MUMBAI CITY REPORT

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1. Introduction

The world is urbanizing at a rapid pace. In 2008, the world crossed a landmark, where more than half of the human population, about 3.3 billion, became urbanized. It is expected that by 2030, almost 5 billion people will reside in urban areas. At the global level, all future population growth is expected to happen in towns and cities. Further, most of this growth will be in the developing countries. Estimates suggest that about 80% of the urban dwellers in the world will reside in cities of the developing world, particularly in Asia and Sub-Saharan Africa, by 2030[1]. Urban growth now stems more from natural increase (more births than deaths) rather than migration[2]. This is also termed as the 'Second Wave' of urbanization, the first having occurred in Europe and North America in the early 18th Century. The difference between the two waves is that of scale. In the first wave, urban population increased from 15 to 423 million between 1750 and 1950. In the second wave, we are expecting an unprecedented increase from 309 million to 3.9 billion between 1950 and 2030 in the developing world[3]. Urbanization is inevitable and essential for future economic growth. What happens in cities in near future will largely shape the global economic growth, poverty alleviation, environmental sustainability and ultimately the human life. Yet, cities on the brink of exploding population, inadequate infrastructure, poverty, growth of slums and rampant environmental degradation do not pose a good picture for sustainable growth.

Asia with 1.5 billion people living in cities has the largest urban population in the world. Out of the 75 million born every year the worldover, six countries from Asia and Africa – Bangladesh, China, India, Indonesia, Nigeria and Pakistan – are accounting for almost half of them[4]. Urbanization in Asia is happening at a much higher rate (1.31% annual average growth rate) than the world average (0.83% annual average growth rate). In South and South-East Asian countries, capital cities like Mumbai, Dhaka, Bangkok, Manila and Jakarta have populations above 5 million. In fact, both Mumbai and Manila support more than 10 million people. There are serious implications of such massive populations for these cities. Their proximity to coast also enhances their vulnerability to weather/climate risks.

A significant proportion of Asia's growing population is living in the large coastal cities that are highly vulnerable to sea level increases, storm surges and floods. Asia's densely populated mega-cities and other low-lying coastal urban areas are described in the IPCC Fourth Assessment Report (AR4) as "key societal hotspots of coastal vulnerability" with millions of people at risk. In recent years,

[1] UNFPA, State of the World Population 2007: Unleashing the Potential for Urban Growth, United Nations Population Fund 2007

[2] *Ibid.*

[3] *Ibid.*

[4] UN-HABITAT, Urbanization Facts and Figures, World Urban Forum III, An International United Nations Human Settlements Programme, Event on Urban Sustainability, Canada, 2006

there have been many extreme weather events, such as, Mumbai floods in July 2005 that have led to massive damages, loss of life and property and affected the economic and social activities adversely. Such events also tend to have long-term consequences for economic development and poverty alleviation in the city and can potentially alter the development trajectory permanently. Accompanied by physical, economic and social vulnerabilities in such areas is the low adaptive capacity due to constraints on physical, financial and human resources. It is, therefore, absolutely essential to assess the vulnerability of Asian coastal cities to climate change and understand the implications for long-term development planning for the cities.

Mumbai is one of the largest mega cities in the world in terms of population and is currently ranked 4th after Tokyo, Mexico City and New York[5]. The city is the financial capital of India with a large commercial and trading base. It plays host to a number of industries, multinational companies and important financial institutions. With a per capita income thrice that of the national average, Mumbai makes huge contribution to the total tax revenues of the country. The city is also an important international sea port and strategic from defence perspective. Unfortunately, the city is also more vulnerable to climate risks due to its flood prone location and the landmass composed largely of reclaimed land. The most vulnerable section is also the slum dwellers and squatter communities in the city that comprise more than half of the total residents. Therefore, it is critical for the city to assess the vulnerabilities and devise adaptation and mitigation mechanism to cope with future climate risks.

This report takes an overview of the weather/climate risks for Mumbai city and identifies the physical, economic and social vulnerabilities. The report reviews the current status of planning and implementation efforts to reduce the vulnerabilities in the city and identifies the knowledge and research gaps in addressing vulnerabilities to direct the efforts in near future. The outline of the report is as follows. The next section creates the profile of the mega city of Mumbai to identify the physical and socio-economic vulnerabilities. The section also reviews the current adaptation and mitigation efforts undertaken in the city. The current perception pertaining to the climate risks in Mumbai is discussed in Section 3. This section reviews recent studies projecting climate risks and vulnerability for Mumbai. Section 4 deals with the expected roles of different stakeholders in the adaptation efforts undertaken at all levels. The concluding section identifies the knowledge and research gaps that academia and policy makers need to address in near future.

[5] *Ibid.*

2. Coastal mega-city – Mumbai

Mumbai (formerly known as Bombay) is located on the western seacoast of India on the Arabian Sea at $18^0 53^{'}$ N to $19^0 16^{'}$ N latitude and 72^0 E to $72^0 59^{'}$ E longitude. It was originally a cluster of seven islands, which were later joined to form the present city. Greater Mumbai Region (referred to as Mumbai in the text) consists of 7 islands in the city area and 4 islands in the suburbs. The present day city is divided into two revenue districts, Mumbai City District, i.e, the island city in the South and Mumbai Suburban District comprising the Western and Eastern suburbs. Mumbai occupies an area of 468 square kilometers (sq. km.) and its width is 17 km. east to west and 42 km. north to south[6]. The entire region encompasses rich natural heritage, such as, hills, lakes, coastal water, forests, and mangroves, alongside built areas. The coastline of Mumbai has been reclaimed for development purposes; *e.g.*, areas like Cuff Parade and Mahim creek were wetlands, later reclaimed for residential and commercial uses.

The Municipal Corporation of Greater Mumbai (MCGM) is the primary agency responsible for governance of the GMR or Mumbai city. The city is divided into different administrative zones known as *'wards'* to ease the day-to-day functioning of the civic authority. The map of Mumbai city, including the location of different administrative wards is shown in Figure 1 below. MCGM has a long history in urban governance. It was the first municipal corporation established in India in the year 1882. Since then, the civic body has been responsible for the provision of civic amenities, education, public health, art and culture and heritage conservation in the city. MCGM holds the distinction of being one of the largest local governments in the Asian continent[7]. For administrative purposes, Mumbai Metropolitan region (MMR) has been designated to combine GMR and the surrounding areas of Thane, Navi Mumbai, Ulhasnagar, Mira Road, Vasai, Virar, Bhayandar, Bhiwandi, Karjat, Alibaug, *etc.* Mumbai Metropolitan Region Development Authority (MMRDA), set up in 1975, is responsible for planning and coordination of the development activities of this region. The total area of the MMR, excluding Mumbai city, is 3887 sq. km., with a population base of 5.90 million as per 2001 census[8]. These surrounding areas hold significance for the economy and transportation in Mumbai, as thousands of people travel everyday from these areas into the city for employment. This puts additional pressure on the transport network and other civic amenities in the city.

