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# Urban Flooding in Changing Environment

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**Abstract** : Urban flooding is currently one of the major and costly environmental hazards. The main causes of urban flooding include uneven distribution of rainfall along with rapid urbanization, encroachment and filling of natural drainage channels and urban lakes to utilize the high-value urban lands for buildings. Rapid urban development combined with the impact of climate change necessitates that more attention is required for urban flood management. Urban flooding can be reduced with measures like maintaining existing drainage channels, providing underground drainage paths, on site storage of rainwater, control of solid waste entering the drainage systems, providing porous pavements to allow infiltration of rainwater, reserve low-lying areas for playgrounds and parks and using state-of-the-art technologies to address current problems such as flood warning and forecasting system. The warning system monitors water levels and discharge rates. Combining this information with weather forecasts, the risk of saturating the sewers resulting in flooding can be predicted. Such systems provide the necessary tools to plan and design for the future as multiple scenarios including climate change. The current urbanization trend clearly indicates shift from rural to urban areas. It is estimated that by the year 2050, about 60 70% of population will migrate to cities and the problem of urban flooding will be more critical. In this paper an attempt has been made to address the problem of urban flooding through a proper planning strategy.

## INTRODUCTION

Floods have had an impact on society since time immemorial. Flooding and flash flooding pose serious hazards to human populations in many parts of the world. According to the Federal Emergency Management Agency (FEMA) of the United States, floods are the second most common and widespread of all natural disasters next to fire (FEMA, 2003). Every year, floods exert a heavy toll on human life and property in many parts of the world. It is considered to be the most common, costly and deadly of all natural hazards. Flooding is not just confined to a certain region of the world but is a globally pervasive hazard (Mahapatra and Singh, 2003). In

India, the area affected from floods increased from 2.29 to 4.94 million hectare from the year 1953 to 2000. During this period, the loss of human lives increased from 37 to 2345 and the monetary damages increased from about 11 to 295 million US dollar (CWC, 1996).

The basic principle involved in all the methods concerned with mitigation of floods is to 'Keep floodwaters away from man and man away from the floodwaters' (Valdiya, 2004). Knowledge of the flood, i.e. the occurrence (temporally) and the magnitude of flood inundation (spatial extent and depth), is necessary to minimize the damage. Hydrodynamic modeling can play an important role in obtaining these characteristics. Progress in hydrodynamic modelling during the last decade has led to considerable improvements in our ability to simulate flooding problems. The impetus for this progress has come from a number of fields and incorporates improvements in process understanding, mathematical and numerical developments and available computational power (Bates et al., 1997).

## DIFFERENT ASPECTS OF FLOODING

Flooding has several aspects, such as climatic, social, economic, institutional, and technical, that are differently addressed for rural and urban conditions.

The climatic aspect of flooding deals with the climatic conditions that may lead to the occurrence of floods. In urban conditions, short and intensive showers proved to be just as critical as long lasting rains, but in rural conditions long lasting rains over an area-wide territory, accompanied with snow melting in the river basin, are recognized as possibly more influential.

The social aspect of flooding deals with the way the floods occur in different settings. In urban conditions, one can negotiate the intensity and frequency of the disruption of public life and traffic, whereas in regional conditions the common term is disaster, although there were many situations where local urban flooding had disastrous consequences (casualties and property losses) as well. However, floods do not necessarily always need to be associated with disastrous consequences.

The economic aspect of flooding deals with the issues of financing the capital improvement, operation, and maintenance of flood protection schemes. Local stormwater drainage and flood protection is usually financed by local revenues, such as local taxation, service fee, or user charge fee, collected on the basis of land use, whereas the regional protection is mostly carried out through general taxation.

The technical aspect of flooding deals with the concepts and works usually applied in flood protection. In urban conditions, the "dual drainage" concept is most commonly applied, introducing the distinction between the stormwater drainage service and urban flood protection, whereas in area-wide conditions flood control measures are always regarded as a part of the regional or state-wide flood control schemes.

