Sustainable Urban Drainage System (SuDS) – its applicability in alleviating flood risk in Mumbai (an Indian megacity)

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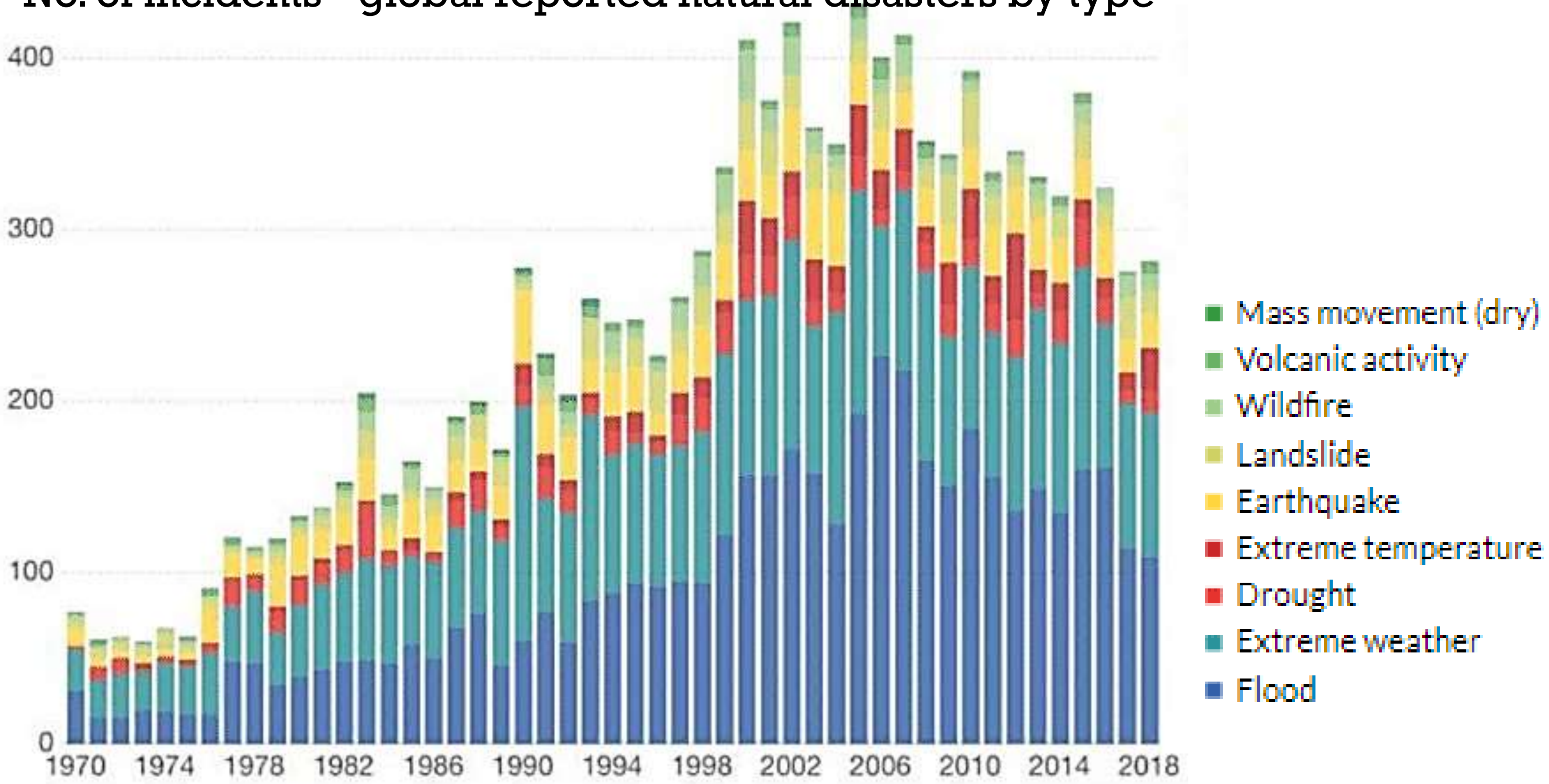
Presentation Structure

I. Introduction to the issue
II. Profile of Coastal Megacity: Mumbai, India
III. Interruptions in Drainage of Mumbai Megacity, India
IV. The probable answer
V. The way forward

Introduction to the issue

The increasing disaster concerns worldwide

No. of incidents - global reported natural disasters by type



Flood is the most occurring disaster around the world.

4 out of 10 disaster events are floods claiming 932 lives in a year, India being part of it. (*U.S. News on Nov. 20, 2018*)

Source: EMDAT (2019): OFDA/CRED International Disaster Database, Université catholique de Louvain – Brussels – Belgium

The Flood Scenario, India

NIDM 2015	**Flood has become the biggest disaster** killing thousands in last few years. Its recurrence and amplified intensity are damaging life & economy. Trend analysis suggests there is a **need for effective pre-and post-disaster mechanism.**
IPCC 2018	Sea levels are rising faster than estimations. With global warming limited to a rise below 2°C and reduced emission, 30-60cm sea level rise by the year 2100 is certain. If emission keeps increasing, then 60-110 cm rise is expected. With a 50 cm rise, 5 lakh people will be flooded in 45 Indian cities. **Coastal cities of Mumbai, Kolkata, Surat, Chennai are under major threat.** 4bn. people will be hit by sea level rise, melting ice & glaciers.
IPCC 2019	Rare extreme **flooding events may begin to occur annually.** Some coastal areas are already seeing frequent higher sea levels during high tides and storm surges and many more low-lying cities and islands are at risk. Coastal migration and urbanization make flooding events even more damaging. **Without serious adaptation measures, flood risks may increase by 2 to 3 orders of magnitude.**
CPHEEO 2019	The problem of disposal of **storm runoff is compounded in the cities having flat terrain, tidal fluctuations in coastal areas and blockage of streams/drains** due to landslides in hilly areas.
German-watch, 2020	Climate Risk Index - **India is the fifth most vulnerable country to climate change**. India's high rank is due to severe rainfalls, followed by **heavy flooding** and landslide that killed over 1000 people

- Coastal Indian cities are most vulnerable to floods.
- Urgent need for a paradigm shift from 'response and relief' to 'prevention and mitigation' to make cities resilient. (Dhankhar, 2017)

Flood-affected Mayong village in Morigaon district, in Assam, India, June 29, 2020. Photo: REUTERS/ Anuwar Hazarika

Navy personnel were called on to carry out high water rescues and evacuations in Mumbai, Sept. 2019. Photo: India Navy

Idukki District in Kerala, India, after rain triggered a landslide burying houses. Photo: NDRF

Flooding in Madhya Pradesh, late August 2020. Photo: Govt. of Madhya Pradesh

Rhinoceros in floodwater inside Kaziranga National Park, in Golaghat district

Floods and Mumbai Megacity

Shanghai Manual 2010	**Mumbai has experienced several major extreme weather events** within the past decade that have effectively brought the city to a standstill & **caused severe human & economic losses.**
Ranger et.al, 2010	The **drainage systems of the city are now inadequate to cope** with heavy rainfall and are impeded by urban encroachment and channel blockages.
IPCC 2014	**Lowland areas** in coastal cities such as Lagos, Mombasa, or **Mumbai** are usually more at risk of flooding, **especially where there is less provision for drainage**.
Dhiman et al., 2018	Mumbai currently ranks as the **5th largest city** in the globe (UNDESA 2016). It is **most vulnerable in terms of flood risks** associated with anthropogenic activities in India.
IPCC 2018	If India continues to violate the Paris deal on low emissions, the **water will rise up to 100-110 cms leaving no trace of Mumbai**
Bobade et al. 2019	Reasons for flooding - extensive reclamation & faulty zoning regulations, **faltering drainage systems, natural drain: Mithi river, incapable storm water drains**, reduction in the catchment area of Mithi river, change in path of the Mithi River due to Airport runway, construction of Bandra-Worli sea link on the mouth of Mithi river, Maintenance of drains, **link between storm water drains & Sewerage network** etc. **Hence, there is need to study and provide an effective sustainable and long lasting under drainage system for Mumbai city.**

Mumbai has been highlighted by IPCC several times as one of the most vulnerable cities in the world.

