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Drivers to Support Adaptation of Cities

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J.Verschuur, B.Kolen and P.C. van Veelen

Flood Delta City Index

Drivers to Support Adaptation of Cities

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Contents

1 INTRODUCTION

From ancient history on, urban settlements are established in low lying coastal areas in the debouch of the river into the sea. These deltas function as magnets of growth because of the excellent conditions for economic development and human settlement at the transition of water and land: deltas are strategically positioned for trade and commerce and equipped with fertile soils and waters (Meyer and Peters, 2016). With sea level rise, increasing frequency and magnitude of extreme events as result of climate change, flood risk will most likely increase and affect millions of people. But next to increasing hazards, projections of ca 650 million people living in delta and coastal areas, which often function as engines of national economies (Meyer and Peters, 2016), will make flood events more disastrous in terms of economic damages and loss of life. This situation is getting even worse because most of this urbanisation is uncontrolled, leading to encroachment and expansion onto flood-prone areas, such as flood plains and lowlands. On the global scale, increase in flood risk due to the effects of human induced geological changes, unplanned urbanisation and socio-economic change is expected to surpass climate change as the most important factor, where climate change can significantly exacerbate this increase in exposure (Hallegatte et al. (2013) ; Rojas et al. (2013) ; Hanson et al. (2011)). These changes leading to increasing flood threats ask for designing more resilient urban systems able to accept, resist, recover and learn from the flood event (Batica and Gourbesville, 2014). This aim of becoming more resilient needs to find its way into flood risk management policies. Over the years, and shift has be initiated from preventive flood risk management, only focusing on technical protection, towards an more integrated flood risk management containing both structural and non-structural measures to prevent, defend, mitigate, prepare, respond and recover from flood events (Raadgever et al., 2014). In the Netherlands, this concept is incorporated in the new Delta act under the name 'Multi-Layer Safety'(MLS), which compromises the three safety layers; flood protection, spatial planning and emergency response (V&W, 2009). However, deciding upon a set of measures is difficult, because decision makers nowadays face the problem of having to take short-term decisions under long-term highly uncertain changes (van Veelen, 2016). Next to this, adaptation plans need to be robust, referring to maintaining desired ability when subjected to disturbances, and flexible, asking for measures which can be changed easily and in short time windows. Urban systems are constantly changing in extent but also within the system by means of redevelopment and maintenance, which opens up adaptation possibilities to reinforce existing urban environments. Therefore, adaptation of urban systems can be applied to retrofit, redevelop and regenerate these existing urban areas, next to implementation in undeveloped area aiming at improving the capacity of the whole urban system (Veerbeek et al. (2010); van Veelen (2016)). For example, strategic maintenance or expansion of infrastructure may enhance the ability for preventive evacuation of a city in case of a flood event. Such an approach would not cost additional investment, but cities can just interlink their recurring infrastructural investments to their flood safety ambitions.

With the increasing attention of future flood threat, sound flood risk management based on flood risk assessments are essential for decision-makers. Risk assessment are generally used and encompasses the identification, quantification and evaluation of risks associated with a given system (Jonkman, 2007). Assessing flood risk and vulnerabilities is needed to create a readily understandable link between the theoretical concepts of flood vulnerability and the day-to-day decision-making process and to encapsulate this link in an easily accessible tool. Indicators should be focused on small, quantifiable, understandable, unambiguous and telling pieces of a system that can give people a sense of the bigger picture (Balica (2012); de Bruijn (2005)).

1.1 SCOPE

The Delta Alliance and Delft University of Technology have decided to do a research to find out if it possible to develop flood-related index for urbanized cities and how such an index will look like. In order to do this, first a literature study of existing indices will be made to get insight in the various indices already available. Based on this, the decision can be made to develop an index and what criteria to set for this index. Indeed an opportunity was found for the development of an index. A first concept will be described in this report, which includes an assessment of 38 delta cities worldwide for their river flood risk.

On the short term, practical use of the index will be tested in collaboration with one or two of the Delta-Alliance wings. By doing this, it will be clear how such an index can help them in their decision making and if they have information sources on city level to improve the index. A discussion session with Deltares, UNESCO-IHE and PBL was held to elaborate on the index and to discuss various possibilities for collaboration and/or further research. In a new meeting, concrete plans for further development of the index will be discussed.

This concept can be considered as only being a first initiative, from which several studies can be done to improve the index to a fully functional concept on the long term. Ideally, on the long term, the index will be reproduced once every few years for all cities participating.

1.2 EARLIER WORK

Delft University of Technology in cooperation with HKV and Deltares has already conducted several research studies to develop a method for assessing flood risk of cities worldwide based on open-data. This has led to flood risk assessments using two different methods based on the methodology intiated by Nootenboom (2015). Over the years, all continents are covered now; Asia (Kosters, 2015), Europe (Nootenboom, 2015), South-America (Van der Veer, 2015), North America (Bader, 2016) and Australia (Suijkens, 2015). In addition, (Schilder, 2016) looked at the importance of including or excluding flood protection standards in flood risk assessment.

Thereafter, Verschuur (2016) made the first steps towards a flood risk index by looking at parameters based on multi-layer safety. The same author also proposed to add a fatality risk component to the assessment. Furthermore, a literature study to existing indices is done in previous work (Winkel, 2016), which has led to several recommendation for a new index. These studies were therefore an ideal stepping stone for this report.

1.3 STRUCTURE OF THE REPORT

Throughout the report, the steps are made and described that has resulted in the 'Smart Delta City Index' for 38 cities. First of all, a theoretical background in the concepts of flood risk and flood risk management are described, as well as several other essential definitions of urban flood risk. Furthermore, a literature study to existing indices will answer the question whether or not to proceed. In combination with the preceding theoretical background, criteria for the new to develop index will be set. Following this, the concept of index will be explained with all subcomponents. The risk assessments will be described explaining the method to determine the flood risk now and for two scenarios in 2030. After that, the radar chart with flood related parameters will be explained in more detail. Next to that, a link between urban development and flood risk increase is made and the ability of cities to bridge the risk increase by means of making smart use of urban infrastructural investments related to urban growth of cities. All results are summarized and the subcomponents are merged together yielding an overview of the total index for all cities. In the end, the conclusions are drawn and more importantly, the possibilities and recommendation for further research are described.

2 THEORETICAL BACKGROUND

First, the theoretical parts related to flood risk and flood risk management concepts are discussed. Important in this is the general definition of risk as $probability * consequences$, which forms the basis throughout the report. The multi-layer safety ideology is explained into more details entailing three layers of safety for adequate flood risk management. After that, the concepts of urban adaptation and resilience are explained in the context of flood risk. A link is made between the decision making process of flood related investments and often applied cost-benefit optimization, also in relation with the multi-layer safety concept and the uncertainty perspective of for example climate change. Furthermore, barriers to effective adaptation of strategies are discussed. This is more focused on the legal, governmental and social aspects instead of engineering aspects. In section 2.8, the literature review of the existing indices are summarized from which a conclusion is drawn whether or not to proceed with the development of a new index. In the end, an opportunity to proceed is identified by recognizing the drawbacks of existing indices. The theoretical framework and review of existing indices form the backbone of the following chapters, especially in the derivation, criteria and underlying reasoning of the new index.

