Adaptation to Water-related Climate Change in cities

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Executive summary

- Impact of climate change on cities is quite well acknowledged at global level
- Flood impacts are addressed much more frequently than droughts impacts
- Global cost of adaption lies between US$ 9-11bn (adaptation only) and US$25bn (adaptation and upgrade)
- Adaptation should tackle 4 risks together: risk of excess, of shortage, of inadequate quality, and risk of undermining the coping capacity of freshwater systems
- Adaptations solutions include structural and non structural measures
- Structural solutions include hard business-as-usual solutions and softer (sustainable) solutions
- Adaptation tends to become a usual item of planning strategies
- Adaptation solutions are in most cases 'no-regret' solutions,
- Cost assessments include empirical approaches and more sophisticated approaches
- Uncertainties are often mentioned but rarely assessed or incorporated in the final estimates
- Lack of data hampers decreasing the uncertainty.

Introduction

How are climate change (CC) impacts channeled through water in cities? Climate change's water related impact is observed in two ways: (i) through the increase in frequency and importance of extreme events (rain and wind related events : precipitations, hurricanes and subsequent tidal, river and surface floods, but also unusual droughts); and (ii) through slow but long term changes, in particular sea-level rise and snowpack decrease.

This leads to distinguish inland cities and those located on sea shores: in the latter case, on top of direct excess or scarcity of water related to growing variations in precipitations, sea-level rise will increase the vulnerability of populations located in lowland or marshy areas, in particular the poorer ones, often illegally settled in absence of land-use control. In addition, in many megacities of the South, rapid urbanization and soil sealing, and groundwater overdraft, provoke land subsidence increasing this vulnerability and the potential CC impacts in the coming decades.

This short review about Adaptation to Climate Change in the water sector in cities aims at:

- gathering information about present and future damages and the share which can reasonably be attributed to CC
- finding elements of adaptation costs vz water-related events and long term changes, and eventually also adaptation costs of the water supply and sanitation sector in several cities in the world,
- comparing these costs with the corresponding costs of the damages
- listing the various methodologies used
- listing and comparing the various solutions proposed, and their cost
- proposing a first analysis of the situation and the gaps to be filled for improving this situation

In this paper we do not cover the issue of CC mitigation in any way. Mitigation roughly focuses on change in energy consumption and reduction of carbon dioxide and other GHG emissions. Adaptation covers a much larger span of measures, among which the reduction of water-related impacts on cities. The first part of the report proposes a synthesis of the major trends on the subject all over the world. The second part summarizes several case studies in different countries and continents, with various levels of urban and economic development and threats linked to climate change.

This study is mainly based on articles and reports available on internet. These reports often have a double objective: on the technical dimension, and on information/communication. Technical aspects include how the question of adaptation is addressed, the solutions proposed; and the communication part aims at explaining urban decision-makers, and eventually citizens, the reasons for implementing an adaptation plan. Depending on the cases, this second part may be more developed, at the expense of the technical one.

The question of CC adaptation of the water sector is of primary importance as one of the largest impacts of climate change is likely to be on/from water resources and their management (Parry et al. 2009). The UNFCCC report (UNFCCC 2007) was the first one to provide global scale estimates of the adaptation cost for water supply. Approximately **US$ 9 –**

11 bn/year are required in 2030 as additional investment and financial flows for water supply adaptation. A critical analysis of this value (Parry et al. 2009) considers that it is under estimated, and that residual impacts not covered by adaptation are likely to be high. In addition, it is only an additional value which does not include the cost of providing a certain level of service where it does not currently exist, and the UNFCCC estimates that the total investment cost to be considered is about **US$32–40 billion /year.**

Moreover, **US$ 11 – 12 bn/year** would be required for adaptation to sea level rise. These values don't only consider cities, but also natural coastal zones. Conversely, concerning water supply related costs, one can consider that they mostly concern urban areas.

According to OECD (2013) good adaptation strategies should not focus on one water risk (like heavy rainfall or drought), but on 4 different risks together: excess of water (destructions with submersions and fast flows); shortage of water (for residents and economic activities); loss in water quality making it unsuitable for some uses; and undermining the sustainability of water resource (eco) systems, which may compromise the huge services rendered by them to human activities. The link between these elements is current in water resources management, and it is getting ever more important with growing megacities and with climate change varaibilities.

I. Water, cities, climate change and its economy

Water, cities and climate change: two types of impacts

Arnell in (Parry et al. 2009) indicates that "*The 'water sector' is very diverse, and climate change is anticipated to impact upon many activities. These activities include: the supply of safe water to domestic, industrial and agricultural consumers (including for irrigation); the provision of sanitation and the removal and treatment of effluent; support of navigation; management of flood hazard (from drains, rivers, groundwater, overland flow and so on); measures to provide protection or reduce exposure; generation of hydropower; and the management of river flows and water levels to support agriculture, recreation and the provision of ecosystem services (such as support for instream and riverine ecosystems)*".

For a better scientific approach, CC impacts in cities have to be split into two categories, which influence the adaptation strategies to cope with them : the impacts directly caused by extreme weather events (for instance hurricanes) and the impacts caused by long term modifications of the water cycle (for instance modification of the flow regime of rivers). Analysing both phenomena separately is needed to better assess their combined impact. If extreme events are bound to increase in number and in force, it will be partly because of a changing long term water context: typically, slow sea-level rise will aggravate the impact of extreme marine submersion events.

Impacts related to rare hydrometerological events

Many authors including (Rosenzweig et al. 2011; Revi et al. 2014), indicate that climate change will lead to increased frequency, intensity and/or duration of extreme weather events.

These extreme weather events are characterized by their catastrophic consequences on human life, private and public goods, and more generally on the usual functioning of the city. A typical example is the Katrina hurricane in New Orleans (2005/08/29). Most of these events are hydro-meteorological ones likes extreme rainfall leading to river and surface floods, intense coastal storm surges leading to exceptional sea-level rise, but also heat events leading to intense and prolonged drought.

On the other side long term climate evolution, with average temperature on the rise, will lead to structural changes of the hydrological cycle or to sea level rise. These changes may impact also the ecosystems in the catchments where the cities are located, with possible retro-actions on them. Indeed, some cities may experience both a reduction of water resources availability, and an increase in flooding episodes.

Water management in cities will be impacted by both categories, and adaptation strategies have to be designed and implemented to cope with their combined impacts. Depending on their location, various cities may suffer different types of extreme events:

- Tidal floods (including erosion)

In their analysis of the impacts of tidal floods on port cities, (Hanson et al. 2011) estimate that about 1 in 10 of the total population in concerned port cities are currently exposed to a 1 in 100 year (1/100yr) tidal flood event. By the 2070s, total population exposed could grow more than threefold due to the combined effects of sea-level rise, subsidence, population growth and surface sealing with urbanisation. Actually CC and subsidence exacerbate the exposure which is mainly driven by population growth, socio-economic growth and urbanization.

Exposure is concentrated in a few cities: collectively Asian megapoles dominate population exposure now and in the future and also dominate asset exposure by the 2070s. Importantly, even if the environmental or socio-economic changes were smaller than assumed here the underlying trends would remain. This research shows the high potential benefits from risk-reduction planning and policies at the city scale to address the issues raised by the possible growth in exposure. Most of the cities identified at risk now and in 2070 are concentrated in Asia: Mumbai, Guangzhou, Shanghai, Ho Chi Minh City, Kolkata, Tokyo, Osaka-Kobe,Tianjin, Bangkok, Dhaka, and Hai Phong.

Unfortunately, illegal settlements and fast in-migration makes planning policies structurally weak in large Global South cities. The same holds with early warning systems and other non-structural measures like insurance super-funds, which end up far more developed in rich occidental cities where population growth is smaller and urban expansion better controlled.

- river floods

On the basis of Global Circulation Models coupled with global hydrology and land surface models, river flood hazard will increase over half of the globe (south and southeast Asia, tropical Africa, northeast Eurasia, and South America) but with great variability (Jimenez Cisneros et al. 2014).

By the end of the 21st century, the number of people annually exposed to the equivalent of a 20th-century 1/100yr river flood is projected to be three times greater for very high emissions (Representative Concentration Pathway 8.5(RCP8.5)) than for very low emissions (RCP2.6) (multi-model mean) for the population distribution as it was in year 2005 (Jimenez Cisneros et al. 2014).

- surface floods

Although experts consider that an increase in extreme events will also occur at the city scale (Revi et al. 2014), there are still large gaps in our understanding of the small scale rainfall related processes (Arnbjerg-Nielsen et al. 2013), relevant at the city scale, which make it difficult to infer precisely the consequences of CC on rainfall at this scale and consequently its impact. The second reason is our lack of understanding of how the urban drainage sector should react to the large changes in precipitation extremes that climate change will potentially generate (Arnbjerg-Nielsen et al. 2013). This is particularly the case if urban policies encourage infiltration and storage of rainfall at private property level: monitoring the take-up of measures is difficult and costly.

- Extreme droughts

There have been few assessments of the potential effect of climate change on hydrological droughts (Jimenez Cisneros et al. 2014), either in terms of river runoff or groundwater levels. Several studies assess the modification of the river-flow regime, including low water periods (see below), but they are not focussed on 'drought' as an extreme or rare event. This is rather surprising as the consequence of extreme droughts may be very serious, especially in relation to water supply in urban areas. Perhaps that, compared to the violence of extreme hydrometeorological events, extreme droughts are much more insidious and progressive. Economic impact analyses are symmetrically scarce too. Another possible explanation is that severe droughts tend to hit the largest water users most, and usually this is agriculture, and also hydropower generation. On top of this, in rich areas like south-west United States, cities have an increasing opportunity to solve scarcity problems through the purchase of irrigation water rights. Therefore they usually do not associate water conservation or integrated urban water management (IUWM) to CC, but rather to sustainable urban water management in the face of anthropic changes (water not wasted ends up cheaper than most other alternatives).

Long term Impacts

- related to disturbance of the hydrological cycle (droughts)

Average annual runoff is projected to increase at high latitudes and in the wet tropics, and to decrease in most dry tropical/Mediterranean regions, although a very large uncertainty remains for some regions. (Jimenez Cisneros et al. 2014). Thus variations in the hydrological cycle may occur but how they modify the river regime remains uncertain and has to be precisely assessed. Typically, higher temperatures would reduce the snowpack while increasing winter runoff in winter snow-covered catchments.

For each degree of global warming , approximately 7% of the global population is projected to be exposed to a decrease of renewable water resources of at least 20% (multi-model mean) (Jimenez Cisneros et al. 2014). For some cities: Paris (Ducharne et al. 2009), London (Greater London Authority 2011b), a decrease of water resources linked to a modification of the hydrological cycle on the catchment is expected. This will impact the water supply in these cities, and possibly, as a consequence, WSS management in cities will undergo fundamental change, favouring water reuse, the development of non-drinking water networks, etc. Such decrease will also impact the behaviour of the river ecosystem and reduce the dilution capacity of receiving bodies. As a consequence an improved quality of treated waste water will be necessary before discharge for reaching the required standards.

- related to sea level rise

Sea level rise is also a long term CC impact. The new IPCC estimates for global mean sea level rise are for between 26 and 98 cm by 2100; this is higher than the 18-59 cm projected in AR4 (Stocker et al. 2014). However major impacts occur when Sea level rise are associated to storm surge and lead to widespread effects on populations, property and coastal vegetation and ecosystems, and present threats to commerce, business, and livelihoods (Revi et al. 2014).

Water, cities: climate change or global change?

In most cities it is impossible to separate the impacts caused by CC and the other causes of changes. Moreover, the impact of these other changes is usually larger than CC impact, and the driver of adaptation in those cases is actually not the climate change.
The main other changes included into the concept of global change deal mostly with the demographic increase in numerous cities in the world including:

- increase of population from both internal (population growth) and external (local, regional or international immigration);
- urban sprawling, and modification of the water balance (infiltration/runoff/ evapotransipration);
- increase of groundwater extraction and surface water abstraction;
- increase in wastewater production and discharge, more or less well treated, with consequences on human and ecosystems health.

Moreover a significant part of people living in cities in the world do not benefit a satisfactory level of water service. A billion people currently lack access to safe drinking water, and 2.4 billion lack access to basic sanitation (Parry et al. 2009). Adaptation is an opportunity, not only to reduce the impact of climate change but also to improve the standard of service.

Water, cities and climate change: costs of damages and adaptation

There is no precise monetary estimation of damages in the water-cities sector, caused, now or in the future, by climate change. However, as more and more people are now living in cities and in megacities, the issue of the adaptation of the water sector in cities has to be carefully assessed in order to have a more accurate idea of the cost of damages and adaptation.

Numerous cost values are present in the literature, but the perimeter of damages taken into account may vary among authors and the perimeter of the area may also vary. For instance damages caused by river floods are frequently estimated at the catchment scale and not at the city scale. Thus a very detailed and careful work remains to be done to compile at the cities' scales all the damages caused by water on the first hand. Rough estimates of adaptation and damage are summarized in Table 1 and Table 2.

Moreover the projection of these costs in the future, taking into account CC effects is a very perilous exercise: up to now, there is no well admitted methodology to downscale the IPCC scenarios at the city scale (Arnbjerg-Nielsen et al. 2013). In addition, we could notice that many methodologies tend to combine the downscaling of IPCC scenarios at local or rather regional level, with scenarios of economic development, urbanization, and of probabilities of extreme events. Thus results tend to be weakened by the adding up (or rather multiplication) of uncertainties.

