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Urbanisation and flooding in Mumbai Suburban District

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Abstract

Urban flooding has become an endemic problem in recent years endangering lives and causing heavy economic losses. The process of urbanisation has played a major role in aggravating the problem as it causes significant alterations to the hydrology, morphology, habitat and ecology of an area. Built up regions are highly vulnerable to flooding because they comprise extensive tracts of impenetrable surfaces. Impermeable areas promote rapid rates of runoff that result in large quantities of water inundating urban drainage networks. The blockage of existing natural drainage systems further exacerbates the problem. This paper attempts to examine the factors contributing to flooding in Mumbai Suburban District in view of the need to implement a range of measures or management practices, which would help alleviate this problem. This is vital as extreme rainfall events are likely to become more common in future due to climate change.

Introduction

In recent decades, the world has witnessed an increasing number of floods in urban areas. They threaten the lives and livelihood of a large proportion of the global population and have a negative impact on local and regional economies. Urban flooding occurs where there has been development within stream floodplains. As cities are the engines of growth, urban floods have a major impact and hamper national development.

Mumbai dominates and controls India's commerce and its economic structures of power. In recent years, however, the city has slipped off the growth path and has experienced a decline on several fronts, including a breakdown of civic infrastructure. The abysmal state of the city's physical amenities came to the fore during the flash floods that occurred in the Suburban District on July 26, 2005. The rains left nearly 1,000 dead, power and water supply were cut off in many parts of the city and public transport came to a standstill. Inter-city train services were suspended and the airports were shut down for two days, affecting domestic and international flight schedules. Industrial units had to shut down, the government's currency, bond and foreign exchange markets suffered due to the snapping of communication lines which also forced the closure of the country's two largest stock exchanges and other financial markets on July28, 2005. Estimates of losses due to flooding ranged from 4050 billion rupees. It took a month for the suburban railway system and telephone services to limp back to normal and the city recorded 474 deaths due to flood-related diseases.

Urban flooding

Flooding is the most common environmental hazard, due to the widespread geographical distribution of river valleys and coastal areas, and the attraction of human settlements to these areas. Floods result when natural drainage channels, or human-made facsimiles, cannot convey all the water supplied to them; excess water spills over the banks and inundates the surrounding areas. The flash floods that submerged Mumbai on July26, 2005 were caused by a cloud-burst that resulted in 944.2 mm of rainfall in the Suburban District in 24 hours. It was the highest rainfall ever recorded in a single day in India. Prior to this, the record for highest rainfall received was in 1910 in Cherrapunji, Assam.

Urbanization increases the magnitude and frequency of floods by increasing impermeable surfaces, increasing the speed of drainage collection, reducing the carrying capacity of the land and, occasionally, overwhelming sewer systems. Large amounts of impervious surfaces in urban areas increase runoff amounts and decrease the lag time between the onset of rainfall and stream flooding. Manmade channels may also constrict stream flow and increase flow velocities.

Topography of the Study Area

The physiography of the study area, as observed in the topographical map of 1944, is dominated by a hill complex to the north centre of the island with elevations reaching 467 m at Kanheri, from which two spurs of ridges extend to the south enclosing in between a horse shoe shaped valley. The western ridge of higher elevation, extends over a distance of about 10 km and ends near Marol. The lower, but longer, eastern spur gradually descends to the level of the plains around Ghatkopar-Kurla.

The hills merge into tidal swamps towards the east; while towards the west are wide plains with a few isolated hillocks. Traversing the plains flats are protrusions and outcrops of lava flows which in places form low hills or low dyke ridges e.g. the low hill ridge of Kalina, the knolls of Marol, and Gilbert Hill at Andheri. Close to the coast on the western side, is a chain of low hills, broken and discontinuous, which is a continuation of the western hill ridge of the Island City. This ridge forms headlands at a number of places like Bandra, Danda, Madh, Manori and Uttan which are breached by tidal creeks, along the mouths of which extensive tidal marshes are observed. To the south east of the study area is a similar hill core, rising to an elevation of 305 m, surrounded on all sides by mangroves and tidal lowlands. This region comprises the erstwhile island of Trombay.

The two hill complexes have a radial drainage system, with numerous short streams, mostly unnamed, running down the slope in all directions. The largest of them is the Mithi river which drains southwards into the horseshoe valley. Due to the constriction of its mouth at Mahim bay, the lower course of the river is relatively broad and flanked by wetlands. The Dahisar river drains the Kanheri slopes to the west and empties into the Marve creek. The rivers have been dammed in their upper reaches to accommodate three small fresh water lakes, the Tulsi, Vihar and Powal, located one below the other. All the other streams are small and many of them disappear into the foothill slopes. The topography of Mumbai Suburban District with hill cores and radial drainage is ideally suited for rapid run off into the creeks and the sea.

Small depressions, forming ponds of fresh water, are found in areas where jointed rhyolites and trachytes, occur in scattered patches in the low lying areas surrounding the hill range, e.g. Padam Talao, located to the north of the Military Camp hill.