## FLOODING IN URBAN ENVIRONMENT

The concentration of domestic, commercial and industrial wastes causes major environmental and health problems for the city inhabitants that are spread by water movement. Principal phases of the urban water cycle are shown in Fig. 1.

The primary cause of urban flooding is a severe thunderstorm or a rainstorm proceeded by a long-lasting moderate rainfall that saturates the soil. Floods in urban conditions are flashy in nature and occur both on urbanized surfaces (streets, parking lots, yards, parks) and in small urban creeks that deliver water to large water bodies. Other causes of urban floods include inadequate land use and channelization of natural waterways, failure of the city protection dikes, inflow from the river during high stages into urban drainage system, surcharge due to blockage of drains and street inlets, soil erosion generating material that clogs drainage system and inlets and inadequate street cleaning practice that clogs street inlets.

Floods disrupt the social systems of the countries and the cities, and cause enormous economic losses. Impacts produced by increased runoff in urban setting are:

- loss of human life
- flooding of housing, commercial and industrial properties
- flooding of streets, intersections and transportation systems, causing traffic delays
- recurring basement backups from surcharged sanitary sewers
- inflow of stormwater into sanitary sewers
- municipal waste water treatment plant by-passing

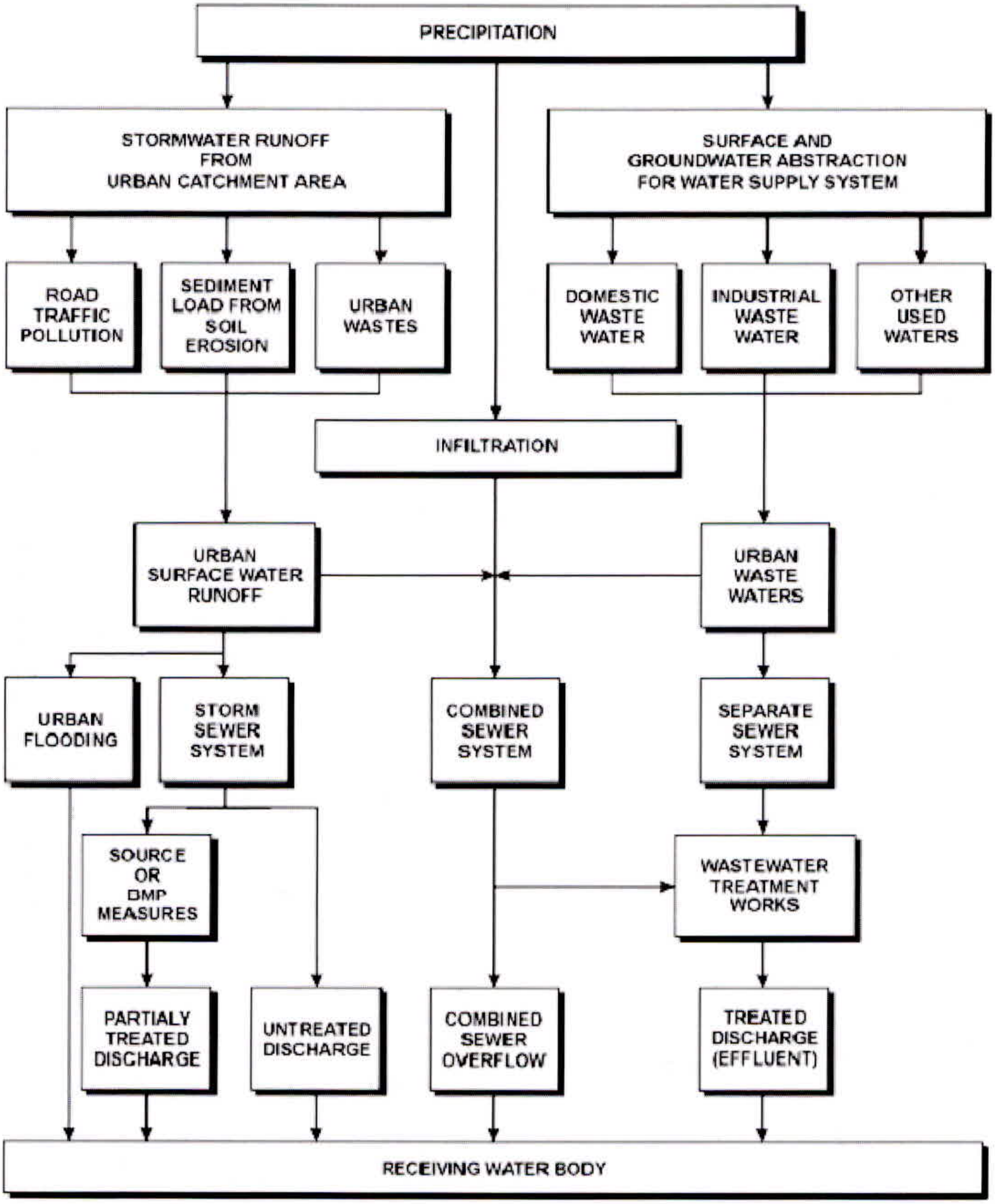


**Fig. 1.** Movement of Water in Urban Environment

- combined sewer overflows
- spilling the surcharged sewers content into streets
- damage to public and personal property
- health hazards
- disruption of services such as water supply, sewerage and power supply
- delays in public transportation
- cleanup demands
- adverse effects upon the aesthetics
- disturbance of wildlife habitats
- economic losses
- pollution of local waterways and receiving water bodies

**Consequences of Urban Floods**

**Communication** Urban Floods results in stagnation of water on roads, railway tracks and in few cases even at airports because of the inadequate storm water drainage capacity. This results in traffic jams and traffic diversions resulting in loss of man hours. In the events of heavy rainstorms air traffic gets diverted. Telecommunication gets disturbed and maintenance of supply of essential commodities becomes challenge.