Yet Revi and collaborators mention that "*Much of key and emerging global climate risks are concentrated in urban areas. Rapid urbanization and rapid growth of large cities in low-and* *middle-income countries have been accompanied by the rapid growth of highly vulnerable urban communities living in informal settlements, many of which are on land at high risk from extreme weather* " (Revi et al. 2014)

Table 1 main adaptation expenses in the water sector in cities (to be completed)

Sector	Purpose	Region	Value of adapation (US$)	Horizon	reference
Water supply	Adaptation	World	9-11 bn/year	2030	(UNFCCC 2007)
Water supply	Adaptation + service improvement	World	32-40 bn/year	2030	(UNFCCC 2007)
Stormwater flood risk	Adaptation	England& Wales	1.4 – 1.7 bn/year	2050	(ICF 2007)
Water supply	Adaptation	China, Huang He	500 million/year		
Waste water	Adaptation	New York City	$315 million in 4 years		
Stormwater	Multiple adaptation	Copenhagen	DKK 8 bn / $1.2 bn		

Table 2 main damage cost estimates in the water sector in cities (to be completed)

Sector	Purpose	Region	Value of adapation (US$)	Horizon	reference
Urban flood	estimation	world	100 bn		Markandya
Rivers flood	estimation	Europe	7.3 bn/year	2030	(Jimenez Cisneros e
River flood	Observation (B2)	europe	6.4 bn/year	19616-1990	(Jimenez Cisneros e
River flood	Observation (A2)	europe	18 bn/year	19616-1990	(Jimenez Cisneros e

As a conclusion, not only the risk, but also the investment necessary for adaptation with or without the upgrade of the service are enormous and become a real challenge in the adaptation to climate change. Typically, enormous costs with small occurrence probabilities make it difficult for politicians and the public to consider related threats sufficiently serious to take action. Indeed, many non-structural measures, which end up much cheaper than structural ones, are not implemented and even not really budgeted. CC frequently remains just a 'ticked' box in an urban policy future agenda. And where IUWM elements are being implemented, it is much more for the sake of urban sustainability in general than specifically for CC anticipation. The same holds with lack of access to water in Gobal South cities: when McDonald (2011) writes that an estimated 150 million people currently live in cities with perennial water shortage; and that population growth and climate variability may increase this number to 1 billion by 2050, we tend to think that this growing shortage is primarily due to the economic incapacity, and sometimes the political unwillingness, to tap appropriate resources and distribute them to poor urban populations. Money scarcity is far more important than water scarcity, and CC threats might not modify this state of affairs.

II. Synthesis of the case studies

Many cities designed and/or implemented adaptation plans. These plans cover a quite wide range of situations. More than 20 case studies have been analyzed on the basis of technical reports either sent by our colleagues in other countries, or available on the internet, and detailed communication documents, also available on the internet. It must be pinpointed that these communication documents are often rather detailed and give a good overview of the adaptation plans; however technical and economic data are unfortunately usually missing. Peer-reviewed papers which analyze the adaptation plans have also been studied.

Analysis of the database

23 case studies covering a wide range of situation have been analysed.

Table 3 : List of cities analysed in this report. These cities designed or implemented water-related adaptation plans

City	Country	Continent	Risk/adaptation (purpose of the adaptation plan)	GDP (PPP)	%GDP/GDP country
New York	USA	North-America	Tidal flooding Surface flooding		
Mumbai	India	Asia	Tidal flooding Surface flooding		
Kolkata	India	Asia	Tidal flooding		
London	UK	Europe	Tidal flooding Surface flooding River flooding Drought/ WSS		
Copenhagen	Denmark	Europe	Surface flooding Sea level rise		
Rotterdam	The Netherlands	Europe	Tidal flooding Surface flooding		
Sub-saharian Africa		Africa	Drought / WSS		
Durban	South Africa	Africa	Drought / WSS		
Alexandria	Egypt	Africa	Erosion/coastal flooding		
Tunis	Tunisia	Africa	Surface/tidal flooding		
Algiers	Algeria	Africa	Earthquake/surface flooding		
Casablanca	Morrocco	Africa	Surface/tidal flooding		
Sao Paulo	Brazil	South America	Drought / WSS		
Manila	The Philippines	Asia	Tidal flooding		
Bangkok	Thailand	Asia	Tidal flooding		
Ho-Chi-Minh-City	Vietnam	Asia	Tidal flooding		
Dar es Salaam	Tanzania	Africa	Tidal flooding		
Mombasa	Kenya	Africa	Tidal flooding		
Jakarta	Indonesia	Asia	Tidal flooding		
Johannesburg	South Africa	Africa	WSS scarcity		
Hérault littoral	France	Europe	Tidal flooding		

For most of the cities located in developing countries, the analysis of damages and/or the design of adaptation strategies was subsidised by international organisations, including the World Bank, and realised mostly by foreign and mainly Western consultants (BCEOM-EGIS-France, Deltares-The Netherlands for instance). For other cities (London, Rotterdam, Copenhagen, New York) in developed countries, municipalities themselves produced their own adaptation plan, in a very pro-active way; it means that a better adaptation to CC, and especially to CC consequences on the water flows and runoff in the city is an opportunity for the city and its economy. Particularly it may give the necessary "activation energy" to change the course of city planning, strategies and habits and to propose new ways of thinking the interrelations between the city and water. The generalised presence of the "blue-green" expression in the texts of the reports is a good marker of this new strategy.

As a consequence it is sometimes difficult on the basis of the corresponding reports to get a comprehensive view of the situation and especially of the interaction between the city's development strategy and the adaptation plan. An analysis of all the intermediate documents, and other city planning related document would be necessary, as well as some meetings with political representatives and technical staffs to discuss their feeling a few years after the end of the adaptation study. This would be very interesting but is obviously behind the scope of this report.

The World Bank promotes the concept of "Integrated Urban Water Management" (IUWM) which is actually a city-scale declination of the catchment scale concept of "Integrated Water Resources Management" (IWRM). This concept which has various interpretations, aims at describing the various kinds of water which are present in a given city (freshwater, stomwater, wastewater, grey water, but also pressure-piped water -potable or not-, ..) as interacting components of the global water cycle, which necessitates for an efficient and sustainable management of water resources an approach which, on the one hand considers all the various kinds of water together, in a holistic approach, and, on the other hand, considers the interactions between 'various waters' and the city, and the role that water has to play in the planning and in the development of the city.

When most of the Western European cities grew during the industrial revolution, water supply and sewage networks contributed largely to the production of a wealthier city and to the increase of the life expectancy. However water management was an engineering issue entirely depending on previous choices and ideas of the urban planners (either following them or anticipating projected growth and expansion). Water engineers had to face the consequences of urbanization with their technologies.

Now the background idea of the IUWM concept is to consider water as a major factor in the fabric of the city and to develop what Australians have called "Water Sensitive Urban Design" (Fletcher et al. 2014).

However this concept remains from our point of view rather theoretical or ideal-typic, as there is no uniform methodology for implementing IUWM strategies[1], but also because, except when a new city is built-up from scratch, the pre-existing organisation of the city's space, and of its technical services (planning, water supply, sanitation) makes an optimal implementation of IUWM strategies quasi impossible (Geldof 1995). Moreover as we live in a more and more litigation_prone society, technical services develop stricter and stricter regulations, firstly to protect themselves from lawsuits and legal actions, which also inhibit the development of innovative solutions in the frame of IUWM (e.g. costly regulations on rainwater reuse for the sake of impeding backflows in the potable supply system).

[1] and fortunately there isn't any, because each case, each city is different.

Starting from this experienced-based position, we do not consider that the various adaptation strategies that we have been looking at fully comply with the concept of IUWM, all the more so that it is the economic dimension of impacts and adaptation measures that was under study; and this led to privilege evaluating measures that could be separated, which in turn might have brought authors to loose sight of the global IUWM type of adaptation. Moreover, in rapidly growing cities (Global South), it is perhaps too complex and difficult to consider an IUWM approach under a global- and not only climate- change perspective,. An in-between and multi-scale approach has probably to be adopted, which on the one hand gives an overview of the water cycle in the cities and identifies the main interactions between the various waters and the urban planning, and on the other hand develops a much more sectoral approach with a focus on each specific water sub-system.

However, it is obvious that in most case studies, the various sectors related to water which may be significantly altered with CC were taken into account. All the previously described impacts are present in one or another case study:

- littoral flooding is probably the most frequent impact
- surface flooding is also very frequent
- river flooding is less frequent, but often concomitant with other flood types
- long term sea level rise is usually included in future littoral flooding
- droughts are mentioned either as extreme weather events or long term trend, with consequences on surface/ground water levels and resource availability.

All the other CC impacts on/from the water sector are only rarely mentioned (relation to water quality, ecosystems, etc.). One noticeable counterexample is the case of London, where a major work, the tideway tunnel, is presently under construction and aims at reducing the combined sewer overflows in river Thames, which are supposed to increase with CC. However, climate change was not the main driver of the project but the improvement of the river Thames water quality during wet weather periods as required by the EU -WFD (Water Framework Directive, 2000/60 EU) and -UWWD (Urban Waste Water Directive, 91/271 EC).

The various ways of adaptation

In general, adaptation solutions aims at (City of Copenhagen 2015):

- reducing the likelihood of the event happening;
- reducing the scale of the event;
- reducing the vulnerability and reinforcing the resilience.

Often, an additional and opportunist consequence is to take advantage of the adaptation measures to contribute to improve the sustainability of the city and its quality of life. This is absolutely clear for cities like Rotterdam, Copenhagen and London for instance. In New York city, the adaptation plan presented in the report ‘A more resilient New York’, devotes 80% of the projected $19.5 bn expenses to repairing damages of recent hurricane Sandy. Hopefully, this rebuilding effort will be at least partly made within an IUWM concept.

Moreover a multi-scale approach is often required in the implementation of adaptation plans.

This means that the solution is not a unique solution at city scale, but a set of solutions at various scales, from the city-scale down to the lot or building scale.

The set of solutions includes both structural and non structural measures. Structural measures are of two kinds:

- hard techniques (dikes, levees, tunnels, networks, reservoirs, …)
- soft techniques (urban planning, SUDS, green roofs, water harvesting

Concerning the flooding risk, 'hard' structural measures aim at physically protecting the city from floods, using static or dynamics structures.

- Levees and dykes are the most usual protection measures and have been used since several centuries in all lowland regions, located along coasts or along rivers. The aim of these measures is to prevent the water propagation in the city, and to keep it either on the coast or in the river. In most cases, it is considered that CC will decrease the return period of extreme intensity events, thus for keeping the same level of protection it is often necessary to reinforce levees and dykes: through all our case-studies, while usually the best B/C ratios are obtained for early warning policies, the highest B/C ratio by far is with the reinforcement of the protection of Mohammmedia's industrial harbor from sea surge in Morocco.
- Dynamic structures are more and more frequent and aim most of the time at temporary suppressing the exchanges of water between the sea and inland water bodies, in estuarine zones. Thus an increase of sea/river water level will not cause an increase of the height of the water bodies and will prevent flooding. These structures are called "dynamic", because they alternate an "open" configuration enabling water exchange and related activities like navigation (most of the time); and a "closed" configuration during alert periods. Such dynamic structures exist in Rotterdam, London and in the adaptation plan of Ho-Chi-Minh-City for instance.

Concerning the drought risk and related water supply threat, various 'hard' structural measures are also often considered:

- The construction of new storage reservoirs within the catchment of the city, but also the development of supply networks at regional scales ('up-scaling') to facilitate exchanges of water from catchment to catchment, or from one part of a catchment to another part (London, São Paulo, Australia)
- The construction of desalination plants which is a costly solution but often used in Australia for instance, where either a decrease in the river flow has been observed for many years (Perth) or where pluri-annual droughts have been observed (Sydney, Melbourne) (Isler, Merson, & Roser 2010). If this solution is obviously an adaptation solution, labeled there "climate proofing", it is not certain that it is a sustainable one: in both cases investing in desal. technology resulted from the political difficulty to impose demand-side restrictions.
- The closing of the urban water cycle, based on treated wastewater infiltration upstream of groundwater pumping for water supply (e.g. Barcelona).

Softer structural measures are frequently combined with 'downscaling' water management: in Germany and in the Netherlands, there are several ongoing projects of eco-neighborhoods, where storm water, gray waters and black waters are collected separately to facilitate their re-use and the valorization of what was previously considered as waste. They are part of IUWM approaches, and CC is only part of the arguments to adopt these costly resilience approaches.

In addition, when surface flooding is recognized as a major flooding risk, sustainable runoff management techniques are systematically proposed, which aim at favoring surface management of water and on-site infiltration when possible. However, increasing rainwater infiltration may influence the behavior of the underground network; but this is usually not taken into account.

Non structural measures include:

- regulations → (e.g. Copenhagen flood control through planning)
- incentive measures, like conditional insurance coverage from a superfund
- they could also include territorial policies to partly replace technology by 'natural capital' (e.g. New York city strengthening land-use control on its water supply production area in anticipation of CC related heavier rainfall)
- More generally, they could encompass all cases where WSS services get directly involved in water resources management at catchment scale, and will propose funding the reallocation of water abstraction and discharge rights, so as to improve the resilience of urban areas they serve.

In a project funded by the French National Research Agency, a partnership co-ordinated by B. Barraqué[2] proposed to study the sustainability of urban water supply (and to a lesser extent, sanitation) by improving knowledge on the four dimensions of it: environmental, economic, equity, i.e. the 3 Es, plus governance, while showing how they interacted in a complex manner. A review of past and ongoing resiliency strategies developed in European member States, USA and Australia, led to propose a typology in 3 broad strategies:

- Up-scaling water services (at least production of drinking water and waste water treatment) at regional level or even at river-basin level; this implies to develop supra-local multilevel governance.
- Downscaling water services at infra-urban scale, like neighborhood, street, even housing levels; this usually implies to develop a new 'internal' governance, i.e. new relationships between water services authorities, technical operators and citizens.
- Going 'smart' and choosing the way of technology sophistication to solve present/ future problems with minimal governance change from existing situation.
- And obviously, actual sustainability improvements may combine elements of these three ideal-types.

This project was more concerned with IUWM than with CC impacts, and reports by different partners do not contain economic evaluations of CC impacts or adaptations per se.

Methodologies to assess adaptation costs (strengths and weaknesses)

From the present literature review, it appears that much more work has been done on floods than on droughts. Typically, in New York, the adaptation study had already been initiated when hurricane Sandy hit the city: it gave an additional impetus and greatly helped to actualize vulnerability and hazard data. Post-hurricane remediation was then the basis for

[2] The project is called EAU&3E, was driven from 2009 to 2013, and it is presented in a blog: http://eau3e.hypotheses.org

proposing the 250 measures. They cover a wide spectrum of actions from housing to transportation, electric systems and waste water management. It remains to be seen whether this impressive set of actions will receive funding, and if implementation will give a large share to IUWM-based approaches.