Today, the topography and configuration of the area has been significantly altered due to human interference. Quarrying for road and plinth material has resulted in the leveling of many low hills, which were subsequently built up. This is observed on an extensive scale around Kurla-Ghatkopar and Andheri-)ogeshwari. Much of the initial surface drainage and streams have been so completely modified that at present there is practically no natural drainage in the area.

Urbanisation and flooding in Mumbai Suburban District

Flooding is a chronic and recurrent problem in the study area, particularly when spells of intense rainfall coincide with high tide. The process of urbanisation however has played a major role in aggravating the problem as it has caused significant alterations to hydrology, morphology, habitat and ecology of the area. An understanding of the factors causing floods is vital in view of the need to implement a range of measures or management practices which will help alleviate this problem in the future.

a) Increase of impervious surface cover (ISC)

Impermeable surfaces such as roads and rooftops stop infiltration and increase surface runoff. The degree of urban surface runoff is typically proportional to the amount of ISC. It has been calculated that as ISC reaches 10-20% within a catchment basin, runoff increases twofold; 35-50% ISC causes a threefold increase in runoff; and 75-100% ISC increases surface runoff more than fivefold over forested regions (Arnold and Gibbons 1996). The increased runoff associated with urbanization affects stream hydrology in many ways. The time lag between the center of the precipitation event to the center of the peak flow discharge decreases as urbanization increases (Espey et al. 1965). Stream velocity and the associated erosive forces increase, as do the magnitude and frequency of flooding events (Schueler 1992).

The increase in ISC in the study area has been examined by comparing the land use before and after the spread of urbanization. The Survey of India topographical map of Bombay, No 47 A/16, 1944, surveyed in 1924-25, was used for the pre-urban analyses, while the Satellite Imageries of Mumbai IRSIC PAN data of 15th November, 2000 and 28th February, 2001, were used to obtain the current scenario (Figs.1&2). The land cover was divided into 6 classes, namely forest, cultivated area, wetlands, built up surface,

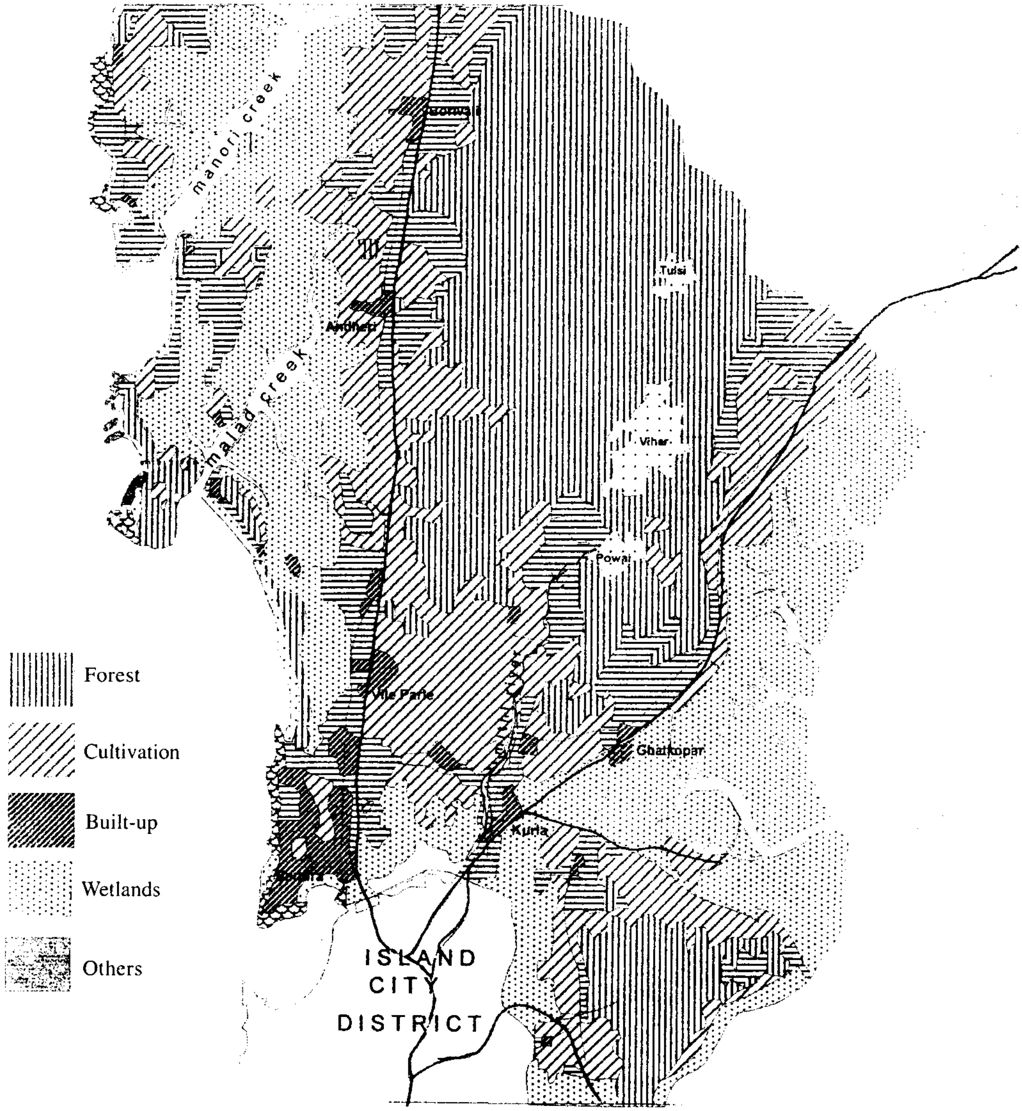

Fig. 1 **Mumbai Suburban District Landuse : 1924-25**

lakes and others and the percentage of area under each land use was determined for the study area for both time periods.

