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COMPARATIVE ANALYSIS OF FLOODING IN GOTHENBURG, SWEDEN AND MUMBAI, INDIA: A REVIEW

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ABSTRACT

To cope with flooding in cities, a combination of well working stormwater system and a resilient city is needed. As the future is uncertain, cities have to be built resilient, meaning that they can be flexible and adaptable, as it is not possible to protect the city from floods totally. Green areas in the city can provide resilience, as water can be led here e.g. during heavy rainfall. In this article the situation in Gothenburg, which is on the list of Swedish cities at risk of getting flooded, and Mumbai, where parts of the city is flooded every monsoon season, are compared. The sewage systems in Mumbai and Gothenburg were built in the same time period, late 1800's and early 1900's, both with British influences. The system in Mumbai has, more or less, not been developed since it was built, while the Gothenburg system has been developed along with the city expansion. Many parts of both cities were built on former marshland areas, close to the sea. Our recommendation, for both cities, is to develop the storm water systems further with sustainability and resilience perspectives in mind, including to build floodable areas close to the city centre. It is also important to educate leaders and practitioners in both cities about resilience and sustainability perspectives.

KEYWORDS
Awareness; city development; flood resilience; urban flooding.

1. INTRODUCTION

Floods are among the most powerful forces on earth, causing enormous damage all over the world. In the last decade, floods have killed about 100,000 persons and affected over 1.4 billion persons (OFDA/CRED, 2013). The statistics show that floods have a large impact on human well-being and economy. Economic damage, eco-system damage and historical and cultural values constitute direct consequences of flood. They lead to the loss of human life and cause human health effects (Hajat et al., 2005; WHO, 2002). Indirectly floods cause the loss of economic and agricultural production and a decrease of socio-economic welfare (Appleton, 2002). Previous studies focusing on floods and its impact includes, among others, Coates (1999) about the situation in Australia and Mooney (1983) and French (1983) about United States. Although every flood can be considered as a unique event with unique characteristics, patterns may be observed when a large number of floods are studied e.g. floods from rivers, precipitation, tides, etc.

In urban area perspective, prevention of flooding may be associated with inadequate sewer systems. With increased property values of buildings and other structures, potential damage from prolonged flooding can easily extend into millions of dollars. However, drainage systems designed to cope with the most extreme storms would be too expensive to build and operate. In establishing tolerable flood frequencies, the safety of the residents and the protection of their valuables must be in balance with the technical and economic restrictions. Knowledge of the social system and its vulnerabilities is still weakly developed, even though it is a key element of the social response to a flood and of the urban dynamics (Hall et al., 2003). The response of the drainage system to rain events in the urban environment is characterized by two main components, the first being the surface runoff on natural slopes; the second component consists of the artificial drainage system and levelling of constructions in the city. In most of the cities, the artificial drainage system is controlled by a combined sewer network, which collects both stormwater and wastewater to the treatment plant.

Since planners must cope with uncertainty (Godschalk, 2003) and a flood-event always can be bigger than what the system is designed for (Liao, 2012), cities must be built resilient. An urban resilience to floods could be conceptualized as *the capacity to remain in a desirable regime while experiencing a* *flood* (Liao, 2012). While a *flood resistant city* can resist floods to a certain degree, but not bigger floods, a *flood resilient city* is flexible and adaptive, and learning from historic events. It is in many cases not possible for a city to be both resistant and resilient. A city that accepts smaller floods, will be better prepared when a bigger flood occur. To be able to handle floods, floodable areas are needed in the city (Liao, 2012), i.e. areas that can store or convey water without incurring damage.

The effects associated with global warming, such as sea level rise, more intensive precipitation and higher river discharges, may increase the frequency and the extent of flooding on a worldwide scale. The frequency of floods has been demonstrated to already have increased during the twentieth century (Milly et al., 2002). Global average precipitation is projected to increase, but both increases and decreases are expected at the regional and continental scales (IPCC, 2001). Global population growth, more intensive urbanization in flood prone areas and the limited development of sustainable flood-control strategies will increase the impacts of floods. As global warming makes the risk of flooding higher in cities, the demand for sustainable city planning is growing.