2.1 FLOOD RISK

Risk is an often used definition in many industries relating a certain consequence to a given probability. In flood risk context, the definition adopted is not always consistent and changes over time. An definition adopted by the IPCC for example defines *flood risk* as : *hazard* x *exposure* x *vulnerability* (Kron (2002); IPCC (2007). In more general terms, flood risk can be defined as the probability of an unlikely event times the consequences:

$$flood\,risk = probability * consequences \tag{1}$$

Both definitions are in essence the same. *Probability* is related to the probability of occurrence of the unlikely hazardous event, in this case a river flood event. *Consequences* indicates the possible tangible or intangible assets affected by a flood event usually expressed as a economical value or number of people. The consequences includes indirectly the vulnerability of the system. The degree in which the exposed assets are damaged can be a function of the demographics, flood characteristics and measures taking like protection standards, precautionary measures in buildings, early warning and so on (Merz et al., 2010). Different flood phenomena can have different flood risks. For example, coastal and fluvial floods can be classified as low-probability high impact floods and may cause economic and societal disruption, whereas urban flooding as a results of heavy precipitation is considered a high probability-low impact flood phenomenon, which may cause substantial damages as well (van der Pol et al., 2015).

2.2 FLOOD RISK MANAGEMENT

From 1990 to 1999 during the 'International Decade of Natural Disaster Reduction' (IDNDR), it was first recognized that the previous paradigm of "flood prevention" is inappropriate and it was concluded that absolute protection is both unachievable and unsustainable, due to the high costs and inherent uncertainties (Schanze, 2006). Over the years following this statement, and shift has been initiated from preventive flood risk management, only focusing on technical protection, towards an more integrated management approach containing both structural and non-structural measures to prevent, defend, mitigate, prepare, respond and recover from flood events (Raadgever et al., 2014). Instead of depending on a single protection measures, risk can be distributed over a large number of individual units which makes it less prone to overall failure at a system level. Despite this, flood protection measures, and especially engineering-based measures, will continue to place significant burden on national budgets and this trend is reinforced by climate change (van der Pol, 2015). The non-structural measures are characterized by the ability to reduce the impact of a flood event after exceeding the flood preventive structures. Examples of non-structural measure are early warning systems, flood proof buildings, evacuation plans and so on. In the Netherlands, this concept is included in the new Delta act under the name 'multi-level safety (MLS)' compromising three layers where flood-control measures are classified in (V&W, 2009). Layer 1 comprises measures for the prevention of flooding, such as dykes and storm-surge barriers; layer 2 includes spatial solutions for the mitigation of losses, such as flood proofing or relocation of buildings to safer places, and layer 3 is made up measures for emergency management , such as evacuation plans (Tsimopoulou et al., 2014).

An example for a project now executed in the Netherlands is the 'Room for the River' project. The goal of the programme is to give the river more room to be able to manage higher discharges. These measures are different for every location varying from lowering winter and summer bed, water retention area, dyke relocations, removing obstacles, depoldering and strengthening of dykes. Another objective of the programme was to improve the quality of the immediate surroundings, making the areas more liveable and better aesthetic embedded in the landscape. However, according to Ebregt et al. (2007), the cost-benefit analysis showed a negative number and focusing on dyke strengthening only would have reduced the costs by almost 50%.

2.3 MULTI-LAYER SAFETY

2.3.1 PREVENTION

Preventive measures are often the first line of defence consisting of dykes, levees, flood walls, storm surge barriers and dunes. Preventive measures are used as the primary way to prevent flooding, because they have a direct effect on the flood probability. They are characterized by high initial investment and long life times up to 100 years. The level of protection implemented in a country can depend on economic strength, potential damage, safety standards and risk-aversion of the government. Because of the high investment level, optimal heights are in a lot of cases based on an economic optimization, where the cost-benefit methodology is the common applied tool as will be discussed later. It is expected that investment in preventive measures will significantly increase in the future (Jongman et al., 2014) and still keep being the focus of flood investment schemes. However, flood prevention is never absolute and only a certain level of protection against flooding can be reached. As floods cannot be completely eliminated, the residual risk should be managed by means of mitigation measures, or measures that decrease the consequences of flood event in case the preventive measures were not enough.

2.3.2 LAND-USE PLANNING

Land-use measures are general spatial solutions that have as objective to mitigate the flood losses, and can be implemented both on the small household scale as well on a bigger scale, for example city scale. In flood-prone areas, land-use planning is expected to contribute to flood mitigation mainly because it can influence the incidence of flooding and its consequential damage by regulating the locations of activities, types of land use, scales of development, and designs of physical structures (Ran and Nedovic-Budic, 2016). The aforementioned 'Room for the River' project is one of the big spatial planning plans executed right now in the world, aiming to reduce reduce the exposure instead of decreasing the probability. On a smaller scale, building flood prove buildings in vulnerable areas is considered one of the easiest way to reduce flood damages. Controlling land-use in flood prone areas, for example by designing flood retention polders, can affect both the flood generation and the flood propagation, because retention polders decrease the run-off and increase the infiltration. Another measures is to prohibit urban development in recognized hazard prone areas. Especially in fast growing urban agglomeration where urban expansion towards the vulnerable flood prone areas is inevitable, including spatial measures in new urban infrastructure is a necessity. Implementing measures in new to develop areas is economically preferable and easier in practise compared to implementation in existing urban environment. An example of a newly developed flood-prove urban area is the 'Hafencity' area outside the main dyke ring in Hamburg. Instead of physical protection, the area consist of elevated grounds, flood proof buildings and evacuation routes above flood level (Verschuur, 2016). In contrast with the economically developed urban area of Hamburg are some African cities with major urbanization problems and low investment budgets. Uncontrolled urbanization onto the flood plains, often referred to as "encroachment" (Pottier et al., 2005), makes it difficult to control the hazard prone areas, because in the time-frame of execution of the measures the situation is already worsened over time. In such situations, population also often lacks awareness of their situation. Making people aware of their situation on a local scale and help governments develop urban management policy can initiate small shifts in settlements with major benefits (McGranahan et al., 2007).

