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Year</th>
<th>Pessimistic</th>
<th>BAU</th>
<th>Optimistic</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2031</td>
<td>16.31</td>
<td>15.66</td>
<td>14.69</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Population trend for Mumbai (MCGM area).

The slum population has increased from 28.77 % in 1981 to 51.80 % in 2001 as shown in Table 3. About 86.0 % of slum population resides in eastern and western suburbs (2001 Census). 0.49 % rise in slum population has been estimated by MCGM. Considering this trend to be continue upto 2031, BAU population has been estimated. Under pessimistic scenario, population is considered to remain steady after 2021 because most of the low-lying areas are already encroached by slums and saturated. Under optimistic scenario, slum population has been considered to be reduced to 39.5 % and 28.0 % for year 2021 and 2031 respectively. These three scenarios are shown in Figure 5.

Table 3. Slum population

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of slum</th>
<th>Slum Population (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>619</td>
<td>2.28</td>
</tr>
<tr>
<td>1991</td>
<td>1065</td>
<td>2.33</td>
</tr>
<tr>
<td>2001</td>
<td>1811</td>
<td>6.20</td>
</tr>
</tbody>
</table>

GDP and per capita income has been shown in Table 4. Optimistic scenario has been developed considering average growth of 18.7 %, business as usual (BAU) and pessimistic scenarios have been developed considering growth rate of 11.0 % and 6.0 % respectively. These three scenarios are shown in Figure 6.
Table 4. GDP and per capita income of Mumbai (Source: Economic survey of Maharashtra)

<table>
<thead>
<tr>
<th>Year</th>
<th>GDP (Rs in Cr.)</th>
<th>Per capita income (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-05</td>
<td>78928</td>
<td>49168</td>
</tr>
<tr>
<td>2005-06</td>
<td>92919</td>
<td>57229</td>
</tr>
<tr>
<td>2006-07</td>
<td>108884</td>
<td>65382</td>
</tr>
<tr>
<td>2007-08</td>
<td>130227</td>
<td>77145</td>
</tr>
<tr>
<td>2008-09</td>
<td>176334</td>
<td>110049</td>
</tr>
<tr>
<td>2009-10</td>
<td>203915</td>
<td>125506</td>
</tr>
<tr>
<td>2010-11</td>
<td>221647</td>
<td>133426</td>
</tr>
<tr>
<td>2011-12</td>
<td>257819</td>
<td>151608</td>
</tr>
</tbody>
</table>

(1 Euro ~ 70 INR)

Figure 5. Pessimistic, business as usual (BAU) and optimistic slum population scenarios.

Figure 6. Pessimistic, business as usual (BAU) and optimistic GDP scenarios (1 Euro ~ 70 INR).

Two climate futures are considered (i) business as usual and (ii) uplift factor of 1.2. Three return periods (1, 10 and 100 years) are used to represent each scenario. Rainfall intensities for these scenarios are given in Table 5.
Table 5. Rainfall intensities for different climate change scenarios and return periods.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business as usual</td>
<td>30</td>
<td>66</td>
<td>93</td>
</tr>
<tr>
<td>Uplift factor of 1.20</td>
<td>36</td>
<td>79</td>
<td>111</td>
</tr>
</tbody>
</table>

4.2 Flood modelling

One of the main objectives of the Mumbai case study in the context of CORFU project was to provide simulation of the flooding for various rainfall intensities and develop hazard maps on the basis of local observations. As LIDAR survey data was not available at the time of study due to proprietary issues, hence we obtained 90-m resolution SRTM DEM from Shuttle Radar Topography Mission (http://srtm.csi.cgiar). SRTM DEM has been analyzed and compared with the elevations derived from available topographical maps of Mumbai and available levels in the critical areas from MCGM. These have been supplemented by ground verification by authors at critical locations.

Rainfall records for 2007-2012 were obtained from the MCGM automatic weather station located at Powai in the Mithi River and water level at one hour interval is from Krantinagar gauging site of MCGM. Three storm events were selected for calibration, while another one was selected for verification. Channel roughness values were adjusted in order to minimize the differences between the observed and the simulated water levels at gauging site.

Three events corresponding to return periods of 1, 10 and 100 years have been simulated for the scenarios (i) business as usual and (ii) climate change with uplift factor of 1.2. The flooding that occurs in the downstream reach of Mithi River of about 7.50 km (from the mouth) is due to high rainfall coinciding with high tide. The water levels and flood spread corresponding to these events and scenarios have been shown in Figures 7 and 8 respectively.