Droughts on the other hand are spread on longer periods of time, which does not facilitate economic analyses of additional CC impacts. Yet it would be now opportune for e.g. southern California and São Paulo urban regions to start some specific study. The fact that Southern California cities can rely on agricultural water wheeling to alleviate their own droughts problems, should not prevent them to draft IUWM-based adaptation plans at their own scale (beyond already existing water conservation encouragements, e.g. regulations favoring xeri-gardening).

The good economic assessments which we found typically progress step by step (Hallegatte et al. 2010): starting from one or a few recent extreme episodes, one first tries to assess its/their impacts, direct on damages, and indirect from economic disruption losses. Then the return probability is estimated, and then a new probability of occurrence is calculated under various IPCC climate change scenarios, downscaled at urban level with various modeling techniques. The model also includes a scenario of urbanization evolution, including, when appropriate, additional wetland occupation, soil sealing and even land subsidence. Once the future economic impact is estimated, it can eventually be averaged over a longer period of time, and eventually can take sea level rise scenarios into account.
Adaptation models can then be run, providing at best benefit-cost analyses confronting the cost of adaptation measures to the reduction in CC economic impacts.

Special mention must be made of the 4 reports on North African cities (Alexandria, Tunis, Algiers and Casablanca), funded by the WB for three of them and by the French National Savings bank for Algiers, because they worked during two years with the same methodology: a first phase of disaster diagnosis; and a second phase where operational actions are confronted to damages in economic terms; these actions cover not only water related issues but also earthquakes (and more superficially heat-waves), and they are presented through 'action sheets'; in turn this detailed work allows to calculate costs of damages and benefit-cost ratios of adaptation measures, at least for the most important and relevant ones. It is noteworthy that in the 4 cases, better crisis management through e.g. early warning systems, remain and will remain the most beneficial adaptation measure.

Another very interesting case is Copenhagen's adaptation plan (City of Copenhagen, 2011), where it is demonstrated that the sewer system already reached the limit of the capacity to face extreme storm water events; and that aggravation of these events with climate change just reinforce a positive comparison of alternative solutions with traditional sewer widening and system expansion. The plan includes measures at building level (backwater valves and doorstep light temporary walls), at street network level (channeling excess water towards watercourses in surface) and green infrastructure and other devices to ease post event recovery. In this case, uncertainty is partly reduced by the existing land use strict control and the limited forecast population growth.

There are however limits of these modeling efforts when addressed to large Global South megacities (Ho Chi Minh City for instance): so many uncertainties add up (which authors admit) that there is a very serious uncertainty on these economic estimates. This is all the more problematic that figures are very high: high and uncertain, this is not to encourage decision makers to move forward and develop serious adaptation plans like New York seems to be doing.

We have also identified other approaches, far more empirical: typically in the London case, the cost of damages is directly derived from the observation of the cost of a recent extreme event which hit southern England. Extrapolation of £3 bn damages gives an estimate of £10 bn, with no further justification. It remains to be seen if such calculations will suffice to trigger an ambitious CC adaptation plan …

Conclusion

It is striking that in most documents we could review, climate and socio-economic changes are described all right; sometimes the losses due to recent dramatic episodes, both direct and indirect, are calculated, and a ‘climate plan’ is announced and budgeted; but in most reports, little is said about the economic impact of projected water-related events under future CC and urban development conditions. Most of cities having performed this kind of study in Asia have benefited from World Bank or ADB specific funding, or from Dutch cooperation in programs like the Delta Alliance.

This is particularly true for potentially CC related droughts. While in the case of floods, recent dramatic episodes have brought opportune support to the analyses of climate impacts through water and to adaptation measures budgeting-financing (typically in the case of New York City), there is little equivalent available for droughts, probably because they do not occur suddenly, but last longer, and hit harder other water users than cities. It remains to be seen whether the ongoing dramatic droughts in cities of southern California and in São Paulo will trigger the same kind of analyses. In any case, the summer 2015 wild fires burning Northern California are probably partly due to climate change, and then a related cost could be calculated, in particular with the loss of housing in urban peripheries. Adaptation costs could include improved insurance systems, but also the reinforcement of fire services, which ironically were reduced after proposition 13 was adopted during the conservative revolution period.

We however found one large city having performed such an analysis of CC impact through droughts with a CBA on several adaptation measures: Barcelona, which also drafted another report on aggravated floods. We are ready to hear from more cities undergoing such risk.

There are very few studies that cost impacts and adaptation options associated with water supply. An exception is a study in the UK by Wade et al, (2006) who estimated that the economic losses to households of foregone water use due to an anticipated water deficit by 2100 in the region of South-East England could be between £41m ($50m) and £388 m ($450m) annually, depending on climate scenario, but that the costs of largely eliminating these deficits would be between £6 million/year and £39 million/year ($7.5m and $46m, respectively).

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CASE STUDIES

AMERICAS

Introduction

A separate count by the Georgetown Climate Center found that in the United States, city, county and state governments have developed more than 100 adaptation plans,. And through a UN-financing initiative, wealthy nations have poured $11 billion into developing countries to help on adaptation in the past few years… Yet "a lot of them tend to be an overarching, big vision document," or focus on a single, massive project, like a floodwall, said JoAnn Carmin, a professor in urban studies and planning at MIT. In some cases, there's no clear work plan in place." A lack of funding to pay for comprehensive analysis, a focus on other municipal priorities and a shortage of qualified staff is often to blame. And local governments rarely have access to data on the specific risks that global warming poses to their particular city. Still, adaptation strategies around the world are maturing as cities and countries build on initial efforts. The world could end up spending between $49 billion and $171 billion a year through 2030 on adaptation, according to UN figures. Some scientists put the figure at up to three times that amount.

Hunt & Watkiss (2011) for instance, recall that: "Hallegatte et al (2007), using a non-equilibrium dynamic model, estimate that the full macro-economic costs of Hurricane Katrina were about 25% more than direct costs alone, giving total damage costs associated with the event of $130 billion". Nordhaus (2006) assessed the economic impacts of U.S. hurricanes (on the Miami coast and New Orleans) and estimated that the average annual hurricane damage could increase by $8 billion at 2005 incomes (0.06 percent of GDP) due to the intensification effect of a CO_2-equivalent doubling alone, in a future, non-specified, time period. Kirshen et. al. (2004) estimated that total losses throughout metropolitan Boston from river flooding would exceed $57 billion by 2100 assuming no adaptive steps are taken, of which $26 billion was attributed to climate change. In this instance, pro-active adaptation was found to reduce these costs by 80%.

New-York City

New York City's ambitious $19.5 bn climate plan appears a leader among US cities.

New York City's analysis of water related impacts and adaptation strategies

Launched on June 11, 2013, by Mayor Bloomberg, a plan entitled "A Stronger, More Resilient New York" (City of New York, 2013), was developed in response to superstorm Sandy, which engulfed 1,000 miles of the Atlantic coastline—delivering a 14-foot (427 cm) storm surge to New York and crippling the nation's financial capital; and cost $19 billion in damage and economic losses to the city of 8.2 million people. The storm showed just how unprepared New York and other coastal cities are to handle flooding from weather disasters.

The 438-pages plan was based on hyper-local climate models specific to New York City, using the most up-to-date science available. The models, which predict climate trends through the 2050s, were crunched by the New York City Panel on Climate Change (NPCC), an independent group of scientists and engineers established back in 2008 as part of PlaNYC, the city's original sustainability and climate strategy.

Yet, the scientists are concerned that even the worst-case projections envisioned in Bloomberg's plan could be too conservative. That's because the model's projections stop in the 2050s, even though they will be used to develop construction guidelines for buildings that could stand in New York's floodplain for centuries. The new models show that nearly one-quarter of the city will be in a floodplain by the mid-2050s, with large swaths of Brooklyn, Queens and Staten Island prone to frequent widespread flooding. The number of intense hurricanes to hit New York City will increase, as will extreme winds and heavy rain.

Sea levels in New York Harbor will likely rise four to eight inches by the 2020s, with a worst-case scenario of 11 inches. By the 2050s, they could rise 11 to 24 inches (28 to 51 cm)—nearly double what the NPCC projected four years ago—with the worst case being 31 inches (80 cm). Rising seas will make storm surge more severe—meaning that in just a few decades even small storms could cause the type of flooding unleashed by superstorm Sandy.

On this basis, the report includes an estimate model of expected loss and a cost benefit analysis to help prioritize the most attractive measures in the plan. The model combines Swiss Re's past natural catastrophes modeling, and NPCC scenarios, to assess the probability of value impact on various categories of assets (buildings, transportation, telecoms, utilities etc.), and this broken down by zip code.

The model focuses on hurricanes and does not cover other climate impacts like heat waves, droughts, heavy downpours on potable water abstraction areas etc. It also does not take into account potential land use changes in the coming decades. Finally, it is limited to evaluate the physical damage to assets plus indirect loss due to physical damage. This is how Sandy's costs can be broken down into over $13 bn physical damage and $6 bn of lost economic activity. But then the event which was estimated a once-in-70-yr could become a once-in-60-yr in 2020 and a once-in-50-yr in 2050. Another once-in-70-yr event taking place in 2020 would raise the impact cost to $35 bn, due to the combination of strong winds and sea-level rise; and in 2050, land-use being the same, the loss would reach $90 bn, i.e. almost 5 times Sandy's loss.

Swiss Re's simulation based on a multiple repetition of events from tropical storms to category 5 hurricanes allowed to add two items in 2050 to the present loss expectation of $1.7 bn: $1.5 bn additional with sea-level rise, and $1.2 bn additional impact from increased frequency of intense hurricanes.

The Bloomberg administration estimates that the cost of implementing and researching the plan's 250 proposals will total $14 billion over a 10-year period. The plan also factors in the cost of certain post-Sandy recovery efforts, bringing its total price tag to $19.5 billion—only slightly higher than the $19 billion in damage and loss of economic activity wrought by Sandy, making it both an adaptation and a disaster recovery plan.

Eighty percent of the money will go to repairing homes and streets damaged by Sandy, retrofitting hospitals and nursing homes, elevating electrical infrastructure, improving ferry and subway networks and fixing leaky drinking water systems. The rest will go to building or reinforcing floodwalls, restoring swamplands and sand dunes, and other coastal flood protections. Wastewater facilities were heavily impacted by Sandy, because the 14 treatment plants and 96 pumping stations are located in low-lying areas. The Department of Environmental Protection has drafted a wastewater resiliency plan amounting to $315 million investment just for the protection of waste water treatment plants and pumping stations. In addition, they consider developing co-generation of energy to help increase the autonomy of waste water treatment facilities during electricity network breakdowns. Several initiatives concern the greening of drainage infrastructure (e.g. bluebelts projects across the city) since Sandy showed that one of the major problems in crisis situations is uncontrolled discharge of combined sewer overflows. Lastly, a third strategy aims at promoting redundancy and flexibility to ensure constant supply of high quality measures: fixing leaks in Delaware aqueduct, improve interconnections between Catskill and Delaware aqueducts, and increase watershed protection from erosion to maintain the quality of water supply from turbidity.

About half of New York's total plan will be funded by federal aid and city capital that's already been allocated, and the city government expects to provide an additional $5 billion. That leaves a funding gap of at least $4.5 billion.

Some components of the plan require approval or action from outside City Hall, including an initiative to set new resiliency standards for electric utilities and rebuilding programs that would use federal housing funding. Multiple city agencies will also have to coordinate with one another to determine how the money is divided up.

California

We have found some literature on CC impacts on hydrology and water availability in South-West US, chiefly with warmer and drier climate. This means that the largest threat form CC is increased and more prolonged droughts, as can be witnessed presently. But this documentation is global and usually does not present economic impact calculations, neither adaptation plans with economic figures.

Concerning our specific study on water and cities, an explanation to this can be found in an interesting paper published online in Climatic Change in 2007, from a study made in 2006 (see Medellin Azuara, 2008): cities are protected from CC additional scarcity because they can eventually purchase water from agriculture, and thus pass the economic costs of a drier and warmer climate onto this sector which is by far the largest water user.

Authors rely on downscaled hydrologic results from a dry-warm climate (GFDL-A2GCM) for year 2085 into an economic-engineering optimization model of California's statewide water supply system at horizon 2050, developed under the leadership of prof. Jay Lund. (CALVIN, http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/).

"CALVIN (CALifornia Value Integrated Network) jointly considers the economic performance and physical feasibility of a wide variety of water management activities and economic performance, including surface and groundwater sources and storage as well as agricultural, environmental and urban water uses (Draper et al. 2003). CALVIN results go beyond simple cost-benefit analysis by using the economic value of water for different users and supply costs to develop economically promising combinations of water management activities from a broad array of options including system re-operation, conjunctive use, water reuse and desalination, water markets, and reductions in water use."

"Compared with the historic hydrology, optimized operations for the dry climate warming scenario raise water scarcity and total operation costs by $490 million/year with year 2050 demands. Actual costs might be somewhat higher where non-economic objectives prevail in water management. The paper examines the economical mix of adaptation, technologies, policies, and operational changes available to keep water supply impacts to such modest levels.”

However, most of these costs are borne by agriculture and by hydropower, not by urban water supply. Anyway the model focuses on California’s State level, so that urban adaptation alternative policies like IUWM are not considered.

Brazilian Cities

Increase in post-disaster reconstruction costs in the country : from US$65 mln in 2004 to US$1.5 bn in 2010 (of which 58% floods, 11% landslides, and 14% droughts).
According to the Painel Brasileiro de Mudanças Climaticas (Nobre, Ribeiro & al. 2012), between 1980 and 2004, there were 50 to 60 flood episodes having provoked an average of 100 casualties, and an average loss up to US$ 10 million. In the same period, about 10 situations of extreme drought took place, almost exclusively in the Nordeste, affecting more than 10 million people and causing losses up to US$ 100 million in average. However this report gives many more data on agriculture and food production losses than on cities.
More local and specific extreme weather events include:

- Drought in Amazonia 2005: ecologic and health impacts linked with fires: for Acre state, losses evaluated US$ 87 million.
- Santa Catarina, Vale do Itajaí, Nov. 2008: 700 mm in 4 days; 1.5 million impacted, 135 casuaties, losses = US$ 350 million;
- Alagoas, June 2010: floods, 268 000 impacted, 37 casualties, total socio-economic and environment losses = R$ 954 million, or US$ 420 million;
- Region of Fluminense mountains (north of Rio de J.) Jan. 2011: 900 casualties, and damages evaluated at US$ 1.2 bn. Federal Government reconstruction grant was up to US$ 466 million.