i) *Forested area:* There has been a considerable decline in the forest cover between 1924-25 and 2000. In 1924-25, it is observed that almost one third of Mumbai Suburban District comprising the central hill complex, including the two ridges, as well as the hill core at Trombay was under forest cover. This declined to one fifth by 2000. The most pronounced decrease in area was on the ridges to the south of the central hill

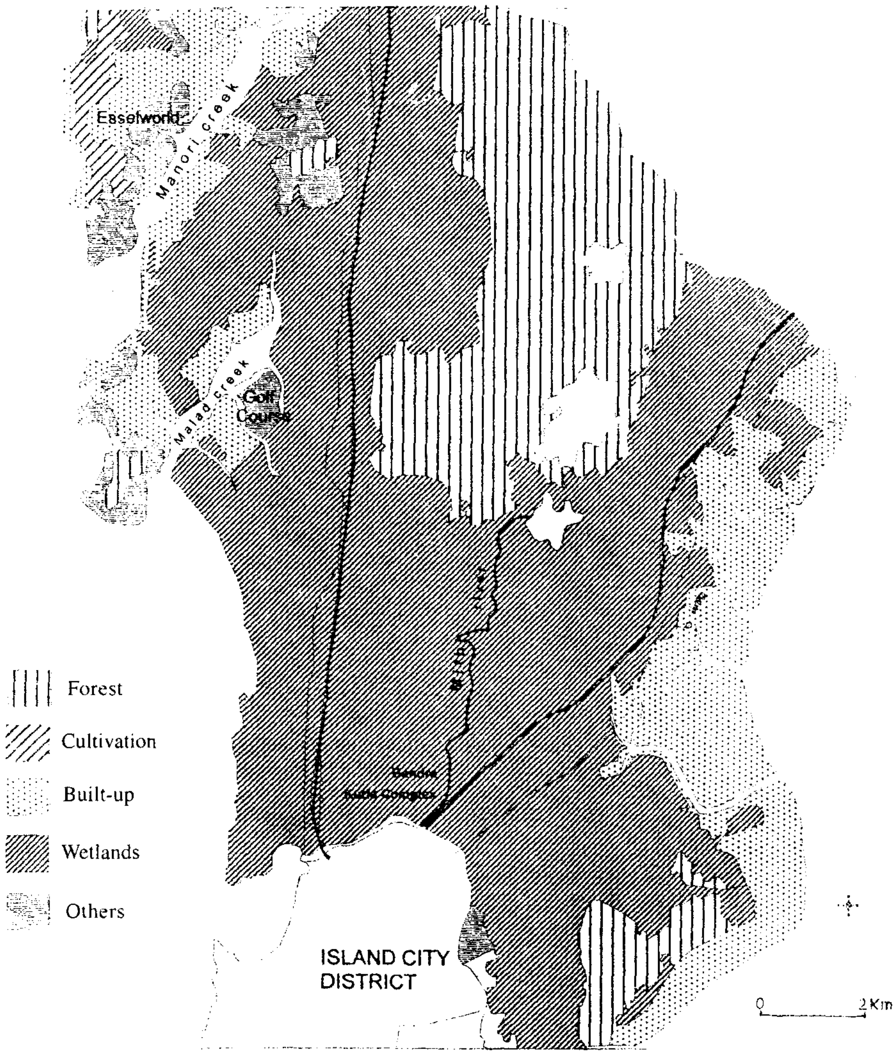

Fig. 2 **Mumbai Suburban District Landuse : 2000**

complex. The forests around Powai lake have disappeared, but the preservation of forests in the catchment areas of the Virar and Tulsi lakes significantly inhibit the amount and velocity of run off in these areas. On 26/7, though the catchment areas of these two lakes received 101.1 cm of rain in a span of 17 hours, unlike Powai, they, not overflow. If they had, the devastation downstream would have been much worse.

Currently, extensive deforestation is taking place along the margins of the

Table 1 : **Change in land use in Mumbai Suburban District 1924-2000**

Landuse	% of area in 1924-25	% of area in 2000
Forest	31.1	20.1
Cultivation	22.1	1.0
Built up	2.6	59.5
Others	13.0	3.7
Wetlands	29.7	15.6
Lakes	1.5	1.5

central hill complex, despite the area being a part of the Sanjay Gandhi National Park.

ii) *Cultivated area:* While the plains, lying between the hills and the tidal flats were extensively cultivated in 1924, the entire belt was built up by 2000. There is only a small patch under agriculture, located to the north of Manori creek, comprising a meagre 1% of the study area.

iii) *Wetlands:* They have shrunk by almost 50%, accounting for only 15.6% of the total area in 2000. Extensive riverine wetlands existed along the lower course of the Mithi river in 1924-25, but had almost disappeared by 2000.

iv) *Water bodies:* The main water bodies in the area comprise the artificial lakes Tulsi, Vihar and Powai, which have been formed by damming, the Mithi and Dahisar rivers. They lie in a narrow valley surrounded by hills and are flanked by steep wooded slopes.

