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AVOIDING NATURAL DISASTER IN MEGACITIES – CASE STUDY FOR URBAN DRAINAGE OF MUMBAI

Att undvika naturkatastrofer i megastäder – Fallstudie av dagvattensystem i Mumbai

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Abstract

"Nature's fury, Man's folly!" As people of Mumbai were getting ready for work and children's for school on morning of 26 July 2005, they had no idea what is coming for them in next 48 hours. It rained heavily leading to massive floods and other related damages to life and property. We still are helpless to the forces of nature when it comes to natural calamities. Can we mitigate the human catastrophe and loss of property with better management techniques? Can computerized models help us in predicting and managing/minimizing losses due to calamities? Could this disaster be prevented in future? This is indeed a hurdle to be tackled by researchers. The present study has shown that improvement in drainage system could help avoid such disasters in the future. Better management practices should be applied along with disaster management programmes. People should be made aware of the civic sense by imparting education and a detailed map of drainage system should be prepared for future studies.

Key words – Natural Disaster, Flooding, Sustainable development, Drainage System, Urbanization, Intensity-Duration-Frequency, Climate Indices, Flood mapping, Climate change, Mumbai

Sammanfattning

Föga anade invånarna i Mumbai som var på väg till arbetet och skolan morgonen den 26 juli 2005 vad som väntade dem de kommande 48 timmarna. Kraftigt regnande ledde till massiva översvämningar och medföljande skador på liv och egendom. Vi är fortfarande hjälplösa inför naturens krafter när det gäller naturkatastrofer. Kan vi mildra människors lidande och förlust av egendom med bättre ledningsmetoder? Kan datormodeller hjälpa oss att förutsäga och hantera/begränsa skador orsakade av naturkatastrofer? Kan liknande tragedier förhindras i framtiden? Detta är en riktig nöt att knäcka för forskarna. Denna studie har visat att förbättrade dagvattensystem kan bidra till att undvika liknande katastrofer i framtiden. Bättre medoder för ledning och katastrofhanterings bör införas. Utbildning om medborgaransvar bör genomföras och en detaljerad karta över dagvattensystem bör skapas för framtida studier.

Introduction

We are aiming for sustainable future but we have a big question to answer – how shall we deal with the effects of a changing climate? In recent times we have seen many examples of effects of a changing climate worldwide including floods, droughts and extremes of hot and cold temperatures. Global average precipitation is projected to increase, but both increases and decreases are expected at the regional and continental scales (IPCC, 2001 and 2007). Most part of the population is living in urban areas making them more vulnerable in situations of natural calamity. A major part of urban infrastructure deals with drainage system and its management which is rather poorly handled leading to floods. Here rises a question in our minds whether the severe consequences of floods in Mumbai in 2005 were due to inadequate drainage, bad planning/management or it was natural calamity where one would feel helpless?

The megacity Mumbai after deluge in 2005

Mumbai serves as the economical hub of India. It is home to almost 14 million people with total area of 437 km^2 leading to population density of around 27 000 people per km^2. Life in Mumbai came to a standstill when it poured heavily on 26 and 27 July 2005 leading to massive floods. The unprecedented rainfall of 994 mm during the 24 hours resulted in that at least 419 people (and 16000 cattle) were killed (Gupta, 2007). It caused, as a result of the following flash floods and landslides in the Mumbai municipal area, death of another 216 from flood-related illnesses. Over 100 000 residential and commercial establishments and 30 000 vehicles were damaged, causing direct economic damages estimated at almost two billion USD and many more indirect monetary damages (Hallegatte et al., 2010). The extremely high rainfall resulted in overflows from the already inadequate drainage system. The storm water could not be drained out to the sea because of the simultaneous maximum high tide level of 4.5 m. There have been changes in trend of rainfall for both short and long period of time. Trends in rainfall for Mumbai are studied in detail by Rana et al. (2010), they presented evidences of a changing rainfall pattern related to global climatic phenomena. Also, the unprecedented rainfall in 2005 was extreme event with return period far more than 120 years which can be easily observed from IDF curves prepared by Rana et. al., 2011.