The geographical location of the city and its physical, economic and social characteristics make the city more vulnerable to the threats posed by climate risks, such as, sea level rises, storms and floods. This section looks at each of these vulnerabilities in detail.

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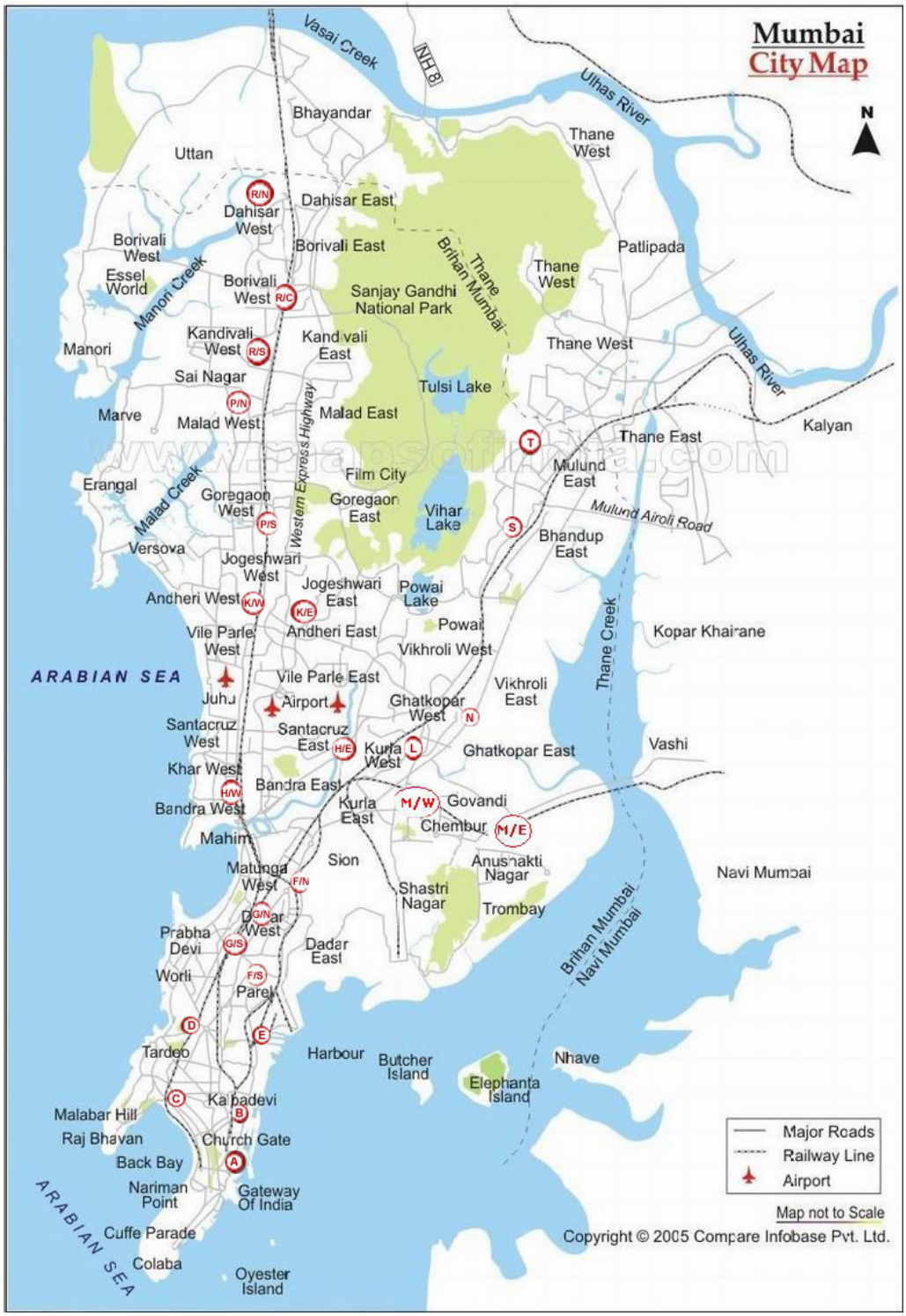
[6] MCGM, (2007), Statistics on Mumbai, Municipal Corporation of Greater Mumbai, available at http://www.mcgm.gov.in

[7] *Ibid.*

[8] MMRDA, (2007) Basic statistics on MMR, Mumbai Metropolitan Region Development Authority, http://www.mmrdamumbai.org/basic_information.htm

Figure 1: Map of Greater Mumbai Region



Source: http://www.mcgm.gov.in

2.1 Physical vulnerability

Mumbai is an island outside the mainland of Konkan in Maharashtra State and is separated from the mainland by a narrow creek known as Thane Creek and a Harbour Bay. The city is surrounded on three sides by the sea: Arabian Sea to the West, Harbour Bay in the West and Thane Creek in the East. The height of the city is just 10-15 meters above the sea level. A large part of the City District and Suburban District is land reclaimed from the sea. The new industrial, commercial and residential settlements have developed along the reclaimed coastal areas which are low-lying and flood prone.

Mumbai, being on the seacoast, experiences a tropical savanna climate[9,10] with a heavy southwest monsoon rainfall of more than 2100 millimeters a year. Mumbai experiences three seasons – summer from March to May, monsoon between June and September and winter during October to February. The city receives heavy rainfall during monsoon and relative humidity is quite high during this season. Similarly, winds are generally moderate but pick up during monsoon months. In the City District, daily average temperatures range from the minimum of 23.7^{0}C to the maximum of 31.2^{0}C. The average total annual rainfall is 2146.6mm. In the Suburban District, the temperatures vary from the minimum of 16.3^{0}C to the maximum of 33.3^{0}C. This district receives the average annual total rainfall of 2363.0 mm. The flash floods that led to the complete disruption of normal life in Mumbai in July 2005 were the result of an unprecedented rainfall of 944.2 mm on July 26th in the Suburban District[11].

