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Flood Risks, Climate Change Impacts and Adaptation Benefits in Mumbai

AN INITIAL ASSESSMENT OF SOCIO-ECONOMIC CONSEQUENCES OF PRESENT AND CLIMATE CHANGE INDUCED FLOOD RISKS AND OF POSSIBLE ADAPTATION OPTIONS

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FLOOD RISKS, CLIMATE CHANGE IMPACTS AND ADAPTATION BENEFITS IN MUMBAI : AN INITIAL ASSESSMENT OF SOCIO-ECONOMIC CONSEQUENCES OF PRESENT AND CLIMATE CHANGE INDUCED FLOOD RISKS AND OF POSSIBLE ADAPTATION OPTIONS

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ABSTRACT

Managing risks from extreme events will be a crucial component of climate change adaptation. In this study, we demonstrate an approach to assess future risks and quantify the benefits of adaptation options at a city-scale, with application to flood risk in Mumbai.

In 2005, Mumbai experienced unprecedented flooding, causing direct economic damages estimated at almost two billion USD and 500 fatalities. Our findings suggest that by the 2080s, in a SRES A2 scenario, an 'upper bound' climate scenario could see the likelihood of a 2005-like event more than double. We estimate that total losses (direct plus indirect) associated with a 1-in-100 year event could triple compared with current situation (to \$690 – \$1890 million USD), due to climate change alone. Continued rapid urbanisation could further increase the risk level. Moreover, a survey on the consequences of the 2005 floods on the marginalized population reveals the special vulnerability of the poorest, which is not apparent when looking only through a window of quantitative analysis and aggregate figures. For instance, the survey suggests that total losses to the marginalized population from the 2005 floods could lie around \$250 million, which represents a limited share of total losses but a large shock for poor households.

The analysis also demonstrates that adaptation could significantly reduce future losses; for example, estimates suggest that by improving the drainage system in Mumbai, losses associated with a 1-in-100 year flood event today could be reduced by as much as 70%. We show that assessing the indirect costs of extreme events is an important component of an adaptation assessment, both in ensuring the analysis captures the full economic benefits of adaptation and also identifying options that can help to manage indirect risks of disasters. For example, we show that by extending insurance to 100% penetration, the indirect effects of flooding could be almost halved. As shown by the survey, the marginalized population has little access to financial support in disaster aftermaths, and targeting this population could make the benefits of such measures even larger.

While this study explores only the upper-bound climate scenario and is insufficient to design an adaptation strategy, it does demonstrate the value of risk-assessment as an important quantitative tool in developing city-scale adaptation strategies.

We conclude with a discussion of sources of uncertainty, and of risk-based tools that could be linked with decision-making approaches to inform adaptation plans that are robust to climate change.

JEL Classification : E20, O18, O20, Q01, Q54, Q58, R11, R52

Keywords: Climate change, global warming, natural disasters, flood management, adaptation, urban planning, government policy, sustainable development, insurance.

RESUME

La gestion des risques liés aux événements extrêmes sera un composant indispensable de l'adaptation au changement climatique. Dans cette étude, nous décrivons une méthode permettant d'évaluer les risques futurs et de quantifier les avantages de solutions d'adaptation à l'échelle urbaine, puis nous l'appliquons à l'estimation des risques d'inondation à Mumbai (Bombay).

En 2005, une inondation sans précédent frappait la ville de Mumbai, faisant 500 victimes et occasionnant des dommages économiques directs estimés à près de deux milliards de dollars. Nos résultats suggèrent que, d'ici les années 2080, en appliquant le scénario SRES A2 et en sélectionnant un scénario climatique dans le haut de la fourchette, la probabilité d'un événement tel que celui de 2005 pourrait plus que doubler. Selon nos estimations, les pertes totales (directes et indirectes) causées par une catastrophe centennale pourraient tripler par rapport à leur niveau actuel (pour atteindre 690 à 1890 millions de dollars), du seul fait du changement climatique. L'urbanisation rapide et continue pourrait accroître d'autant plus le niveau de risque. D'autre part, l'étude que nous avons faite des conséquences des inondations de 2005 sur les populations marginalisées met en lumière la vulnérabilité particulière des plus démunis, qui n'est pas apparente lorsqu'on se limite aux analyses quantitatives et aux chiffres globaux. Par exemple, selon notre étude, le total des pertes subies lors des inondations de 2005 par les personnes marginalisées avoisinerait 250 millions de dollars, une faible part du total des dommages, mais un désastre considérable pour les foyers pauvres.

Notre analyse montre également que l'adaptation pourrait substantiellement réduire les dommages futurs : nous estimons ainsi que les dommages causés par une inondation centennale pourraient être réduits de 70 % si l'on améliore le réseau d'assainissement de Mumbai. Quand on procède à une évaluation de l'adaptation, il importe d'estimer les coûts indirects des événements extrêmes car on peut ainsi à la fois intégrer à l'analyse l'ensemble des avantages économiques de l'adaptation et identifier des options de gestion des risques indirects liés aux catastrophes. Par exemple, nous montrons que si 100 % des habitants étaient en mesure de souscrire une assurance, les effets indirects des inondations pourraient être réduits de près de la moitié. Comme l'indique notre étude, la population marginalisée a peu accès aux aides financières après les catastrophes : les avantages de telles mesures pourraient donc être encore plus élevés si cette population était ciblée en priorité.

Notre étude se limite à un scénario climatique dans le haut de la fourchette et ne suffit pas à élaborer une stratégie d'adaptation à part entière. Néanmoins, elle démontre la valeur des évaluations des risques, outils de mesure importants quand il s'agit de concevoir des stratégies d'adaptation à l'échelle urbaine.

Nous concluons par un examen des sources d'incertitude ainsi que des outils fondés sur les risques qui, associés à des processus décisionnels, permettraient de formuler des plans d'adaptation durable au changement climatique.

JEL Classification : E20, O18, O20, Q01, Q54, Q58, R11, R52

Mots clés : changement climatique, réchauffement climatique, catastrophes naturelles, gestion des inondations, adaptation, aménagement urbain, action publique, développement durable, assurance.

FOREWORD

The OECD is actively working with national governments to highlight the role of urban governance and policy to deliver cost-effective responses to climate change. This report is one in a series under the OECD Environment Directorate's project on Cities and Climate Change. This part of the project aims to explore the city-scale risks of climate change, and the economics of impacts and policy benefits at city scale. For more information about this work see: www.oecd.org/env/cc/cities .

This Mumbai study is the result of a two-year collaborative research effort, which was initiated and financially supported by the OECD. The technical work of the study was led by:

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EXECUTIVE SUMMARY

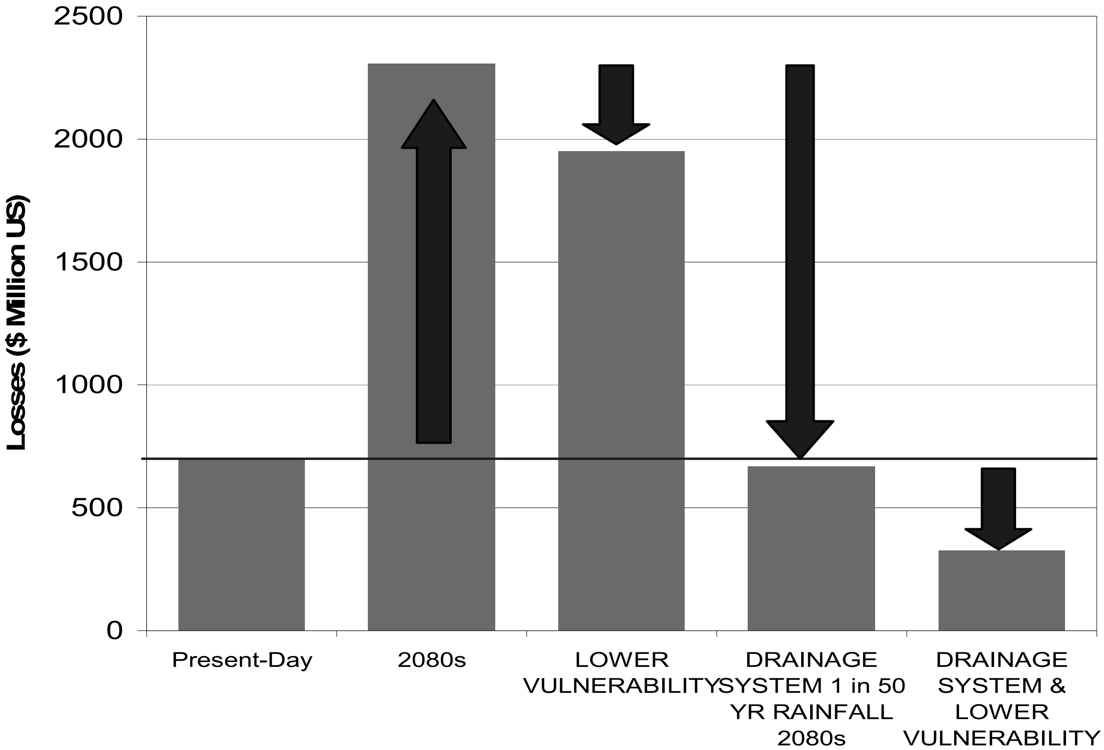
Managing risks from extreme events will be a crucial component of climate change adaptation. In this study, we demonstrate an approach to assess future risks and quantify the benefits of adaptation options at a city-scale, with application to flood risk in Mumbai. The study follows the broad stages of an 'impacts-based' adaptation assessment: firstly, characterising current levels of vulnerability and potential future sensitivities (Section 2); secondly, quantifying relevant risks (Sections 3 and 4) and analyzing specificities of marginalized populations and informal businesses (Section 5); and thirdly, identifying adaptation options and evaluating their benefits (Section 6). In the last section (7) we provide a brief discussion of our approach in this context.

In 2005, Mumbai experienced unprecedented flooding, causing direct economic damages estimated at almost two billion USD and 500 fatalities. Our findings suggest that by the 2080s, in a SRES A2 scenario, an 'upper bound' climate scenario could see the likelihood of a 2005-like event more than double. We estimate that total losses (direct plus indirect) associated with a 1-in-100 year event could triple compared with current situation (to \$690 – \$1890 million USD), due to climate change alone.

Moreover, a survey on the consequences of the 2005 floods on the marginalized population reveals the special vulnerability of the poorest, which is not apparent when looking only through a window of quantitative analysis and aggregate figures. For instance, the survey suggests that total losses to the marginalized population from the 2005 floods could lie around \$250 million, which represents a limited share of total losses but a large shock for poor households.

The analysis also demonstrates that adaptation could significantly reduce future losses. For example, Figure ES-1 illustrates the results of a simple analysis of the potential risk reducing benefits of two potential policy options to reduce direct losses from flooding. These are too simplified to guide specific policy and do not represent a complete list of options, but do serve to demonstrate the potential of adaptation to limit climate change damages and the need to integrate consideration of climate change in decision-making around disaster risk management today.

Figure ES-1. The estimated total (direct + indirect) losses for a 1-in-100 year flood event in Mumbai under five scenarios



Note : See more detail (Figure 13) and discussion in Section 6 of main report. From left to right: (i) present-day; (ii) 2080s – using the one 'high-end' scenario considered in this study and an unchanged city; (iii) 2080s, assuming properties are made more resilient and resistant to flooding (e.g. through building codes); (iv) 2080s, assuming the drainage system is improved such that it can cope with a 1-in-50 year rainfall event; and (v) combined property and drainage improvements.

We show also that assessing the indirect costs of extreme events is an important component of an adaptation assessment, both in ensuring the analysis captures the full economic benefits of adaptation and also identifying options that can help to manage indirect risks of disasters. For example, we show that by extending insurance to 100% penetration, the indirect effects of flooding could be almost halved. As shown by the survey, the marginalized population has little access to financial support in disaster aftermaths, and targeting this population could make the benefits of such measures even larger.

It is also important to note that this study's estimates of future risk and costs do not take into account population and economic growth, considering the current city only. The Indian urbanization rate and economic production are increasing very rapidly and this is likely to continue to increase flood risk in Mumbai in the absence of adaptation. For instance, it has been estimated that the Mumbai population might increase to up to 28 million inhabitants – up from 17 million in 2008 (i.e. in the Regional Plan for Mumbai Metropolitan Region 1996 – 2011, by the Mumbai Metropolitan Region Development authority). This will not only increase the exposure to flooding, but also put further strain on the natural and manmade drainage systems if improvements are not implemented, potentially increasing hazard and risk levels. In addition, without improvements to the drainage systems, sea level rise will also act to limit their effectiveness and further increase hazard and risk levels. Thus continued rapid urbanisation could further increase the risk levels, costs of impacts and benefits of adaptation.

We conclude with a discussion of sources of uncertainty, and of risk-based tools that could be linked with decision-making approaches to inform adaptation plans that are robust to climate change (Section 7). We recognize that an important limitation of this study is that it does not attempt to fully quantify the uncertainties in the analysis even though uncertainty is incorporated at each stage of an analysis. Rather, we aim to draw on and inform a 'policy-first' approach, where the quantitative analysis is designed from the bottom-up to evaluate the desirability of specific adaptation options against a set of defined objectives, as an alternative to help to narrow uncertainties in the analysis.

While this study explores only one upper-bound climate scenario and is insufficient to design an adaptation strategy, it does demonstrate the value of risk-assessment as an important quantitative tool in developing city-scale adaptation strategies. Advancing decisions on the design of a risk-reduction strategies would require further information is available on the cost of risk-reducing measures as well as non-economic co-costs and co-benefits (e.g., on ecosystems, health, or local amenities). In addition given the importance of impacts on marginalized population, more work would be necessary to assess flood impacts and adaptation policy benefits for different social groups. Decisions on risk management cannot therefore be evaluated with a comparison of their aggregated monetary costs and benefits alone. Other dimensions need to be accounted for (e.g., inequalities, long term regional development). Finally risk-reduction decisions will always be political decisions that cannot be made using simple cost-benefit analyses. However a comprehensive cost-benefit, risk analysis of this type can help to inform such decisions reflect the economic trade-offs of policy choices over time.

1. INTRODUCTION

Many of the world's cities are hotspots of risk from extreme weather events (e.g. Munich Re, 2004) and levels of risk in many cities are likely to grow due to a combination of population growth and development and rising intensities of extreme weather events. For example, Nicholls et al. (2007) demonstrate high population and economic exposure to storm surge risks in many of the world's largest and fastest growing port cities. These are also areas where adaptation can have significant benefits and where managing risks from extremes will be a crucial component of adaptation planning.

A challenge in planning adaptation relates to the quantification of the risks from extreme weather events and economic assessment of the benefits of different adaptation measures. This study presents an approach to quantifying city-scale risks that is based on previous work in this OECD series, notable on the conceptual framework laid out by Hallegatte et al. (2008a). It draws on the principles of catastrophe risk modelling commonly used in the developed world but simplified for application for a more data sparse region and coupled with downscaled climate model projections. This approach is applied to quantifying future flood risk in the city of Mumbai, India. Mumbai is the main commercial and financial centre of India, generating about 5% of India's gross domestic product (GDP). The study also aims to demonstrate the importance of capturing the indirect costs of disasters in risk and adaptation assessments.

Aggregate GDP is an insufficient measure of social welfare (e.g., CMEPSP, 2009; OECD 2010) and disasters have large distributional impacts. This is why our study includes an analysis of impacts on marginalized population. Due to data scarcity and of the limited weight of this part of the population in available economic data., it is not possible to examine the distribution of impacts in this model-based approach to catastrophe risk modelling. The modelling is thus complemented here with a survey on the consequences of floods on marginalized population and the informal economy. This is important in the case of Mumbai because, as with other rapidly developing cities in developing countries, the marginalised population can be a large share of the total urban population and represent a significant part of total economic activity (even if informal and not often accounted for). Accounting for marginalised population is also a necessary part of the social agenda, particularly as this population would be expected to have fewer resources with which to adapt and therefore may be particularly vulnerable in the event that disaster hits.

The study follows the broad stages of an 'impacts-based' adaptation assessment (Carter et al. 2007): firstly, characterising current levels of vulnerability and potential future sensitivities (Section 2); secondly, quantifying relevant risks (Sections 3 and 4) and analyzing specificities of marginalized populations and informal businesses (Section 5); and thirdly, identifying adaptation options and evaluating their benefits (Section 6). This study does not complete the adaptation assessment, it only aims to demonstrate various elements; for example, it is limited in that it explores one ('upper-bound') climate scenario and it looks at a limited set of adaptation options (and only benefits, not costs). It also does not enter the next stage of applying decision methods and forming strategies; though in Section 7 we provide a brief discussion of our approach in this context.

2. MUMBAI: CURRENT VULNERABILITY TO FLOODING AND FUTURE SENSITIVITIES

2.1 Geography

A logical first stage of any adaptation assessment is to understand levels of current vulnerability to weather. The city of Mumbai (Greater Mumbai) consists of two administrative districts: the Island City District and the Suburban District. It extends between 18° and 19.20° N and between 72° and 73° E. The city extends from East to west by about 12 km, where it is broadest, and from North to South extends about 40 km. Geographically, Greater Mumbai is an island separated from the mainland by the narrow Thane Creek and the relatively wider Harbour Bay. Thus, the area of Greater Mumbai is surrounded on three sides by the seas: by the Arabian Sea to the West and the South, the Harbour Bay and the Thane Creek in the East.