Present Situation of Drainage System

The drainage system in any city depends on its topography. Mumbai is a cluster of seven islands, and the current system was built well before Independence on 15 August 1947. Mumbai is lined by the Arabian Sea on the western side, and also being intercepted by the Mahim, Mahul and Thane creeks, along with the Mithi, Dahisar, Poisar and Oshiwara rivers and their respective tributaries. The drainage system of Mumbai is a mix of simple drains (nallah) and a complicated network of rivers, creeks, drains and ponds but no natural drainage outlet. At present, the storm water drainage system consists of a hierarchical network of road side surface drains (about 2000 km mainly in the suburbs), underground drains and laterals (about 440 km in the island city area), major and minor nallahs (200 km and 87 km respectively), and 186 outfalls, which discharge all the surface runoff into the rivers and the Arabian Sea. Table 1 represents the summary of storm water drains in Mumbai with their length in km (City Development Plan (CDP), Mumbai). A network of closed drains below the roads has evolved in the city along with drains in the suburbs (figure 1). The southern city area has long complex networks which drains relatively large low-lying areas, while short drains from small areas drain directly to the sea. The central area forms a depression, flanked by hills, and being on reclaimed grounds barely two to three meters above sea level. As in central Mumbai (island city), natural drainage has been visibly affected by urban building activity also in the suburbs.

Mumbai has a two-tier sewerage system. One is the underground sewerage system that discharges about 3.5 km into the sea. The other is storm water drains that carry surface and flood water during monsoon and discharges directly into the sea right at the sea shore. There is a large network of road side open drains in suburbs. The collection, conveyance and disposal of waste water and sewage in Mumbai is divided into seven zones, viz., Colaba, Worli, Bandra, Versova, Malad, Bhandup and

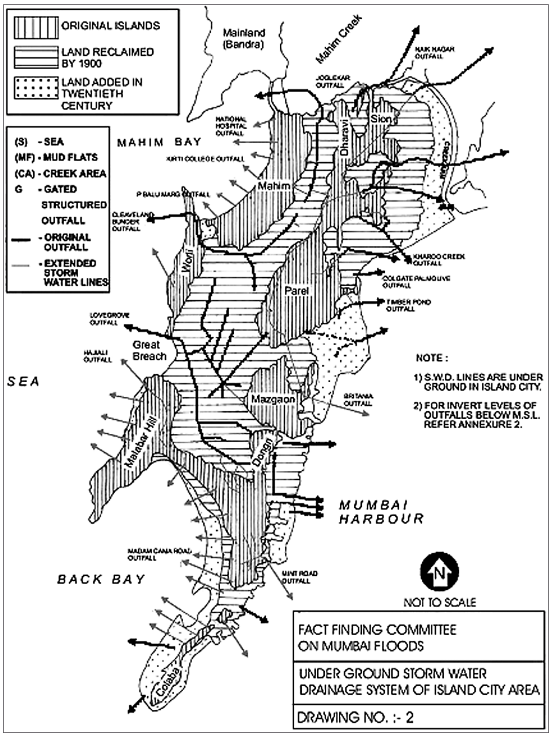

Figure 1. *Drainage of Mumbai City area, Gazetteer of India, Maharashtra State, History of Bombay, Modern Period 1987 (Government of Maharashtra 2006).*

Table 1. *Summary of the Storm Water Drainage System of Mumbai (CDP, Mumbai).*

S.No.	Drain Hierarchy/Type	Length (km)			
		Island city	Western suburbs	Eastern Suburbs	Total
1	Major Nallah (width>1.5 m)	9	90	102	200
2	Minor Nallah (width<1.5 m)		21	66	87
3	Arch/Box drains	59	40	52	151
4	Roadside open drains	20	669	1298	1987
5	Closed pipe or dhaka drains	443	36	86	565
6	Total SWD length	531	857	1603	2991
7	No. of water entrances	27893	609	1706	30208

Ghatkopar (figure 1). From each of these, sewage and waste water is conveyed to the respective final discharge points for disposal through marine outfalls, some three kilometres into the sea. Though sewerage lines are laid in zones, due to rapid expansion, development, dense population and non-accessibility in some of the parts particularly in extended suburbs and slums is connected to storm channels. Out of the 186 outfalls (i.e point where creek meets the sea), there are 107 major outfalls in the city, which drain directly into the Arabian sea (4 at Mahim creek and 4 at Mahul creek). There are 29 out-falls in the western suburbs draining directly in the sea, while 14 drain into the Mithi river, which ultimately joins the Mahim creek. In the eastern suburbs, 14 out-falls discharge in the Thane creek and 6 in the Mahul creek. Table 2 summarises the storm water discharge system of Mumbai (CDP, Mumbai).