Heavy rainfall on 26th and 27th July 2005 led to massive floods in Mumbai, India. The unprecedented rainfall of 994 mm during the 24 hours resulted in that at least 419 persons 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 and the direct economic damages were estimated to almost two billion USD and many more indirect monetary damages (Hallegatte et al., 2010).

Gothenburg, Sweden has also seen flooding recently. In December 2006, heavy rainfall (311 mm) during more than 2 weeks resulted in high river flow. The return period was estimated to 10–50 years and high sea water level aggravated the situation. Many buildings were flooded, and traffic on both rails and roads were stopped. Due to landslide, there were traffic problems in the area for a long time. In December 2011, Gothenburg were again flooded due to high flow in combination with high water level in the sea. The water level was 146 cm above mean sea level and 52 mm of rain fell in 48 hours.

This study investigates the flooding problems and its consequences in India and Sweden. Since 1900, 11 people in Sweden and 60,000 persons in India have been killed because of flooding (OFDA/CRED, 2013). Mumbai and Gothenburg have been chosen due to the characteristic features of flooding in the area. The objectives of the study includes an overview of flooding situation in both cities, consequences of flooding and damage caused by it and finally to assess whether the cities are working in a direction of resilience and sustainability to avoid substantial damage in future. It would provide insight in the magnitude of loss, both social and economic, due to floods and problems faced in the cities.

2. STUDY AREA

2.1 Mumbai

The East India company started development of Mumbai as a naval base, which subsequently metamorphosed as a large port with flourishing trade and commerce. The city has now developed into commercial capital of the country with 13 million habitants. The population density is around 50,000 persons/km^2.

Mumbai is lined by the Arabian Sea on the western side and intercepted by creeks and rivers. The drainage system of Mumbai is a mix of simple drains (nallah) and a complicated network of rivers, creeks, drains and ponds built around 80 years back (Figure 1). At present, the stormwater drainage system consists of a hierarchical network of roadside surface drains (mainly in the suburbs), underground drains and laterals (in the island city area), major and minor nallahs and 186 outfalls. All surface runoff discharges into the rivers and the Arabian Sea. Table 1 represents the summary of stormwater drains in Mumbai with their length in km (MCGM, 2005). A network of closed drains below the roads has evolved in the city along with drains in the suburbs. Reference is made to Rana (2011) for details on the Mumbai drainage system.