Most of the problems of Mumbai floods in Mumbai are related to interruptions in it's drainage system – both natural and manmade

Old Projection For 2050 (by NASA)

New Projection For 2050 (by UN)

Source: The New York Times

Profile of Coastal Megacity: Mumbai, India

Mumbai

- **Most populous** Indian city (14.4mn, 2020), land area of 603 sq.km.
- India's commercial and **financial capital**
- Located along the western coast of India, adjoining the Arabian Sea, with the **largest port** in western India
- Mumbai was formed on **two groups of islands** - Heptanesia and Salsette
- Migration leading to **excessive urbanization** (16% of population growth rate)
- **Slum population is estimated to be 41.3%.** Dharavi in Mumbai is considered as the **largest slum in the world.**
- **Natural disasters** in the city include floods, landslides, cyclones, earthquakes
- **Manmade disasters** include fire, industrial and chemical accidents, terrorist attacks and riots
- Around **10% area of Mumbai is prone to chronic flooding**

Existing drainage system

Fig: Water bodies, Mumbai

The drainage system of Mumbai is **a mix of simple drains and complicated network of rivers, creeks, drains and ponds.** A network of closed drains below the roads has evolved in the city whilst there are open drains in the suburbs (Gupta, 2009). The **central area of the city forms a depression**, flanked by hills, and being on reclaimed grounds barely +2-3 meters mean sea level (msl) is liable to flooding. Mumbai has:

- an average elevation **+10-15m msl**
- low level coast line, with some points **+1m msl**
- **important areas** like BKC, Worli, airport, western railway line are low lying

Dilapidated drainage system, encroachment on river basins, land reclamation, pinching of river mouths, reduction in mangrove areas (Jain, 2006)

Fig: Flood extent map for the 2005 event

Interruptions in Drainage of Mumbai Megacity, India

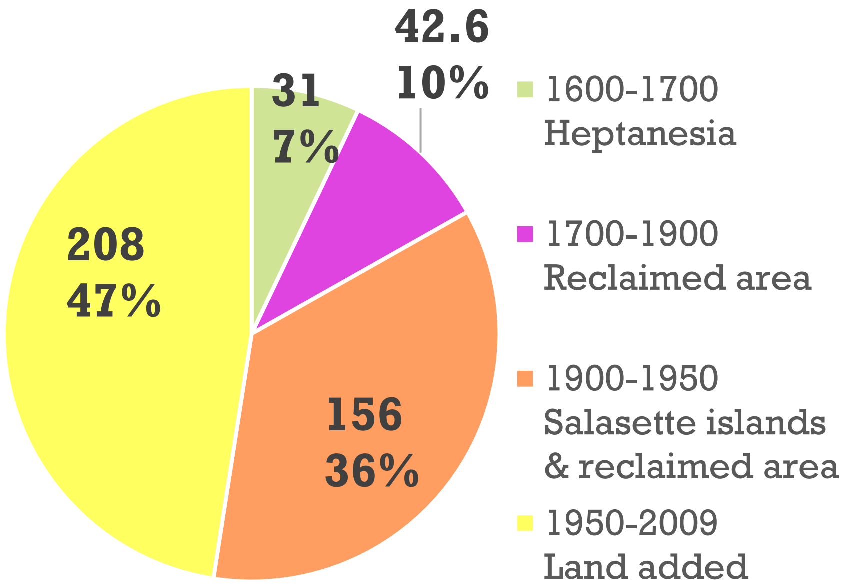
Interruptions in Drainage

1. Land Reclamation
2. Developments on River Basins
3. Design and Capacity of drainage systems
4. Maintenance of Drainage
5. Reduction in mangrove areas
6. Increased runoff coefficient

1. Land Reclamation

- **over 40% of land is reclaimed** land from the sea by filling in of inland lagoons and marginal seas, just at or above sea-level. *(Arunachalam B., 2005)*
- **almost one-fourth of land lies below msl**
- unplanned and **unscientific reclamation** methods adopted

Land Area Distribution (Total = 437 sq.km.)