The city is further divided into 6 Zones and consists of 24 Wards. The island city district consists of 9 wards with an area of 76.8 square kilometres. In 2001, it had around 700,000 households with a population of 3.3 million persons (MCGM 2001). The surrounding suburban district covers an area of 405.9 square kilometres with 1.8 million households residing in this district in 2001. The population of this district was 8.6 million persons, spread over 15 Wards. The density of populations in these districts is 43 and 21 thousand persons per square kilometre respectively, with a total of about 12 million inhabitants in 2001. In 2010, the population is estimated to be 14 million inhabitants. Out of this population around 37% of the population is employed in the formal sector. The distribution of the workforce in the two parts of Greater Mumbai are almost similar with the island city reporting a participation rate of 39% while the percentage of workers population in the suburban city around 36%. Around 95% of the employed persons out of this workforce are main workers and around 5% are marginal workers.

2.2 Flood hazard in Mumbai and the 2005 event

Mumbai is prone to flooding and witnesses severe disruptions almost annually; for example, between 2004 and 2007, Mumbai experienced flooding each summer. But in July 2005, the city experienced the worst flooding in its recorded history.

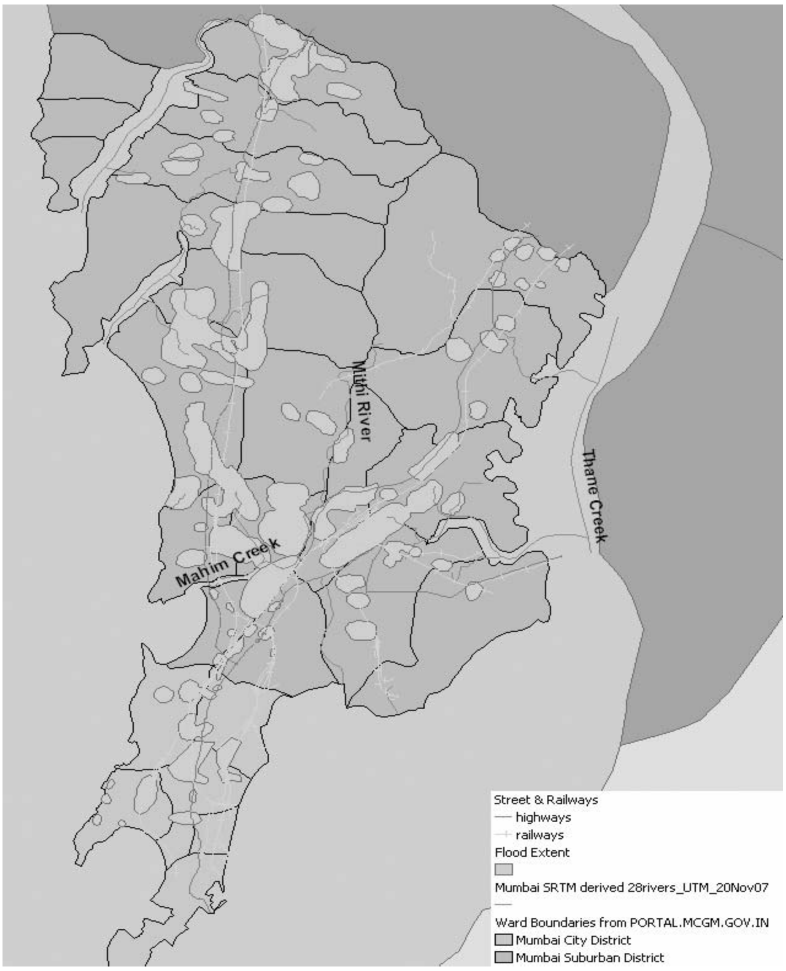
The city receives average annual rainfall of around 2400 mm. Storm water discharges to Arabian Sea/Thane Creek through road side drains, minor nallas (drains) and major nallas. The Storm Water Drainage (SWD) system in Mumbai City is more than 100 years old. In earlier days 40% of urban storm water was flowing through open lands, which was acting as holding pond. Now after development 90% storm water is flowing through drains & 10% water is flowing through open lands.

The 2005 monsoon proved to be extremely erratic for the entire state of Maharashtra and in particular for Mumbai. After a deficiency in rainfall during the initial stages, the situation changed dramatically in the course of a week from July 21, when unusually heavy rains lashed the coastal areas around Mumbai. On July 26, 2005, the highest ever rainfall recorded in the last 100 years in the country battered suburban Mumbai and Thane, and these regions experienced one of the worst floods in their history. According to Gupta (2007), the rainfall was the eighth heaviest ever recorded 24 hour rainfall (944 mm) in India and started in Mumbai at around 8:30 AM on the 26th July and continued intermittently over the next day. About 644 mm of rainfall was recorded in the 12 hour period between 8 AM and 8 PM at the Santa Cruz Meteorological Centre, Mumbai, and a total of 944 mm in 24 hours. The previous recorded highest rainfall in a 24 hour period in Mumbai was 575 mm in 1974. Nearly half of the annual average rainfall in Mumbai (2,363 mm) was received in a 24 hour period.

The continuous rainfall resulted in urban flash flooding. Water levels rose rapidly within 3-4 hours, thereby submerging the roads and railway tracks. Traffic was completely immobilized. All the low-lying areas in the city were heavily flooded. Poor households living in slums in these areas were the worst victims. All the ground floor flats were under water, and there was severe damage to the possessions of people like electronic goods, furniture, clothes, utensils and other household assets. Flooding also crippled the basic services and lifelines in the city for several days (GoM, 2005).

Figure 1 shows a map of the flood extent across the City and Suburban districts of Mumbai (which collectively form the Greater Mumbai region) digitalised from Gupta (2007 and based on Gupta 2007); around 20% of the area was affected, with flood waters to a depth of 0.5 to 1.5m in low-lying areas.

Figure 1. Digitized flood extent map for the 2005 event (based on Gupta 2007), showing the city wards and the location of the Mumbai City and Suburban Districts.



According to the Government of Maharashtra, 447 deaths were reported in Mumbai. While drowning and landslides resulted in 116 deaths, stampede due to tsunami rumour resulted in around 24 persons getting killed. While 16 deaths were reported due to people trapped in vehicles, houses collapsing are estimated to have led to another 70 deaths. About 200 km of road length was submerged in flood water and the traffic was standstill on all such internal roads, major roads and corridors of traffic. Many regions were submerged in flood waters for 12 to 24 hours and thousands of vehicles were left by the people on these submerged roads. More than 20,000 small vehicles, 2,500 buses used for public transportation, about 25%

of trains and thousands of two wheelers/ three wheelers were damaged in rains and were non operational for weeks.

The following points summarize some of the major losses due to the event:

- Most arterial roads and highways in the suburbs were severely affected due to water logging and traffic jams resulting from vehicle breakdown in deep waters
- Commercial establishments damaged: 40,000
- Vehicles Damaged: 30,000
- Submergence of railway tracks and consequent stoppage of services on central (main and harbour lines) and western railways around 4:30 pm on the 26th July
- Electricity supply was stopped in most parts of Mumbai's Western Suburbs in the night of the 26th July 2005
- Heavy rains also led to the closure of the airport

From initial reports, it is estimated that in suburban Mumbai, 174,885 houses were partially damaged and 2,000 fully damaged, costing Rs. 29,800 lakhs ($70 million) and Rs. 800 lakhs ($1.9 million) respectively. The trade and commerce sector was most extensively hit, with over 40,000 commercial establishments damaged. The heavy deluge also caused significant damages to the municipal infrastructure. The Government mounted a large-scale rescue and evacuation operation in all the areas affected by floods. It deployed the Army, Air Force and Navy for the search and rescue operations. A large number of boats were deployed by both the Army and Navy for rescuing people in all the districts including Mumbai.

Across Northwest India, the flooding crippled an area of over 35,500 km2, affecting 20 million people. There are various data on aggregated economic damages, which are not always consistent because of different spatial and sectoral perimeters (e.g., only Greater Mumbai or entire state of Maharashtra; only public assets or all assets). Total losses are estimated around $3 - 5 billions US (Swiss Re 2006, Munich Re 2006). About half of these losses is assumed to affect the region of interest in this study, namely Greater Mumbai. In the following, we use a best guess estimate of US$1.7 billion for these flood related losses in 2005.

The root cause of Mumbai's susceptibility to flooding is its geography, both natural and manmade (Duryog Nivaran 2005). Firstly, the city's location leaves it exposed to heavy rainfall during the summer; typically, 50% of the rainfall during the two wettest months, July and August, falls in just two or three events (Jenamani 2006). This situation is aggravated by the manmade geography; large areas of the land are reclaimed and are situated only just above sea level and below the high-tide level. This inhibits natural runoff of surface water and the complicated network of drains, rivers, creeks and ponds that drain directly in the sea, meaning that during high tides, sea water can enter the system preventing drainage and in extreme cases, leading to salt water deluge. This occurred during the July 2005 event.

Future levels of flood risk are also potentially sensitive to climate change and other drivers of risk. For example, urbanisation has been an important driver of increased flood risk in the city. It is estimated that urbanisation alone has contributed to a significant increase in runoff in the city. The drainage systems of the city are now inadequate to cope with heavy rainfall and are impeded by urban encroachment and channel blockages. Continued rapid urbanisation, particularly in the absence of effective spatial planning and improved drainage systems, is likely to lead to an increase in flood risk in Mumbai.

Over the coming decades, the flood risk pressures of urbanisation may be aggravated by manmade climate change. Like many other areas, the Northwest of India has observed a statistically significant warming of annual mean surface air temperatures over the past century (IPCC 2007, Figure 3.9). While no statistically significant trend in annual rainfall has been observed in the past three decades (IPCC, 2007, e.g. Figure 3.13), there are signs of an increased contribution to annual rainfall from very wet days (Alexander et al, 2006). In the future, an increase in rainfall volume and/or intensity could increase the risk of severe flooding.

3. QUANTIFYING CURRENT AND FUTURE FLOOD RISK IN MUMBAI

The risk quantification approach used in this study follows a standard catastrophe risk modelling framework, which combines estimates of hazard, exposure and vulnerability (Grossi and Kunreuther, 2005). This framework provides an estimate of the direct economic damages and population exposed to flood events with different probabilities of occurrence. In this study, probabilities are represented as return periods of events, i.e. a 1 in 200 year return period (denoted yr RP) event has a 0.005% annual probability of occurrence. To this framework we add an additional component (Section 4) that estimates the indirect damages from flood events, and an analysis of specific impacts on marginalized populations and informal businesses (Section 5). To inform adaptation decision-making it is also important to assess the risk of fatalities or injuries, but this is beyond the scope of this study. In this analysis, we explore only the effect of changes in rainfall on levels of risk. Even with effective adaptation to this increased level of flood risk, continued rapid urbanisation and sea level rise would combine to further increase levels of risk.

Many limitations of the current analysis have to be stated at the outset. First, extreme event return periods are estimated from a single 30-year time series in Santa Cruz. Since very rare events are investigated in this analysis (up to the 200-yr event), the extrapolation from the data series is a major uncertainty source. Second, a unique climate model is used in the analysis, disregarding the large uncertainty in climate projection over India. A comprehensive analysis of adaptation measures would require additional assessments based on other climate models. Third, the risk analysis is carried out on the current city of Mumbai, disregarding future changes in land use, urbanism, and infrastructure (including drainage). Of course, different scenarios for the evolution of Mumbai could lead to very different levels of risks. This issue is discussed in the adaptation section (Section 6), and the influence of adaptation measures on risks is estimated. But, the influence of other important assumptions are not assessed (e.g., possible changes in aggregate Mumbai population, spatial distribution of the population). Finally, the analysis of indirect economic losses is based on economic models that are very idealized views of the real economy, and that only produces very uncertain results. A more detailed discussion of all these uncertainties is presented in Section 7. Obviously, these limitations call for a careful interpretation of the following results, which remain highly uncertain and should not be used as forecasts of future risks. But they are useful in providing ballpark estimates of possible future risk levels and orders of magnitude of benefits from adaptation measures. In particular, results emphasize the need for in-depth risk analysis in the city of Mumbai and highlight potential adaptation options that could yield high benefits and should be investigated in more detail.

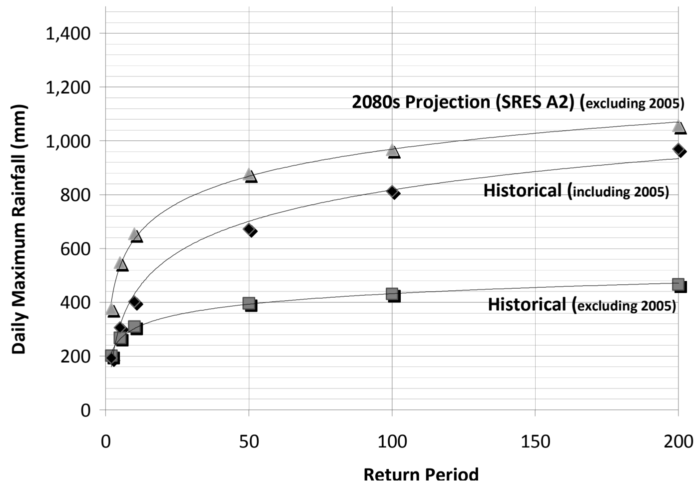
3.1 Hazard Quantification

This sub-section describes the approach to quantify the current and future frequencies of heavy rainfall events for Mumbai and the generation of simulated flood footprints. There are two key challenges in quantifying flood hazard: the short length of available rainfall records for the city and the inadequacies of climate models in projecting changes in rainfall at a city-scale (IPCC, 2007).

Rainfall observations are taken from the Santa Cruz Indian Meteorological Department (IMD) station located in the Mumbai Suburban District (closest to the most extreme flooding). This 30-year record is extended empirically using the WXGEN weather generator (Williams *et al.* 1985; Sharpley and Williams 1990a, b; Wallis and Griffiths 1995) to create a 200-year simulated record. Of course, using a unique weather station and extending it from 30 to 200 years introduces uncertainties in our results, as will be shown below. But limited data availability makes this type of statistical treatment necessary.

The simulation is based on six key statistical characteristics of the timeseries analysed from the historical data[1]. A further challenge highlighted by the analysis is that the rainfall that led to the 2005 flooding far exceeded any daily amount measured since records began; in the 24 hours starting at 8:30am on 26th July 2005, 944 mm of rainfall was measured at Santa Cruz. Including such an outlier in an analysis based on a short rainfall timeseries has the potential to skew the findings of the study. For this reason, two simulated time series were constructed, one with the July 2005 event (denoted Hist_SZ_I) and one without it (Hist_SZ_X). Return periods of daily maximum rainfall for Santa Cruz are estimated by fitting a simple lognormal distribution to the 200-year time series (Figure 2). The analysis suggests that the event that led to the 2005 flooding had a return period of at least around 150 years, and possibly much greater than 200 years. It is not possible to pinpoint the frequency with greater accuracy given the short-length of the available rainfall record. In the following analyses, we use the series without the July 2005 event (i.e., Hist_SZ_X), in which the July 2005 event has a return period of much more than 200 years.

Figure 2. Estimates of the return period of daily maximum rainfall at Santa Cruz historically and in the 2080s (under a high-end scenario).



Note : Further details on each estimate shown are given in the text, where (i) 2080s Projection is denoted A2_SZ_X; (ii) Historical, including 2005 is denoted Hist_SZ_I; and (iii) Historical, excluding 2005 is denoted Hist_SZ_X. Note that A2_SZ_X is comparable to Hist_SZ_X.

There is great uncertainty over how the frequency and severity of rainfall will change in Mumbai with anthropogenic warming. Global climate models (GCMs) give a divergent picture of how precipitation will change in Northwest India over this century. Figure 3 shows projections for Asia based on a multi-model ensemble, from the IPCC AR4. On average, the ensemble suggests an increase in the intensity of the Asian Summer Monsoon, giving an increase in summer (JJA – June, July, August) precipitation. For Northwest India, the average increase is relatively small; roughly 5% of 1990 levels by the 2090s. However, the bottom row of Figure 3 reveals the strong disagreement in the sign of the precipitation change over much of India mentioned above. The figure suggests that only slightly over half of the 21 models included in the ensemble show an increase in precipitation over the Mumbai region.