2.3.3 EMERGENCY MANAGEMENT

Emergency management covers the aspects of warning, disaster planning and evacuation all aiming to reduce the potential number of fatalities and damages to goods. Emergency management is the transition from day-to-day live into evacuation, with number of evacuated people as quantitative measure. Therefore different measures could help shorten the times frames and increase the percentage of evacuated people. First of all, detecting and recognizing the threat with the help of warning systems play an important role in this. Flood early warning systems are often coupled with weather predictions to detect possible threatening event and can collect data for the decision-making situation after the detection. Fully relying on warning system may result in inadequate decisions, because systems can fail or do not recognize the threat. After that, the decision has to be made whether or not the threat is serious enough to continue into evacuation. This decision is made by the respective authorities, where a centralized decision-making process is vital leading to shorter response time and a smaller probability of miscommunication. After the threat is recognized and the decision is made to go into evacuation mode, the phase in between these two is the transition phase. In this phase, evacuation planning should be set in place for example by informing the public, adapting traffic infrastructure and re-locating personnel and resources (Kolen, 2013). Disaster plans come into action and the benefit of practising and testing these plans comes now into play. Lack of plans may lead to chaotic situations, waste of time and the risk of taking wrong decisions. Also, the information penetration by means of the traditional ways telephone, televisions and internet determines for a large part the number of people that could be reached in time. The following phase is the time between the start of the evacuation and the onset of flood event and thereafter. This mainly determines the number of people that can be evacuated or the number of valuable assets that can be replaced. In the context of evacuation management, preventive evacuation is the most executed form of evacuation, which is defined as moving people or assets from a potentially exposed area to a safe location outside this area. As many people want to escape the flood prone area by car, this may lead to congestion on the main roads. Consequently, this can make people even more vulnerable if the time between detection and onset is short. Therefore, in situations with short lead times, vertical evacuation or a shelter in place type of evacuation is a better strategy. Vertical evacuation refers to the movement of goods of people to buildings inside the threatened area that offer protection or are not affected (Kolen et al., 2012). Because of the many factors involved and because of the big dependency on human behaviour in effective emergency management, evacuation fractions are difficult to determine.

2.4 RESILIENCE

Resilience is an often used definition in the context of flood risk aiming at being resilient or climate-proof against future threats. The definition of resilience by the IPCC(2014) is framed as *"the capacity of social, economic and environmental systems to cope with hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (Field et al., 2014)"*. Batica and Gourbesville (2014) defines an urban system or community as being resilient as it is able to accept, resist, recover and learn from a flood event. According to de Bruijn (2005), resilience is often associated with resistance, where resistance is the ability to prevent floods and resilience is the ability of the system to recover from floods. The different definitions in literature making it an ambiguous definition, but in essence they recognize 'adaptation', 'learning' and 'recovering' as the essential components of being resilient against a disturbance. This aim of becoming more resilient needs to find its way into flood risk management policies. Not only to minimize potential damage and coping with the consequences of the impact, but also taking advantage of the opportunity to change something. According to de Bruijn (2005) the concept of resilience can only become an applicable concept in flood risk management if it is made quantifiable. The same author stated that measuring resilience directly is not possible, since it is not clear what to measure.

2.5 URBAN ADAPTATION

Keeping up with the external system changes, like climate, is a major challenge nowadays for policy makers and city planners. Adapting urban environments to future projections of climate change , subsidence and socio-economic impacts is hot topic on the agenda. According to the IPCC (2007), *adaptation* can be defined as *"the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."*. Despite the increasing interest for developing adaptation strategies for urban systems, adaptation is by no means firmly embedded throughout the activities of the majority of cities and urban areas (Carter et al., 2015). This can be explained by the difficult task decisions-makers and urban planners face of taking adaptation strategies under highly uncertain scenarios. This may lead to so-called 'maladaptation' , defined as the time lag between changes in climate and changes in institutions (Veerbeek et al., 2010). In most existing urban areas, there is continual turnover of existing property and infrastructure. Therefore, adaptation of urban systems can be applied to retrofit, redevelop and regenerate these existing urban areas, next to implementation in undeveloped area. With the growing concern of urbanization, making the percentage undeveloped area in delta cities smaller and smaller, less improvements can be made in existing areas, but more in new areas. The opportunities this affords for climate proofing urban areas as part of a resilience enhancing process is a key element of adapting to cope with an uncertain future (Veerbeek et al., 2010). This in line with the research of van Veelen (2016), who states that it is likely to be most effective to adapt existing urban environments and urban assets, and promote flood sensitive behaviour in combination with prevention based approaches, aiming to improve the whole capacity of the urban system to deal with changing and more extreme conditions in the future. However, adapting existing urban areas can be more difficult in practise, because construction standards now are not always in line with construction standards used in the past. A possible solution of successfully adaptation can for example be developing alternative adaptation plans under different scenarios and in the end deciding the strategy than best fit the actual situation. Keywords and balancing factors in adaptation strategies are 'robustness' versus 'flexibility'. Robustness and flexibility are considered the most relevant concepts in describing resilience (Zevenbergen et al., 2008). System robustness refers to the ability of systems to maintain desired system characteristics when subjected to disturbances (Merz et al., 2010). This requires a long term vision and in flood management it commonly refers to technical measures like dykes, barriers, protection walls and retention basins. These measures are characterized with high fixed costs and long lifetimes. Therefore, transforming current protective infrastructure is difficult because of the life spans of decades and considerable sunk costs (de Graaf and der Brugge, 2010). For example, dyke heights are difficult and economically inviable to change over time, because height are in most cases determined with a cost-benefit optimization process guaranteeing the sustainability of economic investments. Flexibility on the other hand asks for measures that can easily be changed in the short term when additional information is available concerning ongoing developments that can influence the potential flood risk of a city. This is for example possible if a close collaboration is maintained between scientists and city authorities, in which new insights are exchanged. Flexibility means therefore more adapting to uncertainties in contrast with being insensitive to uncertainties. Combination of both in one strategy is focusing on the long term with keeping in mind possible changes along the way.