Figure 2 shows the original seven islands and subsequent physical growth of Mumbai. Most parts of the present day city are built on the reclaimed land. The city is about 10-15 metres above sea level in many places[12]. The airport area is only 7.5 metres above sea level. Similarly Bandra-Kurla Complex, Wadala and major residential areas of Worli are low-lying areas. Coastal erosion, landslides, flash floods associated with heavy precipitation and the unprecedented 2005 floods are some of the incidents that highlight the vulnerability of the city to coastal climate hazards.

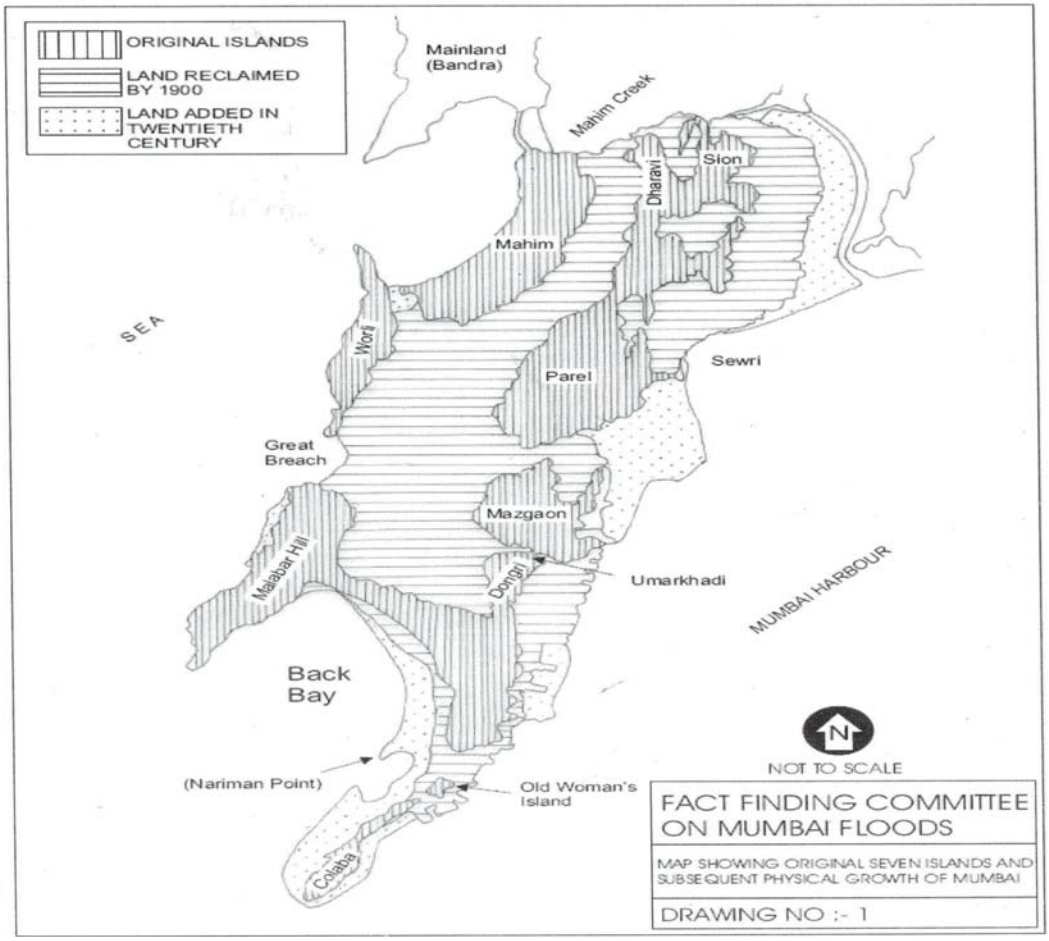
[9] MCGM, (2003), Environment Status Report 2002-03, MCGM

[10] MPCB, (2005), Report on Environment Status of Mumbai Region, Maharashtra Pollution Control Board, Government of Maharashtra

[11] Govt. of Maharashtra, (2007), Greater Mumbai Disaster Management Action Plan, Maharashtra Emergency Earthquake Management Programme, Govt. of Maharashtra

[12] *Ibid.*

Figure 2: Original Seven islands and subsequent Physical growth of Mumbai



Source: Gazetteer of India, Maharashtra State, History of Bombay, Modern Period 1987

Being a coastal city, Mumbai is prone to cyclones and gusty winds. There are a number of wards along the coast (Arabian Sea and Thane Creek) that are vulnerable to cyclonic impacts. For instance, in wards A – D, G-North, G-South, S and T, the Greater Mumbai Disaster management Action Plan (DMAP) has identified settlements that are acutely vulnerable to cyclones. There settlements were originally fishing communities, but are now home to many slums along the coast. Given the poor quality of construction material used by these homes, they are extremely vulnerable to cyclones and winds[13]. In addition to this, there are 40 chronic flooding locations identified in the DMAP that are spread over the island city, eastern and western suburbs. These flooding spots are a worry for the civic administration as heavy precipitation would cause flooding in the local settlements as well as disrupt traffic and normal city life.

[13] *Ibid.*

Mumbai falls in the seismic zone III which is Moderate Damage Risk Zone. As per 2001 census, Mumbai has over 276,000 dwellings (residential, industrial and commercial) of which only 9% are made of reinforced concrete, 31% are engineered constructions and around 60% are non-engineered constructions, which correspond with the large presence of slum settlements[14]. The major risk category is the engineered constructions, some of which are 'cessed' buildings[15]. These buildings, on account of rent control, have suffered from lack of maintenance and apathy from landlords and are now in dilapidated conditions. Such constructions are more vulnerable to extreme weather events as well. Many slum settlements also face the risk of landslides usually occurring during heavy rains with gusty winds. These are generally located on the hill slopes, bottom of hills or near abandoned quarries. DMAP identifies 117 such settlements which are extremely vulnerable to landslides, loss of life and damage to property in case of heavy precipitation.

Mumbai also plays host to around 900 industries that are involved in manufacturing or processing or storage of hazardous goods. Many of these are in close proximity to residential and commercial areas, thereby increasing the risk of fires and explosions. The major concentration of such industries is in the Chembur-Trombay belt (Wards M-West and M-East). The area has major chemical complexes, refineries, fertilizer plans, atomic energy establishment and thermal power plant. The presence of such industries only enhances the vulnerability in case of extreme weather events.