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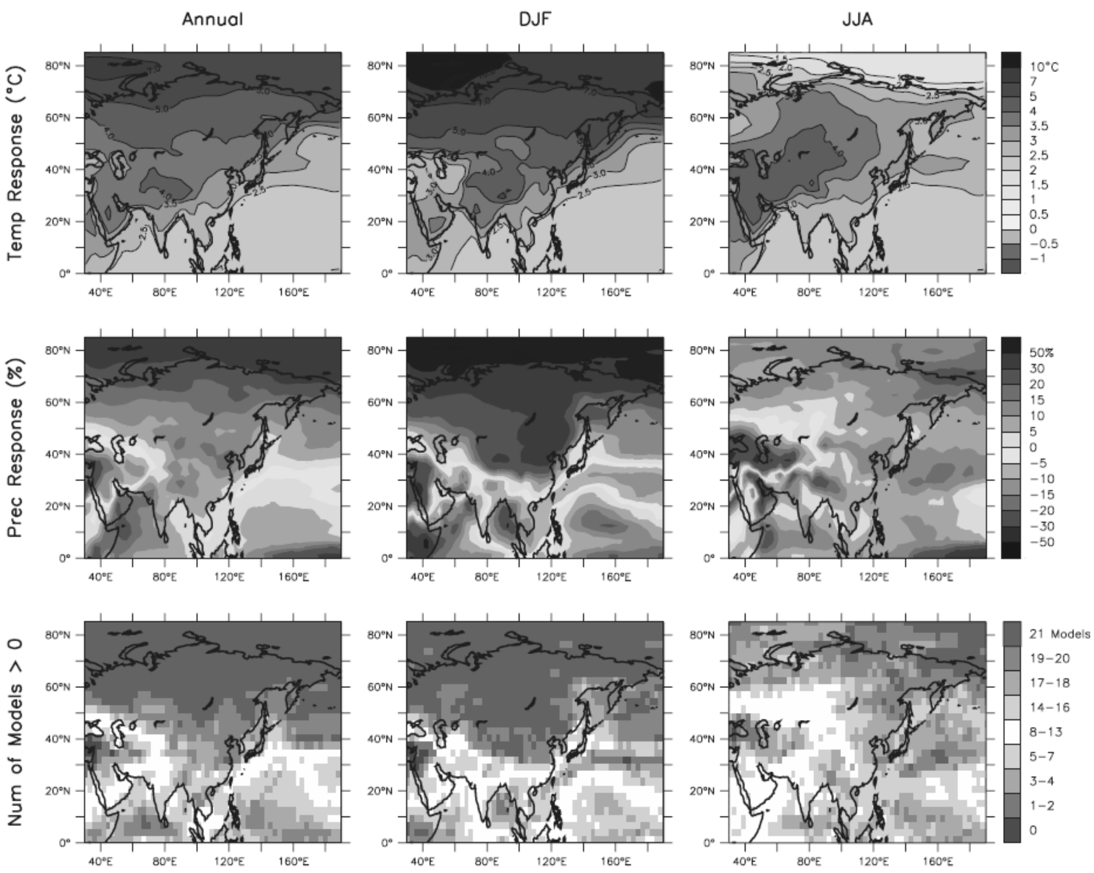
[1] The average rainfall, standard deviation, skew coefficient, probability of wet day followed by dry day, probability of wet day followed by wet day and the number of rainy days

The scale of the uncertainty shown in Figure 3 can be understood when one considers that these same models are unable to accurately represent present-day rainfall over India, mainly because their resolution is inadequate to properly represent the detailed topography of South Asia and cloud microphysics involved in tropical convective processes. Kumar et al. (2006) study the performance of GCMs over India in representing present-day conditions and notes that only the HadCM3 and CSIRO models are able to realistically represent the present-day observed maximum rainfall during the monsoon season (both models with higher resolution). For this reason, here, rainfall projections are taken from the PRECIS2 model (Jones et al. 2004); a high resolution regional climate model (RCM), based on HadCM3.

Figure 3. Temperature and precipitation changes over Asia from the IPCC AR4 multi-model ensemble simulations for emissions scenario A1B (reproduced from Chapter 11 of IPCC AR4 pg. 883).



Note :Top: Annual mean, DJF and JJA temperature change between 1990s and 2090s. Middle: as above, but fractional change in precipitation. Bottom: number of models, out of 21, that project an increase in precipitation.

The 2080s timescale is selected as this is relevant to many long-term infrastructure and building decisions being taken today. The model is driven with the A2 SRES emissions scenario (Nakicenovic et al 2000). Under this scenario, PRECIS projects a 3.6°C increase in mean temperatures a 6.5% increase in seasonal mean rainfall across India by the 2080s. Given the uncertainties in climate, a full adaptation assessment would explore the implications of a range of model-based climate scenarios; however this is beyond the scope of this study. The findings of this study alone could be considered indicative of an upper-

2 PRECIS (Providing Regional Climates for Impact Studies) is regional climate model provided by the Hadley Centre, UK. (http://data.eol.ucar.edu/codiac/dss/id=95.008)

end estimate of possible future risks; we would not consider this a 'worst-case' estimate as it is not clear that the range of current climate model projections fully represent the range of uncertainties. Our interpretation is that given current understanding, this is one of a set of equally probable scenarios.

The PRECIS results are first downscaled and extended using WXGEN to create a 200-year rainfall timeseries comparable to the simulated records for the Santa Cruz station. The downscaling involves mapping the change in the statistical characteristics of rainfall between the Baseline (1961-1990) and 2080s Projected (2071-2100) precipitation in the PRECIS model for the relevant grid box. These statistical characteristics are the same six characteristics used to drive WXGEN. These changes are then mapped as linear multipliers onto the statistical characteristics analysed at Santa Cruz (Hist_SZ_X) to estimate future statistical characteristics at the location. The final step is to run WXGEN with these 'future characteristics' to generate the new 2080s time series (A2_SZ_X). This procedure assumes that the statistical relationships between the large-scale (the PRECIS baseline) and small-scale (Santa Cruz) timeseries remain unchanged such that it is appropriate to map 'future' statistical characteristics between each. This assumption is untested and therefore introduces uncertainty into the findings.

Figure 2 demonstrates that by the 2080s, the intensity of extreme rainfall could be increased at all return periods. The increase is particularly strong for the shorter return period (more frequent) events. For example, under this scenario, the intensity of a 2 – 5 year return period event has close to doubled. The analysis suggests that the return period of an event of July 2005 scale is reduced to around 1-in-90 years in 2080 under a SRES A2 scenario. Even though this analysis has several limitations and is based on only one climate model, this result shows a high potential sensitivity of flood risk to climate change and provides a justification for further investigation.

Given that urban flooding in Mumbai is mainly pluvial, we would expect an increase in the frequency of extreme rainfall to translate into an increase in flood hazard (all else being equal). Rivers in Mumbai tend to act as open drains during extreme rainfall events, carrying excess surface water to the sea and major flooding can occur when the rainfall rates exceeds the drainage capacity of these rivers. Here, we use an urban flood model to simulate the relationship between rainfall and flood extents. There are three main river basins in the study area; here, we focus on Mithi River Basin, where some of the greatest flood damages occurred in 2005, and extrapolate to city-scale in later sections. The Mithi basin is directly fed by the rainfall observed at the Santa Cruz station. The modelling approach uses the Storm Water Management Model (SWMM), modified to represent the Mithi Basin (for details, see Appendix A), to generate hypothetical flood footprints which correspond to the 2005 event and for the simulated rainfall events with the return periods of 50, 100 and 200 years, for today (Hist_SZ_X) and in the 2080s (A2_SZ_X).

The SWMM model flood footprint (with flood depth) for the July 2005 flood event is shown in Figure 4 Table 1 compares the total exposure within the Mithi basin with the July 2005 affected exposure based on the observed flood extents and the SWMM model. There is a minor mismatch between the affected exposure generated with the SWMM model and the affected exposure from the observed flood extents, i.e. the SWMM model appears to underestimate flood exposure compared to the actual flood footprints (Table 1). This is likely due to the coarse scale of the observed flood extent map. This bias is corrected in the 'scaling-up' phase of the analysis.

Figure 4. Modelled flood extent of 2005 event in Mithi River using SWMM.

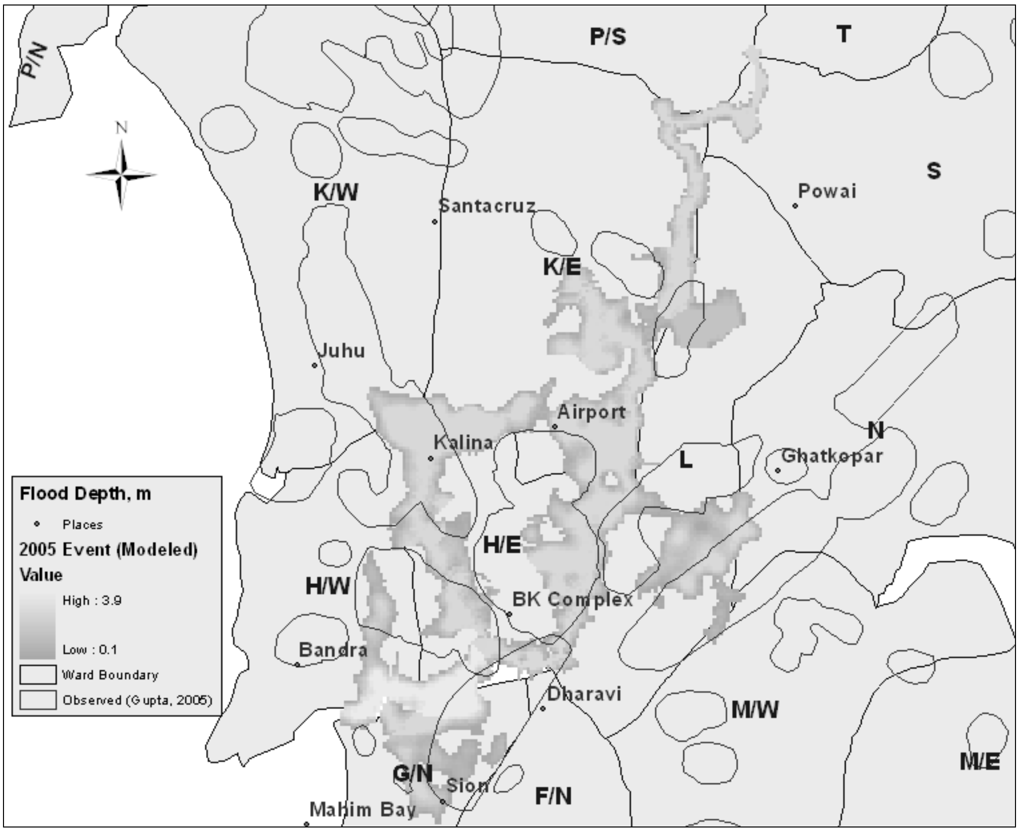


Table 1. Comparison of the total exposure and affected exposure for July 2005 in the Mithi river catchment
(modelled using SWMM)

	Area (Sq. KM.)	Population (thousands)	Exposure Distribution ($ Million US)		
			Residential	Commercial	Industrial
Observed Flood Footprint	20	1,540	35	50	180
SWMM Model Flood Footprint	16	1,220	30	25	100

Figure 5 shows the estimated flood extents and depths for the simulated rainfall events with the return periods of 50, 100 and 200 years, for today[3] (Hist_SZ_X) and in the 2080s (A2_SZ_X). With climate change, we see an extension of the area flooded at each return period and an increase in flood depth. A limitation of this analysis is that it does not take into account the potential effect of sea level rise in limiting the effectiveness of the drainage systems.

[3] Since the July 2005 event is not accounted for in the statistic analysis in Hist_SZ_X, the current return time of such an event is assumed much larger than 200 years in the following analyses.

Figure 5a. 50- year return period flood maps for present day (left) and 2080s (right)

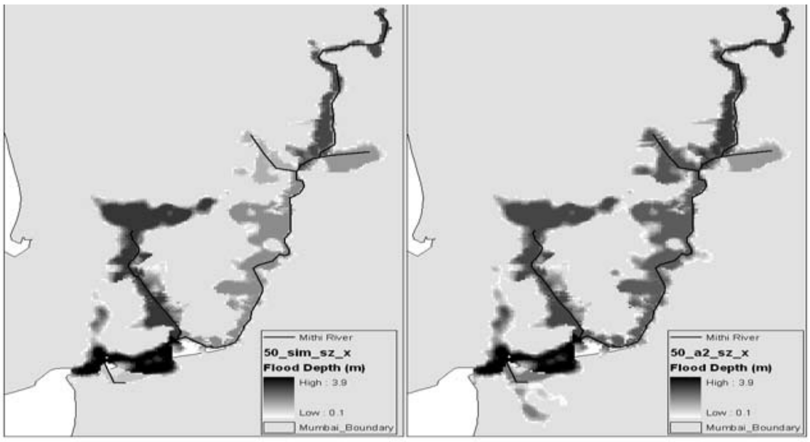


Figure 5b. 100-year return period flood maps for present day (left) and 2080s (right)

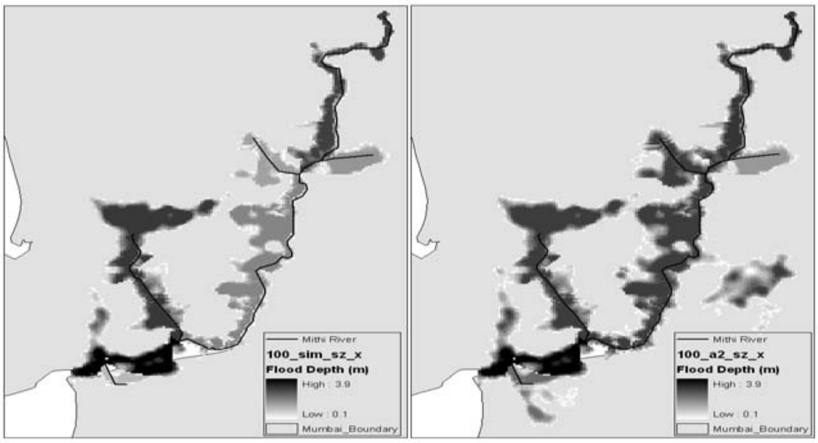
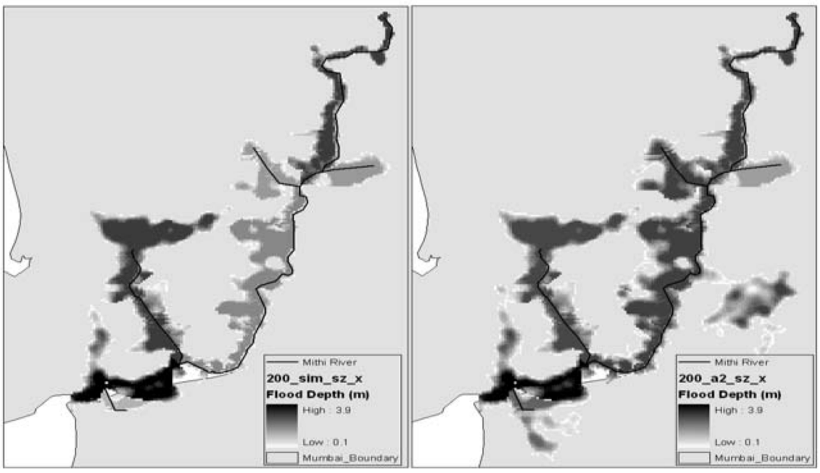


Figure 5c: 200-year return period flood maps for present day (left) and 2080s (right)



We find that the SWMM model underestimates the observed flood extent in 2005 by around 20%, likely due to the low resolution of the elevation data used. This relationship can be used to calibrate the simulated return-period flood footprints. Table 2 shows the uncalibrated area of the Mithi Basin flooded for each simulated event, and demonstrates how exceptional the July 2005 flood was: according to our analysis, the flood extent due to the 2005 event was 33% larger than the 200-yr flood day. In the future, however, such a flood may become much more frequent, and correspond to the 100-yr event.

Table 2. Comparison of (uncalibrated) flood extent areas in km2, under different simulated rainfall scenarios (A2_SZ_X) for the Mithi Basin generated by the SWMM model

Simulated Event ID	Today (km^2)	2080s (km^2)
2005 Event	16	-
50yr RP Event	12	14
100yr RP Event	12	16
200yr RP Event	12	17

3.2 Exposure Mapping

An exposure map shows the spatial distribution of all the people or properties in the study area. In this Section, we focus on private property. The exposure data can then be compared with the flood footprint to estimate the 'affected exposure'. We assume an unchanged city (i.e. population and properties at their mid-2000s values). Population and growth factors can be applied to this to estimate future exposure.

A digitalised population map was developed from publicly-available 2001 census data (MCGM 2001). The data, at ward-level, was distributed evenly over a 100m grid. The distribution of residential, commercial and industrial property types was derived by analysing observations from the IRS LISS III satellite (Indian Remote Sensing Satellite, Linear Image Self Scanning III) fused with a panchromatic image at a resolution of 10m grid. Six exposure property types were defined: two residential (low density and high density), three commercial (low-rise retail and offices; high-rise office blocks; and skyscrapers) and one industrial. The total insured values (TIVs) of these properties were based on the RMS India Earthquake Model® (INEQ), which incorporates proprietary insurance data. This data is distributed onto the 100m grid according to the exposure property types. Across the two study districts, we estimated a TIV of $480 million USD, $520 million USD and $1,960 million USD for the residential, commercial and industrial exposures, respectively. The TIV can be converted to a total value if the insurance penetration is known. Here, the insurance penetration is assumed to be roughly around 8% for residential properties, 14% for commercial properties and 17% for industrial properties, based on RMS proprietary data. Note that these estimates have a high uncertainty, which translates into a high uncertainty on exposure estimates.

Combining the exposure maps with the observed flood footprint from the 2005 flooding (Figure 1), it is possible to calculate the 'affected private-asset exposure' across Greater Mumbai in 2005 (Table 3). This demonstrates, for example, that 35% of the resident population lived in areas directed affected by the flooding.

Table 3. A comparison of total exposure over the Greater Mumbai area to the affected exposure for the July 2005 flood event (using population data for 2001 and the observed flood footprint).

	Area (Sq. Km)	Population (thousands)	Exposure (in $ Million USD)			
			Residential	Commercial	Industrial	Total
Total	**372**	**12,800**	**6,000**	**3,710**	**11,530**	**21,240**
Affected	**78**	**4,200**	**1,880**	**1,070**	**2,110**	**5,060**
Percentage Affected	**20%**	**35%**	**30%**	**30%**	**20%**	**20%**

Table 4 uses the same methodology but with the simulated flood footprints for the Mithi River Basin (Figure 5), giving estimates of the affected exposure at different return periods in that area of the city.