2.6 DECISION-MAKING

The tendency to develop adaptive strategies including non-structural and structural measures sounds like a solid and good way of dealing with flood risk, however when these plans include high investment schemes considering a limited budget, economic viability is still a decisive factor. For decades, cost-benefit analysis are used to optimise investments in flood risk measures in the Netherlands based on the work of econometrician van Danzig. He stated that deciding based on a cost-benefit perspective means that the condition for optimality is that the total cost in the system throughout its lifetime is the minimum possible (van Danzig, 1956). The costs of the investment are compared with the benefits, which are usually expressed as risk reduction in number of people or assets safed during the lifetime of the system. This principle was used to determine optimal dyke heights for the Netherlands after the major flood event in 1953 and is still used in the most recent Delta Act. Many governments worldwide use this to validate investment proposals of flood mitigation strategies and often choose the most cost-beneficial option. Cost-benefit analyses show that limited investment in evacuation management is economically justified in addition to measures that reduce the probability of flooding. Additional investments in buildings (dry- and wetproof building or elevation of surface levels) or increased road capacity are compared to prevention measures and emergency management not attractive from an economic point of view for the Dutch dike rings. This because of the high costs and limited benefits (Kolen, 2013). Therefore, in low probability high exposure situations, the largest investment proportion will still go the strengthening of the preventive systems to reduce flood risk. In situations of lower exposure and higher probability, investing in emergency management measures and spatial planning can be economically viable. Cost-benefit analysis will still be the number one decision making tool, although scepticism arises if this tool is still valid for the use under uncertain future scenarios. Experts are trying to develop methods to design multi-layer safety system based on cost-benefit principle, for example Tsimipoulou et al. (2015). However, these methods are still large built on assumptions and uncertainties regarding efficiency of non-structural measures. Many authors say that investments in protection have often been inadequate (e.g. Aerts et al. (2014)), but under the assumption that climate change and socio-economic developments will significantly increase the flood risk, it is essential to consider both optimal design and optimal timing of dike reinforcements as part of the optimal investment strategy. Each year, measures are taken to develop or reconstruct areas that might influence flood risk (Kolen, 2013). The moment of reconstruction can also be used for additional measures to reduce flood risk as was already discussed as the interlinkage of urban adapation to flood risk. With increasing probabilities and consequences in time, a decision to invest in flood defences is not a one-time decision but a recurring one. And because a considerable part of the costs of dike reinforcements are fixed costs, it is cost-efficient to significantly reinforce the dike periodically and to take longer time intervals in between the reinforcements (Kind, 2014). From this point of view, urging decision-makers to act right now is from an economical point of view not beneficial if past reinforcements did not reach their intended lifecycle. In addition, several political, psychological and social processes play an important role in the evaluation of the risk, making it a subjective process (Jonkman, 2007). According to Jongejan (2008), risk appraisal is a value-laden activity. No scientist can rightfully claim to possess superior knowledge about the risks that ought to be acceptable to all. This means that the amount of risk-aversion of governments and how society interpreter the risks they face varies from one country to another. In general, risk aversion refers to a situation where one accident with 100 fatalities is perceived as more dreadful (and less acceptable) than 100 accidents with one fatality (Jonkman, 2007). How risk averse a government determines there attitude towards investing in protection measures and which safety standards are acceptable to them. In the Netherlands, a pro-active attitude characterises the government. In contrast, in the United States and United Kingdom a more risk neutral and reactionary tendency is embedded in the policies. But then there is still the society, who urges the government to be precautionary. Societal risk appreciation may also lead to a controversy of the urgency to act, which gives decision-makers an incentive to wait until additional information arrives, before they invest in an highly uncertainty management plan. This because a flood event often results in an ”never-again” attitude amongst the affected people leading to forced large investments. This method can however be highly uneconomic, because it does not account for expected discounted damage cost in case of an earlier pro-active investment strategy (van der Pol, 2015).

2.7 BARRIERS TO EFFECTIVE ADAPTATION

Formulating adaptation strategies and doing a cost-benefit analysis are the first two important steps for effective adaptation. In addition, several other factors like legal, governmental and societal come into play determining the effective implementation of these strategies and plans. From a legal framework perspective, governments need to formulate the legal departure points for adaptive spatial planning. Despite the growing need for flexible plans, regulation and fixed procedures are limited in flexibility (van Buuren et al., 2013). Next to this, financial institutions are becoming increasingly important nowadays when taking management decision in the high risk, high uncertainty, large consequence domain making the necessity of adequate flood insurance schemes more relevant than ever. But also the decision-making organisation itself needs to change, because the uncertainty and multiplicity of climate and socio-economic changes put high demand on the organisation of planning process, with possible changes in this planning process as result (van Buuren et al., 2013). Sometimes the lack of control over decision-making is the limited factor. For example, more than half of the Dutch housing stock is owned by semi-privatized housing corporation. Over the past years, government control has reduced and housing has been left to market conditions. A streamlined adaptation of new climate proofing policies is therefore hampered by this lack of central direction (Veerbeek et al., 2010). In the framework of the IPCC 2007 report, Adger et al. (2007) assessed further barriers to climate adaptation. This led to the following five main barriers observed: (1) ecological and physical limit related to the possible limited adaptive capacity of natural systems; (2) technological barriers related to the possible incapability of technologies to be transferable as well as some technologies might be thought to be cultural undesirable or economically infeasible; (3) financial barriers that refer to the overall lack of resources for both addressing adaptation and possible damage; (4) informational and cognitive barriers related to the uncertainty, complexity and lack of knowledge regarding the topic of climate change and the need for adaptation; (5) social and cultural barriers resulting from the differences in the worldviews, values and beliefs of individuals or groups. Many more barriers can come to mind, making it overall a complex problem, leading to frameworks to overcome these barriers for good urban governance in the scope of climate change adaptations. Key factors in literature are decentralisation for quick and effective implementation of policies and programmes, transparency and participation to encourage the involvement of poor and marginalised groups (most vulnerable groups) in decision-making, monitoring and evaluation especially to those living in the informal and exposed areas (Tanner et al., 2009). Experiences in the past can give insight what is most effective in your situation. Also, Learning from successful plans in comparable cities can be beneficial for shaping new plans. This asks for connectivities between cities, overarching development programmes and a platform to communicate. This last sentence is of great importance, since this is one of the main long term objective of the index that will be presented in the next chapter.

2.8 INDICES

Indices are an example of multi-criteria analyses and are especially useful and well suited to aid the resolution of decision problems, because it is easy to read and interpreter without having in-depth knowledge of the methodologies behind it. It is a way to combine information associated to indicators of distinct natures and significances, translating them into a single value (Zonensein et al., 2008).

2.8.1 EXISTING INDICES

Over the years several indices are already developed by various institutions based on their own methodologies, parameters, sources and graphical representations. By orientating the various methods and by critically assessing them, useful ideas and parameters can be found which can form an inspiration for the development of our index. More importantly, shortcomings of existing methods can be identified, which gives insight how to distinguish our index from existing indices. The following existing rankings are reviewed; City Blueprint Index (CBI), Coastal City Flood Vulnerability Index (CCFVI) , Sustainable Cities Water Index (SCWI), Resilience Wheel, Global Competitive Index (GCI) and the Notre Dame-Global Adaptation Index (ND-GAIN). The full assessment for every ranking can be found in the appendix A. Important findings are first of all the variety in methodologies by using different parameters, sources and scoring principles. Number of parameters vary from 17 up to 118, based on mainly open data (GCI) versus making use of only qualitative data by means of a questionnaire (CBI) or judgement (Resilience wheel). Secondly, all indexes lack to include flood risk in its most general definition (hazard x consequences) as parameter. Next to that, a judgement based ranking method makes ranking sometimes to subjective and dependent on the interpretation of the author, whereas a quantitative ranking will lead to a less ambiguous interpretation. Qualitative ways of scoring may also lead to conclusions or estimations, which may not be supported by data. An example is measuring the awareness and preparedness of inhabitants based on the number of reports of policy makers under the assumption that inhabitants are aware of these reports and plans and react in the expected and appropriate way. Notable in the comparison of the existing rankings is the fact that only the indices based on quantitative data are able to make their index reproducible. This is most likely because using a qualitative scoring principle is time consuming or/and to expensive to reproduce year after year. Last observation to notice is the static use of the index. All rankings are a static representation of the situation at a certain time, whereas using external development is more valuable showing the difference between the situation now and the situation in the future under climate, socio-economic and geological scenarios. The CCFVI tries to do this by changing specific parameters under climate change scenarios, but does not manage to achieve the full potential of this by only focusing on climate change.