Mumbai, with a large population to cater to, requires basic infrastructure in the form of a large transport network. Transport network in Mumbai comprises a huge railways and roads network. The length of the railway tracks joining western and eastern suburbs with the island city is 25 km. and 30 km. respectively. Plus, there are other railway tracks catering to smaller sections within the city. Thousands of people avail of this huge network every day. The total length of the road network is 1941.172 km., out of which 506.480 km. are in the island city and 927.05 km. in the suburbs[16]. There has been a massive growth in the number of vehicles (more than 79%) in recent years between 1991 and 2004. Among the total number of vehicles, the number of two-wheelers and three-wheelers has gone up by more than 100% between 1995 and 2004, whereas the number of passenger cars during the same period has gone up by more than 62%[17]. The massive railway and road network, however, is not sufficient for such a large population moving in a single direction during peak business hours. Most commercial activity is concentrated in the island city in the south. The movement between south and north for business purposes in the peak hours places a huge burden on the transport network. The road network has become very congested over the years with increasing number of vehicles and

[14] *Ibid.*

[15] Cessed buildings are constructions prior to 1960, wherein the residents pay a 'cess', i.e., a predetermined amount to the civic authority for building repairs.

[16] MPCB, (2005), Report on Environment Status of Mumbai Region, Maharashtra Pollution Control Board, Government of Maharashtra

[17] Govt. of Maharashtra, (2005), Motor Transport Statistics, Office of the Transport Commissioner

more people traveling to and from the city. For instance, people residing in surrounding areas of Mumbai, known as the MMR, use the railways and roads network to come to the city everyday for employment or business. In addition to this, Mumbai has an international airport catering to more than 4 million travelers and domestic airport servicing more than 4.2 million travelers[18]. Such a huge network of transportation faces the risks from extreme weather events and would suffer from massive damages and costs from flash floods, storm surges and sea level rises.

2.2 Economic and social vulnerability

Perhaps the most important factor enhancing the vulnerability of the city to climate risks is the ever growing population of Mumbai. The city population has grown steadily in the last 5 decades. There is a consistent growth from about 3 million in 1951 to 8 million in 1981 to 12 million in 2001 as per the Census figures[19]. The mid-year population estimates for 2008 suggest that the population has grown to 13.4 million with the density of 30,803 per sq. km.[20] Mumbai, being the financial capital of the country with a large industrial and commercial base, attracts a large workforce into the city. The growing population adds to the pressure on basic infrastructure, civic amenities and housing. It also leads to congestion, heavy vehicular traffic, growth in illegal slum dwellings, unhygienic living conditions and the problem of solid waste disposal.

The estimates for year 2008 suggest that 56% of the population in Mumbai lives in slums[21]. With expanding trade and commerce, more and more people are getting attracted to the city. However, due to increasing costs of land and material, it has become virtually impossible for the poor and low-income households to acquire residential property in the city. As a result, the base of slum-dwellers has increased tremendously. Slums have mushroomed in almost all the wards of Mumbai, along the coast, on the hill slopes, along the highways, railways and in low-lying areas. Many settlements lack even basic infrastructure like water, sanitation and legal electricity connections. Policy makers and society, over the years, have looked at slums with different perspectives. They were earlier seen as unfit settlements and dens of crime leading to decisions about demolishing and replacing them with 'acceptable' housing. The Slum Clearance Programme of 1956 gave enough powers to the government for redeveloping the acquired slum areas. However, redevelopment could not match the pace of demolitions and the pace of growing slums. In 1972, policies were formulated with emphasis on 'improvement in living conditions' rather than 'redevelopment' and 'rehabilitation'. Provision of basic civic amenities such as drinking water, sewerage system, paved roads, community

[18] Govt. of Maharashtra, (2007), Greater Mumbai Disaster Management Action Plan, Maharashtra Emergency Earthquake Management Programme, Govt. of Maharashtra

[19] MMRDA, (2007) Basic statistics on MMR, Mumbai Metropolitan Region Development Authority, http://www.mmrdamumbai.org/basic_information.htm

[20] MCGM, (2008), Public Health Department at a Glance 2007-08, MCGM

[21] *Ibid.*

toilets etc., indicated a level of acceptance of slum communities[22]. However, slums are non-existent on city's developmental plans. None of the 2335 settlements are recognized on the developmental plan of Mumbai and the land under slums has development plan reservations, even though some settlements have existed before development plans were formulated[23]. This deliberately induced invisibility of slums pushes its dwellers to multiple forms of displacements. Regular displacements prevent slum-dwellers from settling in safe and secure localities and they further move towards landslide prone areas, low-lying regions, and unsafe dumping sites etc., which are breeding grounds for hazards in changing weather/climate conditions.

Given the increasing population and more than half living a life of poverty and destitution with limited access to basic civic amenities and infrastructure, health vulnerabilities become imminent. As the Mumbai Human Development Report 2009 indicates, the overall life expectancy in Mumbai is much lower at 52.6 years for males and 58.1 years for females[24]. Tuberculosis (known as a poor man's disease), HIV/AIDS, Malaria and Jaundice are some of the major killers in the city. Infant mortality is 36.66 per 1000 live births and malnourishment is rampant among slum children. In fact, severe malnourishment is marginally higher among slum children in Mumbai than those living in tribal areas of the adjoining district, Thane[25]. The city boasts of enviable health infrastructure compared to other Indian cities, yet the public health facilities are grossly insufficient to cater to such a huge population and in the event of a disease outbreak, the civic machinery does not adequate infrastructure to deal with the health emergency. 75-80% population depends on relatively expensive private healthcare facilities for treatment and coverage of health insurance negligible[26].

As regards economic vulnerability, Mumbai has a pre-eminent position in the country as the commercial and trading base. In the financial year 2004-05, the per capita income of Mumbai was Rs. 69,696[27], which was twice that of Maharashtra State per capita income of Rs. 32,170 and thrice that of the national average per capital income of Rs. 22,946[28]. Mumbai is also an important source of tax revenue for the country, *e.g.*, in 2002-03, Rs. 28,000 crores were collected from the city in the form of taxes, which was 35% of the total tax collection at Rs. 82,000 crores for the entire country[29]. In recent

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[22] Bhide, A. (2009). Shifting Terrains of Communities and Community Organization: Reflections on Organizing for Housing Rights in Mumbai, Community Development Journal, Vol. 44, No. 3 pp. 367-381

[23] *Ibid.* Reservations indicate intended use of the land thereby making all other activities illegal.