**Economical** – As communications is disrupted industrial production gets hampered. Prices of essential commodities shoot up. During and after urban floods the immediate task is restoration of damaged roads, railway tacks, damaged buildings (which is very common for over lived buildings) and other structures and rehabilitation of residents from low lying areas and collapsed buildings. Damages of assets are significant in warehouses and buildings due to flooding by storm and sewage water. Perishable articles add to economical loss. Accidents and fire due to short circuit are also common. Hence there is a lot of financial burdens on relief measures.

**Social** – There is a psychological stress as safe returns of family members is not sure. Schools and colleges get closed. Displacement of population in low lying areas and collapsed structures generally meets stiff resistance. Disruption in supply of essential commodities including power supply results in unrest.

**Environmental** – Water bodies get polluted. Waste disposal gets hampered due to traffic disruption.

**Health** The stagnation of water, pollution of potable water and accumulation of waste at dustbins result in epidemics. Accidents due to open pits, manholes hidden under accumulated water adds to problem. As traffic gets disrupted it is challenging to assist medical assistance.

However during Urban Flood loss to human life is relatively insignificant as compared to that of river basin flood.

**Strategies of Urban Flood Mitigation**

**Structural Measures** - The structural measures involve construction of adequate drainage system. Design capacity of drainage system need to be based on affordable risk of exceedance which is ultimately part of benefit cost ratio.

Theoretically risk of exceeding of storm water discharge than designed capacity of drainage system is estimated by using Binomial Distribution.

If the probability of occurrence of event (say rainfall of given magnitude) is "p" then risk ( R ) of exceedance of this rainfall at least once in next ' N' years is given by:

$$R = 1 - (1 - p)^N \tag{1}$$

If design is based on 20 25 years Return Period (p = 0.05 and 0.04 resp.) then risk of exceedance of the event in next 50 years would be 92.3 to 87% respectively ,say once every year.

If affordable risk of exceedance of given event (R) is 10% or 0.1 and expected life of drainage system (N) Is say 50 years, then structure should be designed for p = 0.0021 that is for the event of Return Period of 475 years.