A project entitled Megacities, Vulnerabilities, and Climate Change (MVCC), covered both Rio de Janeiro and São Paulo metropolitan areas. Unfortunately, the 2012 report on Rio presents this vulnerability to climate change in a very qualitative manner, and does not give any costs for either future losses or adaptation measures. Yet the RMRJ metropolitan area is more at risk than Sao Paulo from CC, due to poor population being located in low land areas on the sea-side. In particular, the fast growing area east of bay of Guanabara is below 10 m above sea level, and that is where important petro-chemical investments were made recently (a complex named Comperj, US$ 8,7 bn).

São Paulo

The largest city in Brazil hosts 11 million people, and 20 million inh. live in the whole metropolitan area (RMSP). In 2006 the Gross regional product was R$450 bn, i.e. 56.2% of São Paulo State’s.

The area is already experiencing more heavy rains in spring, plus more erratic rains (could be linked to Amazon deforestation?). The ongoing severe drought is of course not covered by the study.

The MVCC report on São Paulo presents the Heat Island phenomenon: present temperature is 3 to 10°C above rural in the center of the city. Average increase in temperature is certain.

Average number of yearly rainfall episodes above 100 mm rose from 20 between 1940 and 1960, to 41 between 1981 and 2004.

A study by Haddad and Teixeira published in Habitat International (2015) attempts to improve the assessment of present-day heavy rainfall events. It proposes a methodology to go beyond direct losses, and to assess indirect impacts on the economic activity (local, regional and even national). In order to assess both types of impact for a given local flood, economists need a tripod of information on vulnerability: dependence from the global economy, redundancy (ability to respond to the event) and susceptibility (flood magnitude and frequency probability). In the case of Sao Paulo, the method consists in considering all the flooding events which took place in 2008, and to estimate the number of economic activities located at varying distances (from 50 to 200 m) from each flood point. Dependence is captured through spatial linkages associated with the value chains and income flows embedded in an input-output system used to calibrate the spatial computable general equilibrium (SCGE) model, and on hypotheses on interregional factor mobility; redundancy is contemplated on the strength of substitution effects induced by price effects and supply constraints in the SCGE model.

Specifically, authors "look at the economies of the city of São Paulo and of Brazil in 2008 and estimate what would be the hypothetical economy-wide impact had all flood events not occurred in that year. In doing that, we are able to derive the estimates of the economic costs of the floods related to the value chains disruptions associated with businesses' temporary close downs during the events. By not taking into account the effects of neither disruptions in infrastructure services nor financial flows associated with recovery of the natural disasters, we are able to isolate the economic effects of the flooding and its spatial propagation providing an approximation of the regional consequences from a value chain perspective. Thus, these estimates should be considered as lower bounds of the broader economic costs."

Calculations show that, taking business located within 100 m of the flood centre, the economic impact of 2008 floods on the whole Brazilian economy is 5 times the local damage (US$109 million vs US$ 22 million). The allocation of GDP Impact in all scenarios is similar: the city and the national level both take 44%, while the rest of SPMR takes 4% and the rest of the State of São Paulo takes 9%. The study does not extend its analysis on future water related impacts with CC inputs, nor does it consider the issue of adaptation costs.

A recent ppt presentation (Marengo, 2015) considers that "each inundated point after heavy rain in the Sao Paulo region creates a damage of more than R$ 1 million per day for the whole country, due to the production chains that are directly and indirectly touched. Present-day yearly impact of local flood for the city is R$ 336 million (US$ 105 mln), and if one includes indirect losses, R$ 762 million at national level (US$ 239 mln).

Adaptation : two papers mention that FUNDURB offers R$ 38 million to create 5 local parks. The Department of water and Sanitation of the city calculated that ongoing improvements in the drainage system would bring between R$ 17 and 21 million per year, just in traffic driving time saved. These are quite limited figures indeed.

EUROPE

Copenhagen

The head city of Denmark now hosts a population of 1.81 million (in 2010), and total insured assets value (TIV) chiefly includes the residential sector with more than €120 bn, while industrial and commercial sectors represent resp. about €8 and €50 bn. Copenhagen GDP reaches US$ 85bn (metropolitan area) (US$ 70 000 /per capita)

In an article published in *Climatic Change*, Hallegatte & al. (Hallegatte et al. 2011) chose the city to test the potential CC impacts due to storm surge on top of sea level rise, through a methodology based on a series of steps: (1) a statistical analysis of past storm surges in the area; (2) a geographical-information analysis of the population and asset exposure in the city, for various sea levels and storm surge characteristics; (3) an assessment of direct economic losses in case of storm surge (i.e. of the damages to buildings and occupiers' assets), excluding human life losses and other intangible direct impacts; (4) an assessment of the corresponding indirect losses—in the form of production and job losses, in reconstruction duration, amongst other losses—using ARIO, an adaptive regional input–output model; (5) a risk analysis of the effectiveness of coastal flood protections, including risk changes due to climate change and sea level rise.

Considering the large uncertainty on future sea level rise, several possible amplitudes of sea level rise were considered, from 0 to 125 cm, and results are presented in all these cases without trying to aggregate them for these various possible futures. Indeed, storm surges with levels up to 157 cm occurred several times since the beginning of the 20th century, but damages were either not recorded or not significant.

The exposure analysis shows that around 2% of the population (21,907 people) lives below an elevation of 1 m, 4% (44,446 people) below an elevation of 2 m and 13% (151,859 people) below an elevation of 5 m above sea level. For a sea level rise up to 1 m it is the industrial TIV which is impacted first (24% is below 1 m), but above this level, the residential sector's TIV becomes the most exposed.

In absence of protection, direct losses form a 2 to 4 m level could reach resp. €5/14 bn; using the well documented Katrina example, authors estimate the total direct losses to uninsured assets (incl. public infrastructure) at 40% of insured losses. And then they add up the indirect losses: "The *indirect* cost is the reduction in production of goods and services across the economy due to the disaster. The sum of what is not produced and what is produced but cannot be consumed is equal to the lost consumption, i.e. the cost of the disaster." An input-output model was needed, and authors chose ARIO. As a result, the model finds an important indirect incidence, but non-linear with direct losses. This is partly due to reconstruction which boosts this economic sector while other sectors are more durably hit. In the end, indirect losses remain minor up to 2 m level sea surge, but add €2 bn in the case of 4 m.

In this study, the adaptation dimension is only global, and strictly based on structural measures (e.g. sea walls): it applies uniformly to the whole city a theoretical level of flood protection between 1 and 3 m. As a matter of fact, authors conclude that the city is quite well protected from sea surges naturally, so that expected losses would currently be negligible with a 2 m level protection. However, with future sea level rise (which remains quite uncertain), losses would rise, so that higher levels of protection would be beneficial: Losses "increase to

€ 1 million per year with 25 cm of SLR, € 52 million per year with 50 cm of SLR, and € 4.2 billion per year with 100 cm of SLR. With 300 cm protection, mean annual losses are above zero only if SLR is larger than 1 m. With 350 cm of protection, even 125 cm of SLR does not lead to any losses." The construction cost of a higher protection level would cost of few hundred million €, but maintenance costs and indirect costs to the harbor should be also assessed.

Another report drafted by the city of Copenhagen itself (City of Copenhagen 2012) is an adaptation plan including an economic analysis. But it deals with extreme rainfall events which can occur as of now; it does not calculate additional efforts to be made with climate change in the future. One year before, a more comprehensive Climate Adaptation plan had been published, trying to assess how the risks would evolve from 2010 to 2060 and then to 2110. The major risks addressed were floods due to unusual rainfall and from sea surge. In addition, heat waves were covered. However, CC scenarios tended to show that until 2060, stormwater floods would be the most serious threat (average risk estimated at DKK 350 mln in 2010, 570 mln in 2060, and up to 1.05 bn in 2110; sea surge would become the most serious after 2060. Hence the orientation of the plan on extreme rainfall events for the coming years.

In July 2011 one single storm (150mm during 2 hours) caused damage up to DKK 5 - 6 bn (US$ 800 M, € 700M); it brought into question the previous approach of storing water in floodable areas until the sewer system would be able to drain it again, and triggered the climate adaptation plan in Copenhagen:
"New studies show that storage should be supplemented by measures where the water is led out to sea via roads, canals/urban waterways, and subterranean tunnels. Hence the preferred solution will be drainage out to the sea via new flow routes." On top of drainage system improvement and blue-green infrastructure measures, the proposal of the plan is to accept a temporary street flooding: "In the future: sewer discharge will be allowed to reach ground level once every 10 years, and average water levels will be allowed to exceed ground level by 10 cm once every 100 years, except in areas specifically designated for flood control storage".

Using the model Mike-Urban (which calculates maximum water which can be accommodated in a sewer system) the authors wrote that the system today can not fully accommodate a 1/10 yr event: 48 ha are then flooded chiefly by watercourses' backflow; and 230 ha are flooded with a 1/20 yr event, for the same reasons. For a 1/100yr rain, as occurred indeed in August 2010, 595 ha are flooded, this time because the city itself cannot accommodate the rain. In 2060, due to CC, the area flooded by a 1/10yr event would rise to 58 ha. In 2010 a 1/100yr rain would flood up to 742 ha. For extreme events above 1/20yr, it would be necessary to help evacuate excess water by pumping it from the sewers to watercourses (as is already done in Bordeaux, France). The idea would be to disconnect one third of the volume of water from sewers. This system would help reduce the flooded area by a 1/100yr rain from 595 to 217 ha in 2060, and only 235 ha in 2110.

Economic calculations were based on 5 scenarios, from simple sewer expansion to more complex measures like channeling excess water on surface, SUDS, and backwater valves to protect basements. The result is that for a 1/100yr rain, sewer expansion has a negative benefit cost ratio, while backwater valves plus redirection of water in surface would save above DKK 8.2 bn on an estimated DKK 15.5 bn of damages (resp. $1.23 bn and $2.32 bn). Adding investments on SUDS would improve the reliability of the whole plan, and would only reduce the net saving to DKK 7.5 bn.

The plan proposes three levels of action (before/during/after): (1) prevention measures to reduce flooding occurrences; (2) crisis management to reduce the scale of an extreme event; (3) vulnerability reduction by making it easier to clear up after the event and to recover. At each level actions are proposed at regional, municipality, district, street and building levels. Therefore it includes private property flood proofing (e.g. with anti backflow valves, light walls at ground floor entrances), street design to evacuate water, district-level green infrastructure to store and infiltrate some of it.

Channeling extreme runoff on roads to the sea would be financed through additional per m^3 drinking water charges, and green infrastructure investments would be covered by an increase in municipal taxes. The corresponding investments would reach resp. DKK 1.2 bn, 2.2 bn, and 400 mln, i.e. US$216 mln (€160 M), US$396 mln (€294 M), and US$72 mln (€ 53 M). Most of the investments would be done before 2016, but the plan extends till 2033.

The CC adaptation plan also includes a chapter on sea level rise and related impact of storm surges. Over a period of 100 years, if no protection measure is taken direct plus indirect damage costs could go up to DKK 15-20 bn. In front if this, the cost of protecting the city from a 255 cm surge would reach DKK 2.3 bn in construction, and NPV of construction plus maintenance and operation costs over 100 years would only be DKK 4 bn, illustrating that the measures would be strongly beneficial.

The plan is however subordinated to a revision of financing rules, since the largest share would impact already very high water bills, while it is not yet lawful to fund pluvial investments from water bills, even if they are made by the wastewater utility company (Københavns Energi). This is a recurrent problem in other EU member States like France.

London

London is the capital city of the United Kingdom with a population of 7.7 million, and which by 2016 is projected to reach 8.1 million. London's economy (643 trillion $, 366 trillion £ in 2014) contributes 20% to UK's GDP, with over a third of the workforce employed in the financial and business services sector. (Bulkeley & Schroeder 2008)

Bibliography basis

Our review of the adaptation of London to CC is mainly based on the following documents:

- Greater London Authority. « Managing risks and increasing resilience The Mayor's climate change adaptation strategy», October 2011 (A Nickson et Woolston 2011). . https://www.london.gov.uk/sites/default/files/water-strategy-oct11.pdf. (A Nickson et Woolston 2011)
- Greater London Authority. « Securing London's water future: the Mayor's water Strategy », October 2011. https://www.london.gov.uk/sites/default/files/water-strategy-oct11.pdf.(Greater London Authority 2011b)
- The case study prepared by Alex Nickson for Cities and Climate Change: Global Report on Human Settlements 2011 (Alex Nickson 2011), is largely inspired by these two documents.
- The London plan: the spatial development strategy for London (Greater London Authority 2015) which includes the mitigation and adaptation to climate change

topics. As a consequence mitigation and adaptation are now considered as classical and usual aspects of the local strategy which do not need anymore specific documents.

Actually, we couldn't find post-2011 documents focussed explicitly and entirely on adaptation to climate change. Moreover since that date, the activity related to adaptation on several websites dedicated to water in London and in the UK seemed to decrease: for instance no document related to adaptation was put on the website of Ofwat since 2011 (http://www.ofwat.gov.uk/sustainability/climatechange/). However, the Environment Agency communicates actively on adaptation to climate change and also produces reports, but mostly at UK scale.

The economic data remain scarce as shown below.

London, Water and Climate Change

Nickson considers that London needs to adapt to CC because it will worsen the situation of the megapole, which will experience an increasing risk of floods, droughts and uncomfortably hot weather. He also considers that London is presently not very well adapted to its current climate: recently 'extreme' weather events in 2000, 2002, 2003, 2006, 2007 and 2009 have had a negative impact on the city.