[24] MCGM, (2009), Mumbai Human Development Report 2009

[25] Hatekar N. and Rode S., (2003), Truth about Hunger and Disease in Mumbai: Malnourishment among Slum Children, Economic and Political Weekly, pp. 4604-10

[26] MCGM, (2009), Mumbai Human Development Report 2009

[27] Govt. of Maharashtra, (2006), Economic Survey 2006-07, available at http://www.maharashtra.gov.in

[28] RBI, (2007), Handbook of Statistics on Indian Economy, available at http://www.rbi.org.in

[29] Bombay First, (2004), Statistics on Mumbai, http://www.bombayfirst.org

years, the share of tertiary sector in Mumbai's income has increased, whereas, the share of secondary sector has remained almost stagnant. Further, 2001 census suggests that the total employment in Mumbai is 44.64 lakhs[30], of which 41% are in secondary sector and 58% are in tertiary sector[31]. Most of the industries in Mumbai are located in eastern and northeastern corridor with a few in the western region. The number of factories in Mumbai has declined in the last decade and so also its share of factories in the state from 44% to 34% between 1993 and 2000[32]. As of 2003, there were more than 7800 large, medium and small-scale enterprises operating in Mumbai[33]. Most of these units are in mixed areas as no buffer zone is provided for them. In fact, Mumbai was the first City Corporation to adopt the concept of a development plan under which industrial zones were allowed to be used for residential and commercial purposes[34]. Therefore, there is no clear distinction between residential, commercial and industrial zones for the city. Industrial areas are further being converted into residential complexes, leading to a boom in construction activity, mainly in the suburbs. For instance, most textile mills have closed down in recent years giving way to residential and commercial complexes. The land use pattern in the city has undergone major changes in recent years with the conversion of industrial areas into residential and commercial complexes. The climate vulnerability of Mumbai, therefore, means a threat to the life and property within the city, impact on the entire development trajectory and the economic loss for the entire nation.

2.3 Managing vulnerability

In December 2005, in the aftermath of the unprecedented Mumbai floods, Government of India enacted the Disaster Management Act, under which the National Disaster Management Authority and State Disaster Management Authorities have been created. The Act also seeks to constitute Disaster Response Fund and Disaster Mitigation Fund at national, state and district levels. In Maharashtra, the state government accordingly has prepared the Greater Mumbai Disaster Management Action Plan (DMAP) in 2007. Under this plan, the risks and vulnerabilities associated

[30] 1 lakh = 100,000

[31] Govt. of Maharashtra, (2007), Greater Mumbai Disaster Management Action Plan, Maharashtra Emergency Earthquake Management Programme, Govt. of Maharashtra

[32] World Bank, (2005), For a Breath of Fresh Air: Ten Years of Progress and Challenges in Urban Air Quality Management in India, 1993-2002, Environment and Social Development Unit, South Asia Region, The World Bank (India Country Office), New Delhi, India

[33] MPCB, (2005), Report on Environment Status of Mumbai Region, Maharashtra Pollution Control Board, Government of Maharashtra

[34] World Bank, (2005), For a Breath of Fresh Air: Ten Years of Progress and Challenges in Urban Air Quality Management in India, 1993-2002, Environment and Social Development Unit, South Asia Region, The World Bank (India Country Office), New Delhi, India

with floods, earthquakes, landslides, cyclones, *etc.*, have been identified. The plan further envisages specific relief and mitigation measures for Mumbai[35]:

- ***Infrastructure improvements:*** The mitigation strategy seeks to improve the transport, services and housing infrastructure. These include improvements in road and rail networks, sanitation and sewer disposal system, storm water drainage systems, slum improvements, housing repairs and retrofitting programmes.
- ***Contingency plan:*** This strategy includes plans to provide extra transportation if the major transport systems fail, transit camp arrangements, improvements in wireless communication and public information systems and NGO volunteers' assistance.
- ***Land use policies and planning:*** The Draft Regional Plan for MMR Region 1996-2011 provides a basic framework for the land use policies for the city. This plan includes strategies like protection of landfill sites, control on land reclamation, shifting of hazardous units from residential areas and decongestion.

The DMAP looks comprehensive on paper, yet does not provide any specific timeframe for achieving the mitigation measures. Again, no specific attention is given to adaptation strategies which may be more important in the short to medium-term to deal with the climate risks of flooding, storms and cyclones. Measures related to infrastructure improvements would require a longer time frame given the socio-economic and political dynamics in the city. Also, the land use policies and planning will not be effective unless they are coupled with strategies to deal with slum settlements and migrants into the city. The experience of the city dwellers in the aftermath of 2005 floods only shows that the city administration and other stakeholders would need more specific strategies and an integrated approach to build resilience of the city to climate risks.

3. Climate risks in Mumbai

From the discussion in the previous section, it is evident that a mega-city like Mumbai is an important engine of population concentration, economic growth and innovation for the rest of the country. However, its location on the coast also puts it at greater risk of sea-level rise, flooding, high winds, cyclones and coastal erosion. The prevailing physical and socio-economic conditions make it important that we increase our understanding of who are vulnerable, to what extent, what are the climate hazards that we are exposed to and how do we deal with the vulnerability. This section focuses the discussion on some of these aspects. We try to analyze the climate risks for the city taking into account the past events and future projections based on scientific assessment. We further explore the linkages between climate risks and vulnerability and the framework within which the vulnerability is currently assessed and should potentially be assessed.

[35] Govt. of Maharashtra, (2007), Greater Mumbai Disaster Management Action Plan, Maharashtra Emergency Earthquake Management Programme, Govt. of Maharashtra

3.1 Events in the past and future projections

Mumbai has regularly been facing weather events related to flooding due to heavy precipitation and landslides during the rainy season. Mumbai's vulnerability to extreme weather events was demonstrated on 26 July 2005 when more than 900mm of rainfall occurred in the suburban district in the 24-hour period. The catastrophic event is described in Box 1 below. Before and after this catastrophic event, heavy precipitation and floods have regularly occurred in Mumbai. On many occasions, heavy rains over the city are the result of tropical storms or cyclones that hit the city or pass nearby. Many low-lying and reclaimed areas get flooded, especially when heavy rains combine with high tide or storm surges, with the added difficulties due to unsanitary methods of solid waste and sewage disposal and problems with the drainage systems[36]. Slums and squatter communities are particularly vulnerable to such events as the amenities and infrastructure is typically very poor and the built environment is also in a dilapidated condition. Landslides accompanied with heavy rains are also common in settlements on the hill slopes and in the quarries. There have been landslide events in the past where lives were lost along with damage to property. For instance, in July 2000, between 60 and 160 people were killed due to landslide. The most recent events of landslide occurred during the heavy rains in June and July 2010 in Dindoshi (Ward P-South) where many houses were damaged and families were rendered homeless.