Table 4. Modelled 'affected' exposures for different return period flood events for the Mithi Basin, in comparison to the simulated July 2005 event

	Area (Sq. KM.)	Population Affected (thousands)	Affected Exposure Mithi Basin ($ Million USD)		
			Residential	Commercial	Industrial
Simulated 2005	16	1,220	375	180	590
50yr RP: Present	12	710	250	70	0
50yr RP: Future	14	975	315	145	0
100yr RP: Present	12	710	250	105	0
100yr RP: Future	16	1,225	375	180	560
200yr RP: Present	12	715	250	105	0
200yr RP: Future	17	1,275	375	180	590

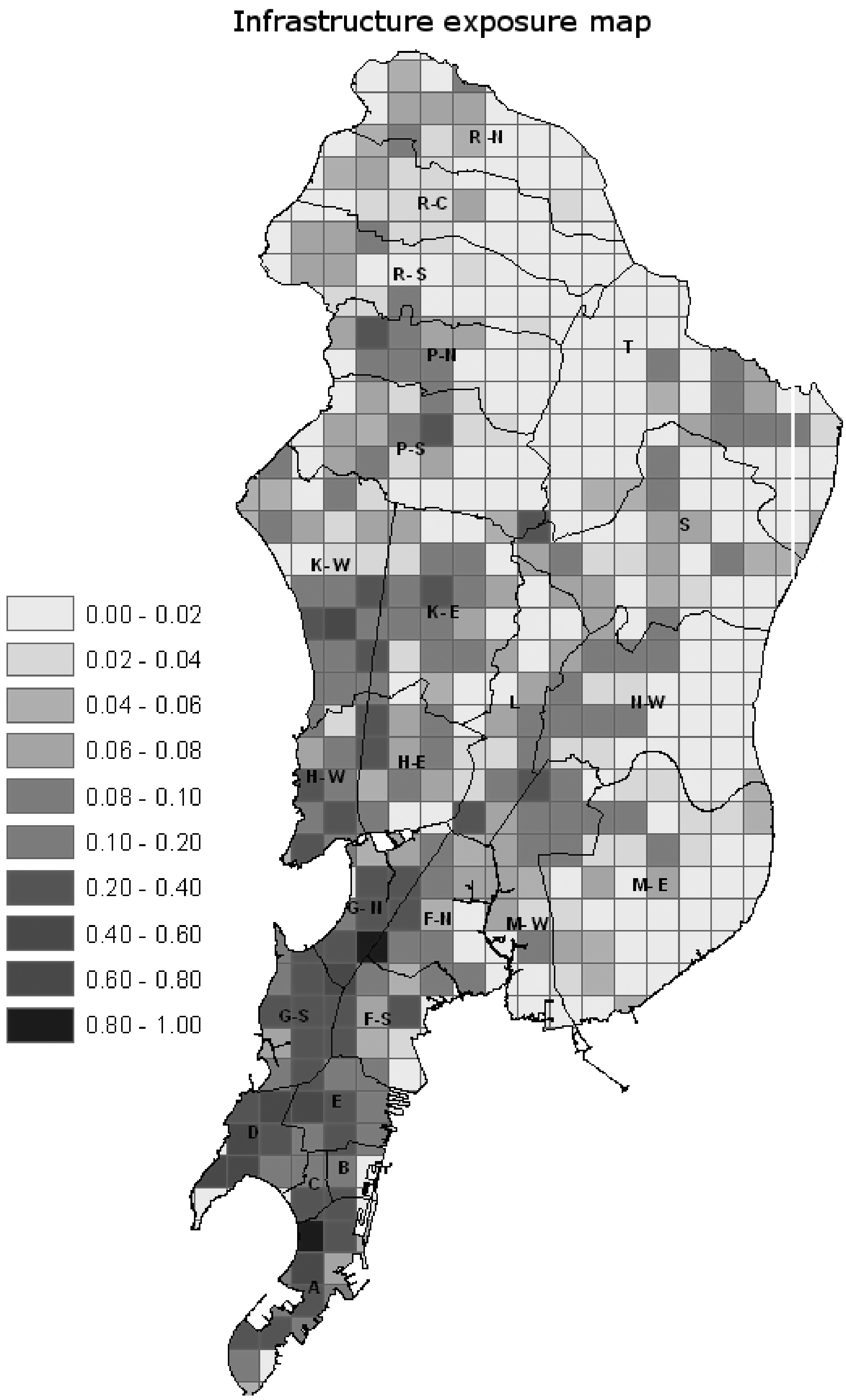
We can extrapolate from these Mithi affected exposure estimates to create 'ballpark' estimates of the affected exposure across the whole of the Greater Mumbai area (Table 2), using the relationship between the observed affected exposure across these districts for July 2005 (from Table 3) and the simulated affected exposure in the Mithi Basin (from Table 4). The uncertainty introduced by this extrapolation is large, for example, it assumes that the relationship between Mithi and Mumbai flooding remains the same for all flood events.

Table 5. Estimated affected private assets exposures for different return period flood events

	Area (Sq.Km)	Population (thousands)	Affected Exposure across the Mumbai City and Suburban Districts ($ Million		
			Residential	Commercial	Industrial
Simulated July 2005	78	4,270	1,875	1,070	2,120
50yr RP: Present	55	2,470	1,250	430	0.0
50yr RP: Future	67	3,400	1,565	860	0.0
100yr RP: Present	56	2,470	1,250	645	0.0
100yr RP: Future	78	4,270	1,875	1,070	2,010
200yr RP: Present	57	2,490	1,250	645	0.0
200yr RP: Future	80	4,440	1,875	1,070	2,120

The estimates contained in Table 5 are for private assets only. Exposure of critical public infrastructure is another important indicator of urban vulnerability. It plays an integral role in public safety, health, and provision of aid. The critical infrastructures considered in this study include schools, hospitals, railway stations, important offices, fire stations, and blood banks. These infrastructures and the location and length of infrastructure networks (e.g., roads, railways, railway stations) have been identified and combined into a unique "infrastructure exposure index" (see Fig.6 and IITB, 2010). This index measures the infrastructure density within a 1-km grid cell.

Figure 6. Infrastructure Exposure Map for Wards of Mumbai.



Note: Infrastructure exposure here is defined as the density of critical infrastructure (including schools, hospitals, railway stations, important offices, fire stations, blood banks, and network infrastructure like railways and roads).

3.3 Estimating Private-asset Vulnerability

Vulnerability here refers to the damage cost to a property expected for a given level of water depth. For private assets, this is expressed in terms of the mean damage ratio; that is, the monetary damage as a proportion of the total value of affected property (infrastructure losses will be estimated at a later stage as a fraction of private-asset losses, see Section 3.4). Usually in risk modelling, vulnerability is defined by a set of 'damage curves'. However, there is a lack of reliable data on building vulnerability in Mumbai. To provide preliminary estimates, we define only an average mean damage ratio for an affected residential, commercial or industrial property type (i.e. three ratios). A consequence of using a mean damage ratio instead of a vulnerability curve is that only the change in flood extent is taken into account and the change in flood depth is not in spite of its potential importance. For example, in Figure 5c, one can see that in the 2080s, floods are expected to become larger and deeper than today. The estimate of how flood losses will change is therefore underestimated compared with a more comprehensive analysis.

The average mean damage ratio that is used here is estimated based on published estimates of damages from the July 2005 event. While it would be preferable to use multiple events, sufficient data were not available. The data available for 2005 was also very limited; for this reason, three approaches were used to estimate the vulnerability, then the results compared, to produce a single estimate with an uncertainty range. The three approaches used were:

- **Using published economic loss estimates:** The mean damage ratio was given by the ratio of the direct economic loss to affected exposure for the July 2005 event. Estimates of residential damages (GoM 2005) were used directly to estimate the residential mean damage ratio. Commercial and industrial economic damages were derived from the total economic damage, using the proportions indicated by their affected exposures. Total direct economic losses at state level were obtained from the Dartmouth Flood Observatory (2008) and Swiss Re (2006); we assume that 50% of these damages occurred in the Greater Mumbai area[4] and that around 70% of these losses were related to residential, commercial and industrial damages (extracting infrastructure as given in Hallegatte et al. 2008b), giving total losses of 1.7 billion USD.

- **Using insured loss estimates:** Here, the mean damage ratio was given by the ratio of the insured loss (from RMS insurance claims data) to affected insured exposure (from the RMS INEQ model) for the July 2005 event. The benefit of this approach is that these estimates are more widely available and they require no assumption about insurance penetration.

- **Using RMS proprietary vulnerability curves:** Simplified flood vulnerability curves for a generic industrial, commercial or residential facility were combined with estimates of flood depth across the Mumbai City and Suburban Districts (obtained from media reports) to derive a mean damage ratio. The mean flood depths were assumed to be around 0.1 – 0.25m in Mumbai City and 0.25 – 0.5m in the suburbs based on Gupta 2007 and local media reports.

Drawing together the results from each of these approaches, we estimate an average mean damage ratio of: 5 – 15% for residential properties; 15 – 35% for commercial properties; and 10 – 30% for industrial properties. These ranges are relatively narrow, giving confidence in the agreement across individual estimation approaches.

[4] Estimated based GoM 2005, e.g. Greater Mumbai accounted for slightly over half of the total residential property losses

3.4 Direct Damage Estimates for Mumbai

The direct damage costs are defined as the costs of repairing or replacing assets that have been damaged or destroyed (at the pre-event price level). Table 6 gives estimates of the direct damages to private assets, from flooding in Mumbai for different return period rainfall events. This is calculated by applying the average mean damage ratios (derived above) to the affected private asset exposure estimates (from Table 5). The ranges reflect the uncertainty in vulnerability.

Direct costs include also public infrastructure and other public asset losses. Section 3.2 provides a map of critical infrastructure exposure, but this is only a partial view of all public assets. To take into account all public assets, in absence of localized information on all assets, we make the simple assumption that these losses are around 40% of the total value of residential, commercial and industrial losses (see Hallegatte et al. 2008b). Table 7 gives an estimate of the total direct losses including infrastructure losses. The loss estimates for the July 2005 event ($690 – $1910 million USD) are roughly in line with the $1.7 billion losses estimated above (see discussion Section 2.2).

The results suggest that losses associated with a 1-in-50 year extreme rainfall event could rise by 35%, but losses associated with a 1-in-100 year event could rise by 200% (i.e. triple) and for a 1-in-200 year event, losses could rise by up to 230%.

Table 6. Estimated direct total economic losses for different return period flood events for the Mumbai, excluding infrastructure.

	Estimated Direct Losses [excluding infrastructure] ($ Million USD)			
	Residential	Commercial	Industrial	Total
Simulated July 2005	100 – 300	170 – 400	220 – 660	490 – 1370
50yr RP: Present	70 – 210	80 – 190	0	150 – 400
50yr RP: Future	90 – 260	120 – 290	0	210 – 550
100yr RP: Present	70 – 210	90 – 220	0	160 – 430
100yr RP: Future	100 – 310	180 – 420	200 – 630	490 – 1350
200yr RP: Present	70 – 210	90 – 220	0	160 – 430
200yr RP: Future	110 – 320	180 - 430	220 - 680	510 – 1420

Table 7. Estimated total direct losses for different return period flood events for Mumbai including infrastructure losses.

	Estimated Total Direct Losses (including infrastructure) $ Million USD	
	Present-Day	2080s
Simulated July 2005	690 – 1910	-
50yr RP	210 – 570	290 – 760
100yr RP	230 - 600	690 – 1890
200yr RP	230 - 600	720 – 1990

It should be noted that this study's estimates of future costs do not take into account population and economic growth. In reality, the Indian urbanization rate and economic production are increasing very rapidly and this is likely to continue to increase flood risk in Mumbai in the absence of adaptation. For instance, the population of the Mumbai Metropolitan Region increased from 13 to 17 million inhabitants from 1991 to 2008 and the population of the city of Mumbai increased from 12 to 14 million inhabitants from 2001 to 2010. In 2025, it has been estimated that the Mumbai population might increase to up to 28 million inhabitants (i.e. in the Regional Plan for Mumbai Metropolitan Region 1996 – 2011, by the Mumbai Metropolitan Region Development authority). This will not only increase the exposure to flooding, but also put further strain on the natural and manmade drainage systems if improvements are not implemented, potentially increasing hazard and risk levels. In addition, without improvements to the drainage systems, sea level rise will also act to limit their effectiveness and further increase hazard and risk levels.

4. EVALUATING THE TOTAL ECONOMIC IMPACTS OF FLOODING

Direct losses, the costs of replacing and reconstructing damaged buildings and infrastructure, account for only a fraction of total cost of a disaster, particularly in the case of large-scale events (Tierney, 1995; Pielke and Pielke, 1997; Lindell and Prater, 2003; Hallegatte et al., 2007). After an event, the total economic costs can be amplified through: (i) spatial or sectoral diffusion of direct costs into the wider economic system over the short-term (e.g. through disruptions of lifeline services, such as communication and transportation networks) and over the longer term (e.g. sectoral inflation due to demand surge, energy costs, company bankruptcy, job losses, larger public deficit, or housing prices); (ii) social responses to the shock (e.g. loss of confidence, change in expectations, indirect consequences of inequality deepening); (iii) financial constraints impairing reconstruction (e.g. low-income families cannot finance rapidly the reconstruction of their home); and (iv) technical constraints slowing down reconstruction (e.g. availability of skilled workers, difficulties in equipment and material transportation, difficulties in accommodating workers). These additional losses are described as indirect economic costs, and they participate in the decrease in available consumption and have significant welfare consequences. These costs are dependent on the scale and timing of the event and on local conditions; as such, they are difficult to project. However, estimates of indirect costs must be included in decision-making to ensure a fair cost-benefit analysis of protection infrastructures or mitigation actions. Understanding the key mechanisms that regulate indirect effects may also provide useful knowledge on how to respond to a disaster.

Indirect costs can be defined as the reduction in production of goods and services, measured in terms of value-added. For example, if a \$100m plant is destroyed and immediately rebuilt, the total loss would be \$100m; whereas, if reconstruction is delayed by one year, the total loss will be the sum of the replacement cost (the direct cost) and the value-added of one year of production (the indirect cost). Here, our estimates of indirect costs include business interruption in the event aftermath, production losses during the reconstruction period and loss in housing services. The value of such production losses, in a broad sense, can be very high in some sectors, especially when basic needs are at stake (housing, health, employment, etc.). Of course, the real cost of a disaster is not only economic, and also includes fatalities, injuries, moral damages, historical and cultural losses, environmental losses, societal disruptions. In this study, however, we consider only the economic costs.

4.1 Indirect Loss Estimation

This study uses the Adaptive Regional Input-Output (ARIO, see Hallegatte, 2008) model to assess indirect economic losses in the Mumbai Metropolitan Region[5]. This dynamic model represents the 'amplifying' processes described above, taking into account changes in production capacity due to productive capital losses and adaptive behaviour in disaster aftermaths. Details of the model and methodology are given in Appendix B. It should be noted that the uncertainties in this type of modelling are large, and therefore, results should be interpreted as indicative of the scale of potential damages.

[5] The economic model, therefore, considers a region that is larger than just the city of Mumbai. We assume, however, that the Mumbai Metropolitan Region is only affected by the flood losses in the Greater Mumbai, where direct losses are estimated.

Indirect losses are calculated by sector based on the upper bound of the direct loss estimates given above. To achieve this, direct losses estimates are distributed by sector. Residential losses are assumed to only affect households, while industrial and commercial (and infrastructure) losses are divided between the ARIO sectors dependent on their activity and size (Table 8). The distribution of infrastructure losses is made according to empirical observations on previous events. Table 10 shows the distribution of direct losses between sectors for the July 2005 event; sectors 15 ("electricity, gas and water supply") and 16 ("transportation") have the largest direct losses because if we take into account public infrastructures, these sectors have the highest quantity of productive capital.

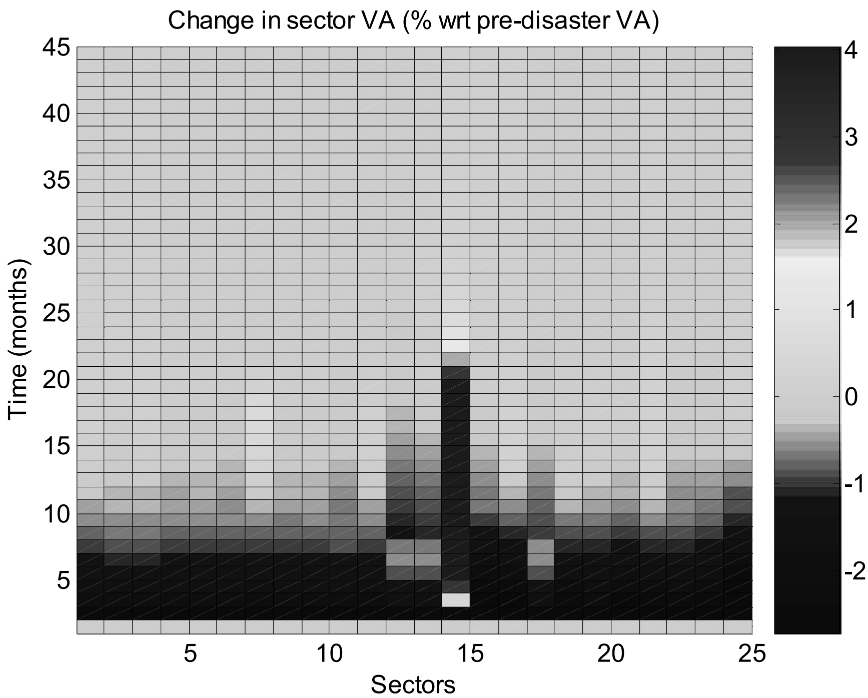
Table 8. The ARIO sectors and their equivalent RMS exposure type. The final column illustrates the distribution of the estimates direct losses by sector for the July 2005 event.