If the affordable risk of exceedance "R" is less, then required, Design Return Period is more and consequently the cost of structure. Hence designer has to make compromise between safety and economical feasibility. Each design should spell the risk of failure at least to planners and administrators.

**Warnings -** The other effective tool is issuing of weather warnings and dissemination of same on wide scale so that one can avoid travelling in water logged area , shift movable assets to safer places, stock essential commodities like milk powder etc . In India weather warnings are issued by India Meteorological Department to Administrators, Civil Authorities, Media, TV and Radio and also displayed on Departmental web site including Meteograms of 4 Metro cities, New Delhi, Mumbai, Kolkata and Chennai giving Quantitative Rainfall Forecast for every 6 hrs for next 7 days. India Meteorological Department has planned dense network of 55 Doppler Weather Radar to explore its full potential of foreseeing weather related disasters including river floods and urban floods.

**Other Measures -** In addition to develop adequate storm water drainage system the other legal and structural measures are restoration of existing water bodies, natural drainage, resettle the encroachment, enforcement of rain water harvesting etc. to moderate the discharge.In India, the Structural and other measures are entrusted to Civic Authorities and Municipal Corporations.

## SIGNIFICANT URBAN FLOODS IN INDIA IN RECENT YEARS

2005 Severe urban floods were reported from 10 cities and Mumbai was worst affected.

2006 Number of affected cities rose to 22. Surat was worst affected. Vishakhapattanam airport was inundated for more than 10 days.

2007 – Number of affected cities rose to 35. Kolkata was worst affected.

2008 Jamshedpur, Mumbai, Hydrabad were worst affected.

This list is not exhaustive.

## CASE STUDY : URBAN FLOOD OF 26TH JULY 2005 AT MUMBAI

The most devastating urban flood in India occurred on 26 07 2005 in Mumbai when historic highest rainfall of 944mm in 24 hr. occurred along with high tide of 4.48m. The highest intensity was observed in 4 hrs between 1430:1830 IST (9 GMT to 13 GMT) and was 120 mm/hr.

Mumbai is India's financial capital of Area of 437.71 Sq. Km. and with Population 11.9 Million people (2001). It is a Coastal city with massive reclamation. City got present shape after merging of 7 islands in city area and 4 islands and hilly areas in suburbs. Over 60% population resides in informal settlements

The 20th century drainage network of Mumbai is capable of carrying only 25 millimeter of rainwater per hour. Only three drains which drain into the sea have gates whereas, other 102 outlets have no such gates. Problem with coastal areas is lack of adequate gradient for water to flow into the sea. During high tides, the sea water incursion takes place through these drains. Drains without gates become vulnerable points and a salt water deluge engulfs upcountry. One of the natural drainage of suburb area is Mithi River. This is Small River of catchment area of 7.3 sq. km. and travels through a distance of 13.7 km before joining Mahim creek. River carries drainage discharge from 22 out of 71drains. Dense clusters of slums right on the river bank, disposal of industrial waste, sludge and domestic waste all along have converted this natural drain to an open sewer. Now choked to capacity this natural facility is of no help during the rains.

Because of the inadequate Storm Water Drainage capacity and heavy rains, Urban Floods is an annual feature of Mumbai. Urban floods of Mumbai disrupt rail and road traffic, flooding of slums and to lying areas, collapse of old structures practically halting all the activities.

**Rainfall of Mumbai -** Mumbai is getting annual rainfall of 2422.1 mm. Main rainy season is SW Monsoon season (June September) when city gets about 95% of annual rainfall.

July is the rainiest month and mean rainfall of the month is 868.3 mm. Twenty four hr Highest rainfall was recorded from 03 UTC of 26th to 03 UTC of 27th July 2005 (Fig. 2) when Santacruz, a suburb of Mumbai located at about 20Km North of Colaba (Regional Meteorological Center of India Meteorological Department at Mumbai), recorded 944.4 mm of rainfall surpassing previous highest record of 575 mm on 5th July 1974 at Colaba. This 94.4 cm has an estimated Return Period of more than 100000 years.