In 1924-25 numerous small ponds of fresh water used to dot the plains surrounding the hill range e.g. Padam Talao. By 2000, most of these depressions were filled up and have become built up.

v) *Built up area:* This category, which represents the impervious surface cover has shown the maximum increase. 2.6% of the area was built up in 1924-25. The development at the time was very systematic with provisions for large open spaces. The buildings were single or double storeyed structures with considerable open area enclosed within compound walls. By 2000, 59.5% of the area was built up. This development comprises mainly of high-rise structures. Though building regulations stipulate that each plot should have 15% mandatory open space, it is observed that this is usually concretised. Moreover, Mumbai has one of the lowest ratios of open spaces amongst cities the world over. An inventory of Open Spaces in H and K wards of Mumbai Suburban District (Kewalramani et al 2002) revealed that parks, playgrounds, recreation grounds account for less than 1% of the project area. The impact of these in controlling run off is therefore negligible and the presence of these amenities was therefore ignored in the calculation of built up area. The increase in ISC from 2.6% to 59.5% indicates that there has been more than a three fold increase in run off due to urban sprawl as most of the construction has taken place is areas which were covered by forests or were under cultivation.

vi) The category 'Others' includes areas not covered under the other classes and includes areas under scrub, bare stony ground etc. In 2000, it also included inter tidal areas which have been converted to a recreational park (Esselworid) or a golf course.

b) Alteration of the natural river channels thereby reducing their capacity.

As urbanization within the study area has increased, river hydrologic regimes have been altered. Much of the initial surface drainage and streams, have been so completely modified that there is practically no natural drainage in the area. The changes include

i) *Damming of the upper reaches of the rivers:* The upper reaches of the Mithi and Dahisar were dammed in the late 19th century to form three lakes - Tulsi, Vihar and Powai, thereby tapping the catchment areas of these rivers and reducing the flow into their drainage channels. As their discharges have been considerably reduced, they now occupy larger misfit valleys. During periods of heavy rainfall the overflow of the lakes is discharged into the Mithi river resulting in the bursting of its banks and inundation of the surrounding area. In addition, the capacity of Powai lake has been considerably reduced in recent years due to siltation associated with rampant construction and quarrying on its southern banks. Currently the mean depth of the lake is a mere 3.2 meters (members.tripod.com). In 2002, it was one of the lakes taken up for conservation by the National Lake Conservation Plan. The Ministry of Environment and Forests gave Rs 6.5 crore to desilt and clean the lake but the results have been far from satisfactory.

ii) *Simplification of the drainage system:* From Map 3, which depicts changes in the drainage from 1924-2000, it is observed that within the confines of the current forested area the drainage system has. remained intact. Elsewhere, extensive changes are observed. Quarrying of Powai hills (depicted as a long ridge with maximum height 209 m in the Survey of India topographical map of 1976), due to rampant construction, has reduced their extent by half and obliterated the small channels draining into the lake. Human intervention has also contributed to dismemberment of the Mithi river. In the vicinity of Powai, first and second order streams joining the river are no longer observed. Along its middle course a major left bank tributary has been filled in. Further downstream, the airport authorities have leveled and raised the lower sections of a right bank tributary. The upper section is connected to a drain running along the north wall of the airport which empties into the river. The upper channels of most of the other streams in the study area have also been dismembered. A large majority of the first and second order streams have been infilled and leveled for construction purposes or occupied by hutments.

iii) *Diverting the course of the Mithi river:* The natural course of the Mithi river was diverted as early as 1805 when the construction of the Sion causeway diverted the river west, away from its original course into Harbour Bay.

During the construction of Mumbai airport shortly after independence, the first and main runway was built across the Mithi river, crossing it on a bridge with a culvert underneath to allow the water to flow. During the 1970s a second runway was built. As it fell short of world standards it was later extended into the river, artificially diverting it to the east (Map 4a). *iv) Constriction of the mouth of the Mithi river:*

The construction of the Sion and Mahim causeways in the first half of the 19th century together with the railway embankments of the Western Railway have restricted the mouth of the Mithi river and its outlet into the sea, in the bay, to a narrow channel. This blocked the natural course of flood waters of the river from flowing into the sea. In 2000 the mouth of Mahim bay was 1,600 m wide. Presently the Bandra-Worli sealink project is underway to improve the flow of traffic between the western suburbs and the Island City. For this, 400 m are being reclaimed at Bandra Lands' End and 270 m at Worli for the construction of the approach bridges, thereby reducing the mouth of the Bay by 670 m. In addition, nearly 100 support pillars for the cable stayed bridge are being constructed in the mouth of the bay. Constriction of Mahim Bay, has reduced its capacity to handle the inflow and outflow of water from the Mithi river. This contributed significantly to extensive flooding on 26/7.