The present storm water drainage system in the city, which was put in place at the beginning of the 20th century, is 70 years old and about 480 km in length. It is capable of handling rain intensity of 25 mm per hour at low tide. This amount is generally exceeded on a routine basis during the monsoon season in Mumbai. The drain system works with the aid of gravity, with no pumping stations to speed up the drainage. Parts of the city like the Bombay Central and Tardeo remain below sea level. All along the shore fringes, extensive areas are flooded during high tides, during the heavy monsoon rains, many low lying areas are flooded and do not readily get drained. Some of the main problems related to the storm water drainage system of Mumbai are elaborated below:

- There is no map of underground cables and pipes: Thousands of underground cables (telephone, water pipelines) need to be mapped, and in some cases, shifted to accommodate the restructured/restructured drains.
- Slums on drains: The large number of people living on the top of and adjacent to the existing drains needs to be displaced and rehabilitated.
- Lack of civic sense: This results in clogging of drains, due to debris and garbage being disposed off in them, by the people.
- Lack of proper maintenance: The Brihanmumbai Municipal Corporation (BMC) often does not complete cleaning the drains before the monsoon sets. Work is also not done properly; garbage is left on the sides of the road and when it rains, it returns back to the drains, thereby choking the water passage.
- Many gradients are flat and the drains are affected by tides.
- A large number of drains are found to be of inadequate capacity.
- Poor workmanship and lack of attention to proper repairs when the drains have been punctured to construct utility services has left many of these locations in a poor state of structural repair.
- Interconnection of storm water and sewerage networks.

Table 2. *Summary of the storm water discharge system in Mumbai (lengths in km) (CDP, Mumbai).*

S.No.	Outfall discharging into	Length (km)			
		In island city area	In western suburbs	In eastern suburbs	Total
1	Arabian Sea	107	29	0	136
2	Mahim creek	4	14	8	264
3	Mahul creek	4	0	6	10
4	Thane creek	0	0	14	14
	Total	115	43	28	186

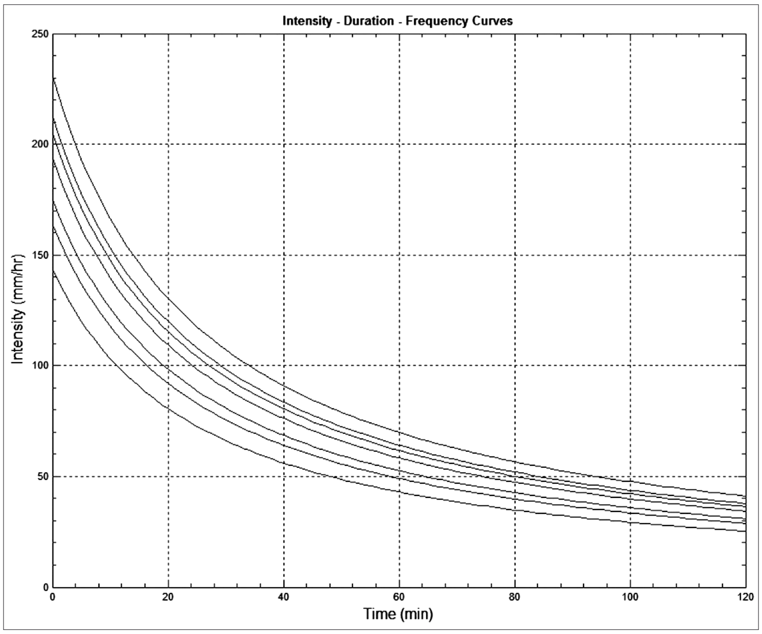

Figure 2. *IDF curves – Graphical representation of relationship of intensity duration and frequency of rainfall for Mumbai. (Return periods are 5, 10, 15, 30, 45, 60, 120 years respectively starting from below in the curves).*

Cause-Effect Relationship

At the Department of Water Resources Engineering, Lund University, the cause-effect relationship of the consequences of the storm in 2005 is analyzed. Historical rainfall data have been collected and statistical analysis is performed to establish a relation between rainfall and frequent flash floods in the city. The rainfall analysis revealed that there is fluctuation in the amount, duration and intensity of rainfall which was further related to climatic indices (Tele-connection patterns of trends/ anomalies in atmospheric or hydrological parameters due to global circulation pattern) arising from different global circulation model (Rana et al., 2010). These fluctuations are on decadal basis and are expected to continue in near future in co-relation with climatic indices. The rainfall analysis was followed by analysis of the drainage system of the city which is in bad condition as the natural drains in the city are absent and man-made drains are either inadequate due to faulty design or clogged due to poor maintenance.