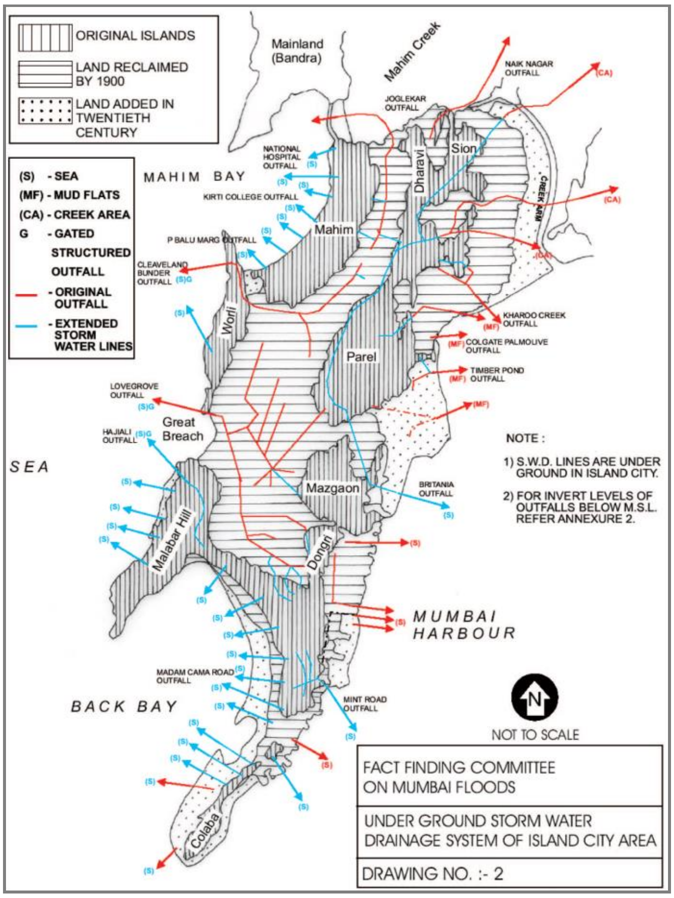

Figure 1: Drainage of Mumbai City area, Gazetteer of India, Maharashtra State, History of Bombay, Modern Period 1987 (Govt. of Maharastra, 2006).

Table 1. Summary of the stormwater drainage system of Mumbai (Govt. of Maharastra, 2006) and Gothenburg (Göteborg Vatten, 2012)

Pipe type	Length [km]	
	Gothenburg	Mumbai
Closed combined drains (stormwater and sewage)	398	565
Major open combined drains	N/A	200
Minor open combined drains/roadsides drains	N/A	2074
Stormwater only	878	N/A
Stormwater (pump system)	1	N/A
Tunnels stormwater	12	N/A
Total pipe length, stormwater system (combined and separate)	*1289*	*2839*
Sewage only	993	N/A
Sewage (pump system)	197	N/A
Tunnels sewage	16	N/A
Total pipe length, sewage system	*1206*	*N/A*

Greater Mumbai has witnessed rapid growth of built up areas in past four decades, i.e. 1971–2001. The built up areas has more than doubled from about 25% in 1971 to 52% in 2001. The shift is from coastal wetlands and agricultural/forestlands into urban areas. Coastal wetlands have experienced a substantial decrease from 29% to 19% and land under forests has reduced from 32% to 19%.

The region as whole is a lowland, lying on the west of Sayhadri hill ranges. The step-like terraces and layered appearance is characteristic of the deccan lava country. The river system consists of five major rivers that drain into the Arabian Sea.

Climatic conditions in the Mumbai region, especially in the summer season, are oppressive because of the high temperature associated with high humidity. Monsoon season brings in heavy rains that averages 2150 mm per annum (Rana et al., 2012). Very heavy rains with intensity of 250 mm/day are not uncommon (T≈2y), leading to major problems of flooding in the area. Most of the rainfall is received in monsoon season (June–September), accounting for 96% of annual rainfall (Rana et al., 2012). The hourly intensity of rainfall for return period of 20, 30 and 40 years are 60, 65 and 70 mm/hr, respectively (Rana et al., 2013).

2.2 Gothenburg

Gothenburg is the second largest city of Sweden, situated at the mouth of Göta River with the harbour as an important part of the export industries. Gothenburg has a population of 526,000 inhabitants (December 2012) (SCB, 2013a). The area of Gothenburg is 450 km^2 and the population density is 1,200 persons/km^2 (SCB, 2012).

The Gothenburg soil condition are stony hills with clayey soils in the low-lying areas between. Only few areas are lying on sandy soils. The clay layer in central Gothenburg is at some places over 100 meters. Göta River, with a catchment of 50,000 km^2 (SMHI, 2010), and the tributary Mölndal River, are flowing through the city centre. Most parts of the riversides are covered with buildings. There are concerns about landslides along the rivers (Göteborg Stad, 2006). The flow in Göta River are controlled by an upstream hydropower plant with maximum draft of 1000 m^3/s (SMHI, 2005).