v) *Destruction of natural ponds:* The numerous small ponds, which existed in the study area have been destroyed due to rampant construction associated with urban sprawl. The destruction of Padam Talao, one of the largest natural ponds in the study area, due to the construction of the airport is a case in point. Due to leveling of natural depressions, water instead of being stored, spreads over the leveled surface. This must have been one of the causes for the flooding of Air India colony, which was under 13 feet of water during the recent floods.

vi) *Siltation and clogging of drainage arteries*: Raw sewage, industrial waste and unchecked garbage are dumped into the rivers reducing their water-carrying capacity. As per the Maharashtra Pollution Control Board Report, 2003, around 5 million litres of sewage are discharged into the Mithi river per day by more than 1,20,000 people living in hutments and more than 3000 unauthorised small scale industrial units located along its banks. In addition, untreated sewage is dumped by the BMC. Free flow of water in the river is also hampered due to choking by an estimated 15 tonnes of plastic bags which are dumped into it daily.

It is observed from the map that the creeks draining into Thane creek have significantly narrowed and excessive siltation has altered the configuration of the coastline.

vii) *Reclamation of riverine wetlands:* The constriction of the mouth of the Mithi river results in the spread of flood waters on either side of its bank along its lower course, giving rise to an extensive tract of wetlands. It is observed from Map 2 that by 2000 most of these wetlands had been reclaimed. Two large institutions, Mumbai University and Bandra-Kurla Complex have been built on these erstwhile marshy tracts (Map 4). Wetlands act as natural storage reservoirs for floodwaters. They absorb water during heavy precipitation and release it slowly thus reducing run-off to streams and decreasing flood volumes. The destruction of this ecosystem along the Mithi, which has a very narrow channel to the sea, has thus significantly enhanced flooding on the low ground adjoining the river in Bandra East, Kurla, Kalina and Bandra. While the significance of wetlands was not appreciated when the area was reclaimed for Mumbai University, there were protests by environmentalists during the construction of the Bandra-Kurla complex, which comprises an area of 370 hectares and extends for 6 km along the Mithi and 2.5 km along its tributary Vakola Nalla. Ironically, the authorities claim its construction has helped to improve the hydraulic features of these two water courses. (www.mmrdamumbai.org)

c) Outdated and inadequate drainage system

The city's drainage system is archaic and is linked to the sewerage system. It was put in place at the beginning of the 20th century, and is only capable of handling rain intensity of 25 mm per hour. However, over the past five years, the meteorological station at Santa Cruz has recorded rainfall intensities exceeding 100 mm/hr. Moreover, as mentioned earlier, built up area in Mumbai Suburban District increased from 2.6% in 1924-25 to 59.5% in 2000, resulting in a threefold increase in runoff. In addition, the drainage system was designed for single-storied houses, which have now been replaced by high-rises resulting in increased waste-water flows. The pressure on the drainage system has thus increased manifold. The dismemberment of the natural drainage channels and the construction of roads on embankments, which compartmentalizes the horizontal surface flow, also aggravates flooding which has been endemic in the study area since long. Not only is the drainage system inadequate its capacity has often been reduced due to faulty policies of institutional authorities responsible for the provision of civic amenities in the city.

Storm water drains in the study area were downsized, damaged and even blocked for road widening programmes undertaken by the Mumbai Metropolitan Regional Development Authority under the Mumbai Urban Transport Project-II and the Mumbai Urban Infrastructure Project. This included the drains along the eastern and western express highways, the two main arterial roads in the study area. From Bandra to Santa Cruz, the size of the storm drains was