Source: Disasters in India-Studies in grim reality; Anu Kapoor

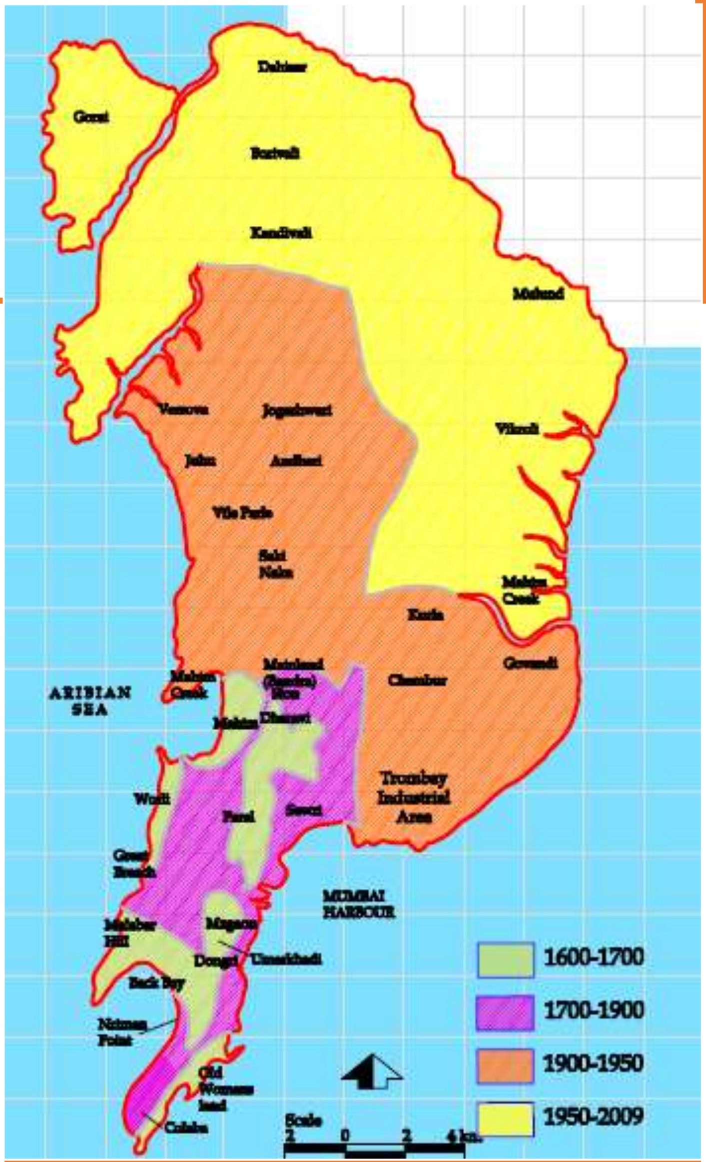
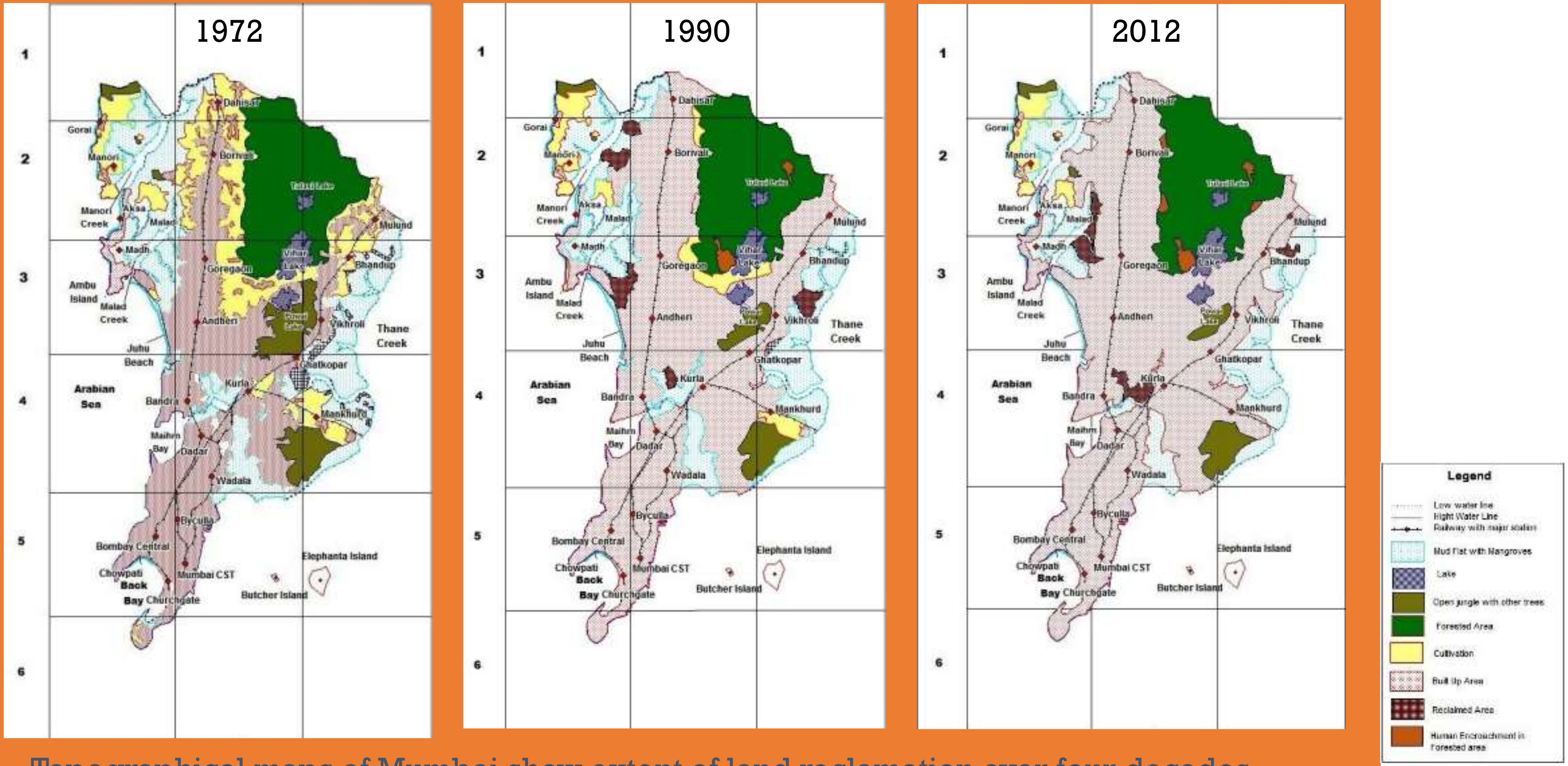


Fig: Reclamations, Mumbai



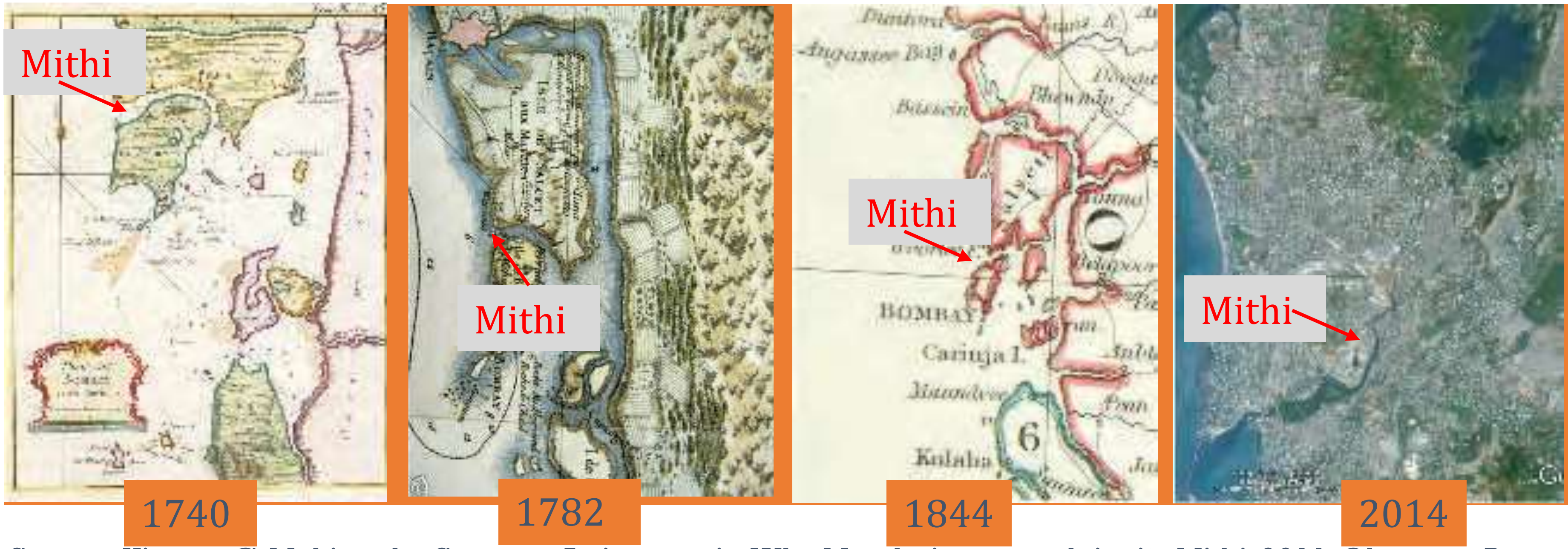
Topographical maps of Mumbai show extent of land reclamation over four decades

Source: MTSU report 2015

2. Development on river basins

The Mithi River and the Mahim Estuary

- Originates in the overflowing water from three lakes and also from the Borivali hills.
- The actual source taken over by a factory.
- The catchment area is around 108 sq.km.
- Mahim estuary was subjected to reclamation over the years and is now an extension of the river.
- Destruction of mangrove ecosystems along rivers
- Most of the flooding Hotspots identified by the municipality (MCGM) are in the Mithi river basin



the extent of reclamation which has sealed one end of the Mahim estuary.