ARIO Sector		RMS Exposure Type	Sector-by-sector distributed direct loss in 2005 (million USD)
1	Primary	Industrial	39.4
2	Food products	Industrial	3.9
3	Beverages related	Industrial	0.9
4	Cotton textiles	Industrial	25.3
5	Wool, silk, jute etc...	Industrial	22.6
6	Textile products	Industrial	16.5
7	Wood & wood products	Industrial	1.1
8	Paper & paper products & printing	Industrial	14.2
9	Chemicals & chemical products	Industrial	43.7
10	Petro-products	Industrial	98.2
11	Basic metals & alloys	Industrial	26.1
12	Machinery & equipment	Industrial	117.5
13	Transport & equipment	Industrial	26.7
14	Construction	Industrial	39.8
15	Electricity, Gas, Water supply	Industrial&Infrastructure	227.5
16	Transportation	Industrial&Infrastructure	279.4
17	Rest of manufacturing	Industrial	59.1
18	Storage & warehousing	Industrial	91.9
19	Communication	Commercial	10.6
20	Trade	Commercial	140.8
21	Hotels	Commercial	11.1
22	Banking	Commercial	53.6
23	Insurance	Commercial	13.4
24	Education, research, health	Commercial&Infrastructure	122.0
25	Public administration	Commercial&Infrastructure	127.3
26	Household	Residential	300.0

4.2 Case study of July 2005

Using the ARIO model, the local Input-Output (IO) table and the loss distribution per sector (Table 8), one can simulate the consequences of the flooding on the Mumbai economy. This simulation is reproduced in Figure 7, which displays the change in value added (VA) in the 25 sectors (x-axis) as a function of time in months (y-axis). The simulation shows both the reduction in VA in the months following the event, and the VA increase in construction sector (sector #14) due to reconstruction needs. The losses and gains partly compensate, but the aggregated VA loss (without housing sector) for the Mumbai Metropolitan Region is still \$395 million, for \$1.5 billion of direct losses. This reduction corresponds to 1.4% of annual regional GDP; a very significant economic impact. Given that we have no empirical information on the economic impact of the July 2005 floods, we are not able to validate these results in a detailed manner. A further study on job losses would be a good indicator of welfare losses; unfortunately, consistent data including formal and informal employment in Mumbai could not be found to cross-check and support further analysis.

Figure 7. Sector-by-sector change in value added (in %).



Note : the large increase in production in the construction sector (#14), and the increase in the wood and wood-product sector (#7), due to intermediate consumptions of the construction sector.

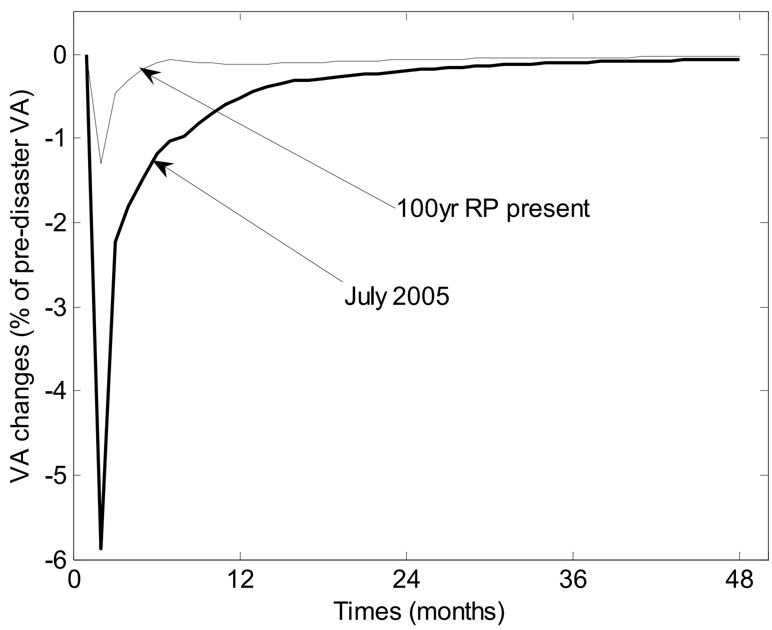
The model also provides an assessment of the "production loss" in the housing sector. Indeed, houses and residential buildings produce a housing service that plays a major role in ensuring local well-being. The decrease in housing services because of damaged houses and buildings has, therefore, to be taken into account. The model, because it reproduces the reconstruction period and duration, can assess the total loss in housing service production. In the July 2005 case, the model estimates this loss at \$30 million. The overall indirect loss, i.e. the sum of the “production loss” in the housing sector and the aggregated VA loss, is estimated to be \$425 millions.

It should be noted that the long term effects (here, more than 20 months after the shock) are due to a budgetary constraint: households that have gone into debt in order to pay for reconstruction, consume less while they pay off their debt, thus reducing the local final demand. In the case of Mumbai, this effect is important because the flood insurance penetration rate is very low. For example, in developed countries, the large insurance penetration and government aid for the non-insured (typically) prevent or mitigate this kind of long-term demand effects.

4.3 Link between direct losses and total losses

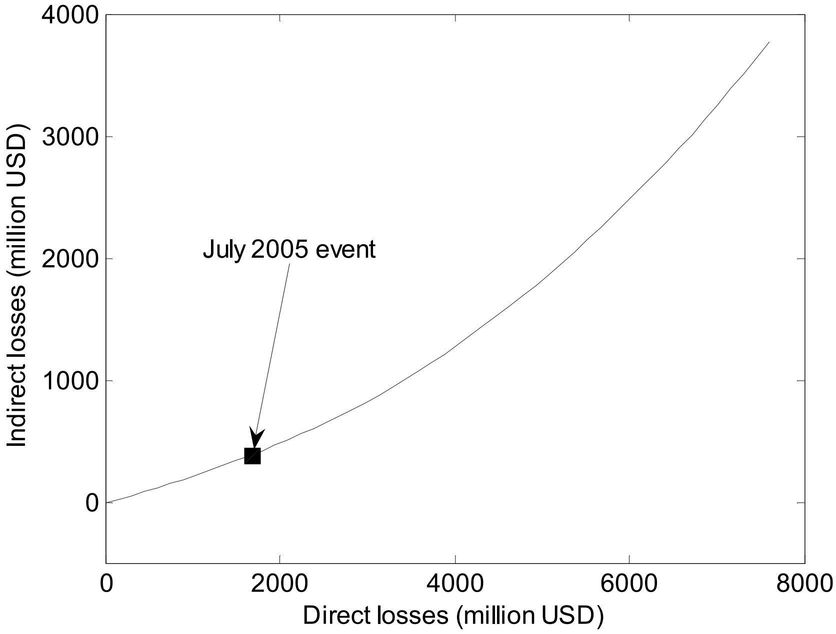
Indirect economic losses, i.e. the decrease in the values added in all sectors during the reconstruction phase, are found to be significant in this analysis, and are strongly non linear with respect to direct losses. This nonlinearity arises from the coupled contributions of different factors. First, a larger disaster causes larger production losses at a given point in time. Second, a larger disaster leads to a longer reconstruction period and, therefore, production losses last for a longer period. Third, in the case of a big disaster and a non-homogenous repartition of damages, production bottlenecks appear in the production system; one or several sectors are not able to produce enough to satisfy the intermediate demands of other sectors. As a consequence, these sectors have in turn to reduce their production. These forward propagations amplify the initial shock. The two first factors are illustrated in Figure 8, which shows the reconstruction dynamics in a 100-year return period event in present conditions (i.e. \$600 millions direct losses) and in a simulated July 2005 event (i.e. \$1.9 billions), corresponding to a return period of between 130-years and more than 200-years in present conditions. In the second case, the instantaneous reduction in value added exceed 6 percent of the pre-event level the month of the event, while it is only about 1 percent in the first case. Moreover, total production is back to its initial level about one year after the shock in the first case, while it takes more than two years in the second case.

Figure 8. Change in total value-added (excluding housing services) as a function of time, for the 100 years return period flood event in present conditions and July 2005 flooding.



As a result, indirect losses amount only to around \$100 millions for the 100-year return period event compared to \$425 millions for the July 2005 event; that is, for direct losses multiplied by 2.5, the indirect losses are multiplied by 4. Figure 9 illustrates the non-linearity between direct and indirect losses: we created hypothetical disasters, with the same reparation of losses as for July 2005 flooding, but multiplying the total amount of direct losses by a factor ranging from 0 to 6. The ARIO model provided the amount of indirect losses for each of these disasters; at roughly $8 billions of direct losses, the indirect losses become equal to half the direct losses.

Figure 9. Relationship between direct losses due to an event and VA losses (productive sectors plus housing sector)



4.4 Projection of future flood risks in Mumbai

With a higher probability of larger direct costs from flooding in the 2080s (Section III), we would expect: (i) more significant indirect costs in the future, but within a larger economy; and (ii) for indirect costs to account for a larger proportion of the total losses. This finding is shown in Table 9 and Figure 10. For example, the total losses for a 100-year return period event are projected to be more than a factor 3 greater by the 2080s. The contribution of indirect losses to total losses increases from 14% ($100 millions indirect losses vs. $700 million total losses) in present-day situation to 18% ($415 millions vs. $2305 million) in the 2080s.

Table 9. Upper estimation of total losses (direct+indirect, including loss in housing services) due to various types of events in present-day and future conditions.

Type of Event	Projected Flood Losses ($ million USD)					
	Present-Day			2080s		
	Direct Losses	Indirect Losses	Total Losses	Direct Losses	Indirect Losses	Total Losses
Simulated July 2005	1910	425(18%)	2335			
50-yr RP	570	95(14%)	665	760	130 (15%)	890
100-yr RP	600	100 (14%)	700	1890	415 (18%)	2305
200-yr RP	600	100(14%)	700	1990	445 (18%)	2435

Note :In parenthesis is the contribution of indirect economic losses to the total losses.

Figure 10. Upper estimation of total losses (direct+indirect, including loss in housing services) due to various types of events in present-day and future conditions.

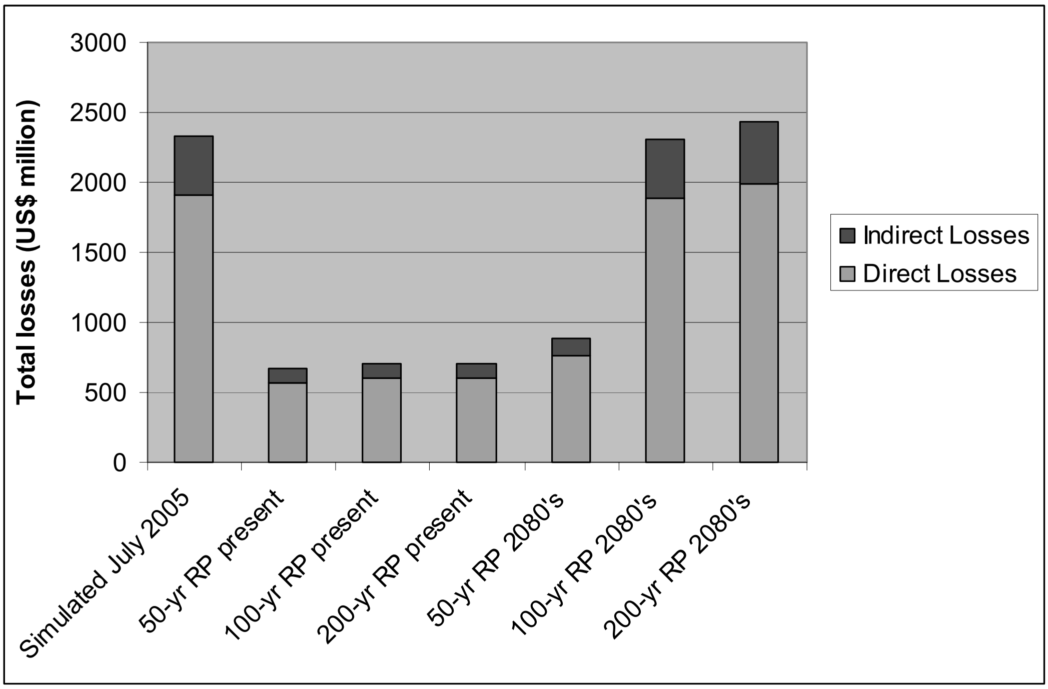
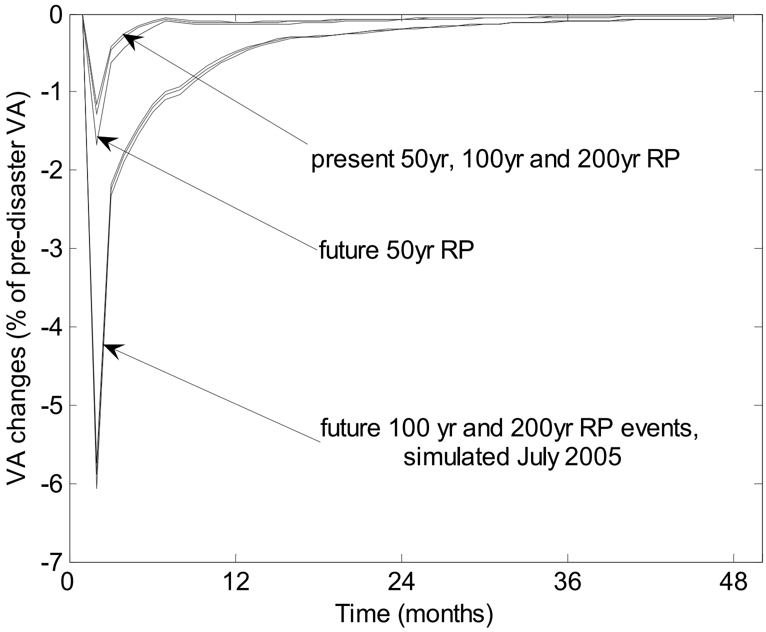


Figure 11 shows the reconstruction dynamics for various types of events in present and future (2080s) conditions, compared to the simulated July 2005 event. It shows that there are qualitative differences between 50-, 100- and 200-year RP events today and the future events. The future 100 and 200 year event, indeed, are close to the July-2005 event, which is really exceptional in the current climate (return time much larger than 200 years, according to the statistical analysis Hist_SZ_X, with July 2005 excluded from the analysis). In Mumbai, therefore, and according to this modelling exercise, the July 2005 event represents a useful proxy for what can be expected to occur on average once a century in the future.

Figure 11. Variations of total VA as a function of time for the 50, 100 and 200 year return period in present conditions and in future (2080s) conditions, compared to July 2005 flood event



5. IMPACT ON THE MARGINALIZED POPULATION AND INFORMAL ECONOMY

Because the type of economic analysis carried out in Section 4 is based on aggregated economic data, it does not allow a detailed investigation of other cost components of floods. In particular, it does not include an analysis of the distributive impact of the flood, and its consequences on the poorest and most marginalized populations, which have a limited economic weight. As a consequence, it does not allow an investigation of flood consequences on inequality and poverty in the urban context. Considering the fact that marginalized populations represent a large share of Mumbai population and that they suffer the most from natural disasters, classical quantitative economic analysis should be complemented by other qualitative analyses (see Hallegatte et al., 2008a, for a discussion on the need for multiple-dimension measurements of disaster consequences, and more general analyses of the limitations of GDP as a measure of social welfare in CMEPSP, 2009, Council and European Parliament, 2009, OECD 2009). This Section focuses on the impacts of the 2005 flood on marginalized population and informal economy in Mumbai, to illustrate the importance of these impacts and the need to take them into account in the design of response policies. It is based on an original survey of this population, carried out by the Indian Institute of Technology Bombay at Mumbai (IITB, 2010). The survey methodology is detailed in Appendix C.

5.1 Marginalized population

As Mumbai is regarded as the commercial capital of the country it possesses a long history of entrepreneurship attracting huge number of migrants. Being an island city with shortage of affordable housing, the city has the largest number of slum population among all other cities in India. During the first half of the twentieth century workers were attracted, persuaded, cajoled and forced to settle in the city to work in its expanding manufacturing sector, from different parts of the country. Some of the major slums affected by flooding are areas where such groups of workers were formally settled by providing land for housing on long lease. The location of slums and the settlement of migrants in slums have been dictated by a number of factors. From the 1960s onwards migrants began to come in on their own attracted by the city's dynamic economy and opportunities, as well as by push factors such as a declining agrarian economy and feudal oppression in the rural areas. While flooding affected most parts of suburban Mumbai, the most affected were the population living and working on either banks of the Mithi river. For historical reasons related to the settlement pattern fostered by the British, and social discrimination against people from other regions, lower castes, and the Muslim minority groups, it is the socially marginalized who inhabit these areas – in an attempt to escape persecution, prejudice, and violence, but also because these were the only areas where they were allowed to settle owing to existing social networks.