The climate in Gothenburg is typical for a coastal city in the temperate continental climate. The rainfall is more or less constant during the year, with monthly precipitation on 40–83 mm (SCB, 2013b). Long dry periods can occur. The hourly intensity of rainfall for return period of 20, 30 and 40 years are 30, 32 and 34 mm/hr, respectively (recalculation with Gumbel distribution of intensities from Hernebring (2006)). In the summer, temperature daytime are about 18–25°C and in the winter a bit under 0°C with snowfall and ice on lakes. Main wind direction is from west, i.e. the sea.

The sewage system covers an area of 163 km^2 of Gothenburg. 20% of this is combined system (Göteborg Stad et al., 2007). Length of the pipe system can be seen in Table 1. According to Jansson (2012), the separate stormwater system of Gothenburg is mainly designed for a return period of two or five years. The combined system is design not to give flooding more often than every ten year. The separate wastewater system are designed never to get flooded, but due to construction mistakes and pumping failures, there are 20–200 cases of flooding every year.

In Gothenburg, the development of an urban drainage system has been driven by the need for sanitation in the city and at least two of the main plans (1866 & 1894) have been initiated because of cholera epidemics. In 1866, J.G. Richert wrote a sewage plan. He wanted to implement water closets, pumping of water from lower areas and treatment of the sewage to utilize nutrients from the water. This was unrealistic at the time and he therefore suggested pipes that could lead the water from every house and road to the inner canals of Gothenburg. During the next 20 years a system with about 20 km pipes was constructed. As the inner canals became smelly, intercepting sewage that lead stormwater and sewage to Göta River directly, was constructed along the canals. The idea came from England, where six tunnels had been constructed in London in 1859–1865. The plans in mid-19th century were inspired by the drainage systems in English cities. Later in the 19th century, inspiration came from German cities as well. In this period, the city grew with new, drained areas like Masthugget. In the beginning of the 20th century, water closets were implemented and the drainage system was developed further: pipes led water to low-lying areas from where it was pumped. The sewage system grew together with the city. Until 1958, combined sewage was still constructed. From 1958, all new areas were built with separate system. In the 60’s and 70’s there was a focus on reconstruction of the old, combined system to separate system, but this was stopped in the 70’s due to high costs and, as mentioned before, 20% of Gothenburg has still combined system. (Bjur, 1988)

3. FLOODING – PRESENT SITUATION AND FUTURE STRATEGIES

3.1 Mumbai

The core of the present SWD (storm-water drainage) in Mumbai is about 70 years old, built during the British rule in India, comprising about 400 km of underground drains and laterals built based on population and weather conditions at that time. This old SWD system is only capable of handling rain intensity of 25 mm/hr at low tide. Flooding occurs often with high intensity rains and high tide in sea. Tidal variations have huge impact on flooding and water logging situation as all the discharge from SWD and treated sewage is into the Arabian Sea. Runoff from the city is retended causing high water stage on the streets because of flat gradients, mud flats, manmade inappropriate levels of outfalls, poor placement of gullies, loss of holding ponds due to land development, new impermeable surfaces, encroachments on drains, enhanced silting and choking of drains due to sullage/sewage inflows and garbage dumping in drains, obstruction due to crossing utility lines, etc. Key issues and strategic plans according to Mumbai Municipal Corporation are outlined in Table 2.