Source: Kirtane G. Making the Sewer… A river again. Why Mumbai must reclaim its Mithi. 2011. Observer Research Foundation Mumbai

A. Morarji Slum

C. Vihar Lake

E. Mumbai Airport

Photo: Vijay Bate

B. Origin of River

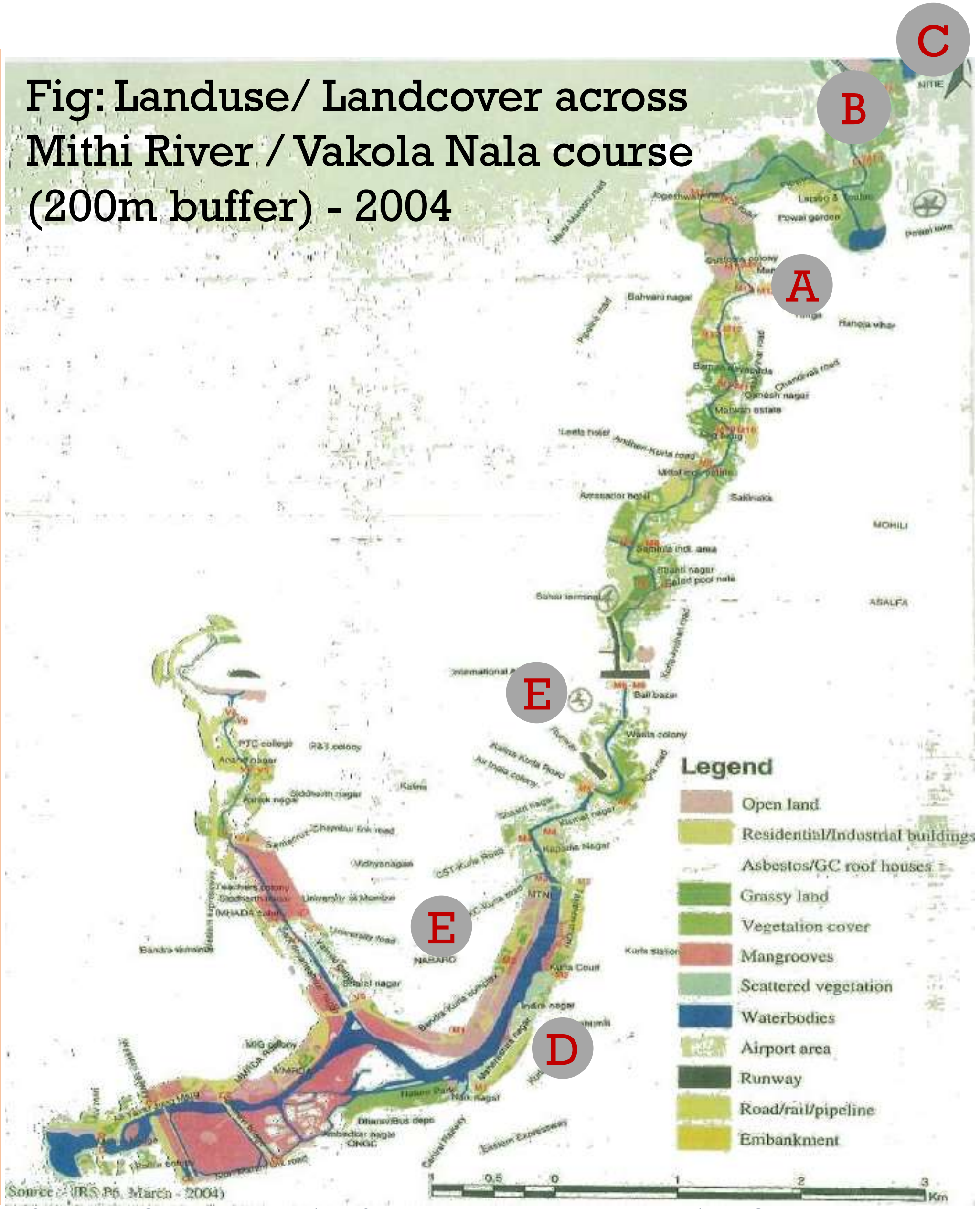
D. Mithi in Kurla

Photo: IIT Delhi, 2014

F. BKC

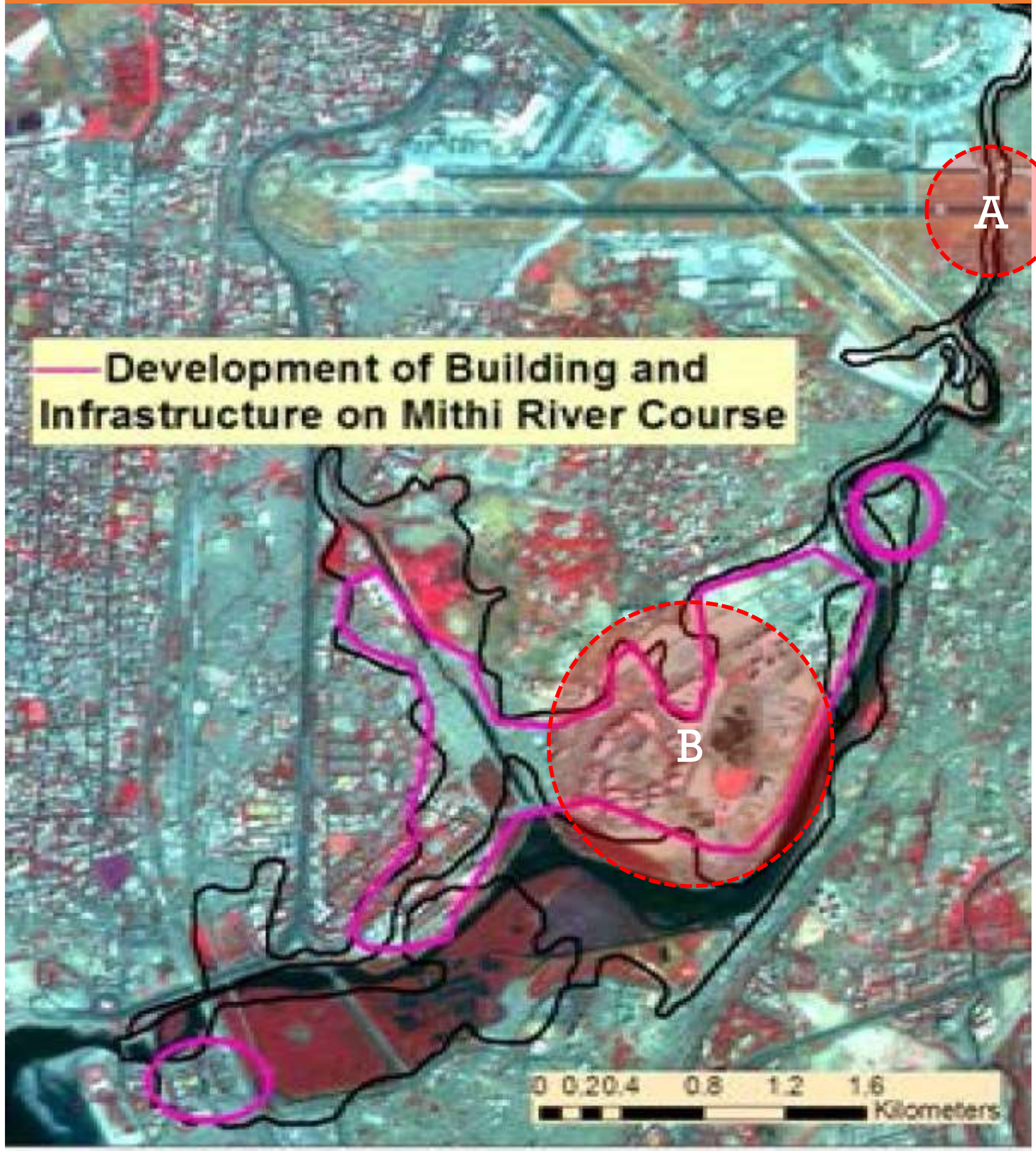
Photo: TOI, Sept. 8,2019

Fig: Landuse/ Landcover across Mithi River / Vakola Nala course (200m buffer) - 2004