In 2005, the rains caused flooding of the Mithi river which originates in the city's northern suburbs and flows into the Arabian Sea at Mahim, separating the suburbs from the island city. Landslide in some of small hills spread over the city due to the excessive rain also resulted in loss of lives and property. While different sections of the population were affected by these events, the poor and those living in risk prone areas were more affected than others. This section is an attempt to describe the impact of the floods on the marginalized population living in disaster prone regions of the city. Data was collected from households through a comprehensive primary survey undertaken in the worst affected regions of greater Mumbai. The primary informal sector activities relates to informal establishments involved in processing of leather products, small lock and key making units, units engaged in making garments and toys and other units manufacturing goods and provisions for day to day living of households in these regions.

The household size in the survey sample varies from a maximum of thirty five members to a minimum of one member. The mean of the sample stands at just above six members. The average number of children in the households stands at around two members. The majority of the households (58.9%) belong to the other backward classes (OBC), followed by the general caste which represented about 27% of the households. The scheduled castes and scheduled tribes[6] form around 11.8% and 2.4% respectively. The households are largely dominated by males as 85.8 percent of the households are male headed households. Women headed households also exist but are limited to only 14.2 percent of the sample.

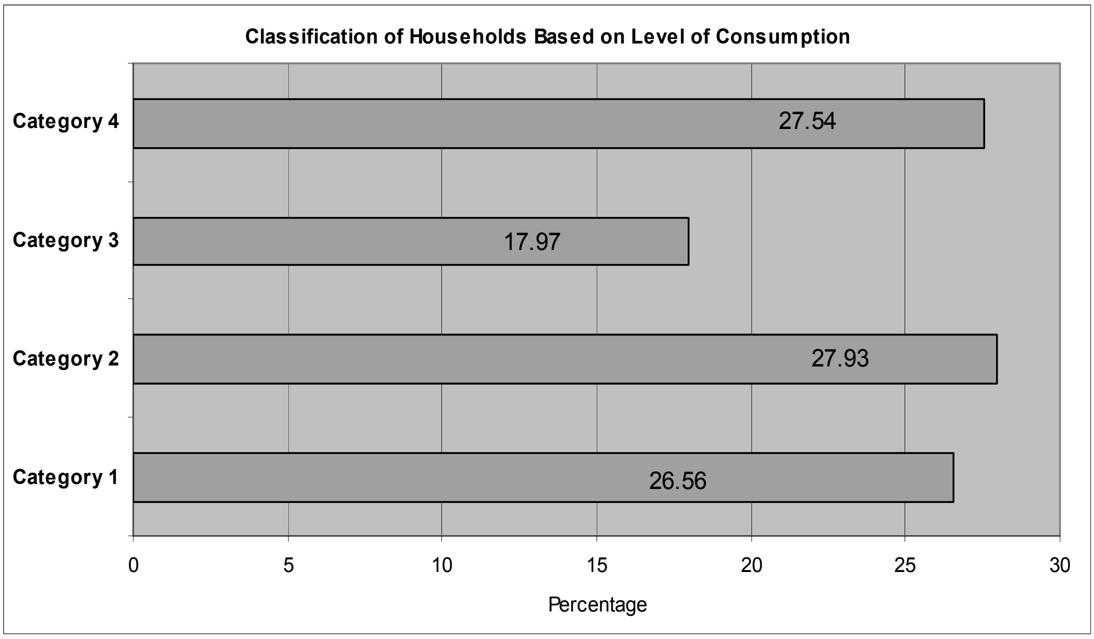
As the sample households are prone to disasters like floods the characteristics of the dwelling place are important in determining the general living conditions of the households. In the sample majority of the households report of staying in pucca houses (around 97.8 percent) while only a countable few stay in semi-pucca houses (2 percent). The primary source of income for the households in the study area is service. As much as 82 percent of the households derive their income from this sector. This is followed by households engaged in business / trade related activities. Around 15 percent of the households derive their income from this activity.

Consumption pattern of a household can unravel the relative vulnerability of that household to natural disasters. In other words, households that are poor may lack the required means to cope with its requirements during the post disaster phase. On the other hand, it might also be the case that these households have suffered less damage as compared to the rich households during the disaster phase. In light of this, it becomes extremely important to study the profile of the households based on the consumption pattern.

For the purpose of analysis, monthly per capita consumption expenditure (MPCE) for a household is defined as “the total consumer expenditure divided by its household size”. Classification is based on the Planning Commission (Government of India) definition for the measurement of poverty. A household is said to be below poverty line if its MPCE falls below a predefined threshold poverty line. The official Poverty Line for Maharashtra (Urban) corresponds to Rs 580 per capita per month or around Rs. 19 per capita per day (i.e. $13 per month or $0.44 per day) (Planning Commission, March, 2007). Following this definition, the households are categorized into four classes: (i) Category 1: Consumption in the range Rs. 0-6960 per year ($0-$160), (ii) Category 2: Consumption in the range Rs. 6961 - 10440 per year ($160-$240), (iii) Category 3: Consumption in the range Rs. 10441 - 13920 per year ($240-$320) and (iv) Category 4: Consumption greater than Rs. 13921 per year ($320). Figure 12 shows the distribution of the households in the sample.

[6] The scheduled class (dalits in local language) and scheduled tribes (adivasis in local language) refer to the depressed classes as recognized by the constitution of India and were provided reservation for education and job vacancies in govt./public sector. The OBC (Other backward castes) were added on to the list at a later stage and are classified as "socially and educationally backward classes" and govt. also provides reservation for them.

Figure 12. Distribution of Households based on Consumption Categories



5.2 The 2005 floods

The flood witnessed in Mumbai during 2005 was rare in terms of the severity of the event. Although small floods are common in the regions during almost every monsoon, the scale of the 2005 event was not comparable with others. Most of the households say that the event during 2005 was an isolated one and they have never faced such a situation before. Almost the entire sample was affected due to the floods in 2005. Similarly a majority of the households (around 90%) also believe that the impact of the floods on their family was very high. Only a select few households amounting to only 10 percent of the sample reported that the impact of the event on their family was medium. Around 39 percent of the households said that they observed a reduction in their food intake due the disaster event.

Also, a majority of the households report that they did not receive any financial support from financial agencies after the event nor were able to payback loan instalments due to the event. It is also interesting to note that around 96 percent of the households also say that there has been no change in their livelihood due to the floods in 2005. From this we can also conclude that even though households suffer losses due to these events there may not be a chance for them to diversify their income. One of the reasons for this as we have seen in the earlier section is that majority of the households derive their income from service sector followed by trade related activities. Hence the scope of these income generating sources may not leave them with enough opportunities for income diversification.

5.3 House structure damages

Households reported that, during the 2005 flood, they suffered damage to their housing structures. The reconstruction cost on an average works out to be around Rs. 4,700 ($108) and is skewed with the median value around Rs. 4,000 ($92). While comparing these figures with the average income and savings of the households we observe that average income reported by the households stand at around Rs. 8,400 ($193) and savings stand at around Rs. 6,900 ($159). In view of this we can say that a major part of the reconstruction cost spent by the households was financed through their past savings although a smaller fraction could have been financed through their income also. Now, looking at the source of the funds for undertaking the reconstruction of their damaged houses we find that around 97 percent of the households depended on their past savings. A few households also report that they depended on other sources but they are very few in number. Only 0.2 % of the households reported that they took money from money lenders to finance their reconstruction cost. Similarly around 1.7 percent of the households say that they have secured the money for reconstruction of their houses from family members and another 0.7 percent report of having the money from other sources.

5.4 Household asset and man-day losses

The mean damage to the household assets reported by the sample households stands at Rs. 7700 ($177). The range of damages suffered by the household ranged from no loss at all to a loss of more than Rs. 1 lakh.[7] The average total value of assets for the households stands around Rs. 35,000 ($805). In other words it can be said that on an average around 20 percent of the household assets were destroyed due to the flood event during 2005. The minimum average loss to household assets is reported by the people residing in Zone VI of Mumbai and amounts to roughly around Rs. 5,500 ($126). The sample households residing in Zone III reported their losses to be around Rs. 6500 ($149) due to the flood event in 2005. With this background information we try to calculate the total loss to all the households that reside in the Zones III, IV and VI in Mumbai (see below and a map in Appendix C).

Looking at the loss of man-days due to this event we find that the average man-days loss is around 6.5 days during 2005 floods. While the minimum number of days lost due to floods stood at one day the maximum value stood at 30 days. Therefore we can say that there is a wide variation in the loss of man-days reported by the households in our sample. The people most affected were those who commute to the city for work, education and other activities.

5.5 Total household loss distribution

Comparing the aggregate losses in these three zones (see a map in Appendix C) we find that highest loss of household assets is for zone IV and works out to be around Rs. 435 crores (about $100 million). While the losses in zone III turn out to be around Rs. 391 crores ($90 million) that for zone VI stands at around Rs. 192 crores ($44 million). Combining the losses of all these three zones we find that the total losses for household assets in the most vulnerable regions of the suburban city district stand at Rs. 1020 crores ($235 million) approximately. Therefore, the loss suffered by households in these three regions is in excess of Rs. 1000 crores (i.e. of $235 million). To arrive at this figure we combined the average losses of the three zones separately and then upscaled it by the number of households living in these regions.

5.6 Informal businesses

As described above, the household survey questionnaire, which was used for primary data collection, also had a section designed to capture the impacts of the 2005 floods on the informal economy. This sector coexists with the residential sector in some regions of the city. In some cases the residential structure of the household is also used as a place of business. Small businesses, which are informal in nature, are operated from the households with the support of family members as well as labourers who may be hired in some cases. A limited amount of machinery may also be present depending on the nature of the business and production process.

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[7] 1 lakh = 100,000 rupies, i.e. approximately $2,300; 1 crore is 10,000,000 rupies, i.e. approximately $230,000.

The total cost of setting up the informal business within a household is estimated to range from Rs. 10,000 ($230) to Rs. 50,000 ($1150) with the mean value standing at around Rs. 20,000 ($460). Looking at the business income generated from these activities we find that the average is around Rs. 6,000 ($138) and is highly skewed. Therefore the observed median value is around Rs. 4000 ($92).

Damages to buildings resulted in an average damage of Rs. 10,000 ($230). Similarly the loss of man-days due to the building damage is around five days. Households also reported damage to business machinery due to the flood event. The average damage to the equipment was around Rs. 7,400 ($170) with the corresponding median value standing at Rs. 7,000 ($161). Households also reported suffering from disruption to their informal business because of interruption of electricity and water services; on an average these resulted in the loss of around 12 working days for households with informal businesses established on their premises. The floods also required repair of damaged equipment and, on average, the monetary value such repair cost is estimated to be around Rs. 8000 ($184).

Overall, we estimate the losses to informal business due to flooding across a range of possible incidence values. We consider four different possibilities, drawing on previous analysis suggesting approximately 2% of the households in these areas have business activities In the first case it is assumed that around 1.5 % of the households in the three disaster prone regions of Mumbai have informal business at their home; this would correspond to a loss for informal business of approximately Rs. 50 crores ($11.5 million). If the share of informal business is higher, at at 1.8 to 2% of these households the corresponding losses increase to Rs. 60 and Rs. 66 crores respectively ($13.8 and $15.2 million, respectively). The fourth case assumes that around 3 percent of the total households living in the three disaster prone regions of Mumbai are engaged in informal business; this would lead to of about Rs. 100 crores approximately ($23 million).

5.7. Summary

This section considers the economic impact of the 2005 flood event on the marginalized population in Mumbai. The aggregation of these results for the three zones that were analyzed (i.e. zones III, IV and VI in Mumbai, see Appendix C) gives an estimate of about $235 million in household asset losses, and $11-23 million in informal business losses (assuming that a proportion of 1.5 to 3% of households have informal business in their home). This gives an estimate of total losses from the 2005 floods to the marginalized population between $240 and $250 million.

6. ADAPTATION TO FLOOD RISK IN MUMBAI

6.1. Actions implemented to reduce flood risks

A number of works were proposed and undertaken to reduce the city flood risks. The works have been going on over the years and are in various stages of completion. To study the storm water drainage (SWD) system and to prepare a scheme for quicker disposal of runoff thereby reducing flood duration, consultants were appointed. The consultants divided the SWD networks in 121 catchments, studied the deficiencies, identified difficulties in cleaning and maintenance, reviewed design criteria and prepared a Master Plan for augmentation of S.W.D. System. The consultants submitted final report in the year 1993, known as BRIMSTOWAD Report. Table 10 shows the provision for expenditure in the BRIMSTOWAD project implementation, for different regions of Mumbai. Table 11 shows the present expenditure status of the various works undertaken as a part of the BRIMSTOWAD project for different regions of Mumbai as of the current time period.

Table 10. Approved support in BRIMSTOWAD project for different regions of Mumbai

Area	Support for Project Works
City	Rs. 504.95 crores = $116 million
Eastern Suburbs	Rs. 383.31 crores = $88 million
Western Suburbs	Rs. 312.27 crores = $72 million
GRAND TOTAL	Rs. 1200.53 crores = $276 million

Table 11. Expenditure Statement for the BRIMSTOWAD project in different regions of Mumbai

Area	Cost as approved	Expenditure incurred till Nov. 2009	Expenditure As Percentage of Approved Costs
City	246 crores = $56m	23 crores = $5m	9.44%
WS	204 crores = $47m	116 crores = $27m	56.99%
ES	228 crores = $52m	112 crores = $26m	49.13%
PS	156 crores = $36m	Nil	0%
Total	835 crores = $196m	252 crores	30.17%

A fact-finding committee (CHITALE committee) was established by Government of Maharashtra post 2005 floods to investigate the causes of the disaster and make recommendations to reduce future risks. Several recommendations were made, with much emphasis on measures to improve the city’s drainage systems, including desiltation, widening, deepening and evacuation of encroachers. Some engineering options were also suggested in the report which included creation of an urban hydrology authority and installation of automatic rain gauges for early warning and a Doppler radar system for the coast of Mumbai as a part of an advanced early warning system.

The Chitale Committee findings were implemented in two phases. During Phase I, widening of the river channel, cross-drainage work in the catchment area, removal of encroachments along the river banks, solid waste disposal systems, cancellation of license of the polluting industries, curbing effluent discharge in the river and construction of public toilets was undertaken and the work was reported to be completed by June 2007. Table 12 shows the expenses incurred during the Phase I of the project. Phase II was launched in November 2007. Works to be undertaken during this phase involve deepening of the river for creating green buffer zones, additional widening and deepening of the river, lengthening of 18 bridges and river crossings, and many other smaller projects.

Table 12. Expenses incurred during the Phase I of the project in different regions of Mumbai

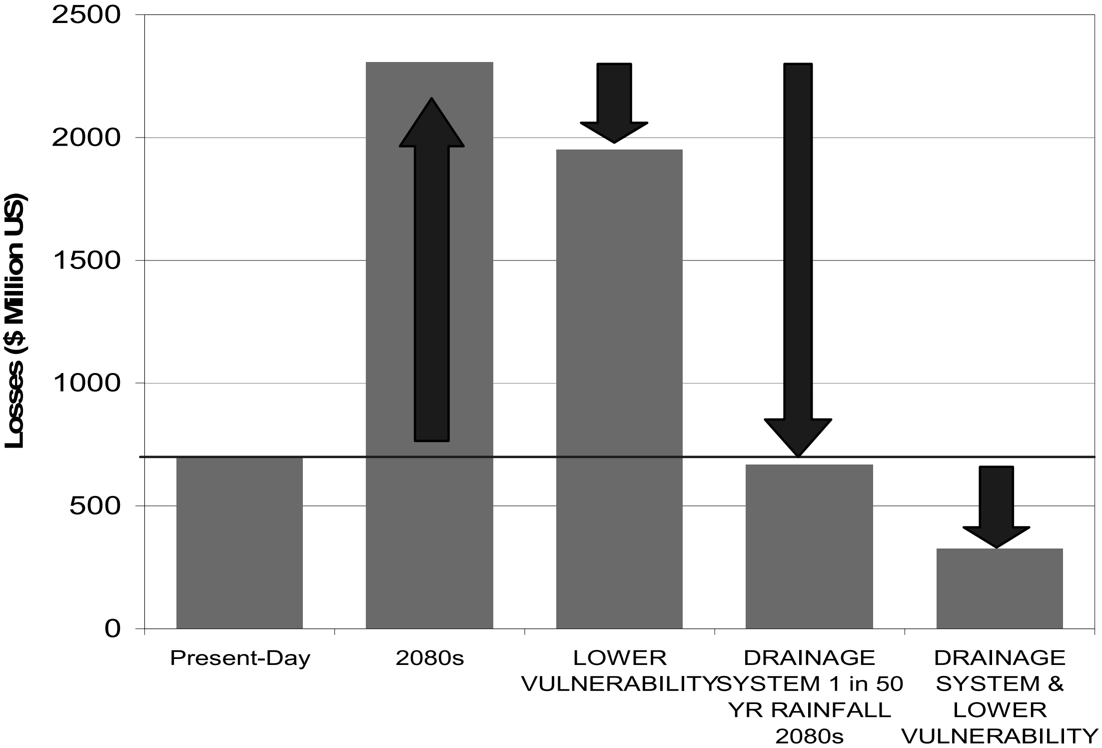
Area	Approved Cost	Expenditure incurred till Nov. 2009 (In Rs. Crores)	Expenditure As Percentage of Approved Costs
City	104 crores = $24	38 crores = $9m	36.82%
WS	61 crores = $14	86 crores = $20m	140.10%
ES	48 crores = $11m	71 crores = $16m	149.40%
PS	144 crores = $33m	96 crores = $22m	66.80%
Total	357 crores = $82m	291 crores = $67	81.72%

6.2. Climate change adaptation

While these actions are commendable, they do not appear to consider the potential impacts of climate change on the long-term planning horizon. Not considering climate change in present-day disaster risk management can increase potential future vulnerability and limit flexibility to adapt, leading to costly maladaptation (Fankhauser et al. 1999, Hallegatte, 2009). In addition, to the changes in rainfall explored in this study, Mumbai will also be exposed to sea level rise and potential increases in the risks associated with of heat waves, tropical cyclones and storm surges. Managing these combined risks could require significant revision of urban planning practices across city to integrate disaster risk reduction and climate change adaptation measures (as well as greenhouse gas mitigation) into day-to-day urban development and service delivery activities (Revi, 2005).