Studies carried out over the past decade indicate that Mumbai is likely to be highly vulnerable to climate change with majority of its population living on the flood prone and reclaimed land. Estimates obtained in 2001 from the Goddard Institute for Space Studies[37] suggest that in the Canadian Climate Centre's business-as-usual emissions (A2) scenario and sustainable path (B2) scenario, the average annual temperatures in the city would increase by 1.75^0C and 1.25^0C respectively. Mumbai is also predicted to have an average annual decrease in precipitation of 2% for the A2 scenario and an increase of 2% in the B2 scenario. Perhaps, the most damaging scenario for the city would be the predicted sea-level rise of 50cm by 2050[38].

[36] Sherbinin A., Schiller A. and Pulsipher A., (2007), The Vulnerability of Global Cities to Climate Hazards, Environment and Urbanization, Vol. 19(1), Sage Publications on behalf of International Institute for Environment and Development

[37] *Ibid.*

[38] *Ibid.*

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Box 1: Mumbai floods on 26 July 2010

On this fateful day, Mumbai recorded the highest rainfall the country during a 24-hour period in the last 100 years. Santacruz monitoring station (in Western suburbs) recorded 944mm rainfall between 8.30am and 8.30pm with the highest precipitation for a few hours between 11.30am and 2.30pm. The rainfall coinciding with the high tide brought the city to a standstill. Civic amenities such as electricity, water supply and transportation and communication networks were completely shut down. The worst-hit were the low-lying areas and the poor living in slums or squatter settlements along the pavements and near railway tracks.

Floods claimed more than 700 lives in the city. More than 14,000 houses were completely damaged and more than 357,000 houses were partially damaged. The total cost of damages has since been estimated at Rs. 306 crores (US$ 68 million @ 1US$ = Rs.45). The most extensive loss was suffered by trade and commerce as a large number of shops, commercial establishments and warehouses suffered heavy losses due to flooding. The Indian Merchants Chamber has estimated these losses to the tune of Rs. 5000 crores (US$ 1100 million). In the immediate aftermath, Mumbai also saw 3000 hospital admissions due to gastroenteritis, malaria, hepatitis, dengue and so on.

Source: Govt. of Maharashtra (2005), Maharashtra Floods 2005, Relief and Rehabilitation Department, Govt. of Maharashtra

An OECD study[39] has analyzed the recurrence of an extreme weather event like July 2005 for Mumbai. Its findings suggest that in the current scenario, the return period for an event of this magnitude is greater than 200 years. However, with imminent climate change, today's extreme events could become more frequent. For instance, a 1 in 10 event could occur every other year. Using the Storm Water Management Model of USEPA, the study further explores the future flood footprints for Mumbai. By 2080, the study finds extended flood footprints in the city with deeper flooding in more vulnerable areas. The total costs of such an event by 2080 would dramatically go up to US$ 2300 million from the present-day costs of US$ 650 million.

Yet another OECD study[40] has done a global screening of 136 coastal cities to identify their exposure to storm surges and high winds. The study has also investigated how climate change is likely to impact these cities through coastal flooding by 2070s. For the present day conditions (reference year 2005), Mumbai is ranked the first among top ten coastal cities in terms of exposed population. The total exposed population to weather events resulting from current climate conditions in Mumbai is estimated at 2.787 million. Under the future climate conditions, the population exposed to weather events like storm surges and flooding will go up to 11.418 million. Similarly, the value of exposed assets is currently US$ 46.20 billion, which would dramatically increase to US$ 1598.05 billion by 2080. Further, the city is ranked 2nd in terms of population exposure to future climate conditions by 2080, second only to another vulnerable coastal city in India, Kolkata (Formerly Calcutta). Mumbai is also among the top 20 cities with greatest exposure to extreme sea-level and with greatest exposure to wind damage from tropical cyclones. The city is also expected to have a high exposure to coastal flood risk in the 2070s. The study further emphasizes that exposure will not necessarily translate into impact if effective adaptation and risk management strategies are in place. However, for a city like Mumbai with far lower standards of adaptation and risk management or flood defences, the impacts of extreme weather events are likely to be large in future.

3.2 Mapping climate risks

Revi (2008)[41] has reviewed the climate risks for Indian cities in general in order to highlight the importance of infrastructure investments and urban management and the need to connect these with the official adaptation initiatives. As mentioned in the paper, climate change is expected to increase the frequency and intensity of current hazards and the probability of extreme weather events. The cities will further face the new hazards in terms of sea-level rise. This will degrade the resilience

[39] Hallegatte S., Coastal Cities, Climate Change Vulnerability and Adaptation, OECD Project led by Jan Corfee-Morgot, available at www.oecd.org/dataoecd/31/34/44104953.pdf

[40] OECD (2008), Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates, Environment Working Papers No. 1

[41] Revi A., (2008), Climate Change Risk: An Adaptation and Mitigation Agenda for Indian Cities, Environment and Urbanization, Vol. 20(1), Sage Publications on behalf of International Institute for Environment and Development

of urban poor, which make up almost half of Mumbai's population. There is a broad consensus among the scientific community on the first-order climate change impacts in India. There may be a general increase in both mean minimum and maximum temperatures by 2-4^{0}C depending on the atmospheric GHG concentrations[42]. This could lead to a mean surface temperature increase of 3.5-5^{0}C by the end of the century[43]. The regional temperature rise coupled with changes in the global climate system and Indian Ocean monsoon system may lead to a mean increase of 7-20% in annual precipitation[44]. Simultaneously, there might be a decrease in total number of rainy days over much of India, along with an increase in heavy rainfall days and frequency of such days in the monsoon season[45]. A substantial increase in extreme precipitation (e.g., Mumbai floods 2005, Gujarat floods 2005, 2006) is also expected over a large area of the west coast (including Mumbai) and central India[46]. Further, a sea surface temperature rise of 2-4^{0}C is expected to induce a 10-20% increase in cyclonic intensity[47]. A sea-level rise of 30-80 cm has also been projected over the century along India's coast based on multiple climate change scenarios[48]. Such sea-level rises, cyclones and storm surges could have a devastating impact on a large urban centre like Mumbai, which falls into a low elevation coastal zone (LECZ). Another important climate risk for Indian cities, in particular Mumbai, is the onset of water-borne diseases (diarrhea, cholera and typhoid) and vector-borne diseases (malaria and dengue). In fact, the recent reports emerging from the city suggest that malaria cases have doubled over the last year and in the first two weeks of July alone over 8600 cases of malaria have been reported[49]. Malaria is expected to expand its endemic range to western southern India in future[50] and the city of Mumbai with its large population will be at further risk.