2.9 CONCLUSION

Based on the review of the existing indices, it was decided to further proceed with the initial development of a new flood-related index. This review also gave insight what kind of criteria to set. What was learned from the theoretical part are especially the difficulties city-authorities and city planners face nowadays to keep their city robust for the intensive pressures that are acting on the city now and in the future. Therefore, next to looking at the risk now, it is even more interesting to take into account the expected developments that increases the risk. Not only to identify the main drivers, but also the indicate the uncertainty a city faces. Moreover, flood risk management is not only focused anymore on preventive measure, but an integrated approach of structural and non-structural measures is now often used to not only prevent but also mitigate the damages of flooding. What was also recognized is that urban adaptation is more important, since cities are not considered as static systems, but a constantly changing system, which provides opportunity for adapting new and existing urban environments to make them flood prove. This can coincide and coupled with the lifecycles of recurring urban infrastructural investment, so these moments in time form a perfect opportunity to enhance the flood safety of the urban area. Therefore, flood risk increase and urban development are strongly interconnected phenomena. These points will be taking into account for the criteria of the new index as we will see in the next chapter. The idea of a new index was also discussed during an information session with Deltares, PBL and UNESCO-IHE. The summary (in Dutch) can be found in the appendix B. All partners were enthusiastic about the idea and provided some useful input how they thought was the best way to move forward. First of all, they though focusing on the flood risk is a good idea, because several more broader indices, for example focusing on resilience, are already developed. Also, the index can raise several research question that can be the initiation of new research. Also, they all agreed that in the future, coastal and pluvial flooding should be included, whereas the first index (as will be explained later) is only focused on river flooding now. Moreover, they suggested ways to incorporate models they are currently developing in the index. For example, UNESCO-IHE has developed a model to predict urban growth of cities based on a genetic algorithm, whereas PBL is also currently trying to develop such a model. Both models can be used in combination with a flood risk model like the one we are using.

3 APPROACH DELTA CITY FLOOD INDEX

The aim of the 'Flood Delta City Index' is to rank and compare delta cities worldwide related to flood vulnerability and urban adaptation possibilities by recognizing the potential change in flood risk under future climate and socio-economic developments. This index provides decision-makers and urban planners with a quick and readable overview to set ambitions and to keep track on their urban adaptation strategy. Furthermore, its for a communicate platform to boost the debate, share best practises, ideas, and to decide upon the direction of further research. Three layers of information are recognized. The first layer and in fact the further scope of the report is the *open-data* index for river flooding only. The most important criteria set for the index are:

- Reproducible: The ranking should be updated every few years and published independently by the representative institution. The parameters used should therefore be updated in the same time frame, so an evolution of the ranking over time can be made.
- Universal: The ranking can be applied to delta cities worldwide independent of their geographical characteristics. To be able to fulfil this requirement, the focus should be on the general characteristics of a city related to flood risk to be able to compare small and large cities. Next to that, the ranking should be universal for different flood phenomena.
- Quantitative: The ranking should reflect cities in a quantitative way to be as objective as possible and to avoid the subjective perception of the one performing the analysis. The ranking will be based on a mix of open data and models to quantify the parameters. Only in case of lack of data or appropriate models, surveys or expect judgement will be used to fill in the missing gaps.
- Risk-Based: A measure of flood risk, both economic and fatality, in its most general form shall be used as main indicator (probability x consequences).
- Multilateral: Recognizing that flood risk management is an integrated approach of *prevention*, *land-use planning* and *emergency management*.

Furthermore, a *self-assessment* will make it possible to let city authorities participate and fill in the gaps in case of data scarcity or correct indicators based on their own data. Additionally, *tailor-made research* can be derived for a specific area or topic based on the index. In the section below, the approach for the open-data index with three components 'risk assessment', 'flood index' and the 'adaptive capacity of urban cities' are outlined forming the basis of the following chapters.

3.1 CRITERIA

Based on the analysis of other indices and the theoretical background, it was decided to proceed with the development of an index. Because of the shortcomings of other indices, several criteria were set for the development of the new open data index, namely 'Reproducible' , 'Universal' and 'Quantitative'. These three criteria will help to achieve; 1) to be objective, so the index can be produced independent of the one that makes the index, 2) that the index can reproduced every few years in a time-efficient way and 3) that a large quantity of cities are able to participate. In line with previous work done and because everything will be related to the flood risk of a city, flood risk will be the main component of the index. Furthermore, as was already recognized in the theoretical background, flood risk management is making a shift towards an integrated approach of multi layers with measures since absolute protection against a flood event is unachievable and/or economically inviable. In this manner, a multi-lateral approach of flood risk management should be incorporated in the index. Furthermore, it was recognized that urban development en flood risk management are highly interconnected phenomena.

To accompany this need, a 'Flood Delta City Index' is developed based on the criteria described. The aim of the 'Flood Delta City Index' is to rank and compare delta cities worldwide related to flood vulnerability and urban adaptation possibilities by recognizing the potential change in flood risk under future climate and socio-economic developments. This index provides decision-makers and urban planners with a quick and readable overview to set ambitions and to keep track on their urban adaptation strategy. Furthermore, its for a communicate platform to boost the debate, share best practises, ideas, and to decide upon the direction of further research. This objective can be extremely useful for decision makers who are having trouble making decisions under highly uncertain future projections as was mentioned in section 2.7. In here it was stated that experience can give insight what is most effective in a city's situation and that learning from successful plans in comparable cities can be beneficial and could help cities in their decision making. This asks for connectivities between cities, overarching development programmes and a platform to communicate, where the latter one is exactly the objective of our index. In the blue box in the beginning of this chapter, this all is shortly summarized. Next to this open data index, there are also an opportunity to create a platform for *self-assessments of cities.* This can be related to the open-data index in case of data scarcity or to measure parameters more directly by provided data from cities. This can also enhance the participation of cities. Furthermore, *in depth research* can be based on the index and complement the index, for example by developing a new model to measure a parameter in a more sophisticated way. However, these two are not the scope of this report, and only the open-data index will be discussed further on.

3.2 APPROACH

In the table below, the three components of the new index are briefly summarized. These three sections will guide the reader trough the following sections. First the 'flood risk assessment' is elaborated. This flood risk for all cities is determined using an open-data global flood risk model. Economic and fatality risk are calculated and in the end added together to come up with the total risk of the city (table 1). Furthermore, two scenarios for the year 2030 are calculated to show the development of the risk in time. Secondly, the 'flood index' with parameters related to the multi-layer safety concept are discussed and presented in a radar chart. These parameters are derived from the available open data and normalized to a scale from 1 to 10, where 10 means most vulnerable (table 2). Finally the 'adaptation capacity of urban cities' is briefly summarized. This urban capacity of cities is the link between urban development and flood risk increase (table 3). It is the possibility to couple moments in time for recurring urban infrastructural investments to achieve risk reduction in a smart and effective way. With the alarm sign, it is indicated if the transition is easy with just some policy adjustments (green) or that the flood risk is developing too fast compared to the urban expansion and this transition needs extra investment to bridge the gap (red). In the end, everything comes together in the indices for all cities, combining all aforementioned parts.