To demonstrate the importance of an integrated approach to disaster risk reduction and climate change adaptation, below we provide a simple analysis of the potential risk reducing benefits of four potential policy options, two relevant to reducing direct losses from flooding and two relevant to reducing indirect losses. These are not intended to guide specific policy (they are too simplified to do so) and do not represent a complete list of options, but do serve to demonstrate the potential of adaptation to limit climate change damages and the need to consider climate change in decision-making around disaster risk management today.

Figure 13. The estimated total (direct + indirect) losses for a 1-in-100 year flood event in Mumbai under five scenarios



Note : (from left to right): (i) present-day; (ii) 2080s – using the one 'high-end' scenario considered in this study and an unchanged city; (iii) 2080s, assuming properties are made more resilient and resistant to flooding (e.g. through building codes); (iv) 2080s, assuming the drainage system is improved such that it can cope with a 1-in-50 year rainfall event; and (v) combined property and drainage improvements.

Reducing direct losses from flooding: Figure 13 shows the estimated total losses (direct and indirect) associated with a 1-in-100 year flood event in Mumbai under five scenarios (respectively, from left to right in Figure 13): (i) present-day; (ii) the 2080s (note, under the one 'high-end' climate scenario considered in this study and with an unchanged city); (iii) the 2080s, with a reduction in the vulnerability of properties (e.g. representing strengthened building codes); (iv) the 2080s, with an improvement in the drainage system; and (v) the 2080s, with a combination of reduced vulnerability of built properties and improved drainage. The 'lower vulnerability' scenario assumes a 15% reduction in vulnerability for a 1-in-100 year event (achieved through, for example, building improvements incentivised by building codes) and the improved drainage scenario assumes that the drainage system has been upgraded such that it can cope effectively with a (2080s) 1-in-50 year rainfall event[8]. The uncertainties in individual estimates are great and the effectiveness of measures will depend strongly on the quality of implementation, however, the figure demonstrates that with certain options or combinations of options, Mumbai may be able to offset the increase in risk due to climate change (even under this high-end scenario) and also that such measures can also have significant benefits today; for example, upgrading the drainage system such that it could cope with a 1-in-50 year event today, could reduce losses from a 1-in-100 year event (today) by around 70%.[9]

[8] A 50-year standard is higher than what is usually used for drainage system (i.e. 10 or 20 years), but the Mumbai climate and the vulnerability of the city to heavy precipitations may justify such a strict standard. Such an increase in drainage capacity would probably require both a restoration of the existing drainage system, and investment in new drainage infrastructure.

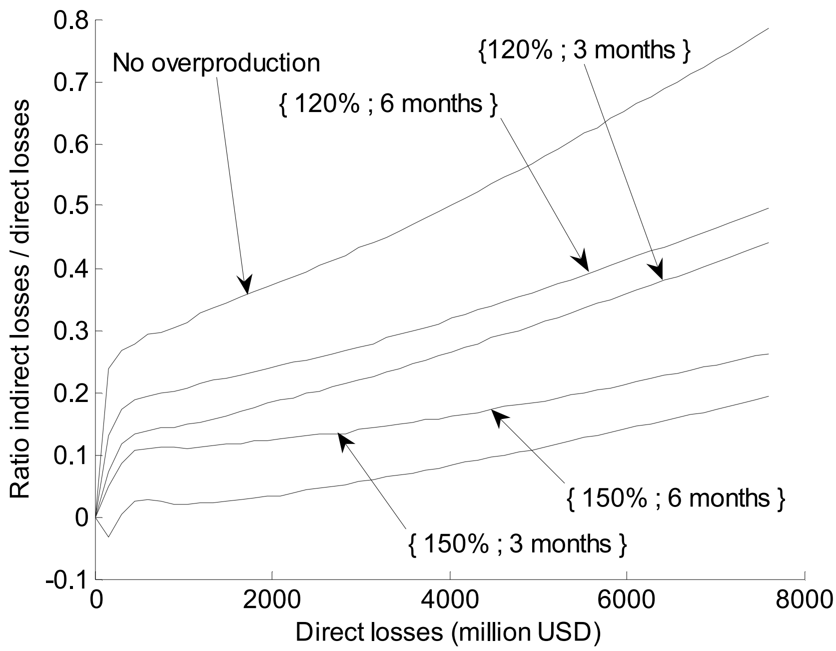
[9] The impact of an improved drainage system is assessed very simply in this study and so should be treated as illustrative only. To make this estimate, we define a relationship between affected exposure (E) and rainfall (P) at

The cost data from the BRIMSTOWAD project and the Chitale Committee Phase I provide a broad order of magnitude of the cost such adaptation measure could have: the cost of improving drainage infrastructure can easily reach hundreds of millions US dollars. However the benefits of such action, as estimated here, are potentially an order of magnitude greater than this suggesting that there is potentially a large net benefit to be gained from such an investment. A more precise estimate would require an in-depth engineering analysis, which is out of the scope the present study.

Reducing indirect losses from flooding: The ARIO model allows us to assess the benefits of sets of policies that aim to enhance disaster recovery; reducing the lost production due to property damages and therefore the indirect costs of flooding. Two instruments are explored here: firstly, increasing flexibility in the capacity of the construction sector, to speed reconstruction; and secondly, the provision of insurance.

Adaptive capacity of the construction sector: Increasing the flexibility of capacity of the construction sector means that damaged buildings and infrastructure can be repaired or replaced more quickly following a disaster, reducing lost production. This can represent, for example, the ability of workers to increase their productivity, or the possibility of workers and equipments from outside the affected region to move there to speed up reconstruction. ARIO allows us to explore the benefits of such flexibility in terms of avoided indirect costs through running scenarios of its sectoral overproduction parameters. We find that, for the July 2005 event, the indirect effect of the disaster on the local economy can vary by a factor of 4 (Figure 14), depending on the amplitude and quickness of response of the construction sector.

Figure 14. Indirect losses to direct losses ratio, as a function of the amount of direct losses, for four sets of adaptation parameters



each return period (i.e. $E_{RP} = f(P_{RP})$) from the original 'un-adapted' scenario. For the adapted scenario, we estimate a new function f' (by shifting f) such that $E_{50} = 0$. We then assume: (i) no flooding for rainfall events with a return period of up to 50 years; and (ii) rainfall with a return period of above 50 years leads to an affected exposure (E') given by $E'_{RP} = f'(P_{RP})$.

From a policy perspective, this high sensitivity is good news, as it suggests that large economic losses can be avoided with increased flexibility in the construction sector production capacity. The flexibility depends heavily on the pre-event conditions; for example, if idle capacities are present (e.g. unused equipment) they can be mobilized to cope with the disaster (West and Lenze, 1994; Hallegatte and Ghil, 2008), whereas if capacities are fully used then no additional capacity can be mobilized. The flexibility of the construction section could be enhanced through:

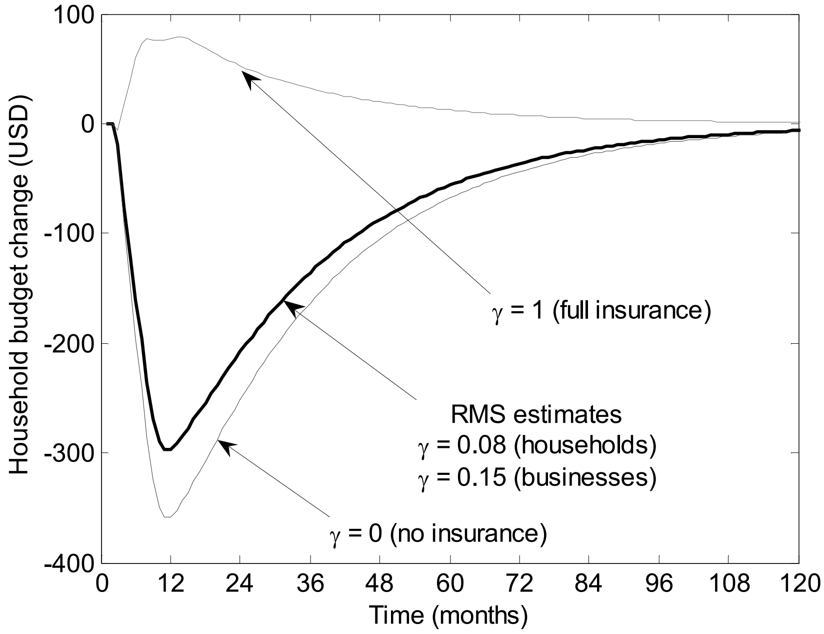
- Enabling qualified workers to settle down temporarily in the affected region (e.g. by providing working permit or helping workers to find accommodation).
- Organising and sharing reconstruction resources among regions, states or cities and setting super-national policies to ensure reconstruction capacity is adequate to cope with possible disasters.
- Empowering governments to mobilizing their workers (e.g., soldiers) and their equipments to speed up reconstruction.

Past disasters illustrate the barriers to efficient reconstruction and suggest good practices. For instance, in the Katrina aftermath, many qualified workers from the entire U.S. moved to New Orleans to help reconstruct the city and capture higher construction-sector wages. Most of these workers, however, had to leave the area rapidly because they could not find proper accommodation or because of insufficient public services. Providing housing to temporary workers, therefore, seems to be extremely important to speed up reconstruction. Also, these workers left the region because the reconstruction of many buildings was delayed by legal problems, either due to delays in insurance claim payments or to the slow approval of building permits. For reconstruction to be as effective as possible, therefore, it seems that all administrative and legal issues must be solved rapidly, to benefit for the mobilization of internal and external resources.

The Benefits of Insurance*:* Financial constraints can play a significant role in delaying reconstruction (Benson and Clay, 2004), and can even lead to a suboptimal reconstruction with consequences on productivity (Hallegatte and Dumas, 2008). Insurance allows individuals to share risks; in exchange for a regular premium payment individuals receive a payout if they experience damage. This means that individuals do not absorb all their reconstruction costs and have fast access to capital in the aftermath of a disaster.

We can use the ARIO model to investigate the benefits of insurance by exploring the sensitivity of indirect losses to the insurance penetration rate (γ) assumed in the model. In ARIO, the insurance penetration affects the response to the shock through two mechanisms: first, if the insurance penetration of households is low, they have to pay for their reconstruction (either directly, or by getting into debt and then paying off later), and reduce their consumption in order to so. Second, if the insurance penetration of firms is low, firms have to pay for reconstruction, reducing their profits. As a portion of these profits normally goes to local households, this affects the household budget, also reducing their consumption.

Figure 15. Household Budget as a function of time, for 3 different penetration rates.



Note : γ=0 (no insurance), current value estimated by RMS (γ=0.08 for households and γ=0.15 for businesses) and γ=1 (reconstruction is entirely paid by the insurance system).

Figure 15 illustrates the effect of insurance penetration on the household's budget, for a July 2005 like flood estimated using the ARIO model. Three scenarios are included: (i) γ=0, equivalent to the absence of insurance system, but with an access to credit; (ii) the current value of flood insurance penetration estimated by RMS (γ=0.08 for households, γ=0.15 for firms); and (iii) γ=1, representing the situation where all the reconstruction is paid for by insurance. It is important to note that our "insurance penetration rate" does not represent the fraction of the total amount of houses that is insured, but the fraction of the total value of goods that is insured (never equal to one in the real world, because of ceilings or deductibles). Where the budget is positive in Figure 15, it can be interpreted as the total amount of savings of households, and where negative it represents debt. We assume that the budget is equal to zero before the disaster and that it tends to return to the initial situation. Figure 15 shows that the lower the penetration rate the more households have to get into debt in order to pay for their reconstruction. When the penetration is very large, households make savings after the disaster. This occurs because in this case, the decrease in production is more important than the decrease in demand (through the decrease of incomes). Households are rationed and consume less than what they would like to and as a result, they involuntarily save money.

Variations in household budget affect the local demand, as households in debt reduce their consumption. This decrease in demand affects local production in the long term, as shown in Table 13. When the reconstruction is paid for by the insurance system, indirect losses are reduced by 37%, compared to the best guess situation, and by 42% compared to the no-insurance situation. This demonstrates that even though the gap between two insurance systems does not exceed 0.1% of the baseline value-added at a given point in time, the overall effect on total indirect losses can be very important.

Table 13. Total indirect losses, as a function of the insurance penetration rate, for a July-2005-like flood

Insurance Penetration Rate	Total Indirect Losses ($ million USD)
0	455
RMS estimates	425
1	265

The difference in indirect losses between the no-insurance and the full-insurance cases arise from two factors. First, in presence of insurance or perfect access to credit, businesses and households can restore their productive environment and equipment, allowing for a more rapid recovery of the economic activity. Second, insurance prevents a reduction in the final demand from affected businesses and households that have to rebuild their savings or pay back their debt. In this analysis, it is the second mechanism that explains the difference, since households are assumed to have full access to credit in absence of insurance. With a limited access to credit, a case that will be investigated at a later stage, indirect losses would be even larger than in the worst case presented here.

These results provide insight on the aggregated losses that can be avoided at the macroeconomic level due to a well developed insurance system. In addition, a generalized insurance scheme (that can be accessed by all households and businesses) would help the poorest households and the most fragile businesses to cope with floods. This means that insurance would yield macroeconomic benefits (estimated here), and microeconomic benefits at the household level (not explicitly estimated here, but suggested by Figure 15). As shown by the survey presented in Section 5, microeconomic benefits could include in particular the avoidance of increased poverty and inequality, the avoidance of the reduction in food intake (observed for about 40% of households), and facilitate and accelerate reconstruction. Even though they are difficult to estimate in monetary terms, these benefits should be taken into account, e.g. in the cost-benefit analysis of the implementation of a micro-insurance scheme.

Flood insurance coverage would, therefore, be an interesting strategy to reduce flood vulnerability and improve aggregate economic resilience in Mumbai, and to prevent poor households from falling into poverty after a flood. Insurance, however, has to be combined with risk-reducing land-use planning and other regulations to avoid incentivising over-development and growth in exposed areas. In the UK and for many commercial properties in the developed world, flood insurance is obtainable from the private insurance market. For residential coverage, many countries have established national flood insurance systems (e.g., the French Cat-Nat system, the Florida Hurricane Catastrophe Fund). These systems may provide useful models for Mumbai; a full discussion of their relative advantages and disadvantages is beyond the scope of this paper. It is worth mentioning the benefits of insurance relative to other 'financial safety pools'. Local and familial solidarity is an established mechanism in many developing countries, but the survey (Section 5) suggests a very limited use of such solidarity during the 2005 floods. Government support is often necessary to some extent (for instance, after Katrina, the U.S. Federal government more or less replaced insurance for households that had no flood insurance; Lubell, 2006), but is hardly observed in the Mumbai case. Moreover, relying on it creates inefficient uncertainty for economic actors (e.g., because, after an event, they cannot known the exact scope of the government support they will receive) and can lead to moral hazard (e.g. if households know that they will be compensated by government, they will have little incentive to reduce their own risks or to pay for insurance). International support (grants or goods provided to affected people) can help reconstruction, but (in addition to the moral hazard issue) is very volatile and unpredictable. Finally, the survey shows that credits was almost absent in the 2005 recovery and reconstruction. An improved access to credit (especially for the underprivileged) could help during the post-disaster period; e.g. the government guaranteeing reconstruction credits. As a conclusion, if the frequency and intensity of extreme events in Mumbai is to increase, the development of the insurance system could have significant benefits in combination with other existing risk sharing mechanisms.

Land use planning*:* One limit of this analysis is that it investigates the potential consequences of climate change on the current city of Mumbai, without taking into account future developments. Considering the importance of expected evolutions (see, e.g., MCGM, 2008), a priority for future research is to create scenarios for the future of Mumbai, and to assess the corresponding resilience of the city to heavy precipitations and climate change. This would make it possible to investigate additional risk-reducing measures, and especially zoning. Risk-based zoning defines where new constructions should be prohibited, where they should be allowed with restriction (e.g., banning one-floor building, or making compulsory to build on stilts or to use water-proof materials), and where relocation is necessary. Over the long term, zoning can help achieve large risk reduction compared with no-policy scenarios.

Zoning is usually based on risk maps comparable to Fig. 5. To introduce policies, however, more detailed analyses than this one would be required. These analyses could follow the same methodology, but include more details in hydrological modelling and include several climate change scenarios and a systematic robustness analysis. However, in a city like Mumbai where informal settlements represent a large share of the population, enforcement of these land-use policies would be critical, and most difficulties probably lie in enforcement, not in policy design.

Consistent risk management policies: In managing flood risks in a city like Mumbai, the various policies are no substitute to each other, but complement themselves. An appropriate risk management strategy would include all measures and policies discussed here (decreased building vulnerability, improved drainage, insurance schemes, support to reconstruction, land-use plans), and others that are not presented in this study (e.g., information and communication to the population, early warning and evacuation). In practice, different strategies are necessary to cope with different risk layers:

- Frequent low-impact events like the floods that occur several times a year in Mumbai (i.e., regular precipitations) could be avoided thanks to improved drainage;

- For rarer events that cannot be avoided through improved drainage or at an excessive cost (i.e., heavy precipitations), population information, zoning and land-use plans could reduce the exposure (i.e. the population and assets at risk) by preventing inhabitant to settle in flood-prone zones and favouring safe settlement locations.