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[42] Sharma S., Bhattacharya S. and Garg A., (2006), Greenhouse Gas Emissions from India: A Perspective, Current Science, Vol. 90, No. 3, February 2006

[43] Planning Commission (2006), Report of the Expert Committee on an Integrated Energy Policy, New Delhi

[44] Ramesh R. and Yadava M. G., (2005), Climate and Water Resources of India, Current Science, Vol 89, No. 5, September 2005

[45] Rupa Kumar K., Sahai A. K., Krishna Kumar K., Patwardhan S. K., Mishra P. K., Revadekar J. V., Kamala K. and Pant G. B., (2006), High-resolution Climate Change Scenarios for India for the 21st Century, Current Science, Vol 90, No.3, February 2006

[46] *Ibid.*

[47] Aggarwal D. and Lal M., (2001), Vulnerability of Indian Coastline to Sea-level Rise, Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi, India

[48] *Ibid.*

[49] Times of India, (2010), http://timesofindia.indiatimes.com/city/mumbai/Malaria-cases-double-in-city-since-09/articleshow/6202936.cms

[50] Bhattacharya S., Sharma C., Dhiman R. C. and Mitra A. P., (2006), Climate Change and Malaria in India, Current Science, Vol. 90, No. 3, February 2006

A few studies are attempting to map the climate risks specific to Mumbai. For instance, the Canadian Climate Centre's business-as-usual emissions (A2) scenario[51] predicts that with the annual precipitation decrease of 2%, Mumbai may suffer from acute water shortages due to its heavy dependence on rainfall for water supply in future. Also, draughts might become more common in areas surrounding Mumbai triggering migrations into the city. Further, the predicted sea-level rise may have a disastrous impact on the city. Flooding along coastal and low-lying areas would increase dramatically endangering the slums located there. Vulnerability assessment undertaken by Schiller et al. (2007)[52] further suggests that a 'bundle' of stresses, such as, Mumbai's flat topography, geology, wetlands and flood prone areas, projected sea-level rise, building conditions including not meeting building codes, squatter settlements, flood-ravaged buildings, poor sanitation and waste treatment and low incomes reducing the ability for disaster preparedness will create an enhanced vulnerability for the city. However, it must be noted that Mumbai's informal coping mechanism – a strong social network and cooperation among people – would become an important part of the city resilience and reduce vulnerability to some degree[53].

An OECD study is also currently underway in Mumbai to demonstrate an approach to assess the future risks from extreme weather events and quantify the benefits of different adaptation options on a city-scale. The study will focus on applying this approach to flood risk in Mumbai. The findings of the study (soon to be published) suggest that by 2080, in a SRES A2 'upper bound' climate scenario, the likelihood of a 2005-like event will more than double. The total direct and indirect losses from such an event would also triple to around US$ 1890 million. The study specially looks at the marginalized population comprising a large number of households in the city (engaged in the informal sector) who would suffer from the total losses of US$ 250 million. The analysis also shows how the adaptation efforts could significantly bring down the costs of extreme flooding events in future.

4. Adaptation efforts: Role of different stakeholders

The Greater Mumbai Disaster Management Action Plan (DMAP) prepared by Government of Maharashtra in 2007 identifies the risks and vulnerabilities associated with floods, cyclones, earthquakes, etc., and outlines the measures to deal with these vulnerabilities. However, as mentioned earlier, the DMAP, comprehensive on paper, does not provide any specific timeframe for achieving the mitigation measures. No specific attention is given to adaptation strategies which may be more important in the short to medium-term to deal with the climate risks of flooding, storms and cyclones. The report has, however, identified the stakeholders in the government machinery and

[51] Sherbinin A., Schiller A. and Pulsipher A., (2007), The Vulnerability of Global Cities to Climate Hazards, Environment and Urbanization, Vol. 19(1), Sage Publications on behalf of International Institute for Environment and Development

[52] *Ibid.*

[53] *Ibid.*

others and the specific tasks they need to perform as a part of the mitigation strategies. We identify these and other stakeholders to take a comprehensive overview of the roles different stakeholders are currently performing or expected to perform as a part of the efforts to reduce the climate risks. Table 1 below summarizes these roles.

Table 1: Role of different stakeholders in Mumbai to tackle climate risks

Stakeholder	**Current / Expected roles**
National, state and district disaster management authorities	❖ Prepare policies, plans and guidelines for disaster management ❖ National Disaster Management Authority to declare nation-wide policies ❖ Constituting National Institute of Disaster Management that imparts training and research and develops nationwide database on policies and prevention mechanisms ❖ Constituting National Disaster Response Force ❖ State Disaster Management Authority to prepare the state-level plans ❖ District Authority as district planning, coordinating and implementing body for all disaster management functions ❖ District Authority functions include mitigation and preparedness, response, relief and rehabilitation
Local authority (MCGM – specific to Mumbai)	❖ Impart training to employees to cope with disasters ❖ Maintenance of resources for managing any extreme events ❖ Ensuring that all construction activity conforms to prescribed standards and specifications (building codes, earthquake and fire proof construction, coastal zone regulations, FSI regulations, etc.) ❖ Relief, rehabilitation and reconstruction activity in affected areas

MCGM and MMRDA	❖ Infrastructure improvement in terms of transport, services and housing ❖ Projects like MUTP and MURP to work towards these objectives ❖ Constructing flyovers, additional roads and road over bridges to reduce the traffic density and congestion in identified spots of high traffic density ❖ Road improvement programme to improve the conditions of roads particularly before monsoon ❖ Slum Rehabilitation Scheme to improve the quality of housing for slum dwellers and scatter communities
MCGM – storm water drainage department	❖ Regular de-silting (cleaning) of nallahs (narrow waterways) to reduce the tendency of flooding or choking during heavy precipitation ❖ Augmenting the capacity of the present storm water drains ❖ All flood gates manned to operate them during high and low tides ❖ Chronic flooding spots management by deploying special sqauds
MCGM – early warning system	❖ Automatic weather stations with rain gauge monitoring system to be installed across city to monitor rain intensity to facilitate early warning ❖ Anti-flood control rooms in all wards with equipped staff, wireless equipments, etc. ❖ A list of days when there is a hide tide of 4.7 mtrs and above to be prepared and distributed to railways, police and the district collector ❖ Nodal officer of MCGM to brief print, audio and visual media to provide timely and clear information and put a stop to rumours ❖ Electronic information display monitors controlled to be installed at different places in city ❖ Booklet of all important contact numbers to be distributed widely