Source: Comprehensive Study, Maharashtra Pollution Control Board, Mumbai 2014

Changes in Mithi River Course 1966-2009



A. Mithi River – Airport junction

- River was made to pass through a tunnel below the runway
- River was first bifurcated and then reunited forming a small island which was then utilized for airport extension.
- Airport runway extended on river course

B. Developments along the river

Source: TOI, 5 Aug2019

- Mudflats, acting as holding pond, were encroached upon during 1992-2009 with BKC, slums
- Environment Ministry had warned about the disaster potential of construction of BKC, replacing swampy areas but no action was taken.
- Mithi & Vakola rivers encroached upon by development works, slums

3. Design and Capacity of drainage systems

Manmade drainage system:

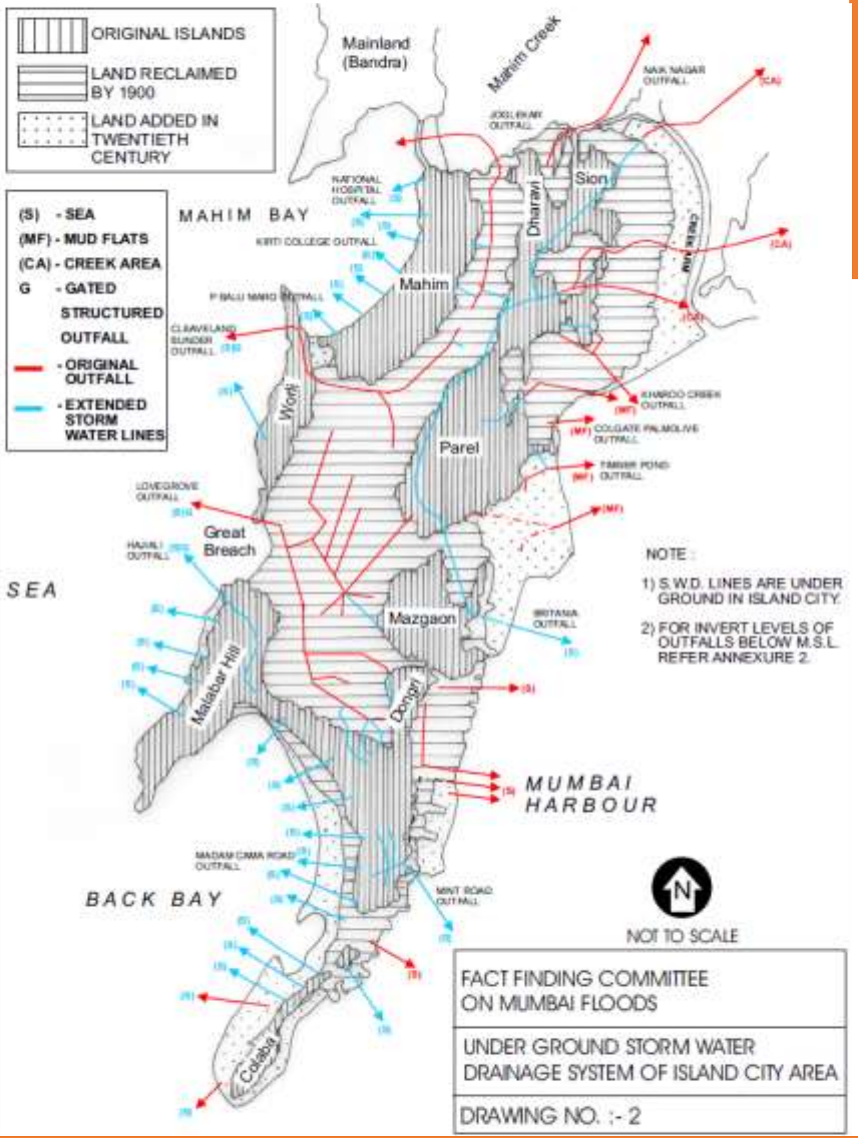
- **about 80-year-old installation,** with 480 km of underground drains and laterals.
- designed to handle **rain intensity of 25mm/hour** at low tide with **runoff coefficient of 0.5.**
- since the outfalls are into the sea, **tidal variation has a major bearing on the drainage system** resulting in flooding/ water logging during heavy rains.
- **45 outfalls of 186,discharge below the msl** and only 3 outfalls have floodgates.
- combined sewage & drainage system

Natural drainage system:

- drained by several rivers, like Mithi, Poisar, Dahisar, and others and Mallad & Mahim Creeks.
- increased pressure on the system due to **rainfall pattern, development, runoff, dumping of waste,** etc.

The new piped drainage system is being planed the city with a rainfall intensity of 50mm/hour and a runoff coefficient of 1.

Cleaning of Mithi is carried out during monsoon but the dumping is much more



Drainage outfalls, Island City, Mumbai

Source: Fact Finding Committee on Mumbai Floods

Sewage System, Mumbai

Toxic foam has started forming on the surface of Mahim Creek.
Photo: Hindustan Times

MPCB has identified 70 drains that discharge untreated sewage into the 17.8 km long river

- Sewage flow is connected to stormwater drainage system at many places.
- The slums also invariably discharge 'sullage' into the drainage System. Slum Colonies generate garbage which finds its entry into drainage and causes siltation and obstructions.
- Mixing of sewage & storm water has aggravated the silting processes at outfalls and in estuaries.
- Preliminary treatment of sewage is carried out in island city. However, the sewage collection and conveyance arrangement for the suburbs.

Interconnection of sewage and storm water network leading to siltation and loss of drainage capacity. (Bhattacharjee, 2018)

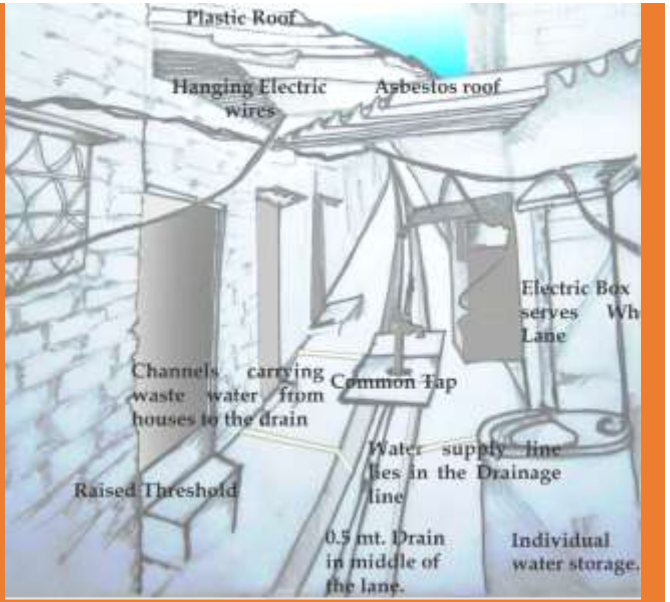
The earlier the sewage drainage and storm water drainage are segregated, the cleaner the city environment. It is also time Mumbai is decongested. (B. Arunachalam, 2005)

4. Maintenance of Drainage

- **Slums** along the rivers, especially Dharavi along Mithi are **discharging their waste water** directly into the rivers through open nallahs / closed pipelines.
- **Open drains**, at many locations, act as **entry for refuse**, obstructing the flow
- Poor workmanship and lack of attention to proper repairs when the drains have been punctured.