Category	Parameter	Definition [unit]	Source / Model
Risk	Economic Risk	Expected monetary damage per year [€/yr]	Flood Risk Assessment
	Fatality Risk	Expected loss of life per year [# fatalities /(yr)]	Flood Risk Assessment
	Total Risk	Total Annual Expected Damage (Economic+Fatality) [€/yr]	Flood Risk Assessment

table 1: Risk given for both the situation now as well as the situation in 2030.

Category	Parameter	Definition [unit]	Source / Model
Preventive	Flood Probability	Probability of flooding, or to what extent protection standards are in place [1/yr]	FLOPROS
	Flood Cover	Area of a city that will be flooded [%]	PCR-GLOBWB, GADM
	Properties at Risk	Percentage of properties in flood prone areas [%]	PCR-GLOBWB, GADM, Atlas of Urban Expansion
	Loss of Life Potential	Number of people at risk divided by total population [/yr]	Flood Risk Assessment (see above), City Population
Economic	Population Density	Number of people per area [# / km2]	CityPopulation
	GDP-capita	Gross Domestic Product per capita [$ / person]	OECD-database, IMF-database
	Economic Impact	Percentage of national GDP produced in the city [%]	OECD-database, UN-database
Emergency	Flood History (Awareness)	Number of flood events experienced last 30 yr [#]	Dartmouth Flood Observatory
	Vulnerable People	% of people under 15 and above 64 [%]	OECD-database, World Urbanization Prospects (WUP)
	Preventive Evacuation Capacity	Likelihood to congestion: population density divided by the road density [# people / (km)]	Atlas of Urban Expansion CityPopulation
	ICT Infrastructure	Number of people with fixed lines/cellular /broadband internet access [# / 100 persons]	UN-Database
	Shelter Capacity	Number of high-rise buildings (>35m) [#]	Skyscraper database
Land-use	Vulnerable Urbanization	Share of urban expansion settled in flood prone area over period 2000-2014[1-5]	PCR-GLOBWB, Atlas of Urban Expansion

table 2: The Flood Index based on open data and models divided into four categories; preventive, economic, emergency and land-use.

Category	Parameter	Definition [unit]	Source / Model
Adaptive Capacity of Cities	Urban Expansion	The expected urban expansion of cities based on trend over the period 2000-2015 [%]	Atlas of Urban Expansion

table 3: The adaptive capacity of cities

4 FLOOD RISK ASSESSMENT

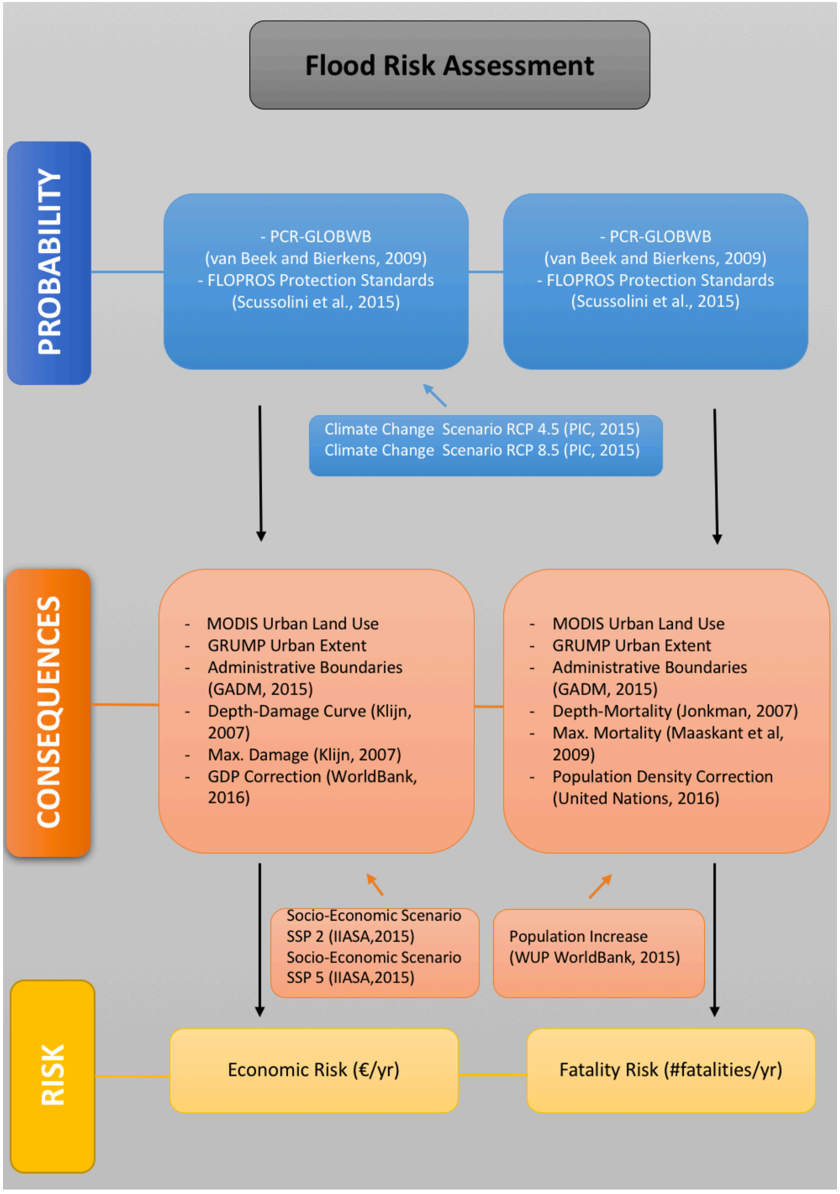


figure 1: Brief Overview of components and sources used to calculate the economic and fatality risk.