Police and fire brigade departments	❖ Police departments to work with municipal authorities to respond quickly and effectively to extreme events ❖ Identify and get equipped with specific equipments and facilities required to respond to extreme events ❖ Commissioned six command centres of fire brigade capable of acting independently ❖ Three highly trained search and rescue teams to be deployed and each team equipped with enhanced equipments
MCGM – public health department	❖ Preventive measures to stop the spread of water, food borne and vector borne diseases ❖ Information to be disseminated to the general public about prevention and cure of such diseases ❖ Keep stock of essential medicines, vaccines and pest control chemicals and equipments ❖ Provide immediate and urgent health services through primary health centres and hospitals run by the civic authority
MCGM – contingency plan	❖ Each ward to identify five schools as temporary transit camp during disasters ❖ BEST (transport authority in Mumbai) to put in service extra buses in case of transport failure ❖ Disaster management Cell to be equipped with all state-of-art communication equipments and networks to control the rescue and relief operations
NGOs	❖ Role in setting up an effective communication and public information system ❖ Role in rescue, relief and rehabilitation activities by providing volunteers ❖ To create awareness among people and educate them about extreme events and level of preparedness
Communities	❖ Based on past experience, perhaps the most crucial role performed by communities and individual people in helping with rescue and relief work

5. Knowledge and research gaps

It is apparent from the discussion so far that Mumbai is acutely vulnerable to climate risks. It is one of the largest mega-cities in the world supporting more than 13 million residents. Given its unique geographical location along the western coast of India, surrounded by water from three sides, and the physical, economic and social characteristics, the city experiences enhanced vulnerability to the threats posed by climate risks like sea level rises, storms and floods. Studies carried out over the past decade indicate that Mumbai is likely to be highly vulnerable to climate change with majority of its population living on the flood prone and reclaimed land. Under the future climate conditions, the population exposed to weather events like storm surges and flooding will go up to 11.418 million. Similarly, the value of exposed assets would dramatically increase to US$ 1598.05 billion by 2080. Against this backdrop, we need to look at the mitigation and adaptation efforts in Mumbai.

The state government prepared a Disaster Management Action Plan for the city in the aftermath of the 2005 devastating floods. This Plan broadly identifies the risks and vulnerabilities associated with risks like flood, earthquake and so on and outlines measures that need to be undertaken. The role of different stakeholders is also identified in the Plan. However, there are no specific mitigation and adaptation strategies or the timelines for achieving them outlined in the Plan. Besides this Plan, there are no visible mitigation and adaptation efforts currently underway in Mumbai that would target to reduce vulnerabilities to climate risks.

In general, vulnerability reduction and adaptation to the adverse impacts of climate change is an important area for policy formulation at national, regional and local levels. An interdisciplinary approach is needed to create an information and knowledge base to help identify, develop and implement effective responses to reduce vulnerability and enhance adaptive capacity[54]. Specific information needs to be built on what are the available adaptation options, under which climatic conditions will they work effectively, anticipated benefits, resource requirements to implement them, requisite institutional structures and processes and potential spillover effects[55]. In addition to this, more fundamental research is required on different adaptation and mitigation options, requirements for such efforts at all levels, potential performance of these options and strengthening institutional capabilities to manage adaptations.

The research gaps and challenges that need to be addressed for Mumbai in immediate future in order to reduce climate vulnerabilities and build city resilience can broadly be classified into three categories: Information, Assessment and Knowledge. There is a need to compile information regarding different climate-related risks. We further need to assess how and where different models &

[54] Patwardhan A., Downing T., Leary N. and Wilbanks T., (2009), *Towards an Integrated Agenda for Adaptation Research: Theory, Practice and Policy*, Current Opinion in Environmental Sustainability, 1:219-225, Elsevier

[55] *Ibid.*

tools can be applied to look at changes in hazards, exposure & vulnerability. We also need to build on the fundamental knowledge about topics where there is inadequate understanding currently, e.g., health impacts of climate change, intra-seasonal variability in the monsoon, studies of subsidence and stability of reclaimed lands, etc. The focal areas for further research in Mumbai in respect of climate change vulnerability, adaptation and mitigation are given in Table 2 below. These areas are developed on the basis of the review of adaptation literature, in particular, the strategy paper developed by Patwardhan et al. (2009)[56].

Table 2: Scope for further research

Theme	Focal area	Specific research activities
Information	Risk identification (who is at risk?)	* Moving from broad and generic projections about future risks to the identification of specific risks * Identifying exposure, sensitivity and capacity to cope for people and institutions * Understanding interaction of climate change with other stresses to assess amplification or diminution of risks * Risks at different spatial and temporal scales
	Vulnerability characterization (what is at risk?)	* Specific risks to city infrastructure, civic amenities, economy and society and risk magnitudes * Vulnerability of marginalized population, informal sectors * Mapping current as well as future physical, economic, social and cultural vulnerability

[56] *Ibid.*

Assessment	Adaptation measures	* Identifying specific adaptation measures taking into account current and future technological, socio-economic, political and institutional conditions * Identification, planning and implementation of adaptation responses considering the past experience of responses to climate risks
	Integrating adaptation into mainstream planning	* Identifying contexts such as disaster management or infrastructure development activities for mainstreaming adaptation into current planning and policies * Carrying out policy oriented studies to understand where such integration is possible
	Institutional mechanism	* Identifying and defining specific roles of public and private stakeholders in adaptation * Capacity building in institutions to strengthen adaptation decision-making

Knowledge	Health impacts	* Establishing the link between climate variability and health impacts * Assessing the vulnerability of the city to water-borne and vector-borne diseases * Sensitizing city stakeholders including health professionals, public health administrators, municipal officials and citizens' groups to health risks of climate change
	Geo-climatic studies	* Understanding the intra-seasonal variability in monsoon * Studying the subsidence and stability of reclaimed land