It was observed from Radar echoes that the cloud cells with height of more than 10 km were responsible for exceptionally heavy rainfall. Such high growth of Cumulonimbus (Cb) Cells is an indication of high degree of instability in the atmosphere. During SW Monsoon large moisture is available. Hence occurrence of heavy rains was expected and accordingly warnings of Heavy Rainfall (> 13 cm) were issued to Local Authorities by India Meteorological Department though 94.4 cm of rain could not be anticipated. India Meteorological Department is installing Doppler Weather Radar for better forecasting.

**Consequences -** When the historic rainfall of 994 mm in 24 hrs occurred for which city was not prepared immediate implication was collapse of communication system bringing traffic to total halt. Thousand and thousand people got stranded. Rainwater rushed in many houses on ground floor and hutments. It is also realized that public awareness of this type of disaster was low so their reactive actions to face the calamity. The resources were not mobilized as per any set practices. At many places there was no mechanism of rescue and relief operations. The sufferings to public could have been minimized had there been proactive actions taken which are then identified while reviewing the reasons of failure. The loss was estimated to be in tune of US $ 100 million.

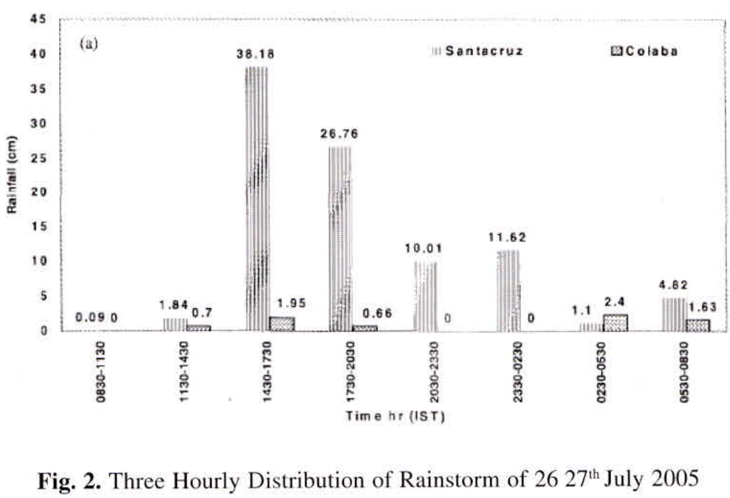


**Fig. 2.** Three Hourly Distribution of Rainstorm of 26 27th July 2005

## PROACTIVE ACTIONS PLANNED

**Maintenance of Drainage System -** Learning lesson from this unprecedented flood and in order to avoid flooding & water logging, Civil Authorities started giving more attention to carry out number of works such as systematic desilting of Storm Water Entrances (laterals and manholes) and open drainages both natural and man made, their repairs and removal of obstructions in it like cables, cross pipes etc.

**Structural Measures -** As it is observed that inadequate storm water drainage system was prime reason of Urban Flood of 2005, Mumbai Municipal Corporation is undertaking revamping the system by changing of design criteria from 25 mm/hr to 50 mm/hr. rainfall intensity and coefficient of runoff as 1.00 from the earlier value of 0.50 with tidal effects, rehabilitation of old/dilapidated SWD system in the City, training, widening and deepening of drainage channels like Mithi river, augmentation of railway culverts at various flood prone areas, removal of obstructions of water mains, cables, etc. in the SWD system, removal of encroachments, structures coming in the water courses and provision of pumping stations at three city outfalls .

With storm water drainage designed for rainfall intensity of 50 mm /hr and assuming same intensity persists for 3 hrs that is 3 hr rainfall is 15 cm, and the rainstorm follows the same temporal distribution as that of 26$^{th}$ July 2005 rainstorm, then 24 hr. rainfall will be of 37.2 cm of rain is about Return period of 50 years that is probability of occurrence or exceedance of this event is 0.002. Thus the risk of failure of drainage system in next 50 years may be 64 % that is about 32 times in 50 years.