On the basis of a risk assessment approach the three above-mentioned major risks were identified: floods, droughts and overheating. Here, we will just cover the two first ones.

Floods

London is vulnerable to flooding from the three chief typical sources of risk:
1. **Tidal flooding** from the North Sea, principally due to tidal surges.
2. **Fluvial flooding** from freshwater: River Thames and the its tributaries to the Thames.
3. **Surface water flooding** when the drains are overwhelmed by heavy rainfall.

The probability of flooding in the future is projected to increase because:

- Sea level is projected to rise by approximately 1 metre over the century (and possibly 2 metres under an extreme scenario).
- Tidal surges may increase in height by up to 0.7 metres by the end of the century.
- Wetter winters, with more frequent and intense heavy rainfall events, resulting in higher peak river flows, are expected to increase by between 20–40 per cent by the end of the century.

Under projected changes, assuming no flood risk management measures are taken, CC will increase not only the frequency, but also the extent and depth of flooding.

Concerning tidal flooding, the Thames Estuary 2100 project (Environment Agency 2012), initiated in 2002, identifies the future flood management options for London and the Thames estuary. It is based on a "decision pathway" which enables a flexible approach to managing the uncertainty associated with predicting sea level rise.

Concerning river flooding, the combination of low protection standards of protection, short warning times and relatively few management options, implies that managing flood risk on the tributaries to the Thames is a priority. In the short-to medium run non structural measures based on local flood warning will be implemented. However in the long run, expensive structural solutions based on the raising of flood defences and on the creation of flood storage will be necessary.

Surface flooding is presently the most important flooding risk in London. Several factors (low permeability of London's urban landscape, new development pressures and the poor maintenance of parts of the drainage network) magnify this risk. In order to bring together all the stakeholders involved, it was decided to create a multi-agency partnership: the Drain London Forum which is developing a surface water management plan for London. An interim version of this plan was expected to be launched back in April 2015, but has been delayed.

Economic impacts

The assets and people at risk in the tidal Thames floodplain are summarised in Table 4.
15 per cent of the city's surface area lies on the floodplains of London's rivers. Currently 1.25 million people (16% of London population), 481,180 properties, and a substantial proportion of the capital's schools, transport network, and emergency services are at tidal and fluvial flood risk, though most are well protected. More than 800,000 properties lie at risk of surface water flooding.

During June and July 2007, two severe rain episodes occurred in South England. They came after the wettest ever May to July period since national records began in 1766. Met Office records show that the total cumulative rainfall in May, June and July 2007 averaged 395.1 mm across England and Wales – well over double usual levels (Pitt 2008). CC is also expected to bring more extreme winter rainfall events to London, raising the annual likelihood of severe rainstorms; and floods of at the scale seen in 2007 should be expected in the future (Greater London Authority 2011b).

Table 4 Assets and people at risk in the tidal Thames floodplain

350 sq km land area
55 sq km designated habitat sites
1.25 million residents (plus commuters, tourists and other visitors)
Over 500,000 homes
40,000 commercial and industrial properties
£200 billion current property value
Key Government buildings
over 3100 hectares of sensitive heritage sites
400 schools
16 hospitals
8 Power stations
More than 1000 electricity substations
4 World Heritage sites
Art galleries and historic buildings
167 km of railway
35 Tube stations
51 Rail stations (25 mainline, 25 DLR, 1 international)
Over 300 km of Roads

The estimated insured cost of the 2007 event was £3 billion, which suggests that a similar event in London could cost tens of billions (Greater London Authority 2011a). However these numbers don't seem based on a comprehensive assessment of the potential impacts of such an event.

It was estimated that per day :

- the cost in lost staff time reaches £10 million
- the cost in train and metro passenger delays reaches £0.74 million

Adaptation to climate change

As noticed previously, it is rather difficult to assess the cost of CC adaptation, as the strategy of adaptation is embedded into the general strategy of flooding protection of London (Greater London Authority 2015). Moreover, CC is only one of the factors influencing how risk might evolve in the future. Other factors like asset deterioration and new developments in flood plains should also be taken into account.

One of the most noticeable points is that this strategy aims at being well balanced between structural and non-structural measures, even though in the end structural measures have the favour of the people exposed to flooding risk (Harries et & Penning-Rowsell 2011).

The main structural measures are the Thames estuary 2100 Plan with its two major aspects : Thames tidal defences operation, maintenance and development; and Thames floodplain management, with and the Thames Tideway Tunnel project, which aimed initially aimed at reducing the combined sewer overflows (CSO's) for the protection of the Thames ecosystem. It is also partly an adaptation project; as the occurrence of overflows is supposed to increase because of climate change.

Other structural measures mostly deal with surface flooding mitigation and include sustainable urban design systems (SUDS) and green infrastructures which also partly contribute in a double manner to CC adaptation: runoff control and heat islands mitigation.

Item	Cost	Type of funding	Reference
manage surface water flood risk (including greenroofs$	£3.2million (300 000 £)	Partial, incentive	(Greater London Authority 2011a) (Drain London Forum)
Thames defence	1.5 b£ (2010-35)	Total	(Environment Agency 2012)
Thames defence	1.8 b£ (2035-50)	Total	(Environment Agency 2012)
Thames defence	6-7 b£ (2050-2100)	Total	(Environment Agency 2012)
Tideway tunnel	4.6 b£	Total (estimation)	(Consumer council for water, 2011)

At the UK scale, and not London scale, it is mentioned (Environment Agency 2014) that the cost of funding all those flood and coastal erosion risk management actions where benefits are greater than costs would cumulate around £25 billion over the next 100 years. It would provide an overall benefit to cost ratio of about 5 to 1; other interventions with lower benefit-cost ratios could go ahead provided they later score a positive economic benefit. Benefits are valued according to the economic damages avoided by making the investment, including the benefits of protecting homes and businesses, farmland and infrastructure. They estimate that this will lead to a 12% reduction in flood damages over the next 50 years.

Drought

In the future, lower summer rainfall, greater demand for water and greater restrictions on the volume of water which can be abstracted from the environment will threaten the security of supply. The region of London is presently considered as under a "serious water stress" by the

Environment Agency, and the situation will worsen because of CC. Adaptation measures are necessary and will include both structural and non-structural measures, like for flood protection.

Non-structural measures will include governance improvement and actions to decrease the per capita water consumption. Among structural measures, a reservoir (Upper Thames Reservoir in Oxfordshire) is planned, its cost of building is in excess of £1 billion and it would be paid for through water bills.

To conclude about the UK: the sectors requiring significant investment in large scale infrastructure have invested more heavily than those that do not in identifying potential impacts and adaptations. Thus one finds a higher level of adaptation activity by Water Supply and Flood Defence. Sectors that are not dependent on large scale infrastructure appear to be investing far less effort and resources in preparing for climate change. We conclude that the UK government-driven top-down targeted adaptation approach has generated anticipatory action at low cost in some areas (Tompkins et al. 2010).

Rotterdam (NL)

Late 2008 was launched the Rotterdam Climate Initiative, a joint program of the city government, the regional environmental protection agency, the port authority and the port employers' association.

"Rotterdam Climate Proof" aims to make the city of 1.3 million people "fully" resilient to climate change impacts by 2025 and to maintain Rotterdam's status as one of the safest port cities in the world. The adaptation strategy contains five themes: flood management, accessibility for ships and passengers, adaptive buildings, urban water systems, and quality of life within the city. The city set aside about $40 million for implementing the plan's short-term projects.

A 2010 follow-up report notes the program is making "full progress" toward its initiatives and broader goals. Perhaps the most notable project to come from the plan is Rotterdam's trio of floating pavilions. The bubble-shaped domes are anchored off the city's waterfront and measure a total of 12,000 square feet. The project is a pilot for future floating urban districts that will be able to rise with the changing sea levels.

The Ecorys study shows that making Rotterdam climate proof will result in an investment of 4-5 billion euros (2010). cf. http://www.deltacities.com/cities/rotterdam/climate-change-adaptation

Hérault County, France

In France, we did not find many quantified analyses of economic impacts or adaptation costs of CC. However we found an interesting economic and legal approach of Populations relocation in anticipation of Sea surge and sea-level rise.

The economic impact of water related extreme events is better evaluated thanks to the para-insurance mechanism put in place in 1982. A super-fund is generated by a compulsory 12% increase on housing- and a 6% on car-insurance premiums. The money is kept by insurance companies and it is mobilized in support of victims of natural catastrophes (90% are floods), only if the event is recognized as a “cat’nat’” by the Government. The amount of damages reimbursed helps estimating the direct damage cost of a disaster.

While this system really brings relief to families and businesses which previously were just ruined, it has been criticized for lacking to develop a real incentive to adaptation projects. This of course because insurance companies pay for damages after they occurred, not before. This is why in the 1990’s minister Barnier managed to take some money out of that fund to support relocation projects, and later to fund the ‘PAPI’ which are indeed adaptation plans to reduce vulnerability to floods at catchment level.

A research project SOLTER, develops an analysis of the legal conditions and economic costs of relocating people and activities at risk of sea level rise and storm surges André & al., 2014). It provides a few data on present-day adaptation costs: like in other European countries, ‘strategic retreat’ projects were developed after 1980. Today six have concerned ‘de-polderisation’ (no economic data available, since it was a choice of ‘dykes no-rebuild’; three have relocated coastal roads on the Mediterranean littoral (both for protection and biodiversity enhancement reasons), for a cumulated cost of €83 million; only 2 projects concerned private residences which were relocated in anticipation: 14 in Criel/Seine and 5 in Wimereux both on the Channel; however, after the 1999 Xynthia sea surge on the Atlantic coast near La Rochelle (53 casualties) up to 1200 houses were deemed un-habitable and were bought and destroyed by government for a cumulated cost of €315 million.

The innovative part of SOLTER is to study the possibility of AOT (temporary authorization to occupy sites at risk), after the amicable acquisition of private properties by local authorities in charge of land use plans, so as to reduce the collective economic loss. Two cases are studied in practice on the Mediterranean coast: one with only 30 houses, the other with a complete tourist sea-front relocation (500 houses, 1500 apartments and 80 boutiques). In the first case relocation cost is €22 mln, but can be reduced with re-renting policies down to €5.8 mln. In the second case, a much higher relocation cost would be €835 mln, but would also be reduced by AOTs to €250 mln. This approach could be included in a benefit-cost analysis of adaptation projects. But SOLTER does not extend to estimation of future economic impacts in Montpellier urban area due to climate change.

Barcelona

This large coastal city in Spain experienced a very severe drought in 2008; and this triggered a reflection on CC adaptation. It is then one of the rare cases where economic impacts and adaptation costs are based on water scarcity and not only on floods. According to Ecologistas in Accion, the water input in Spanish rivers has decreased by almost 15% in average in the last decade compared to the 55 previous years, and by almost 20% in the internal basins of Catalonia (Barajas, 2009).

We did not find a study of CC adaptation for Barcelona itself, but for the Llobregat river basin, the population of which is mostly composed of the Barcelona metropolitan area with 4.4 million inh. (Pouget & al. 2012). This study, *Water Change*, was a three year duration project (2009–2012), funded by the LIFE+ programme of the European Union, and coordinated by CETaqua (Water Technology Centre) the research subsidiary of AGBAR group, which supplies water to Barcelona Metro, with the collaboration of CRAHI (Centre of Applied Research on Hydrometeorology). “The main objective of the project [was] to improve the integration of Global Change in water resources planning. As such this project works on different aspects:

• Develop a methodology to 1/ evaluate Global Change impacts on water resource quantity and quality, and 2/ define strategies of adaptation base on scenario results and cost–benefit analysis. The methodology can be applied to any river basin or water system.
• Develop a modelling tool able to integrate existing user's models, making it possible to simulate the impacts of different Global Change scenarios on the water cycle.
• Apply the methodology to the Llobregat river basin, involving local project stakeholders (Catalan Water Agency, regional councils and SGAB, the company in charge of water distribution in the Barcelona area).
• Collaborate with project stakeholders (seven river basin agencies and Spanish Office of Climate Change) to consider the needs in the project development and give recommendations to contribute to the implementation of water and environmental policies."

Relying on the well known DPSIR framework of the OECD, authors made a framework model to confront climate change influenced water resources modeling to socio-economic changes forecast in the area. This was done through the generation of scenarios, which were confronted to alternative strategies. A cost-benefit analysis was applied on the matrix of scenarios and strategies. Comparisons were made on Net present values of strategies/ scenarios, with a low discount rate of 1%, supposed to match the adaptation of demand context to sustainability.

The framework was applied on the one hand to scarcity issues (Guiu & al. 2015), and on the other hand to flood resilience (Velasco & al., 2015). In the scarcity study, the analysis allowed evaluating the benefits of adaptation in terms of resource costs, both for market and non market effects. The first ones are calculated through losses/gains in the gross value added (GVA) of the regional economy; and the other ones via contingent valuation (WTP/WTA). 4 scenarios (from zero to major water deficit) were confronted with 4 strategies (from no to high adaptation). Strategies were compsed from 11 precise measures, some on demand and others on supply. "… Apart from the desalination plant that is included in all strategies (the desal plant is already in use) the low adaptation strategy consists on a modernization of the irrigation channels, water reuse for non-drinking purposes in the metropolitan area and the restoration of the quality in the Anoia river. The medium adaptation target is achieved with the previous ones plus a seasonal tariff, more intensive aquifer recharge, reinforcement of a seawater intrusion barrier to improve groundwater resources, the promotion of graywater reuse in new buildings, subsidies for adoption of water-efficient domestic appliances and, finally, the implementation of direct potable water reuse schemes. The final strategy combines the largest measures, such as desalination, irrigation modernization, the restoration of the quality in the Anoia river and, above all, the transfer of water from the Rhone River in the south of France."