Table 2: Key issues and strategic plans for the city of Mumbai

Key Issues	Strategy options/plans
• Encroachments alongside drains, disturbing catchments runoff • Adulteration of stormwater in drains by garbage and sewage infusions, which are in turn discharged into the environmentally sensitive creeks and the sea • Increase in overall runoff coefficient • Silting of drains and poaching of space by utility lines, reducing carrying capacity • Structural deficiencies due to age and poor workmanship	Various recommendations suggested by the BRIMSTOWAD report 1993 and subsequent studies: • Divert sullage water flow to sewage pumping station, improve flood gates at various places and increase the capacity of drains wherever necessary • Remove obstruction of water pipe lines, cables etc. from SWD • Widen, deepen and extend the nallahs and outfalls, remove encroachments along the nallahs/drains and rehabilitate them • Desilt and maintain stormwater drain during rainy season
Project implementation hurdles: • Encroachment removal and relocation • Multiplicity of agencies associated with permissions, ownership of water channels/bodies • Shifting of utilities • Lack of funding sources (projected cost is around 3 billion USD)	• Formation of coordination committee comprising representatives from all associated stakeholder agencies to sort out institutional/procedural issues • Framing and implementation of slum rehabilitation plan to rehabilitate displaced families due to encroachment removal and land rehabilitation • Generation of funds required through a combination of routine budgetary allocation, enhanced revenue through financial reforms, special levy for SWD improvement and additional grants from State/Central government

In the backdrop of ever changing externalities due to globalisation, Mumbai needs to be prepared to adopt a systematic change of urban fabric to overcome the threats of rising population, limited resources, limited capacity of infrastructure stock and decelerating economy. The quality of life in Mumbai has worsened and the decline is quite steep. Slums have proliferated and congestion, pollution and water problems have increased. As per the city development plan for 2005–2025 of Mumbai, development of city will depend on various strategies across sectors to address the needs of its citizen and ensure socio-culturally and environmentally safe city.

3.2 Gothenburg

As a part of the work with the EU directive, 2007/60/EC, Swedish Civil Contingencies Agency (MSB) has finished an assessment where Gothenburg is considered as one of the 18 Swedish cities at risk of flooding (MSB, 2011). Gothenburg is one of seven cities matching all five criteria in the assessment. Higher precipitation and sea level rise are expected in the future due to climate change (Göteborg Stad, 2009).

SMHI made a mapping of flooding from Göta River in 2000 and Mölndal River in 2008. According to the SMHI (2000) and SMHI (2008), Gullbergsvass in central Gothenburg is at risk of getting flooded by the Mölndal River with a return period of 100 years (Figure 2, right). The central station, the railway and several buildings along Mölndal River are situated in the risk area. The analysis where conducted with a 1D-model with interpolation of the water level on the surface with a rough digital elevation model (DEM). According to MSB (2011), 2,800 persons are living in the area that would get flooded by a 100-year flow in Göta River. 21,000 persons are working in the same area.

No general mapping of flood risk from heavy rainfall have been done for Gothenburg. However, several minor studies have been conducted for smaller areas of interest, leading to a good overview for the city planners (Ljunggren, 2013).

In 2006, Gothenburg Municipality made an assessment of consequences of flooding from the sea (Göteborg Stad, 2006). They came up with a minimum level under which no new building are supposed to be built. They also suggest building a pilot test area with the principles of SUDS (sustainable urban drainage system). This area is suggested to be Södra älvstranden, Norra älvstranden or Gullbergsvass, which are low-lying areas. Other topics on the agenda are to spread awareness among all branches of the municipality, find out how to protect valuable constructions, show the river flow on the Internet, make a risk assessment of the city and to make responsibilities for climate change effects clear (Göteborg Stad, 2010).

4. RESILIENCE AND SUSTAINABILITY PERSPECTIVES

Reforms are fundamental to improve the situation in Mumbai. The Municipality Cooperation of Greater Mumbai (MCGM) has embarked on various innovative measures and reforms program in several areas of its operation. Remedial measures suggested for improving the situation in Mumbai (MCGM, 2005) includes complete review of the drainage design, de-silting and improvements to the watercourses before monsoon and improvement in municipal solid waste management system. They also suggest restoration of the existing degraded rivers and riverbanks to initiate recovery of the urban ecosystem. Degraded urban ecosystems (lakes/ponds, rivers, creeks, and costal zones) needs to be rejuvenated and monitoring of environmental and ecological status-related activities strengthen.