- For exceptional floods that cannot be avoided with drainage or zoning (because it would prevent construction in very large areas, at an unacceptable cost in a rapidly growing city), early warning and evacuation can reduce human consequences, and reduced building vulnerability, support for reconstruction, and insurance can mitigate economic losses.

7. DISCUSSION: ADAPTATION PLANNING AND UNCERTAINTY

This study has demonstrated a number of approaches to enable an adaptation planner to quantify risks associated with climate change and the benefits of adaptation. An important limitation of this study is that it does not attempt to fully quantify the uncertainties in the analysis. Uncertainty is incorporated at each stage of an analysis (Table 14). Fully quantifying uncertainties at each stage is likely to lead to the characteristic 'explosion' of uncertainty (Carter et al. 2007). A number of previous studies have suggested a 'policy-first' approach, where the quantitative analysis is designed from the bottom-up to evaluate the desirability of specific adaptation options against a set of defined objectives, as an alternative to help to narrow uncertainties in the analysis (Dessai et al. 2009). Recognising the scale of the uncertainties, such a process can utilise methods such as robust decision-making to design strategies that are flexible under a range of climate scenarios (Lempert and Collins, 2007; Hallegatte, 2009). These types of approaches still require quantification of potential risks and benefits of adaptation. For example, the risk-based tools presented here are able to demonstrate that there are strong benefits from a number of adaptation measures with or without climate change. The tools can also be used to identifying if and where current disaster risk management plans may become future maladaptations and how these plans could be adjusted to make them robust to long-term climatic changes.

Table 14. Summary of uncertainties incorporated into final estimates

Source of uncertainty	Description
Present-day hazard	Includes uncertainties introduced by statistical analysis of rainfall events from short data records; the urban flood model; and extrapolations from one catchment (Mithi) to city-scale. Figure 2 suggests that uncertainties related to statistical analyses could be large (e.g. estimates of rainfall at given return periods were doubled when the 2005 event was included in the analysis).
Future hazard	Includes uncertainties in emissions scenarios; climate modelling and those introduced by statistical downscaling.
Exposure	Our approach to estimating property values is sensitive to uncertain estimates of insurance penetration. Estimates of future exposure trends can be expected to significantly impact estimates of risk and the benefits of adaptation
Vulnerability	Uncertainties in estimates of 2005 vulnerability were quantified by the analysis (section 3.3) and could be further refined through study of other flood events. Extrapolation of 2005 vulnerability estimates to future events incorporates uncertainty.
Indirect loss modelling	Local economic data are largely unavailable, and there is a large uncertainty in the local economic structure. Economic modelling of disaster consequences is difficult and various modelling strategies coexist (e.g., CGEs, Input-Output, econometric models), leading to large differences in results.

Each of the uncertainties outlined in Table 14 could significantly affect estimates of risk. Some are likely to be irreducible on the timescales that many adaptation decisions must be made; for example, uncertainties related to emissions scenarios and climate models. However, many of the other uncertainties are reducible and further study in these areas could help to refine risk estimates in the near-term. Of particular importance is monitoring and research into understanding current levels of hazard, exposure and vulnerability; these elements form the starting point of an analysis of risk and therefore, reducing these uncertainties is likely to be of high value in adaptation decision-making as well as present-day disaster risk management.

Regardless of climate change uncertainty, the information produced in this project can inform decision-making but is insufficient to make a decision on the design of a risk-reduction strategy. First, little information is available on the cost of many several risk-reducing measures. For instance, the cost of zoning is unknown but is likely significant since zoning makes city development more difficult and increases housing cost in a city where housing is already problematic. Also, risk reduction measures have non-economic co-costs and co-benefits (e.g., on ecosystems, health, or local amenities) that need to be assessed in a full analysis.

Second, Section 5 shows that aggregated measures of disaster impacts can hide large distributive effects, especially on marginalized population. More work would be necessary to assess flood impacts on different social groups. Also, there are non-economic impacts of urban floods (e.g., on health or on the environment) that need to be taken into account.

Decisions on risk management cannot therefore be evaluated with a comparison of their aggregated monetary costs and benefits. Other dimensions need to be accounted for (e.g., inequalities, long term regional development), and risk-reduction decisions will always be political decisions that cannot be made using simple cost-benefit analyses.

7. CONCLUSIONS

This study has demonstrated the application a series of tools aimed at quantifying risk and the benefits of adaptation to inform adaptation strategies, using the case of flood risk in Mumbai. While the study does not aim to provide a complete assessment, it does demonstrate the significant current vulnerability of Mumbai to heavy precipitation, as well as the high potential sensitivity to climate change and the strong need for effective and integrated climate change adaptation.

The findings of the study show that disaster risk management and adaptation can have significant benefits both today and in the future, for example, our estimates suggest that by upgrading the drainage system in Mumbai, losses associated with a 1-in-100 year flood event today could be reduced by as much as 70%, and through extending insurance to 100% penetration, the indirect effects of flooding could be almost halved, speeding recovery significantly. Moreover, the survey on the consequences of the 2005 floods on the marginalized population reveals the special vulnerability of the poorest, which is not apparent when looking only through a window of quantitative analysis and aggregate figures; addressing the needs of the poorest may require specific public actions, especially during the recovery period.

Given the uncertainties in future rainfall projections, it may be prudent to explore win-win measures that provide benefits under the broad range of climate scenarios – we demonstrate that upgrading the drainage system and supporting an effective insurance mechanism may be examples of such no-regrets measures, others include spatial planning to manage new construction out of high risk areas and increasing public risk awareness. Targeting some of these measures to the special needs of the marginalized population could offer large co-benefits in terms of poverty reduction and health. This calls for integrated development—adaptation strategies and for mainstreaming climate policy within urban planning and economic development.

The Government of Maharashtra has, indeed, laid out comprehensive plans to reduce and better manage risks associated with flooding in Mumbai, with significant investment after the 2005 floods. However, these investments have to be maintained over the long term to produce their positive effects. Moreover, it is not clear whether these plans adequately account for the potential increases in flood hazard with climate change. Several studies have shown that not considering climate change in long-term planning and investment decisions today can lead to potentially costly maladaptation. In planning disaster risk reduction, it is also important to consider other hazards to which the city is exposed and the effects of climate change on each (in particular, sea level rise, heavy precipitation, storm surge, high tides and tropical cyclone risks). Policies to limit long-term flood hazard will need to be considered alongside policies related to other risks and objectives (e.g. improving overall housing quality or reducing greenhouse gas emissions) to identify synergies and minimise conflicts. For example, measures to mitigate sea level rise and inland flooding must be considered in tandem as sea level rise could impair any drainage improvements in the city.

Further research is also required to consider the implications of demographic and economic changes for future risks, and uncertainties in climate projections for adaptation planning in Mumbai. For example, this study should be extended through the use of multiple projections from a range of available Global Climate Models and Regional Climate Models. A single scenario of future climate, as used here, is not by itself adequate to inform robust adaptation decisions. Uncertainties in climate model projections are not likely to be significantly reduced on the timescale of many adaptation decisions and therefore, further research is required to demonstrate the integration of quantitative risk analysis tools, like those presented here, with approaches to decision-making under uncertainty. We also discuss the benefits of focussing future research and monitoring towards reducing the more 'reducible' uncertainties associated with managing extreme events, in particular related to understanding levels of current hazard, exposure and vulnerability; such investments would have significant benefits for both climate change adaptation and present-day disaster risk management.

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APPENDICES

A. SWMM: Urban Flood Modelling in Mumbai

The Storm Water Management Model (SWMM) was been developed by the US Environmental Protection Agency for use in the urban hydrology and is widely applied in flood simulation studies. The basic model components include the physical characteristics of the basin such as topography, soil types, land use characteristics, and climate characteristics such as evaporation, temperature and precipitation. SWMM has the capacity to model every aspect of urban drainage; combining sewers and the natural drainage, whereas other river flood models are generally restricted to natural drainage. This makes it most appropriate for modelling flood risk in the Mumbai area.

One of the most important inputs to the model is topographic data in the form of a digital elevation model (DEM). This data is obtained from the Shuttle Radar Topography Mission (SRTM). The SRTM instrument obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. The 90m DEM derived from SRTM has been used as primary source for elevation data and is smoothened using standard interpolation techniques. The DEM is further enhanced through validation against topographic maps from the Survey of India.

Table 15 gives an overview of the input assumptions and data sources used in the SWMM model for the Mithi River Basin. It should be noted that tidal effects are neglected in this analysis, giving a potential negative bias on flood extent estimates. Further information on SWMM can be located at: http://www.epa.gov/ednnrmrl/models/swmm/index.htm

Table 15. The input assumptions of the SWMM model for the Mithi River Basin

Summary of Input Assumptions and Data Sources
Rainfall data as collected and simulated from the Santa Cruz IMD rainfall station
The total catchment is divided into 9 sub-catchments with channel characteristics taken from Google Earth.
The Slope values in % are derived from SRTM Digital Elevation Model (DEM).
The soil is assumed to have a slow infiltration rate (Hydrologic Soil Group C). The impervious area depression storage is assumed to be 5 mm.
Assume manning's coefficient of 0.014 for irregular channels and impervious area; and 0.035 for pervious areas (based on Sharma and Gupta, 2006)
Infiltration parameters from Soil Conservation Service Curve Number, based on the land use type.
The Kinematic Wave method of flow routing is used.
Tidal effects are neglected.

B. The ARIO Model

The ARIO model (Hallegate, 2008) is based on IO tables and a hybrid modelling methodology, in the spirit of Brookshire et al. (1997). The model takes into account (i) the propagation among sectors of reduced productions due to disaster damages; (ii) the propagation among sectors of reduced demands due to disaster damages; (iii) the large demand in the construction sector due to reconstruction needs; (iv) the economic-agent behaviours to cope with disaster consequences (e.g., by increasing their production when demand is large, or by finding alternative suppliers when the original ones cannot produce); (v) the limitations in resource movement between sectors (e.g., the construction sector cannot grow instantaneously by hiring workers from other sectors; it is limited by the availability of qualified workers); (vi) the interaction with outside the affected regions (through imports and exports). Importantly, the model assumes that the economy will eventually return to its initial situation. Also, impacts outside the Mumbai region are not assessed, because these impacts are distributed over a large number of economic actors, and are therefore small (often negligible) on a per capita basis.

The model is applied to Mumbai using sector-by-sector macroeconomic data from the National Council of Applied Economic Research downscaled to the Mumbai region. For this study, we introduced three main modifications in the ARIO model initial setting, which is used in the Copenhagen case study in this project (Hallegatte et al., 2008b):

- The modelling of reconstruction demand has been modified to take into account the urgency in reconstruction. In the new version, it is assumed that, in absence of any constraint in construction-sector production capacity, all damages would be repaired 3 months (τ) after the disaster. Of course, because of these constraints, the actual reconstruction time can be much longer.

- The rationing scheme is modified. In the current version, there is a three-stage rationing: (1) intermediate consumptions are served first, to ensure that total output is maximum; among industries, the rationing is proportional, with each sector receiving the same fraction of its demand; (2) reconstruction needs and local demand is served second, with again a proportional rationing between the two; (3) exports are served last, if all other demands can be fully satisfied. Compared with the previous version, this rationing scheme gives a higher priority to local demands and lead to more optimistic results.

- When applying ARIO to Mumbai, the assumption that all losses are paid by insurance claim is not acceptable any more. According to RMS, flood insurance penetration in Mumbai is around 8% for households and 15% for businesses. The fact that businesses and households have to pay for their reconstruction can have important impacts on the reconstruction duration and causes a crowding-out effects on consumption and investment. Budget constraints (for households and businesses) may thus have macroeconomic consequences that need to be accounted for. To do so, we assume first the businesses pay their reconstruction by reducing the profits they redistribute to households. As a consequence, house hold income will decrease. Second, household budget constraints have been introduced. In this modeling, we assume that households can borrow to fund their reconstruction (without borrowing constraints), but that they then have to pay back over a 2-year period. To reimburse this additional debt, they reduce their consumption and investment. This factor introduces a *consumer backward propagation* in additional to the mechanisms described in Hallegatte (2008).

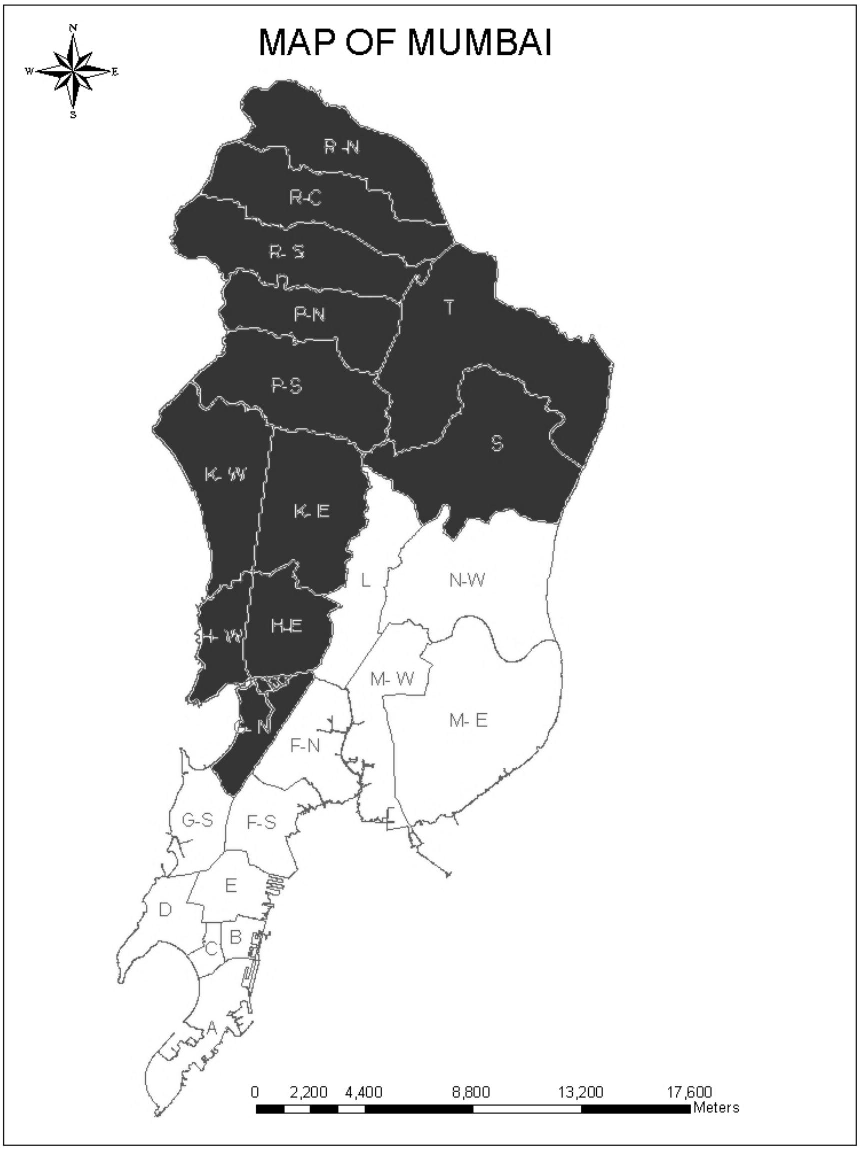
C. Survey methodology

The focus of the survey was on the areas that belong to the suburban part of the city as a greater percentage of population lives in this part of the city; and this part of the city is also prone to flooding during the monsoon season. Flood prone areas are present in almost all the wards except for the wards B, C, F-South and R-Central. Since the target of the survey was to analyze the impact on the marginalized population, and the informal economy specifically, with respect to the floods of 2005, the survey was undertaken in the zones III, IV and VI which reported the maximum damage due to this event.(see Tab. 16 and Fig. 17).

Table 16. Zonal Distribution of Flood Prone regions in Mumbai

Zone	Wards	Area (Sq.Km.)	Households	Population	Density
III	H East	13.5	114,423	580,835	42,929
	H West	11.6	73,874	337,391	29,211
	K West	23.4	149,161	700,680	29,956
	K East	24.8	175,859	810,002	32,688
	P South	24.4	95,188	437,849	17,915
IV	P North	19.1	171,009	796,775	41,651
	R South	17.8	95,188	437,849	17,915
	R North	18	83,433	363,827	20,213
VI	N	26	129,228	619,556	23,866
	S	64	148,731	691,227	10,800
	T	45.4	73,540	330,195	7,270
Data Source: 2001 Census					

Figure 17. Map of Mumbai wards; in red the wards in which the survey has been carried out.



Since a full scale census survey of the study area was not possible, the aim was to design and undertake a sample survey that is representative of the study area. Primary data was collected through surveys. The reference unit of the surveys was households. The responses from households were collected through interview techniques used in the primary field level surveys, through the direct asking method. Data were collected from the head of the household; he/she were asked to recall the economic activity of the family and answer questions about the coping strategies adopted by the household. Roughly around 50 households were chosen randomly from each of the Wards listed in the above table. The sample size of the survey was around 530 households drawn from the above selected regions of Mumbai. The data collection started during August, 2009 which marked the end of the monsoon season for the year and lasted till December, 2009.