As a result of the CBA, "Benefits are significantly higher than costs and thus adaptation to global change is desirable in all scenarios — except for the no deficit scenario. The reason is that the damages caused by a potential water supply deficit are considerably impactful in economic terms, as compared to the costs of avoiding them." Authors conclude that: "First, the framework effectively guides water planners in evaluating whether adaptation to future water shortages is desired or, on the contrary, the costs of adaptation exceed the expected benefits […] Second, the overall assessment also includes the consideration that the strategies may not be 100% effective in some scenarios, implying that significant residual resource costs would still be assumed by society after adaptation […]Third, the framework highlights the relevance of considering demand-side management measures and policies (technological improvements of water use, pricing policies, etc.). Policy-making hence should not downplay their role, as defended by Olmstead and Stavins (2007) or Leflaive et al. (2012)."

The resilience to flood study concentrated on one neighborhood of Barcelona, Raval, which seems particularly exposed. Here again various climate scenarios were confronted with adaptation strategies including structural and/or non structural measures. Expected annual damages are cumulated in a net present value obtained under a 4% discount rate over a 2050 horizon. To make it short, authors conclude with a mixed observation: "Consequently, several conclusions can be driven of this study. The non-structural strategies present higher net benefits than the structural ones, due to their low cost. However, the structural strategies can better cope with flood impacts, but at higher costs. Nevertheless, the economic benefits of these strategies are only related to the Raval District. By extending the domain analysed, the results would be different."

SOUTH-EAST ASIA

Introduction

Marcotullio (Marcotullio 2007) rightly points that many of the urban development processes that occurred slowly in the western developed world are occurring now at fast speed in South East Asian cities. This '*time-space telescoping*' is now posing unprecedented challenges in terms of sustainability in general. Climate change is then becoming a crucial element, because most of these large cities are located in lowlands close to rising seas.
Rural-to-urban migrations result in poor people, more vulnerable to floods and droughts, being much more numerous and at risk in cities than in rural areas. This should change the general approach by the United Nations, previously biased towards rural areas. As pointed by a World Bank Group report (The World Bank 2010) on Viet-Nam, urban expansion was frequently made on former wetlands, concrete structures adding soil sealing effects to more violent rainfall and sea-rise and land subsidence.
However, most of the reports we have found do not propose calculations of climate change effects. We have found relatively good case studies on Ho-Chi-Minh-City in Vietnam, Kolkata and Mumbai in India, Manila in the Philippines, Bangkok in Thailand, and Jakarta in Indonesia.

Kolkata

Kolkata Metropolitan Area is one of the largest megacities in the world: in 2011 its population reached 17 million, and it may reach 21 million in 2021. Kolkata accounts for 5 % of the national GDP (2009) (US$ 104 bn). It is a city struck by poverty, with more than 30% of the population living in slums, i.e. usually more vulnerable to flooding events. The CC impact and adaptation analysis, made for the World Bank by Maria Sarraf (Task Team Leader), Dr. Susmita Dasgupta (Co-Task Team Leader) et al., focuses on urban flooding due to (i) increases in extreme precipitation, (ii) sea level rise and (iii) storm surges arising from climate change (Sarraf & al. 2011).

Additional damages forecast

Overall the study finds that the damage from a 100 year flood will increase by about US$ 800 million to more than US$6.8 billion in 2050 due to climate change (A1FI scenario). The impacts by sector in Indian Rupees are shown in the chart below. These are computed at 2009 prices. Local currency is converted to US $ using the Purchase Power Parity index for India of 2.88 (IMF, 2009). The largest component of damage under both the 100 year return period flood and the A1FI climate change scenario (fuel intensive) are accounted for by residential property and buildings and health care. Commerce, industry and other infrastructure like roads and transport services also witness significant damage. It is important to note that due to data constraints, some impact could not be quantified in this analysis. Therefore the estimates provided are likely to *understate* the overall impact of climate change.

The total loss in each sector is calculated by combining the stock damage and the flow damage. The sector-wise break down of total losses is shown below.

Total losses in major sectors in Kolkata Municipal Corporation (in 2050)

	100 Year Flood	**A1FI Scenario Only**	**Δ Climate Change**
Residential building	24,700	27,900	3,200
Residential property	34,000	38,600	4,600
Residential income loss	4,300	5,000	600
Commerce	7,800	9,300	1,500
Industry	2,600	3,000	400
Health care	17,200	18,400	1,200
Roads	2,100	2,400	400
Transport	3,200	3,800	600
Electricity	300	400	100
Total (Rs. million)	**96,200**	**108,800**	**12,600**

The additional losses resulting from the A1FI climate change scenario (fuel intensive) in 2050 was estimated to Rs 12,600 million. For a meaningful comparison it is appropriate to convert the loss in local currency to US $ using the Purchase Power Parity index. Using PPP US$, and under some hypotheses on the evolution of the exchange rates, the additional loss from climate change effects under the A1FI scenario in Kolkata Metropolitan Corporation (KMC) area in 2050 amounts **to $790 million**.

The estimated additional loss of $790 million in KMC from climate change effects is based only on damage resulting from increased flooding and leaves out impacts from other weather related incidents like increased wind damage. Land subsidence was also not included in the analysis as it was considered a second order effect in connection with the increased damage from climate change. In addition, the damage estimates are based on a partial equilibrium analysis and do not include losses in consumer surplus. It is important to note that this estimate is likely to underestimate to total damage due to climate change because many impacts were not quantified in this analysis due to data constraints. Thus the estimated loss of $790 million represents a **lower bound** and actual damage is likely to be even higher.

Adaptation Measures

The current adaptation deficit

Urban flooding is a recurring phenomenon that Kolkata faces every year during the monsoon period. The local population has learned to adapt by developing a number of coping strategies for facing such periodic episodes of flooding. However, climate change is likely to intensify this problem through a combination of more intense local precipitation, riverine flooding in the Hooghly and coastal storm surges. If such intense precipitations are accompanied by extreme weather events such as cyclones, it can lead to widespread and severe flooding that can bring the city to a standstill for a few days. A major cause of such periodic flooding during the rainy season is the current *adaptation deficit* that Kolkata faces to cope with such recurrent events. This arises not only from deficiencies in physical infrastructure that lead to flooding but also from problems with land-use, socioeconomic and environmental factors that can aggravate the impact of such flooding.

Adaptation Strategy

As the impact of flooding is likely to grow in the time horizon of 2050, the city needs a comprehensive and effective strategy that invests in both *soft* and *hard* infrastructure to tackle flooding problems in Kolkata. The goal of the strategy is to (i) reduce the percentage of people affected by flooding and sewage related diseases in Kolkata Municipal Corporation; and (ii) target the most vulnerable areas. The strategy should include preparedness both *before* and *during* the event as well as *post*-event rehabilitation strategies.

Investing in hard infrastructure

In order to fulfil the adaptation deficit currently faced by the city investment in hard infrastructure are needed. However the strategy to invest in hard infrastructure should take into account the following:

- The strategy needs to follow a comprehensive approach to planning that recognizes drainage system complexity and interconnectivity of its elements such as storm water drainage, water supply, wastewater, water pollution control, water reuse, soil erosion, and solid waste management.
- A strategy that protects major urban services including roads, traffic, water supply, electricity and telecommunications and that recognized the importance of open space, and green areas as an integral part of city development.
- A strategy that spells out the climate risks and mitigating factors needed in operational plans for key relevant agencies.

Investing in soft infrastructure

To ensure a longer term financial, institutional and environmental sustainability the adaptation strategy should also include:

- Strengthening of disaster management and preparedness for both pre and post disaster situations.
- Enforcing land use and building codes to reduce obstruction and encroachments of floodplains and environmentally sensitive areas such as canal banks and wetlands and to prevent conversion of green spaces and natural areas that can act as retaining zones during flooding to delay runoffs or reduces their volume through infiltration.
- Introducing sustainable financing for infrastructure investment and maintenance from two angles – cost reduction and cost recovery.
- Increasing the budget for sewerage and drainage maintenance and greater allocation of money for silt removal and mechanical sewer cleaning.
- Adopting flood insurance that incorporate suitable incentives for adaptation and minimize flood damage.
- Strengthening regulatory and enforcement process including improving institutional management and accountability.
- Enforcing pollution management frameworks including introduction of incentives and disincentives to ensure compliance with regulations.

The Government of West Bengal has already started investing in adaptation

Among the suggested adaptation measures, a number of projects are either currently under way or are planned for future implementation in Kolkata Metropolitan Area under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and the KEIP scheme funded by ADB. The selection and prioritization of projects for adaptation have to be made based on cost benefit analysis using the net present value (NPV) approach. Factoring in the additional impact due to climate change in such cost benefit analysis may render many projects ─ that did not show an adequate return on investment earlier ─ economically viable.

Summarized Cost Estimates for Sewerage and Drainage Master Plan under KEIP

Item	Cost in Rs Million	Cost in US$ Million
Desilting and Rehabilitation of Trunk Sewers	49,290	1,069
Pumping Station Upgradation	3,418	74
Outfall Canals Upgradation	6,883	149
Trunk Sewer Upgrades including Immediate Action	6,534	142
Provide Additional Gully Pits	108	2
Extending Sewerage System in Non-sewered Areas	37,610	816
Tolly‟s Nullah Lock Gate and Pumping Station	1,130	25
Wastewater Treatment Plant	5,500	119
Storm Drainage Tunnel	12,051	261
Intervention Studies	88	2
Grand Total	**122,612**	**2,660**

Source: Kolkata Environmental Improvement Project,: Sewerage and Drainage Master Plan for Kolkata City

In addition to these structural measures, some additional adaptation options that are considered a part of City Development Plan include:

- Conservation of wetlands and other natural water bodies
- Rain water harvesting
- Strengthening and regular maintenance of sewer network
- Restricting encroachment by settlements on canal banks
- Control of growth of aquatic vegetation which decreases the carrying capacity of canals
- Proper maintenance of the old pumps, increase the hydraulic capacity of sewerage system and discharge canal system by de-silting
- Use of state of the art technologies for integrated data management, information gathering, sharing, dissemination
- Use of modern technology including satellite remote sensing and Geographic Information System (GIS), and modelling tools to assist in developing and assessing alternative decision making options.

Since poor management of solid waste leads to problems with drainage, solid waste management schemes have been proposed at a number of locations. In addition 75,000 numbers of Septic Tank/Pour Flush Latrines of capacity for 10 users have been proposed for use by people who do not have such facilities.

One aspect that needs closer scrutiny is the implication of climate change on the requirement of strengthening and raising of embankments on the Hooghly river. In the study, hydraulic modelling was used to route the flood hydrographs corresponding to 100 year return period under the A1FI scenario with and without tide effect. This exercise has helped quantify the extent of strengthening needed for embankments to ensure that there is no over topping from increased river flow.

Selection of projects currently being implemented or in the pipeline in KMC have been made using cost benefit analysis based on impact estimates from current weather related data. The impact from climate change were however not included in such analysis. Due to the increased flooding and damage caused by climate change, it is likely that use of cost benefit analysis that takes into account climate change effects will increase the viability of many projects not found viable earlier with only current weather data. Hence, there is a need for making climate change effects an integral part in all future planning for adaptation in Kolkata.

Mumbai

The city of Mumbai extends from East to west by about 12 km, where it is broadest, and from North to South extends about 40 km. The density of populations in the central districts is 43 and in the suburban district 21 thousand persons per km^2 respectively, with a total of about 12 million inhabitants in 2001. In 2010, the population is estimated to be 14 million inhabitants. Mumbai's GDP is about US$ 150 bn (6.5% of India's GDP)

The study written for the OECD (Hallegatte et al. 2010; Ranger et al. 2011) offers a good illustration of how a very extreme flood event can trigger (1) an analysis of the additional economic impact due to CC through a combination of sea rise and heavy downpour on a megapolis; (2) an assessment of the benefits of adaptation strategies in terms of avoided losses; and (3) a reflection on the remaining uncertainties within the approach itself.

In 2005, an unusual heavy rainfall hit the Mumbai metropolis, probably the worst recorded ever (e.g. 944 mm in 24 hours), with a return probability between 1/150 yr and 1/250 yr. The estimated economic impact is close to US$2 bn, and around 500 casualties were reported. On top of infrastructure and traffic disruption, resp. 175 000 / 2000 houses were partially / fully damaged; 40 000 commercial sites were damaged too. For the marginalized population alone, including impact on informal economy, the loss was estimated at US$250 million.

Climate change scenarios provide contrasted and uncertain futures for India, and in addition, time series of rainfall records are only going back 30 years. Choosing the IPCC SRES A2 scenario, and extending it to year 2080, authors consider that the return period of a 2005-event might be halved, so that the losses of a 1/100 yr event could treble to around $1.9 bn.

The future loss estimates for residential, commercial and industrial sectors were derived from a combination of public economic estimates, insured losses estimates and regional input-output models to assess the indirect losses.

"With a higher probability of larger direct costs from flooding in the 2080s, 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. […] 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 million vs. $2305 million) in the 2080s."

As concerns adaptation policies, a ‘Brimstowad’ report[3] had been made back in 1993 by consultants on reducing flood risks through improving the drainage system and to a lesser extent reducing vulnerabilities. By 2009, partly because of the 2005 event, up to $276 bn expenses were approved by the Maharashtra government, but only 31% had been effectively invested. Investments were hastened after the 2005 disaster and the Chitale committee assessment: phase one in 2006-2007 approved $82 bn and was fulfilled at 81%; we do not have figures for phase 2, which was still ongoing at the time of the OECD report.

But in these investments there was no direct account taken of CC additional impacts. In the OECD report, Hallegatte & al. consider that a 1/100 yr return flood occurring in 2080 would cost up to $2.3 bn (vs $700 mln today), but that thanks to vulnerability reduction measures, the figure could be lowered to around $1.9 bn, and thanks to improvement of drainage system (structural measures) to $650 mln. Together, all these measures could bring the impact down to around $300 mln.

Ho-Chi-Minh City (HCMC)

HCMC’s metropolitan area is home for more than 9 million people (including ‘floating’ population), and accounts for 23% of the national GDP. The city's population is expected to grow to 13.9 million in 2025. HCMC is vulnerable to tidal, river and surface flooding. Tidal and river flood risks may increase with CC. Moreover it experiences groundwater related subsidence which aggravates the flooding impacts.