The stormwater management also includes regulating the use of land in flood plain to restrict or reduce the damage caused by floods. The stormwater runoff coefficient is said to have increased, which has necessitated re-designing the stormwater system for Mumbai. Therefore, the design criteria has been change from 25 mm/hr to 50 mm/hr for rainfall intensity and runoff coefficient set to 1.00 (earlier 0.50). Plans for avoiding loss of drainage capacity by way of proper maintenance shall also explore the possibilities of reducing the run-off. Besides maintaining existing open spaces as ponding areas, nonconventional methods like rainwater-harvesting, introducing “porous paver blocks” for pavements and provision of detention/retention ponds can be effective to reduce storm run-off. This retained run-off can subsequently be let off in the stormwater system during lean times. Mumbai’s systems will have to be managed keeping the principles of sustainable development in view and encouraging wide participation through partnerships and networking institutions.

In 2009, Gothenburg Municipality passed a new core strategy (Göteborg Stad, 2009). The plan is head for the next 20 years and includes 13 strategic objectives where *Resilient city* are most relevant for the flooding issue. In addition, *More housing* and *Changed transport requirements* are linked to the flooding problem, as a more dens city potentially could cause higher risk for flooding. According to the core strategy, building a resilient city requires a flexible and aware planning with safety margins in the construction. An important decision in Gothenburg is to never build new, vulnerable functions or buildings lower than +2.8 meters from the mean sea level (Göteborg Stad, 2008). In addition, permanent flood dikes and walls, temporary walls and building a floodgate at the estuary of Göta River are discussed. Close to the city centre, a bigger urban renewal project will take place (Figure 2, left). Industrial areas will be transformed to mixed areas with housing, parks and social services. The area is low-lying, at the waterfront of the harbour. Future higher water levels need to be considered in this area (Göteborg Stad, 2009). Parts of the areas planned for transformation are considered at risk of flooding, see Figure 2 (right). The projects have been criticised, as parts of the area are already today sensitive to flooding (Hjerpe and Glaas, 2012). The demand for building barriers along the river to avoid flooding increases as these areas are developed. According to Ljunggren (2013), though, the need for barriers is already there.

Gothenburg has no bigger green areas in the city centre or close to the riverside, which makes the city static and not resilient. Most of the green areas are in the hills, where they are least needed when it comes to flood resilience. Cettner et al. (2012) describes how the stormwater system in Sweden today are caught in old structures, with a pipe-bound system that cannot be developed to more nature-oriented and local solutions without breaking social-institutional barriers (Cettner et al., 2012; Stahre, 2008). Gothenburg is now implementing strategies to build more resilient in newer areas, inspired by the Swedish Water & Wastewater Association’s report no. P105, but it seems like they do not consider this is the old areas, except for the pilot test area mentioned in chapter 3.2.