Urban drainage system: how and why?

Drainage system of any city is designed based on IDF Curves (Intensity Duration and Frequency) of rainfall. The IDF curves, used for designing drainage system in Mumbai, were poorly developed and have not been revised for a long time. We further proceeded with development of fresh IDF curves based on long time historical data from Indian Metreological Department (IMD) for period 1951–2004 (figure 2) (Rana et. al., 2011). While designing new IDF curves the future scenario/projections for rainfall over the grid point of Mumbai were taken into account. It was important to take this future scenario in consideration as experts have expected change in atmospheric phenomena's owing to climate change.

The climate change scenario is further supported by different IPCC (Inter-governmental Panel on Climate Change) reports. When the statistical analysis was carried out it was revealed that there is some change in rainfall expected in near future in relation to climate indices. So, for development of historical and future IDF curves there were a need of high quality fine time resolution data of rainfall which is not available in case of Mumbai, as is the case in many developing countries. There are daily rainfall data for the city available from Indian metrological department. For the future climate projections, data was taken from two different climate models namely PCM1 (Parallel Climate Model) model output – SresB07.58 experiment for 1990 to 2099 and CMIP5 (5th coupled model inter-comparison project) model output – HadGEM2-ES model experiment rcp45 for 2005 to 2099 from National Centre for Atmospheric Research and British Atmospheric Data Centre respectively (accessed from ESG – Earth System Grid Gateway). This daily data was disaggregated into finer time scale using cascade based model for development of IDF curves fitting Gumbel distribution to data. Readers can refer to Rana et. al. (2011) for detailed procedure on disaggregation of rainfall and development of IDF curves. The developed IDF curves for future scenario gives a clear idea of the rainfall intensity increasing in the study area. They can be very handy for planning and development of city in future infrastructure works. Once these curves were established it could be seen how frequent flooding could be expected and planning can be done accordingly. According to Rana et. al. (2011), where both historical and projected IDF curves have been developed, the intensity of rainfall is increasing in future climate scenario. They have provided a detailed account of different intensity v/s time scenario with different return period.

Future work and prospects

It is evident from the analysis of drainage system that the infrastructure for city of Mumbai is not able to cope with intensity of rainfall as they are found to be inadequate in capacity along with many other problems namely development of slums on drains leading to decrease in capacity, lack of civic sense resulting in clogging of drains due to debris and garbage, flat gradients and poor workmanship and lack of attention. These problems were also highlighted by other authors. Gupta (2007) discussed the inadequate capacity of drainage systems. He showed that by recent data analysis for the years 1999 to 2004, the peak rainfall intensity for a 15 min duration exceeds 72 mm/h which is over 80 % of the times the drainage capacity of the city. There is a clear need for upgrading the drainage systems along with other soft skill measures to control the burden on city (Gupta, 2007).

The research presented here does not only include analysis of rainfall but also aims for looking at the consequences of flooding and finding solutions for mitigating flooding problems. Flood simulations are performed to prepare for better management of disasters. The synthesis of this modeling would be presented in form of flood hazard maps, which then can be used for management and finding system for controlling the storm water. A sustainable solution for drainage of city is sought for. Possibilities for rain water harvesting will be investigated with the intention to use rain water in the households, in industries and for groundwater recharge. Measures of flood prevention, safe disposal of waste and wastewater handling in slums forms a significant part of the work in urge for finding best possible solution. Soft skills development and education on the same issue by issuing guidelines, seminars and talks in society forms the final part of the work. Suggestions for development of permeable green zones and reduction of urban heat island affect in the city forms a major part of the suggestions.

The case scenarios where sea level rise or failure of drains could lead to heavy damages of human life and property, will also focused in the study and emphasis would be laid on finding sustainable solution for Mumbai as an example of a megacity situated by sea. Some studies suggest that by the 2080s, in a climate change scenario could see the likelihood of a 2005-like event more than double. The estimated total losses (direct plus indirect) associated with a 1-in-100 year event could triple compared to current situation (to $690 – $1890 million USD) (Hallegatte et al., 2010). Estimates have also suggested that improvement in the drainage system can reduce the losses of 100 year return period flood by almost 70 percent. The present work would help achieve sustainable solution for the city of Mumbai and would serve as a guideline for many other urban centers across the world dealing with same problem. Although there are uncertainties about the magnitude and direction of future climate variations at various places, measures must be initiated to minimize the adverse impacts of these changes on society and resources for a sustainable future.

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