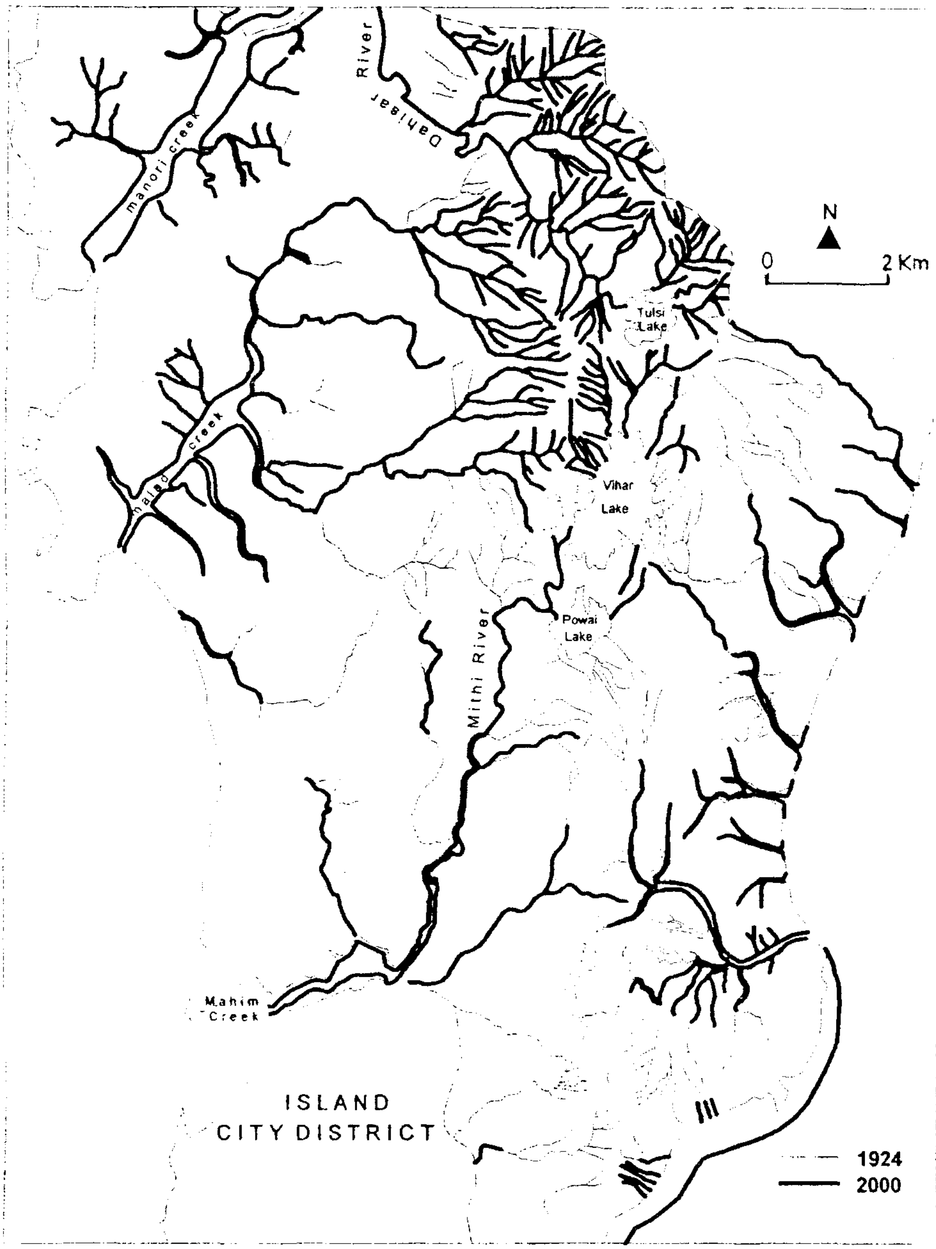

Fig. 3 **Mumbai Suburban District - DRAINAGE**

reduced to one third the original size. Though an alternate smaller drain was provided, this was broken and in places washed away by the rain on 26/7. The water on the expressway could be cleared only after 12 hours by using pumps. On the Andheri-Kural road, several inlets and outlets of the drains have been filled up permanently and the connectivity of the sewerlines near the Mahananda dairy has been destroyed. On the Eastern Express Highway, the nullah passing through Ambedkar Nagar and Samarth Nagar was blocked. Other areas where drains were blocked were Pestom Sagar in Chembur and Police Parade Ground, Ghatkopar.

Encroachments, both authorised and unauthorized, on and along the drains which not only clog them but come in the way of them getting cleaned, further aggravate the problem. For example, as per the data available from the Municipal Corporation, in M-West ward 25% of the storm water drains are encroached. Municipal officials admit that not one of the 77 major nullahs in Mumbai is free of encroachment. Indiscriminate dumping of garbage further compounds the problem as the choking of the surface drains increases the pressure on the underground drains consequently leading to the failure of the entire drainage system.

Lack of foresight has contributed to the collapse of the system during critical periods. The pumping station at Versova, which was built in 1990, was submerged for a week post 26/7 as it is located in a saucer shaped depression. The area, which was open scrub at the time of construction, was subsequently reclaimed for upper class residential complexes, which now stand on higher ground. Other pumping stations in the study area were unable to discharge flood-water on 26/7 due to power failure. Pumping stations should have a dedicated power supply connection. This was the case till the privatisation of power supply in Mumbai Suburban District recently.

Due to recurrent flooding, in 1990 the Brihanmumbai Municipal Corporation appointed Watson Hawksley International consultants to scientifically study Mumbai's storm water drains (SWD) network and suggest measures to overcome the problem. The consultants submitted their final study to the BMC in the form of a report, Brimstowad, in which they recommended the widening and deepening of storm water drains, in addition to creating diversions within the SWD system to remove obstructions from nullah paths. The construction of additional drains and provision of pumping stations was advised. It was intended to increase storm water carrying capacity to 50 mm per hour. The cost of the project, which was to have been completed in 2002, was pegged at Rs 650 crore. However, it was kept in cold storage as India's richest municipality, with an annual budget of Rs 7,500 crore, cited costs as a deterrent for its implementation. Gradual implementation of the Brimstowad recommendations was undertaken towards which Rs 200 crore has been spent (For 2005-06, a provision of Rs 31 crore was made). Despite this, major components of the plan have not been executed to date. Post 26/7 the project has been revived. Today the cost of the project is estimated at Rs. 1,200 crore and the approximate time required to implement it, once funds are made available, is 12 years.