![Figure 7. Water levels for different scenarios in Mithi River, Mumbai](image-url)
Figure 8 shows the flood spread and water depths in the downstream reaches of Mithi River for rainfall events of return period of 1, 10 and 100 years. Flood spread has been observed at tide influenced portion of the river. The model outputs have been used to compute the water depth in the drains due to rainfall and backflow from the river. The overflow over the footpaths/roads in the slums and the buildings in flood prone areas has been computed. Then using depth damage curve the total damage corresponding to the flood water levels in these areas are calculated. Water depths of less than 15 cm have not been considered, because it has been observed that less than this value there is no quantifiable damage.

![Flood spread and water depths in the downstream of Mithi River](image)

**Figure 8.** Flood spread and water depths in the downstream of Mithi River for rainfall events of return period of 1, 10 and 100 years.

### 4.3 Impact assessment

As already mentioned the flooding that occurs in the downstream reach of Mithi River of about 7.50 km (from the mouth) is due to high rainfall coinciding with high tide. This results in damages to goods and properties located in the flood plains. To determine the cost-effectiveness of several adaptation strategies, an economic appraisal of the potential damages has been carried out. The direct tangible damages have been computed using the flood levels simulated earlier.

The depth-damage curves (DDC) for the flood prone buildings in the Mithi River catchment have been developed based on site visits and interview surveys (McBean et al., 1988) with people residing in the flood prone areas. The interview survey questionnaire was modified to adapt to local conditions. Site information has been compiled to develop a data base characterising the contents and structure of residences representative of those located in the flood plains of Mithi River. The DDC have been...
developed for different types of land-use and building occupancy types. Four different categories of land use/ building types have been identified: (i) slum at ground level, (ii) slum with elevated plinth levels, (iii) building at ground level and (iv) building without elevated plinth.

The DDC are shown in Figure 9. These curves can then be used to obtain damage costs for predefined increments of water depth. Then, multiplying the obtained value by the affected area of the building, the damage cost in the area can be obtained.

![Figure 9. Developed depth damage curves](image)

![Figure 10. Land-use classes.](image)
For each sub area, there are many land-use types. Multiplying these values by the relative damages obtained from the DDC, the total damages of the areas can be obtained. The vulnerability map has been developed based on depth damage curve and this shows the maximum potential damage in monetary units and these are shown in Figure 11.

Figure 11. Vulnerability map, showing the potential damage of the areas at risk for rainfall events of return period of 1, 10 and 100 years. (1 Euro ~ 70 INR)

Figure 12. Flood damages in the downstream portion of Mithi River for rainfall events of return period of 1, 10 and 100 years. (1 Euro ~ 70 INR)
The indirect tangible impacts are the ones which have not been created due to the direct contact with water but can be economically assessed. Such impacts are the disruption of businesses activities and transport networks, etc.

The impacts induced by floods caused by high tide coinciding with high intensity rainfall are localized, and the retention time of the water is short. In the area studied there is no large business activity or any transport network. Therefore, such damages are not included in this study.

Using the flood maps presented in Figures 5 and 6 flood damage maps are obtained for the studied area these are shown in Figure 12.

The detailed analysis carried out in this study has enabled the formulation of a methodology to determine the water levels, flood spread and depth, DDC, vulnerability and flood damage.

The expected damage estimates will enable the decision maker to decide on the adaptation measures to be implemented.

The damage – return period curve for the downstream portion of Mithi River is presented in Figure 13. The aggregated damages are plotted against its probability. As mentioned, this figure is an overestimation of the annual damage that may be caused by floods, but it provides an estimate of the order of magnitude in which this value ranges.

4.4 Flood management strategies

Flood protection walls of average height of 6.0 m have been completed for first 7.80 km. Real time rainfall monitoring and alert system are updated every 15 min and are available to the public on www.mumbaimonsoon.in. Future adaptation measures like completion of retaining wall for the remaining (approx 8.0 km) length of river, setting up of flow gauges at various critical locations and issue flood warnings based on real-time flood forecast mechanism.
5. LESSONS LEARNT

Internal and external collaborative working, in particular cooperation with research institutes, has facilitated a stronger adaptation response. Flood modeling and depth damage curves are useful tools for assessing potential economic damage and enhancing awareness and understanding of flood risk. The involvement of the stakeholders as end users enhances the efficiency of flood mitigation process.

6. RESULTS AND CONCLUSIONS

A methodology to characterize flood susceptibility using a 1D model has been developed taking the Mithi River catchment in Mumbai, India as a case study. Calibration and validation of the model has been carried out using the rain gauge data and flow depths recorded by water level gauge and reports of flooding in the river basin. The depth-damage curves have been developed for the case study area and damage assessment has been carried out. This will enable the determination of the critical areas in the catchment in terms of flooding impacts and help the decision makers to decide on adaptation strategies. This methodology can be extended for determining water levels, flood spread and depth, depth damage curve, vulnerability and flood damage of other flood prone areas in other cities with similar conditions.

7. ACKNOWLEDGEMENTS

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8. REFERENCES