A comprehensive CC adaptation report was drafted by the Asian Development (Asian Development Bank 2010). After reviewing the data on climate and CC (increased precipitations and droughts, salinisation due to sea intrusion, plus extreme events), the report presents the 6.5 million people settlement in a very low level geography. The poverty dimension is addressed. Then the report describes implications on HCMC in 2050 vs 2005. Due to increased unplanned urbanization, without flood control measures, the percentage of population directly affected by normal/extreme flood events would rise from resp. 15/26% to 49/62%. With the proposed flood control measures, these figures would only be brought down to 32/52%, but hopefully affected people would suffer reduced flooding duration and height. Several socio-economic sectors are covered both in terms of exposure and adaptation: transport, WSS, energy, industry, agriculture and natural systems, public health. Poor management of solid waste and potential impact of toxic contaminants dispersion in extreme events is also mentioned.

Costs of potential impacts were calculated using two different methods: loss in economic value of land, and loss in GDP, were calculated for the 2006-2050 period and for extreme events in that period. Under various scenarios, the loss in the economic value of land would range from $6.69 bn to $22.1 bn for regular flooding, and from $0.46 billion to $6.68 billion for extreme flooding. And the gross domestic product (GDP) loss would be $48.3 billion for regular floods and $0.48 billion for extreme floods in present value terms. The significant difference between these estimates may be due to undervaluation of urban land under present administratively determined land prices in a socialist system, and also to absence of

[3] See: http://www.hindustantimes.com/india-news/mumbai-may-get-new-drainage-system-by-2011/article1-237175.aspx

disaggregated figures for GDP at district level, which may lead to over-evaluate the losses.

Through a cooperation project with the city of Rotterdam and the Ministry of Infrastructure and the Environment of the Netherlands (VCAPS project), an assessment was made of the CC impacts on Ho-Chi-Minh mega harbor, and of strategies for adapting to these impacts. In the resulting 2013 report (Vietnam Climate Adaptation Partnership consortium: Ho Chi Minh City, Vietnam. 2013), three cumulating change processes are presented: rapid population increase, water-impacting CC (rising sea level, change in precipitation patterns, rising temperature), and land subsidence due to high rise buildings construction. The adaptation strategy comprises 6 directions:

- Base development direction on soil and water conditions
- Use a stepwise approach for flood protection
- Increase the water storage and drainage capacity
- Prevent salinisation where possible, adapt where necessary
- Create alternatives for groundwater use
- Strengthen the blue-green network and ‘urban ventilation’

Two pilot districts were investigated to test “the Strategic Directions of the Adaptation Plan to CC”; District 4 and Nha Be district.The report only gives quantitative economic estimates for district 4, close to the center and to Saigon river. It is the smallest district in the city (4 km^2), with a population of 183 000 in 2010. According to the urbanization scheduled in the master plan, and given a sea level rise of 30 cm average, the impact of a 1/100 yr flooding event would rise from $173 mln to $627 mln. And the damage caused by floods with a 1/10 yr return period would rise from $82 to $488 mln. District 4 will however be undergoing redevelopment. Space made available by the departure of port facilities offers opportunities for climate adaptation measures contributing to urban attractiveness at city scale.

A more recent model-based risk analysis has been conducted, also on district 4 (Lasage et al. 2014). The results of this study indicate that the current flood risk in District 4 averages US$ 0.31 million per year, increasing up to USD 0.78 million per year in 2100. Various adaptation strategies were tested, most of which unfortunately conclude to negative net present values (NPV) and Benefit-Cost ratios <1. Authors however indicate that several indirect benefits have not been taken into account in the model. At the scale of HCMC, (Dahm et al. 2014) developed another model-based risk analysis comparing three solutions imagined within the HCMC Flood and Inundation Management (FIM) Project. Their results are much more positive, with benefit/cost ratio varying between 2 and 7 depending on the hypothesis.

In both case studies, various sea level rise hypotheses are tested and enable a rough assessement of CC impact.

Bangkok

Bangkok metropolitan region already had 10 million inhabitants in 2007, not including a non-registered population of more than 3 million. The total projected population in 2050 is estimated by the authors at 15.9 million. Local GDP was $101 mln in 2006 (42% of Thailand’s GNP), and is projected to grow to $723 mln in 2050.

In March 2009, Panya consultants produced a World Bank funded *Climate Change Impact and Adaptation Study for Bangkok Metropolitan Region*, largely following the World Bank and ADB methodology (Conable 2009).

Under A1FI nad B1 CC scenarios, local temperature would rise by resp. 1.9°C / 1.2°C; precipitation would increase by 3 and 2%; and sea level would rise in the gulf of Thailand by resp. 29 / 19 cm. In addition a land subsidence phenomenon is ongoing, which will exacerbate CC effects. Depending on locations, it would cumulate between 5 and 30 cm in 2050. By then, flood prone area will expand, authors assess, and flood volume will increase with additional precipitation, but peak discharge will increase even more; storm surges will also increase, but to a lesser extent.

The impacted population will rise to 1 million, and affected vulnerable population should double. Economic damage would be multiplied by 4, considering a 1-in-30 yr flood: from $1 bn to $4.22 bn. 70% of that second figure should be attributed to land subsidence. Buildings and houses would bear the high impact cost (300 000 units, for a cost of $3.14 bn); for commercial and industrial sectors, value-added income losses would reach resp. $0.63 bn and $0.29 bn.

Two types of adaptation measures have then been considered, structural and non-structural. The first ones include dike reinforcement, additional pumping capacity, and coastal erosion protection through mangroves support. Total estimated costs are $1.05 bn to face a 1/30 yr event, and $1.47 bn to face a 1/100 yr event.

A cost-benefit analysis was then performed taking into account various discount rates between 8 and 12%. Benefit-cost ratio of the structural measures is positive for both return period events if the opportunity cost of capital is valued at no more than 8%. In addition, if real economic growth is taken into account, then benefit cost ratio is positive with opportunity cost of capital under 10%. Authors then recommend to target the more ambitious program to face the 1/100 yr event.

Non-structural measures include real-time reservoir operation, land subsidence reduction, flood forecasting and warning systems, watershed management, disaster management, and flood insurance and incentive financing schemes. More detailed measures are proposed for housing and commercial and industrial buildings, WSS, energy, transportation, and public health sectors. May be the most important is the adaptation of the land-use plan with the strengthening of controls on illegal settlements. These measures are not evaluated in budget terms.

Metro Manila

In 2010, Metro Manila sprawled on a vast territory and reached almost 12 million inh., while representing 37% of the country's GDP.

A report written by Muto, M., Morishita, K., and Syson, L. from JICA, illustrates the impacts of CC through increase in floods upon coastal area, with the Manila case (Muto, Morishita, et Syson 2010). The methodology followed 6 steps:

- Downscale IPCC Climate Models for temperature expected in 2050 under B1 and A1FI scenarios
- Assess local effects on precipitation and combine with sea level rise / storm intensification

- Simulate different types of hydraulic effects: 1) through river systems,2) through accumulation of water in Laguna de Bay, and 3) through sea level rise and storm surge at the coast (combination depends on city)
- Based on the flood maps produced for 18 cases (3 climate scenarios x 2 infrastructure scenarios x 3 return periods), estimate socioeconomic impact (both direct and indirect) with available data to estimate benefits derived from adaptation options.
- Consider investment mix and cost of adaptation options.
- Calculate Economic Net Present Value and Estimated Internal Rate of Return

It is noteworthy that the report was written in 2008, and thus could not take into account the hurricanes Bhopa in 2012 and Haiyan in 2013, whose damages were evaluated resp. at $1 and 2 bn with resp. 1901 and 6241 casualties.

Estimates of severe flood impacts included direct loss based on conventional flood control project analyses, plus incremental additional transportation costs and lost wages and sales incomes.

"If flood control infrastructure improvements were stopped now, and the A1FI climate scenario is assumed, a 100-year return period flood could cause aggregate damages of up to 24% of the GRDP, while damages from a 30-year return period flood would be about 15% of the GRDP. If, however, infrastructure improvement based on the 1990 Master Plan is continued and climate scenario B1 is assumed, the projected damages would be only 9% of the GRDP for a 100-year return period flood, and 3% for a 30-year return period flood."

Under the A1FI scenario, a 100-yr return period flow would entail losses almost double of present day ones if the protection infrastructure remains as it is today: $2.53 bn vs $1.46 bn. But if the 1990 master plan on infrastructure investment is completed, total damages would go down to $1.31 bn. For a 30-yr return period, equivalent figures are resp. $1.56 bn, $910 mln and $440 mln.

The report does not summarize all the investments proposed for various catchments at risk in Metro Manila region, and the reader has to fetch them in various tables. Basically however, adaptation measures proposed are only a continuation and a reinforcement of structural measures like flood barriers, pumping stations, embankments to bring the impacts to minimal losses. There is only one alternative presented: with/without the construction of a dam in Marikina.

Unsurprisingly, the conclusions are that the best way to control climate change is to go on with flood control projects as they were projected before climate change considerations.

Jakarta

The capital city of Indonesia is a megapole of 9.6 million inhabitants (2010), and it is increasingly subject to storms and flooding. Jakarta GDP has reached US$ 100bn in 2011 (13% of GDP of Indonesia)

There is a long history of floods in the city, in particular in the wettest month of January. But the episode of 2013 was particularly severe: economic losses of ca. US$ 3billion; 47 fatalities;

and the damage or destruction of at least 100,000 houses. Other major floods in the 21st century include those of 2002 and 2007, which are estimated to have caused direct losses of resp. ca. US$ 1.5 bn and US$ 890 million.

A cooperation between technology institutes of the country and two Dutch universities (VU Amsterdam and Wageningen) led to form a Delta Alliance to develop JCAT (Jakarta Climate Adaptation Tools) (Ward et al. 2014). The aim of the project was to help Indonesian academics building capacity on flood risk assessment, integration between land-use planning and water management, and subject adaptation strategies and projects to cost-benefit analyses. A number of existing methods and tools have been adapted or improved so as to be applicable in Jakarta.[4]

Under present day conditions, implementation of this series of models allow assessing that 3400 ha should be impacted by a 1/100 yr return period flood, resulting in an economic exposure of ca. $4.0 bn. A 1/1000 yr return period event should increase the inundated area and economic exposure by a factor of 1.3 (i.e. $5.2 bn). The maximum value of exposed assets in both cases is resp. 1.2 and 1.5% of Indonesia's GDP. Reinforcing coastal protection is this critical, even under current conditions.

The outcome of a scenario approach is that with ongoing land-use change and land subsidence, climate change would result in a river flood risk increase by a factor of 2.2-5.7: the large span of this figure results from high uncertainty with sea level rise; the main driving factor remains land subsidence, due chiefly to groundwater overdraft, but also to construction loading, alluvium consolidation and geotectonic adjustments. In addition, land subsidence and sea level rise together should increase the risk of coastal economic exposure four-fold between now and 2100, reaching ca. $17 bn with an inundated area around 15 000 ha.

Just between 2000 and 2030, urban expansion alone may cause annual expected damage as a percentage of total GDP to increase by 76% (river flooding) and 121% (coastal flooding), with the most rapid increases in West Java. Until 2030, the influence of climate change alone on national scale river flood risk is highly uncertain. However, for coastal flooding, projected increases in sea level rise could cause a doubling of the annual expected damage as a percentage of GDP.

2 types of adaptation measures are analyzed: land use planning limiting settlement in flood prone areas could reduce exposure by 65% in 2030. And structural flood protection measures like dikes and retention areas would also be quite effective: even a target of 1/10yr return period could reduce exposure by 63%. But corresponding costs are not yet available.

[4] The models are: a water-balance assessment model (STREAM-Jakarta); an erosion and sediment-delivery assessment model (SDAS-Jakarta); a coastal economic exposure assessment tool; a city-scale river flood risk assessment model (Damagescanner-Jakarta); an economic modeling tool for the selection of flood protection measures; a method for assessing local actual damages for a specific flood event; a cost benefit analysis of flood protection measures; and a national scale probabilistic flood risk assessment method for Indonesia.

SUB-SAHARAN AFRICA

Johannesburg

Johannesburg metropolitan area population reaches 3.9 million, Its GDP reaches US$ 52 bn, 15% of South Africa GDP

In a 2007 paper published by the IIED's periodical (Environment & Development), Mike Muller from South Africa, who worked many years in Mozambique, addressed the issue of water management for urban adaptation to climate change (Muller 2007). He does not provide economic estimates of climate change impacts on specific cities, but merely calculates additional investments to face increased climate variability.

The metropolitan area of Johannesburg is already facing water scarcity, and within the next decade, it will have to look for additional water resources. Actually, it is one of the rare global cities, where the water adaptation to climate change deals mostly with water resources rather than flood hazard.

It will either have to expand the Lesotho Highlands Water Project, already transferring water from the upper Orange River to the Vaal system; or to capture water from rivers flowing to the East like the Thukela and transfer it to the Vaal basin. In both cases, the cost is above a billion dollars, and the difference lies in operation costs and in cash injection to Lesotho with the first project. But the long term sustainability depends upon reliable predictions of regional patterns of climate change (drier in the west, wetter in the east?). "Many practitioners argue that it is not possible for water managers in low-income countries to take climate change in their designs … The present challenge is thus to improve … by reducing the uncertainties that multiply at each step of the hydrological cycle … If climate change is driven by the activities of certain communities or countries, it may be appropriate to apply the polluter-pays principle, which would have significant implications for financing the costs that may be incurred. However, the boundary between 'normal' and 'new' variability is not obvious. It is thus difficult to determine what proportion of a dam helps to manage … the 'new' variability 'created' by climate change."

Based on 'relatively obvious' impacts of change in rainfall patterns and river flows the author estimated costs of water supply/demand adaptation, added waste water treatment to face decreasing dilution capacities of streams, improved flood protection works and stormwater drainage, hydropower dams failure; he left aside indirect effects like loss of available land due to worse floods and sea-surges, and costs of inter-city competition for water.

Assuming a decrease in dams' reliable yield of 30%, a rise of 40% in the unit cost of water, and a reduction of electricity production by 30%; and a doubling of wastewater treatment costs, Mike Muller estimated roughly the adaptation costs for existing urban water infrastructure in Sub-Sah. Africa: between US$ 1.05 and 2.65 bn. Including for urban water storage, $0.5 to 1.5 bn in capital cost, or $50 to 150 million annual equivalent; for waste water treatment, $ 100 to 200 million annually; and for electricity generation, $900 to 2,300 million annually.