Flood Management Strategies

Floodwater management in Mumbai Suburban District is vital to remedy the recurrent problem of flooding which is a regular feature during the monsoons and to prevent the occurrence of new problems. It involves the development and implementation of a combination of structural and non-structural measures to reconcile the conveyance and storage function of the drainage and storm water systems within the space and related needs of an expanding population.

a) Conservation of Sanjay Gandhi National Park

Mumbai is the only metropolitan city in the world which has a national park within the city limits. Quarrying and slums are gnawing at its fringes and in view of the ecological significance of forests (inhibiting the degree and velocity of surface runoff in the present context) the government must exercise the political will to ensure conservation of the park.

b) Improving Trunk Drainage

The traditional approach to 'improving' a natural urban waterway, creek or overland flow path, to increase its capacity by excavation should be undertaken at the earliest. Natural creeks and gullies should be retained wherever possible as part of the stormwater and flood flow design. The government has already set up a committee for the scientific clean up of the Mithi river and has sent notices to 1,500 illegal industrial units located along its banks. However, it must muster the political will to tackle slum encroachments. Widening of creeks should t~ also be undertaken to ensure proper draining out of low-lying areas e.g. widening Kurla-Mahul Creek will prevent flooding in of Kurla (East).

c) Speedy implementation of the Brimstowad project

Augmentation of the storm water drainage system is vital to ensure that the city does not come to a standstill for a few days every year. The proposed storm water carrying capacity of the project at 50 mm per hour needs to be enhanced as during the last five years rainfall intensity exceeding 100 mm per hour have been recorded in the study area.

d) **Drainage**

Drainage system should be separated from the sewerage system: The sewerage system adds to the pressure of the drainage system and should be segregated. In this context the Model Municipal Law drafted by the Union Urban Development Ministry in October 2003 should be implemented. The law states, "For the purpose of effectual drainage of any premises..... there shall be one drain for sewage, offensive matter and polluted water, and an entirely separate drain for rain water or unpolluted sub-soil water or both rain water and unpolluted sub-soil water, each emptying into separate municipal drains or other suitable places."

e) Banning of plastic bags below 80 micron thickness

Currently plastic bags below 20 micron thickness are banned due to regular choking of the storm water drains, but the absence

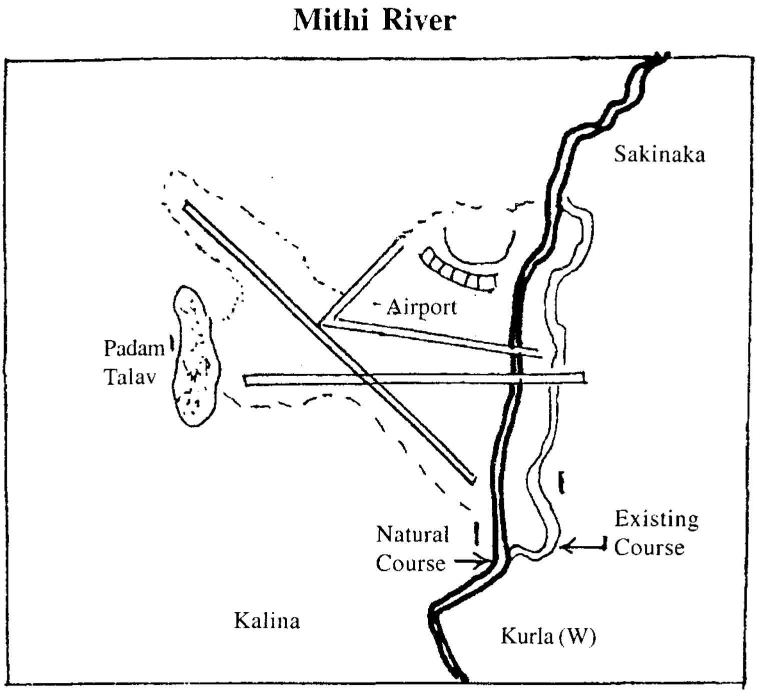

Fig. 4 (a) **Mumbai Suburban District - MITHI RIVER**

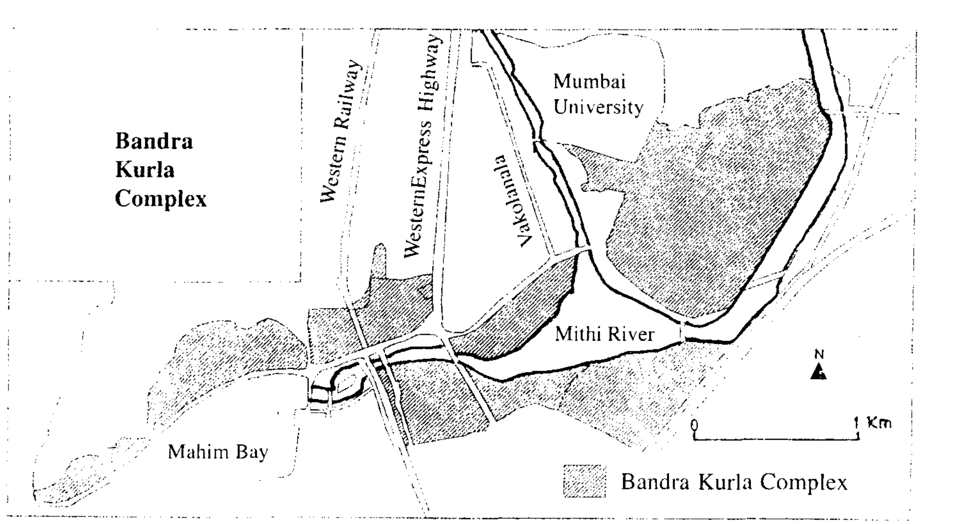

Fig. 4 (b) **Mumbai Suburban District - Bandra Kurla Complex** of an effective implementation programme has kept them in circulation. In the aftermath of 26/7 the state government is planning a complete ban on the use of plastic bags. This may not be practical and it is suggested that bags below 80 micron thickness should be banned. The neighbouring state of Goa has effectively banned plastic bags of thickness below 40 microns.