**Flood Warning Systems -** Mumbai Municipal Corporation, India Meteorological department, National Disaster Management Authority, State Government are jointly setting warning system by installing 35 Automatic rain gauge stations make it possible to warn the concerned staff when rain exceed the prescribed limit (10 mm) in 15 minutes, two flow meters. India Meteorological Department has planned installation of one Doppler Weather Radar at Mumbai. The network density of Automatic rain gauge will further strengthen. Data is transmitted to Emergency Operations Centre (EOC) every 15 minutes through LAN. The arrangement is made to disseminate the warnings to public through electronic media, internet and media.

In addition India Meteorological Department is making efforts of increasing lead time of warnings by customizing NWP outputs, radar and satellite pictures for local areas.

## IMPACT OF CLIMATE CHANGE ON URBAN FLOODS

Problem of urban floods will get aggravated in future as climate models are projecting increase in rainfall with decrease in rainy days that is increase in high intensity rainfall events, resulting in further rise in peak discharge in many parts of India. India meteorological Department with trend analysis of rainfall of 100 stations reached similar conclusions (Table 1).

**Table 1.** Trend Analysis of 100 Rainfall Stations

| No. of Stations | Increasing Trend | Decreasing Trend |
|---|---|---|
| No. of Heavy Precipitation Days ( > 7.5 cm / day) | 17 | 2 |
| No. of Very Heavy Precipitation Days ( > 12.5 cm / day) | 08 | 1 |
| One day Extreme Rainfall | 15 | 1 |

This impact of climate change needs to be incorporated in hydraulic design of drainage system. Increase in urbanization, no. of heavy / very heavy rainfall days and also rainfall intensity will result into change in urban run of hydrograph with steep rise and higher peak discharge. If the runoff can be retained temporarily and released slowly, runoff time can be increased with decrease in peak discharge.

This can be achieved by rain harvesting techniques both from roof tops and open area. From a catchment of 1 sq. km area if one can effectively harvest 1 cm of rainfall the volume of runoff is reduced by 10000 cu. m which will add to ground water table and reduce the peak discharge. Same water can be available during lean period. National Geophysical Research Institute at Hyderabad developed Rain Garden in 3 hector area by digging small canal around the periphery and filling the same with locally available rubbles and coarse material. During SW Monsoon of 2007 this garden could harvest 2180$m^3$ of rain water and rise in ground water level was of the order of 1.5 m from 45 cm of seasonal rainfall. Roof top harvesting is also effectively implemented in many Government buildings and gardens at Delhi.

In mega cities open areas are not easily available and available one are also encroached. However, roof top rain harvesting can be enforced legally at least to permanent buildings. Rain harvesting may be effective during low intensity rainfall but cannot be ultimate solution during extreme events.

## CONCLUSION

In India, there is shift in mitigation policy of Government and Civic Authorities towards natural calamity/disaster from conventional which is mainly reactive, ex-post, ad-hoc to strategic that is pro-active, anticipate and prevent ex–ante with comprehensive approach of sustainable development. Applications of scientific and technological tools are also wide in use. Though total immunity from floods is not possible, aim should be to minimize the losses by preparedness and effective warning system in place. In Indian context prior requirement of preparedness is Public Awareness. People should be made aware of warnings and how to react without getting panic. As urban floods are inevitable, the citizens need to be groomed partially for self help by forming part of organizations for the purpose and partially on Civic Bodies particularly for rescue operations. The other instruments like flood insurance may be made mandatory to cover partial loss to business. Civil authorities should ensure urban development in planned way and maintenance of drainage system etc. At the same time authorities should enforce removing of encroachments in natural drainages and flood plain areas. Urban flood mitigation has a multi disciplinary facet and to be considered from all angles social, economical, technological, meteorological and institutional both social and Governmental.

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