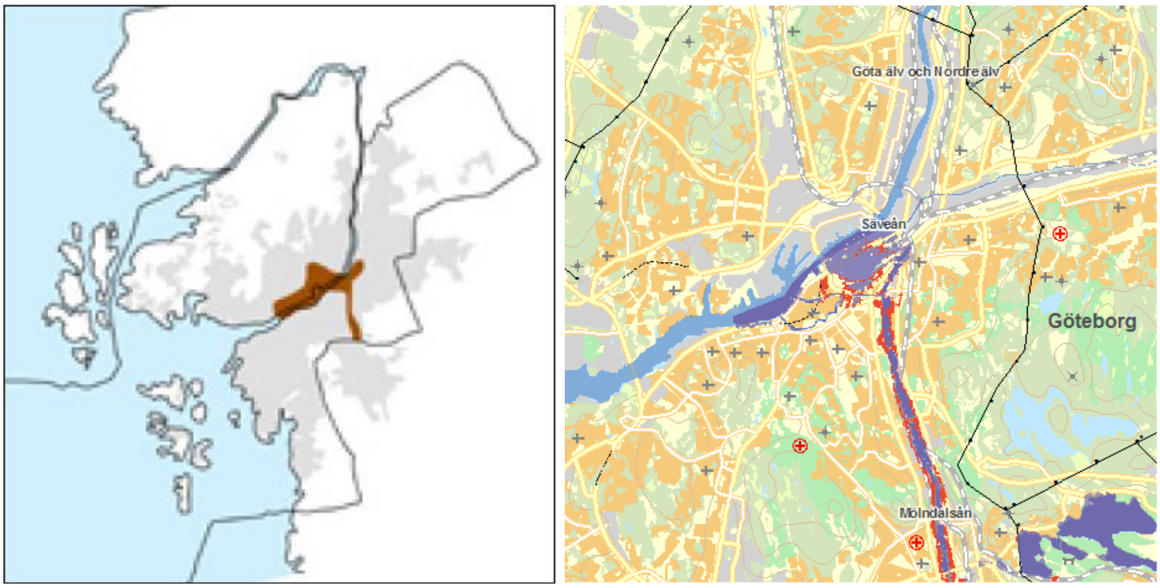

Figure 2: *Left*: areas in the city centre planned to be developed into dense housing areas, marked with brown, according to Göteborg Stad (2009). Gothenburg itself is marked with grey. *Right*: areas at risk of flooding, marked with blue/red, according to SMHI (2000) and SMHI (2008).

5. CONCLUSION

In this article, insight in the magnitude of loss, both social and economic, due to floods and problems faced in the cities of Gothenburg and Mumbai have been provided. The sewage systems in Mumbai and Gothenburg were built in the same time period, late 1800’s and early 1900’s, both with British influences. The system in Mumbai has not developed since it was built, while the Gothenburg system has been developed along with the city expansion. Many parts of the city were built on former marshland areas in both cities, close to the sea. Gothenburg city struggles with rising sea level in the future and has seen a few severe flood events in the last years, while parts of Mumbai are flooded during the monsoon season every year.

Gothenburg city wants to cope with climate change by being restrictive in building on low-lying areas, but the low-lying areas are close to the city centre and attractive for building. Important buildings and constructions in the city centre are at risk of flooding when the sea level rises. It seems like Gothenburg is more heading for flood resistance, building high floodwalls to prevent from flooding with a certain return period, instead of building a flood resilient city, with floodable areas in strategic places.

The main problem in the Mumbai drainage system is clogging from solid waste, authorities with overlapping responsibilities, low level of awareness among citizens and problem with relocation of slums. The work for flood resilience and work against poverty must go hand in hand, as the areas along the open stormwater system (creeks and rivers) are needed as floodable land. The same areas are today slum areas where people need better housing. Mumbai are struggling with severe flooding every monsoon season. There is huge loss of life and property due to floods. Large areas are under heavy stress, and the situation is especially hard to solve due to high population density and no new land to build on. The municipality corporation in Mumbai is working on all aspects of flood prevention and control, but economic instability is a huge drawback. They are working mainly with flood forecasting and management systems, emergency response, de-silting of main drains before monsoon season, and redevelopment of drainage system according to the increased capacity along with education for awareness.

Our recommendation, for both cities, is to develop the storm water systems further with sustainability and resilience perspectives in mind, including to build floodable areas close to the city centre. We are concerned about the high risk for lives in Mumbai, and the willingness in Gothenburg to build in low-lying areas. The problems in Mumbai are much bigger, because of the insufficient storm water system and the climatic conditions, and harder to solve, as the population density is very high. In Gothenburg, the low frequency of floods today might be a problem when it comes to local awareness. The flood risk of tomorrow seems to be forgotten in the overall city development planning. In this perspective, building of a resilient system might be easier Mumbai, as the every-year monsoon season is a good reminder of the importance of good storm water management. It is important to educate leaders and practitioners in both cities about resilience and sustainability perspectives.

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