Household waste entering Mithi in the slums of Bhim Nagar
Photo: Scrolls.in

These nallahs have now become sites of toxicity.



One foot wide open drain in Rajiv Gandhi slum, Dharavi, for carrying storm water and waste water.

Photo: SPA, New Delhi, 2009

Interconnection of storm water & sewerage networks. Photo: untreated sewage discharged into Mithi

Encroachments on and around service manhole

Freshwater pipeline passing above the Mithi river

Makeshift bridge over Mithi river
(Photos: Rohit Sharma)

"Many municipalities in India today **outsource the actual de-silting of drains.** Typically, the waste that is cleared out is **kept alongside** the drains because it would add to the costs to transport them long distances. When it rains heavily, all **that waste goes back into the drains**." (Patralekha Chatterjee, 2005)

Desilting is outsourced

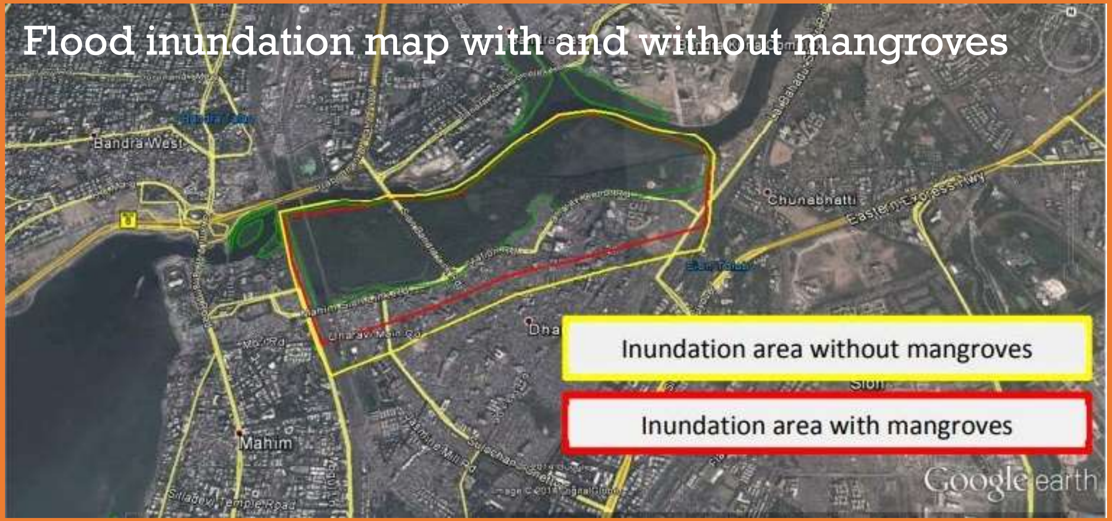
5. Reduction in mangrove areas

Deonar Landfill
Image: NASA 2017

Essel World (Theme park)
Image: Googleearth 2020

- **Mangrove ecosystems** which exist along the Mithi River and Mahim Creek are being **destroyed by construction.**
- It is estimated that Mumbai has lost about **40% of its mangroves between 1995 and 2005**, some to builders and some to encroachment (slums).
- **Sewage and garbage dumps** have also destroyed mangroves.
- The Bandra Kurla Complex(BKC) had been developed over **300 ha of mangrove land.**
- The basins in the western suburbs that flow into the Malad creek have been built upon without accommodating the natural drainage pattern.

Mangroves and their mudflats act as a buffer between sea and land. They have ecological, environmental and flood reduction benefits and hence it should be preserved around the banks of Mithi River.



- **Presence of mangroves reduces the flood affected area by 21 %.** (Khan, M. 2014)
- **Land reclamations and industrial effluents** are the major causes of mangroves degradation. It creates a barrier for sea water to enter the mangroves, eventually killing them.

Figure Legend: Gorai
(1) Bhyander
(2) Dahisar
(3) Gorai jetty
(4) Essel World; Versova
(5) Malad Creek
(6) Dharavali
(7) Aksa Beach
(8) Pascalwadi
(9) Near CIFE; Juhu
(10) Versova Beach
(11) Rajiv Gandhi Institute; Bandstand
(12) Chimbai
(13) Shirley
(14) Bandstand; Bandra
(15) Near BKC
(16) Mithi River; Sewri
(17) Chembur-Wadala road
(18) Mahul jetty
(19) Sewri Flamingo watch; Vikhroli
(20) Vikhroli
(21) Ghatkopar
(22) Mankhurd; Elephanta Island
(23) Mangrove point1
(24) Mangrove point2
(25) Mangrove point3.