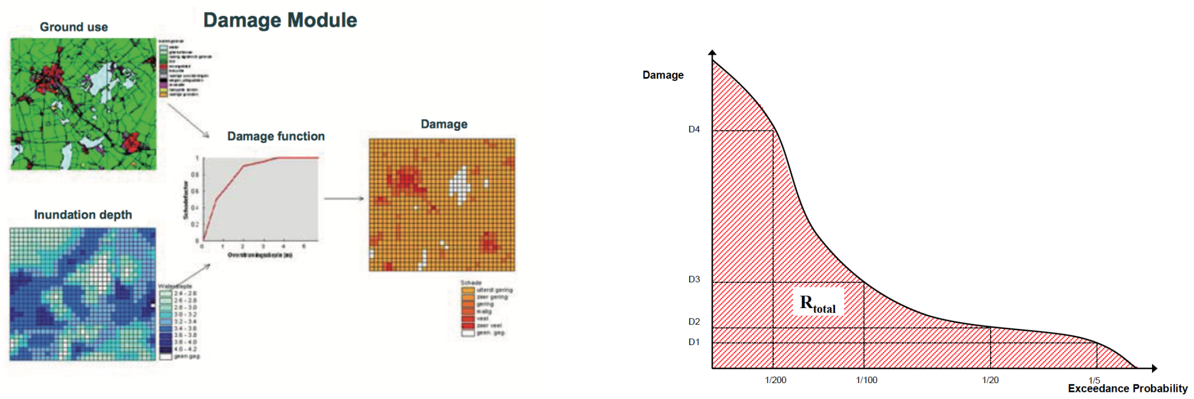
In this chapter, the methodology of the flood risk assessment will be explained. First a short general description will be given about flood risk assessments. Thereafter, the subcomponents for the economic and fatality risk assessment are described including sources and approach. The total risk is simply the addition of the both and expressed in a monetary value €/yr . In the end, two scenarios for 2030 are explained, respectively a moderate scenario (2030-low) and an extreme scenario (2030-high). In section 4.6, everything comes together for an example city, which is eventually the graphical representation used in the index. Because for non-experts, after reading, it may still be difficult to imagine how all subcomponents work to determine the risk, two examples maps are made for a 1/1000 flood event in the Netherlands and Bangladesh, see appendix C.

Methodologies to determine the expected damages and fatalities or to derive flood hazard maps are widely used nowadays, all following approximately the same concept. Some models are useful on the small scale, for example city or neighbourhood level, whereas others can be applied on a global scale. A model to do the latter is for example the 'Flood Impact Assessment Tool' (FIAT) developed by HKV and Deltares. This model is largely based on open data to assess flood risks on city level worldwide. Because of the open data structure, it can be updated using newer data sources and the assessment can be done quickly. This model uses a combination of a hydrological model together with data on flood protection standards to determine the probability. Land-use maps and depth-damage curves determine the given consequences for the inundated areas. The flood risk is expressed in a monetary value, or annual expected damage (€/yr), or in fatalities depending on the maps and values used. The components to calculate the risk in a typical flood risk assessment are shown in figure 2a, where figure 2b shows the damage probability function. The damage probability function represent the expected damages for every return period of the hazard. The Annual Expected Damage (EAD) is calculated by means of multiplying the probability to the corresponding damages expressed in €/yr, or any other currency preferred.

$$Risk = Probability * Consequences \quad (2)$$

$$EAD[€/yr] = p_i * D_i \quad (3)$$

The probability is related to the flood protection standards in place keeping the area behind it safe until a certain threshold is reached. This probability corresponds to a certain return period (Poisson distribution). In general, the consequences of a flood event are related to the potentially affected tangible or intangible assets in a flood prone area. These assets can be further subsidized in direct or indirect assets based on the nature of the damage. These do not need to be restricted to assets that are located in inundation areas, since indirect flood effects may damage assets outside the flooded area (Merz et al., 2010). Examples of indirect damage outside the affected area are unemployment and social and economic disruption (de Bruijn, 2005). Direct economic damage is by far the most used indicator, because it is relatively easy to measure and expressed in a monetary value. This in contrast with intangible and indirect measures, which are very difficult to quantify (de Moel et al., 2009). Loss of life is considered to be the most important loss type in the public perception of disasters (Jonkman and Vrijling, 2008). This has led to significant developments in the field of loss of life estimation and although these methods provide first insights in the range of loss of life that could be expected, there are still a lot of questions related to the empirical foundation of these methods and their application for policy decisions (Jonkman et al., 2016). In contrast with damage to tangible assets like houses and infrastructure, humans have the ability to respond to prevent them from the possible impact of a flooding. People can reduce the risk of loss of life by moving to relatively safe places, such as shelters, safe havens, or even places prepared at home (Kolen et al., 2012). The response to Hurricane Katrina in 2005 in New Orleans demonstrated that people and goods that can be moved might be saved, but other goods will still be affected by the flood (Kolen et al., 2012). Evacuation of people from a potentially affected area is the most important used mechanism to prevent people from flooding in case of an actual event. However, due to circumstances like short time window and limited road capacity , it may not be possible to remove all inhabitant. Despite the difficulties of assessing loss of life, we try to included both a measure for the economic risk, as well for the loss of life risk in our risk assessment. Additional benefit of the use of this model in the scope of our research is the possibility to include climate and socio-economic projections in the model to estimate the future risk. The different components will be discussed in more detail. Further reference is made to the report of Nootenboom (2015) or the article of Winsemius et al. (2013).



(a) (b)

figure 2: a) Overview of components to calculate the EAD (en Waterstaat, 2005) b) Damage Probability function to calculate the EAD (Messner et al., 2007)

4.1 ECONOMIC RISK

4.1.1 PROBABILITY

To simulate river discharge and inundation areas in all river branches, a global hydrological model is needed forced by a global climate model (GCM). Models describing hydrological processes at a global scale are now frequently being used to assess the effect of global climate change on the worlds water resources. For the assessment of inundation spreads for different return periods, a global hydrological model called PCR-GLOBWB, which is derived from PCRaster GLOBal Water Balance model, is used developed by the Department of Physical Geography of Utrecht University (Van Beek and Bierkens, 2009). More information about the model in detail can be found in appendix C. The model is calibrated and extreme discharges are calculated for different return periods. The model is capable of calculating the extreme discharge for a return period of 5, 10, 25, 50, 250, 500 and 1000 years. This directly shows the weakness of using this model, because cities with protection up to a level higher than the once every 1000 years return a risk value of zero because no inundation is expected. We will see the implications of this later, but it can be said that this model is suitable in case of low-protection situations. To protect a country or city from flooding, protection measures are incorporated all around the world. These protection measures prevent a flooding of the protected area up to the certain design level. Talking about protection measures in this context, we are mainly focused on structural protection measures like dykes, levees and barriers. Design heights of these structures are usually expressed as an exceedence probability for a certain flood event. Because flood prone areas are protected upon this exceedance probability, this part of the damage probability curve can be truncated as is done in figure 3. These return periods corresponds to the return periods of the extreme discharges. Therefore this return period, or simply protection level, can be seen as the probability of a flood event.
For example, in the Netherlands dykes are designed to protect the hinterland against a 1/1000 year flood in the less exposed areas up to a design level of 1/10000 years for the densely populated areas with high economical exposure. The exceedance probability of protection standards worldwide are dependent on economic possibilities, risk-aversion, available space, technical knowledge. In current flood risk assessment, flood protection standards are often neglected or included on the basis of assumptions by means of an uniform value (Ward et al., 2013), related to GDP/capita (Feyen et al., 2012) or a risk based approach (Jongman et al., 2014). However, the accurancy