f) Installation of high power pumps at floodgates

Most modern coastal urban settlements use pumps to move stormwater to the sea or to a catchment area when high tide prevents natural drainage. This should be implemented in the study area.

g) Construction of a sluice gate structure west of Mahim Causeway

Flooding in the city becomes acute when heavy rainfall coincides with high tide so a sluice gate structure to prevent the entry of sea-water into the Mithi river during high tide should be built. An empty reservoir should be created by dredging upstream to absorb the flood waters of rains. This could be discharged into the sea by opening the gates during the next low tide. Though the design for this was finalised after model studies were carried out at the Central Water and Power Research Station, Khadakwasla, Pune, the project was never implemented.

h) Construction of Detention Basins:

Detention basins are typically designed into a residential development scheme, to ensure that the overall discharge from the scheme is held at predevelopment levels, or even reduced to lower levels. These basins can also be retro-fitted within existing urban areas. Currently, unlike cities in other parts of the world (e.g. Melbourne), new developments and redevelopments in the city do not chalk in plans for simple storm water management systems to slow the flow of water being carried into drains. The retro-fitting of a detention basin off the Mithi river near the airport would help to reduce the flooding in Kurla. Adequate holding ponds for water retention should be provided all over the city. Large open areas which have not yet been concretised, can be used for the purpose. Aarey Milk Colony, Bhavan's college, Yusuf Ismail College and the Kalina campus of the Mumbai University, all of which still have considerable unbuilt areas are examples in point. The construction of these basins should also be made an integral part of all new large development projects. As the finance for this will be provided by the developer, capital outlays from stormwater management authorities will not be required. Inlet and outlet-protecting screens should be provided on these basins to trap litter, debris and coarse particles. Once constructed regular de-silting will have to be ensured for proper maintenance of the system.

i) Other mechanisms for reducing flooding

These include measures like filter drains, permeable and porous pavements and infiltration basins. Permeable and porous pavements allow rainwater and run-off to infiltrate into permeable material placed below ground to store water prior to discharge.

j) **Rain water harvesting**

There should be a focus on retaining and reusing as much stormwater as possible. Since October, 2002 the state government has made rainwater harvesting mandatory for all buildings that are being constructed on plots that are more than 1,000 sq m in size.

This is a step in the right direction, as water has to brought from a distance of 120 kms and the city currently faces a shortfall of 900 million litres of water per day. Not only can the stormwater be reused for non-drinking purposes like toilet flushing, gardens and playing fields, car washing, fire extinguishing systems etc. but it will decrease the pressure on the drainage system.

Conclusion

Endemic flooding is an annual ritual in Mumbai Suburban District. Indiscriminate alteration of the natural landscape has resulted in a significant change in the land use and land cover. The rapid increase in impervious surface cover has resulted in a tripling of the run off. Simultaneously dismemberment of the natural drainage channels has reduced their capacity to absorb the discharge and transmit it to the sea. The storm water drainage system has not been augmented during the last century; on the contrary, in some areas its capacity has been reduced. The problem has been compounded as the system feeds into sewers of limited capacity. Augmentation of the drainage system by speedy implementation of the Brimstowad project is vital.

The construction of a sluice gate structure and the installation of high power pumps at floodgates should be undertaken to counter the impact of high tide. Drainage systems, however, can be overwhelmed in that they will only deal with the rainfall event for which they are designed. This is significant as climate change can impact the intensity of heavy rains. As mentioned, during the past five years rainfall intensities exceeding 100 mm/hr. have been recorded. The study area should thus be planned and designed to increase its sustainability. Natural drainage channels should be maintained and preserved. Sustainable drainage systems should be used to manage flood risk and other environmental damage by controlling surface water run-off as close to its origin as possible, thus reducing the environmental impact of development. Multiple decentralized rainwater management techniques shouldtadopted to reduce the peak load and avoid an overload !~the system. These techniques include construction of detention basins, active infiltration systems, partly permeable surfaces, and rainwater utilization systems. These should be made mandatory in all new development projects. This has been initiated in many parts of the world. Some examples include Potzdamer Platz, the largest building site in Europe, which was built under very strict storm water management conditions; Beta-/ Ludeckestra6e; a housing project renovated by the city of Berlin and the Institute of Physics, Humboldt University Berlin. The integration of ecology in the planning process of the metropolis will ensure that the grim scenario of 26/7 is not repeated in the financial and commercial capital of the country.

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