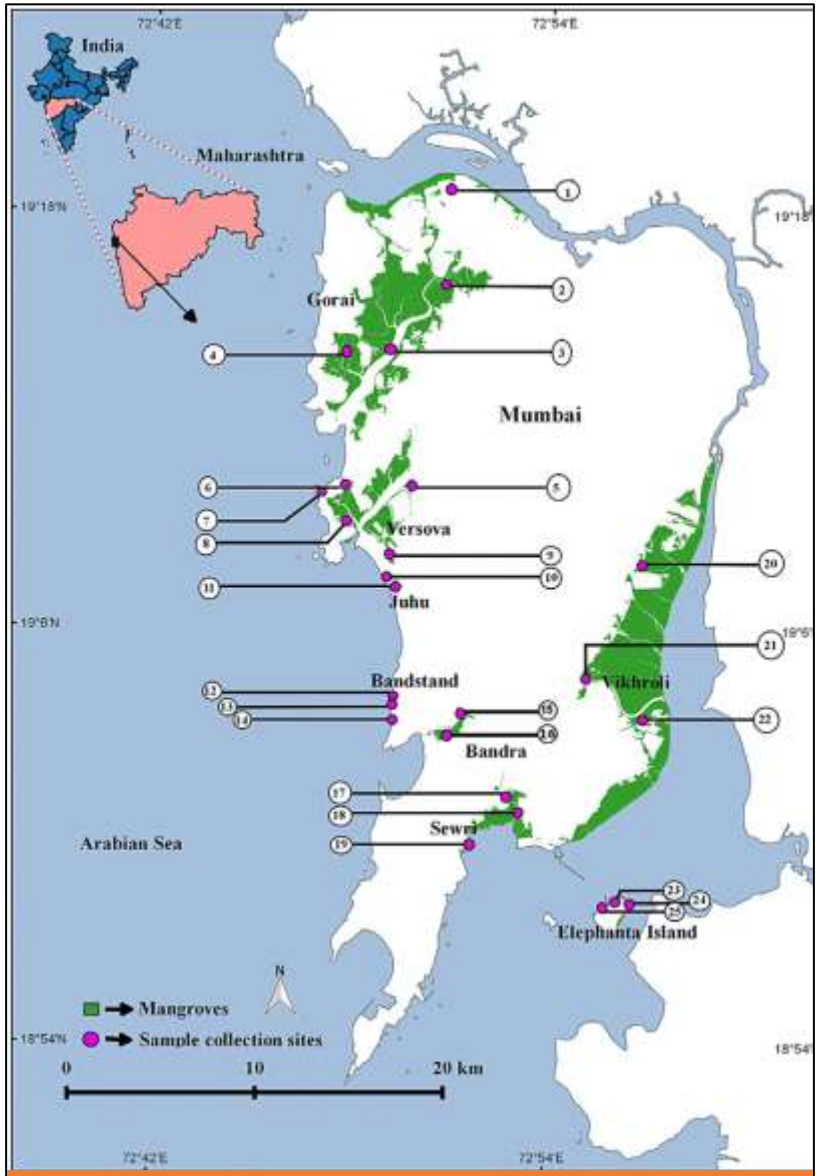


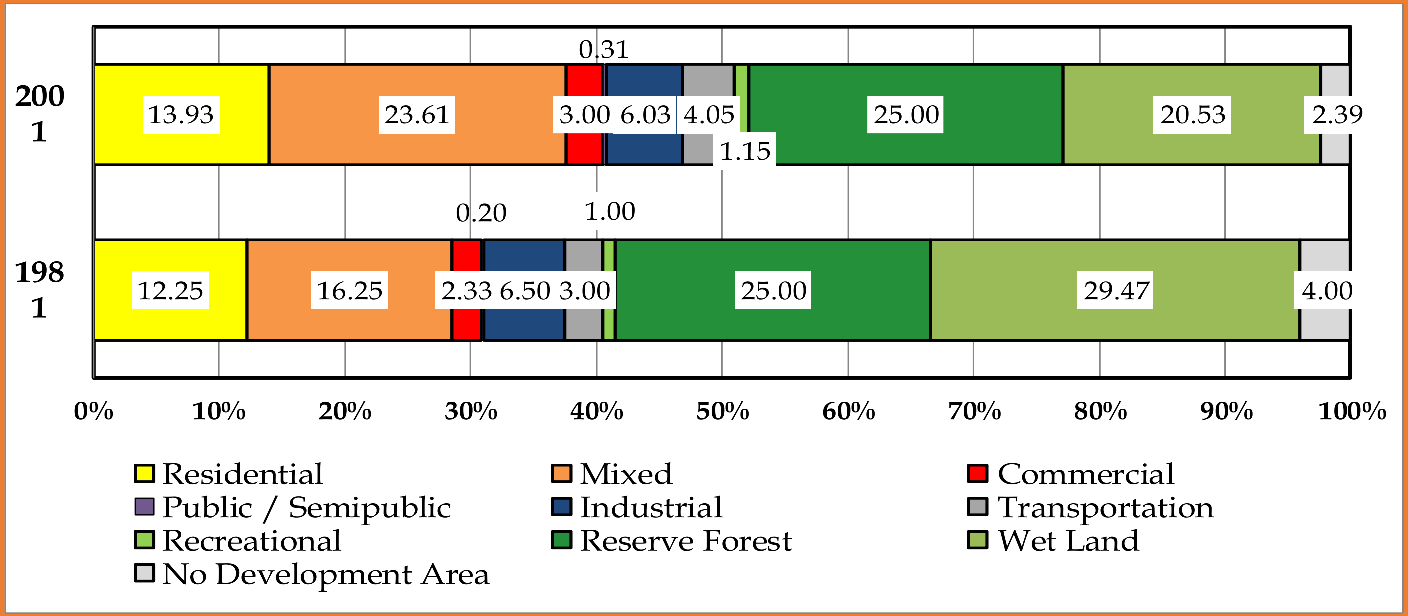
Fig: Developments on mangroves

6. Increased runoff coefficient

Arunachalam , 2005	The **increasing extent of built-up areas by way of buildings, concretisation and macadamisation of a widening network of road arteries, an increasing population in the buildings and the hutments in the niches between built-up areas** releasing more sewerage all add to the gravity of the situation. This is the reason why waterlogging continues for days together in the central depression.
Sörensen et al., 2016	Impermeable surfaces, sea level rise and river discharge is threatening 15% of the world's population
SPA, New Delhi, 2009	Since 1994-2009, over 1000 plots of public land has been released for construction. **50% of the city's no-development zones have been built upon**
CDP 2005-25, Mumbai, 2006	Storm Water Drainage capacity inadequacies are due to **increase in overall runoff coefficient due to loss of holding ponds and encroachments alongside drains**, disturbing catchments runoff
Gupta, 2009	Most **detention ponds have been lost to development** and it is estimated that urbanisation has contributed to increased **runoff by 2-3 times**
Ranger et.al, 2010	Urbanisation has been an important driver of increased flood risk in the city. For example, it is estimated that urbanisation alone has contributed **to a two or three fold increase in runoff in the city.**

The progressive reduction of open lands has substantially reduced the natural percolation areas of water into the ground and thus contribute to the storm water collecting on the surface. (Arunachalam B., 2005)

Landuse distribution



Source: City Development Plan 2005-25, Mumbai

- Shrinkage of wetlands & marshy areas by 9% (39 sq.km), due to increased residential, commercial & mixed landuse. These lands act as sponges during floods and absorb all excess runoff in the city
- Reduction in no development area by 1.6%
- 1972 to 2011, the **built-up area in the region increased 4.5 times**, from 234 sqkm to 1,056 sqkm. The decline in population density of the urban areas is at the expense of cultivated lands, forests and water bodies. (Source: Applied Geography, IIT-Bombay, 2019)

Excessive Concretization (high rise = planned development)

Difference between Authorized and Unauthorized development?

Excessive Concretization (slums = unplanned growth)

Source: IIT Delhi, 2014

Planning authorities have permitted construction on floodplains. But for obvious reasons, the consequences of encroachments in the Mumbai area seem to be far worse. **More than 55% of city's population**, are living in slum areas and hutments. (Jain, 2006)

Runoff **coefficient for paved surfaces is 0.95** (Mr. Haestad's International standard handbook)

Increased footprint area leading to impervious land.