He then added costs of new developments with the same ratios as for adapting existing infrastructure: US$ 15 to 50 million annually for supplying water to 150 million new urban residents, $ 75-200 million annually for serving 100 million additional persons with waste water treatment, and $ 900-2,300 annually for doubling the hydroelectricity generation capacity.

The total amount reaches between US$ 2-5 bn, which can compare to the total aid funding of US$ 23.3 bn in 2004: feasible but adding a significant burden on a policy area yet recognized as under-funded. It also compares with an estimate of the costs of climate change mitigation by the IPCC for the same area of the world, between US$ 60 and 240 bn.

Durban – eThekwini

Durban population reaches 3 million and Total population of the metropolis reaches 3.5 million. Its GDP (US$ 27 mln) is about 7.7% of South Africa GDP.

In the same IIED periodical, we found a more recent contribution by Debra Roberts focusing on the city of Durban, where she heads the Environmental Management Department (Roberts 2008). Impacts of CC include more variable rainfall patterns, sea-level rise affecting economic and tourist areas, and damaging infrastructure and coastal vegetation; decrease in water availability from Mgeni river is also expected (158 million m^3/ yr after 2070).. Informal urban settlements and waste water infrastructure would be more vulnerable, causing increased health risks.

Facing this prospect, the city is primarily addressing the water availability issue. “Management techniques, particularly those of integrated water resources management … include both supply-side (i.e. changes in water supply) and demand-side (e.g. differential pricing, public awareness campaigns and statutory requirements)”. Reduction of freshwater needs includes recycling sewage to potable standards.

The CC adaptation strategy project (phase 2) also includes studies on land-use based water variability regulation (stormwater retention/detention ponds and constructed wetlands; improved shoreline stabilization etc.). In phase 3, the city is partnering with the Tyndall CC research centre in the UK to “factor CC considerations into its long term planning and budgeting, and to develop appropriate responses in terms of adaptation and mitigation plans”.
Ms Roberts indicates that the first step is to create a new CC branch in the Environmental Management Department to deal specifically with the issue. Unfortunately no economic and financial figures are provided in this article.

Mombasa

This well known harbor is the second city in Kenya with up to 650 000 inhabitants, with more than 210,000 people (in 2005) located within the LLCZ (low Lying coastal zone). In its working paper n°146, the Tyndall centre for CC research produced an assessment of existing and future exposure to CC impacts (Kebede et al. 2010). Disasters are part of the city’s history, but the 2006 rain induced flooding was one of the worst recorded, affecting 60 000 people and causing much damage to infrastructure.

Using a GIS approach, authors estimate, both now and through the 21st Century, the number of people and associated economic assets potentially exposed to coastal flooding due to sea-level rise and storm surges in Mombasa. The current exposure to a 1:100 year extreme water level for the whole of Mombasa district is estimated at 190,000 people and US$470 million in assets. About 60 percent of this exposure is concentrated in the Mombasa Island division of the city where about 117,000 people (2005 estimate) live below 10m elevation. By 2080, the exposure could grow to over 380,000 people and US$15 bn in assets assuming the well-known A1B sea-level and socioeconomic scenario. Future exposure is more sensitive to socio-economic than climate scenarios. However, there is significant scope within the city limits to steer future development to areas that are not threatened by sea-level rise. Hence, forward planning to focus population and asset growth in less vulnerable areas could be an important part of a strategic response to sea-level rise. No quantitative figures are proposed in this rapid adaptation part of the study.

Dar Es Salaam

The capital city of Tanzania is one of the fastest growing cities in Africa: 3.2 million inh. in the metropolitan area in 2009, 4.36 million in 2012, and above 5 million today; but it is one of the poorest countries in the world, and 70% of this population lives in informal settlements. Its GDP (US $ 8bn) is about 20% of Tanzania GDP.

The same team form the Tyndall centre used the same GIS-based methodology to estimate populations and economic assets at risk of coastal submersion in the coming century. This time the report was drafted for the Global Climate Adaptation Partnership (GCAP) (Kebede & Nicholls 2011) .

“The study particularly considered a worst-case scenario assuming that even if defences (natural and/or artificial) exist, they are subjected to failure under the most extreme events. As such, it provides a first detailed quantitative context of the potential exposure, and hence worst-case impacts due to extreme sea levels under a range of possible futures […] The results show that about 8% of Dar Es Salaam lies within the low elevation coastal zone (LECZ), *i.e.*, below the 10m contour lines. This area was estimated to be inhabited by more than 143,000 people (*i.e.*, about 5.3% of the total city population) and associated economic asset estimated to be worth at least US$168 million in 2005, of which over 30,000 people and US$35 million assets are located within the 1 in 100 year flood plain. By 2030 with no climate-induced sea-level rise, the exposure to a 1:100 year coastal flood event is estimated at 60,000 people and US$219 million assets (under the population growth distribution (PGD) scenario 2), and 106,000 people and US$388 million assets (under the PGD scenario 1)[5]. Under the PGD scenario 3, assuming potential future population and economic growth occur outside the city boundaries, the exposure is significantly reduced (*i.e.*, about 30,000 people and US$35 million assets by 2030). When sea-level rise is considered, a total number of people ranging between 61,000 and 64,000 people (under the PGD scenario 2), and between 107,000 and 110,000 people (under the PGD scenario 1) across the sea-level rise scenarios are estimated to be potentially exposed to coastal flooding by 2030. Similarly, considering the sea-level rise scenarios the exposed assets are estimated between US$223 and US$236 million (under the PGD scenario 2) and between US$392 and US$404 million (under the PGD scenario 1). The exposure increases significantly with time, reaching over 210,000

[5] PGD scenario 1 gives the largest growth in coastal population, assuming uniform population distribution per district. PGD scenario 2 gives a smaller population growth as people are presently most concentrated away from the coast in areas not threatened by sea-level rise. A third scenario (*i.e.*, PGD scenario 3) is considered assuming that potential population growth occur outside the city boundaries to demonstrate the possible effect of climate change over socio-economic change as a control scenario.

people and about US$10 billion assets by 2070 under the highest sea-level rise scenario and the PGD scenario 1. These results highlight that socio-economic changes in terms of rapid population growth, urbanization, and spatial population distribution and associated economic growth are higher than sea level rise changes, and this will potentially play a significant role in the overall increase of population and assets exposure to coastal flooding in Dar es Salaam. This is illustrated by the population growth distribution scenarios 1 and 2, which are consistent with observed trends of the city growth and demonstrate that exposure will increase substantially from now to 2070 even if there is no change in extreme water levels."

In this study, adaptation is not analyzed specifically, except through the urban development scenarios, i.e. through land-use planning measures.

NORTH AFRICA

Four Large Sea-side Cities on the Southern Mediterranean Coast

The study funded by the World Bank and the governments of Egypt, Tunisia and Morocco, *"Climate Change Adaptation and Natural Disasters Preparedness in the Coastal Cities of North Africa,"* allowed a French-led consortium[6] using the same framework to make a global economic assessment of disasters' economic impact in the coming 20 years on three large North African coastal cities: Alexandria, Tunis and Casablanca; the proportion of damages due to CC is estimated. In a second phase, a series of adaptation measures were proposed under the shape of synthetic information sheets, to address successively earthquake, coastal erosion, sea-surge, urban floods risks; in turn and despite well known important uncertainties, theses measures are confronted to an economic analysis of their net present value (NPV) and benefit/cost ratio (EGIS-BCEOM & al. 2011). The study was carried out between June 2009 and June 2011 with financial support from the Global Facility for Disaster Risk Reduction and Recovery (GFDRR), the Norwegian Trust Fund Private Sector and Infrastructure (NTF-PSI) and the Trust Fund for Environmentally and Socially Sustainable Development (TFESSD). The Arab Academy of Science, Technology and Maritime Transportation in Alexandria, and the European Space Agency provided analytical support. The Marseille Center for Mediterranean Integration (CMI) has played a key role in the dissemination of the study and public discussion of its findings and recommendations.

Two years later, a quasi-similar consortium, this time sponsored by the French CDC[7], published a report following the same method and framework on Algiers (EGIS-Eau & al, 2013). In this section, we just intend to present the common methodology of the second phase, and to provide a table of the results in the 4 cities. Each report starts with an executive summary in English, French and Arab. A second chapter (similar in all reports) recalls the context and the framework of the study. In chapter 3 the diagnostic on multiple risks of phase 1 is recalled. Chapters 4 present the objectives and orientations on institutional support, urban planning, ground instability and earthquakes, coastal erosion and marine submersion, flood control, and water resources management. Chapters 5 include all the action sheets devoted to

[6] The consortium was headed by Egis-BCEOM International and included IAU-IdF (Planning agency of Paris region)and BRGM (French Geological Survey), in consultation with local partners.

[7] Caisse des Dépôts et Consignations, the national savings bank in France.

the above-mentioned orientations, and partly specific to each city. Chapters 6 develop the economic analysis after a common and systematic presentation of the methodology to choose a reasonable discounting ratio for such long term impacts/actions. The results are presented for some of the orientations in chapters 4 and 5, and this is what we are trying to gather together here. The reports all end with a chapter proposing an action plan and another one discussing an institutional and operational framework for implementing the plan.

Table summarizing the results of the 4 case studies

	Alexandria	Tunis	Algiers	Casablanca
Population 2010-2030	4.3 => 6 million	2.25=> 3 million	3=>4 m Wilaya 5.3 m metropole	4 => 6 million
Territory	2300 km^2	3000 km^2	1190 km^2	1615 km^2
Local GDP 2010 / 2030	93 bn EGP = $18 bn	18.4 bn TND = $13.1 bn	2000 md DZD = $24.8 bn	447 bn MDH = $18 bn (56 bn)
Cost of disasters (multiple risks) 2010 - 2030	NPV $1.72 bn (18% = CC)	NPV $1.1 bn (21% = CC) $100 mln/yr 2030:$35/cap/yr 0.29% of GDP	NPV2040 $1.49bn (15% = CC) 10% of 2010 GDP	NPV $1.32 bn 20% indirect cost (CC negl.) $139 mln/yr 2030:$27/cap/yr 0.26% GDP (0.1-0.4)
Cumulated CC health impacts (2010-30)	$48 mln/yr = 0.3% GDP (2010-50) total NPV $520 mln	Cumulated $21.8 md; resp 10%/6% of GDP 2010-30	No data	Impact= $63mln Casablanca + $1.07 mln Bouregreg; 0.12% of GDP
Earthquake risk	(2010-50) $3.6 bn 20% of 2010 GDP Adapt. measures : B/C negative	(2010-30) No data economic impact Adapt. Investment $53 mln but NPV only $2.8 mln	Impact (2015-40) mean/median: $1 / 0.5 bn 0.36 / 0.17% GDP housing adapt. TBX level: B/C >1.4	Negligible
Coastal Erosion	Not quantified	Adaptation: benefit = $ 129k NPV = $0.78 bn B/C= 1.4	Impact (2015-40) = cost of sand refill = $124 / 74 mln (mean/median) Adaptation: investment $80 mln and B/C = 0.25: some retreat should be accepted	*Maintaining present shoreline: $36 mln investment + 0.7mln/yr ; benef. $1.5 mln: not viable * retreat: $25 mln investment + $2.3mln/yr; benef. $1 mln: even worse
Marine submersion	Not quantified		Impact of 3m surge: $56 mln both in 2010 and in 2030 damage expectation 2015-40 = $24 m, 0.16% of cumulated GDP; 2.9% of current GDP	Coast adaptation: $3.24 mln invest. +$ 0.32 mln/yr; benefit 1st yr = $0.88 mln; B/C 2.3 Specific protection of Industrial zone Mohammedia

				harbour: creates NPV of $22.8 mln; B/C = 92! It's a priority investment
Urban floods	Not considered significant	*Urban planning measures <2030 $199 mln invest. + $4 mln/yr; NPV = $55 mln; (lack of space) * Lot-level actions: $42 mln investmt/yr + negl. current costs NPV $2.1 m; B/C= 1	2015-40 Impact: NPV moy/median = $435/286 mln (50% from CC) or 0.14% of cumulated GDP. Adaptation cost: $74.5 mln; NPV positive; B/C between 1.4-2.4	*Adaptation via planning measures: $300 mln investmt + $6 mln /yr; initial benef. $34 mln; large uncertainty, but average NPV = $181 mln; B/C= 1.4 *Lot level adapt.: $65 mln investmt; current costs not calculated; benefit $5.4 mln; NPV = $120 mln; B/C= 2.6
Resources / scarcity	Item either not calculated or considered not important			
Early warning system	Cost = $3.44 mln Best B/C ratio	Cost = $5.7 mln invest. + $0.85/yr; NPV= $124 mln; B/C = 5.7 (very high)	Not quantified but high B/C	$5.3 mln investmt + $0.8 mln/yr; benef.= $12 mln; NPV= $348 mln; B/C =13.7
Total Adaptation	Not quantified	(early warning + coastal maintenance + flood control) benef.= $619 mln ; cost= $436 mln; NPV= $183 mln; damage reduction = $2.3 bn (8.5%); B/C = 1.42	Only earthquake and flood control worth implementing: total benefit = $273 mln; B/C = 2.1	Erosion control dropped; all other measures together: benef.= $1181 mln; cost = $569 mln; NPV= $612 mln; damage reduction = $720 mln (17.6%) B/C = 2.07

With NPV = Net Present Value or net benefit; and B/C for benefit/cost ration.

NB: Variations in calculations are produced in the reports according to varying discount rates. Her it is the average discount rate of 7% which has been retained.

Authors frequently insist that structural measures based on traditional infrastructure construction or reinforcement are quite costly (with the exception of the dyke for Mohammedia's Industrial zone and harbour). They recommend to first develop sound planning measures (e.g. flood risk maps and action plans) to reduce vulnerabilities, plus early warning systems to help people reduce their damages. They also recommend the development of appropriate insurance mechanisms. But most of these measures are not easily quantified.

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