Retaining walls along the river near its origin

The probable answer

Identified issues and probable solutions

Drainage issues contributing to flooding	Probable Solution
Encroachments on river basins and buffer zones of water bodies	Restore natural drainage system
Mixing of sewage with storm water	Disconnection from sewage drains
Increased runoff coefficient, Reduction in softscapes, open spaces	Create / re-create open spaces reduce built spaces/ footprint/ increase percolation areas Detention basins to catch the run off

Possible?

to have one magic bullet for all these problems

Answer:

Sustainable Urban Drainage System (SuDS)

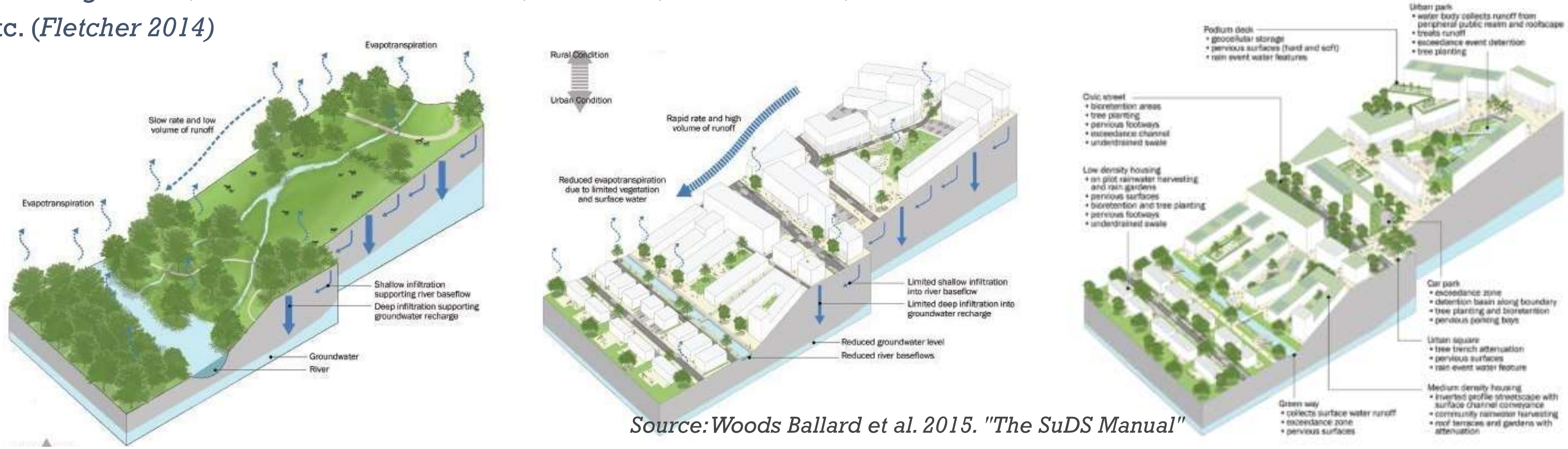
The principle & objectives of SuDS

The philosophy of SuDS is about maximizing the benefits and minimizing the negative impacts of surface water runoff from developed areas.

Increasing integration and sophistication of urban drainage management over time includes flood mitigation, recreation & aesthetics, water quality, flow regime restoration, ecology of receiving waters, storm water as a resource, resilience, micro-cliamte, etc. (*Fletcher 2014*)

BENEFITS

Water Quantity	Water Quality
Amenity	Bio-diversity



Source: Woods Ballard et al. 2015. "The SuDS Manual"

Successful experiments

Perales-Momparle et al., 2013	Inner-city **SUDS retrofitted sites** to promote sustainable stormwater management in the Mediterranean region. The analysis confirmed that the current combined sewer networks are insufficient to appropriately manage the runoff, and flooding occurs in several parts of the networks. Also, different climate change scenarios have been introduced in the analysis. **Location and type of the SUDS demonstration infrastructures was decided and checked for suitability.**
Boogaard, 2015	The research has demonstrated that most of the **bioretention swales and permeable pavements tested in the study have met the required hydraulic performance levels even after years in operation and without maintenance.** Also, some SuDS show their suitability in particular land type (groundwater levels, permeability). **Treatment train approach achieves increased efficiencies**.
Chan et.al, 2018	A coordinated approach to the design and construction of urban green-space, particularly w.r.t. management of drainage discharge; the utility of space for stormwater storage; the relationship between soil type, infiltration, and discharge volumes; and minimum allowable discharge rates during the normal and wet conditions to maintain required soil field capacities. Landuse planning is important alongwith sponge city guidelines.
Bo Yang et al., 2010	Correlation analysis shows that **open drainage watershed generated less storm runoff** than the conventional drainage watershed, given the similar impervious area in both watersheds. **Rainfall response of open surface drainage watershed is similar to its predevelopment natural forest conditions**, indicating effective flood mitigation post development in contrast to the conventional drainage watershed.

Many countries have adopted the concept like, France, U.S.A , U.S., U.K. Australia Singapore U.S. NZ China, the Netherlands, Denmark, Sweden, Germany, South Africa, etc.

The need of SuDS in Mumbai, India

Jain, 2006	Indian cities frequently face the problem of flooding caused by poor drainage, and severe shortage of water, especially before the monsoons. **This is largely a consequence of adoption of borrowed concepts of urban drainage**, together with indiscriminate and unplanned developments in the natural drainage channels. **There is an urgent need to resort to bio-drainage.**
Stovin et al., 2007	**The concept of SuDS retrofit offers an exciting and versatile, yet currently underexploited, opportunity for stormwater management in urban areas.**
Sieker, 2010	**Much needed paradigm shift from conventional drainage to a modern approach.- from "Getting rid of stormwater as quick as possible" to "Maintain natural water balance"**
Das, 2012	Implementation of the BMPs of the **principles of SuDS can help tackle the threat posed by the mismanagement of urban stormwater runoff** & also regenerate fast depleting groundwater aquifers.
Sörensen et al., 2016	**Alternative ways to manage floods have evolved since traditional methods often harm the riverine ecosystems** in urban as well as rural areas and increase the long-term flood risks.
Chana et.al, 2018	**Sponge city can achieve the dual goals of sustainable water-use and better flood control.** It is influential and revolutionary in its approach to land-use planning, urban water-resource management, urban flood and climate risk mitigation, ecological enhancement and social wellbeing.
CPHEEO Manual, 2019	**Storm water is now increasingly being valued as a resource to address water security in urban areas.** Some developed countries are integrating smart practices such as WSUD, SuDS, LID and other BMP in their urban planning to economize storm water management on one hand & water security on another.

- Alternative / Modern drainage systems available for flood management
- India has realized the potential through world scenario

The way forward

Implementation

- Most urban areas in India cannot handle more than a spit of rain and aren't geared up to handle disasters of any scale.
- **SuDS may be capable of solving flood problems in large parcels** of Mumbai Megacity
- It may be able to solve the problem **of water scarcity** in Mumbai just before the monsoon (flooding) season
- A **detailed plan, along with policy level interventions** will be required to implement the drainage system
- Can be initiated with implementation on fresh sites and later on the option of retrofitting can be taken up

- **A set of guidelines to be integrated with urban planning** for better output in terms of open space developments such as parks, playgrounds, greens, etc.
- Compliance with these guidelines may be made **mandatory for new developments**
- For **retrofit sites, disconnection from existing system** may be carried out for proper implementation
- **Citizen participation** is a must in developing sites and even maintain them.
- For **selection of SuDS** or SuDS management train, **simulations to be carried out** before installation for best suitable options.

It cannot be achieved in one day!

But it has to start one day!

Some areas of research in the field of SuDS related to floods

Integrated approach to planning all water related infrastructure	**Vulnerability assessment** of flood prone areas	Assessment of cost-benefits, maintenance and whole lifecycle costing	**Retrofitting potentials** and feasibilities	**Climate based approach** for best application of SuDS
Possibilities for fund and grant arrangements	Assessment of multi-functionality of SuDS elements and their ecological and social benefits	**Multiple benefits of SuDS** other than water quality and quantity assessment	**Easy/ quick tools and models** to assess the suitability of the systems	**Community acceptance** and engagement; Involvement of NGOs
Institutional arrangements to implement the concept	Assessment criteria for measuring success by local officials	Site-specific technical guidance and certification of products	Decision support tools for life-cycle assessment, scenario planning, expert knowledge	Assessment of **ecosystem benefits**

Thank you for your attention!

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