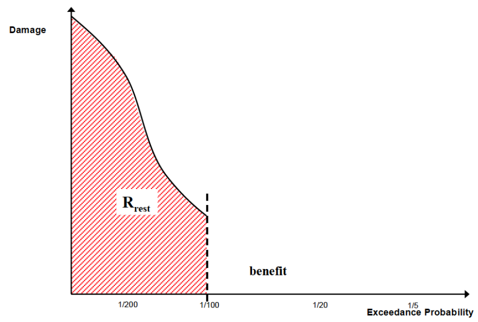


figure 3: Truncation of the risk due to protection standards (Messner et al., 2007)

of these flood risk assessment is limited by lack of re-
liable information. For example the study of Schilder (2016) made it clear that ignoring flood protection standards in flood risk assessment can cause huge overestimations of the resulting flood damage and a shift in results for including or excluding them. Scussolini et al. (2016) tried to develop a database showing the protection standards worldwide, which can be used for more reliable flood risk assessments. The database consist of three layers, *design*, *policy* and *model*, where the first layer is considered most reliable followed by the second. The *design layer* contains empirical information about the actual standard of existing protection already in place; the *policy layer* contains information on protection standards from policy regulations; and the *model layer* uses a validated modelling approach to calculate protection standards. The policy layer and the model layer can be considered adequate proxies for actual protection standards included in the design layer, and serve to increase the spatial coverage of the database (Scussolini et al., 2016). In absence of information from the first layer, information from the second layer will be used. In the end the different layers are merged into one map covering all countries as is shown in figure 4. Despite the intended benefit of the database and the great potential, some shortcomings are recognized asking for a cautious use of the database. First of all, reliable information in especially developing countries is scarce making the protection values used still quite uncertain. Secondly, the spatial scale is sometimes not in line with the lowest level of variation of the flood protection standards. Most of the time, an uniform value for a certain state of province is assigned, whereas these standards sometimes differ on city scale in this state or province (Verschuur, 2016). Next to that, the use of protection standards assumes that failure only occurs as a result of overtopping of the dykes or other preventive measures, whereas geotechnical failures like instability or piping are nowadays recognized as most probable failure mechanisms also due to their large uncertainties. Keeping this in mind, including flood protection standards is an improvement of current global risk assessment, but should be handled with care.

The probabilities of the FLOPROS database are used as probability of a flood event and linked to the associated inundation area of the hydrological model. It should be mentioned that only *the most probable* flood event is chosen and used for calculation of the flood risk, whereas using all extreme events above the protection threshold yields statistically speaking a more correct result.

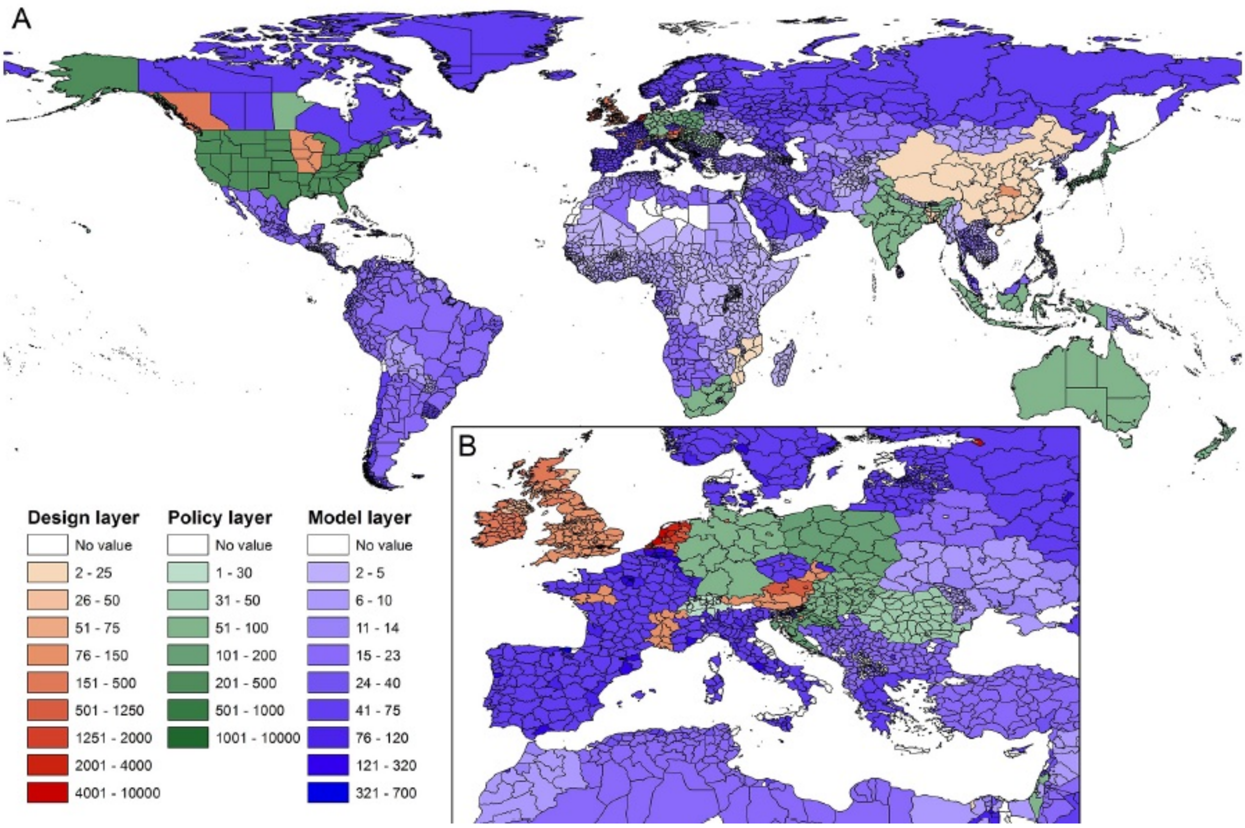


figure 4: Global overview of flood protection standards according to the FLOPROS database divided into information from the design, policy and model layer (Scussolini et al., 2016)

4.1.2 CONSEQUENCES

To calculate the consequences of an event, we make use of a population based method, where population is scaled to the local GDP. As we will see later, this method is used for the calculation of economic risk and fatality risk. This method is especially useful in case of absence of high quality land cover maps, which are generally used in flood damage modelling studies (Winsemius et al., 2013). This method uses urban land cover data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) data with a spatial resolution of 0.5 x 0.5 km. Next to that, urban extent data from the Global Rural-Urban Mapping Project (GRUMP) is added to the MODIS data with a resolution of 30 arc seconds (Nootenboom, 2015). Two types of urban land cover are recognized; urban-dense and peri-urban area. The higher accuracy MODIS data is used to define the densely populated urban area. The difference between MODIS and GRUMP is assigned the peri-urban land cover class. In terms of raster data, a grid cell with 75% urban cover is assumed to be urban area, whereas grid cells with 25% are classified as urban area. Because these urban and peri-urban areas are sometimes covering almost a whole country, the urban extent need to be defined in line with our assessment on city level. City administrative boundaries are therefore required. A database of country administrative areas with a spatial resolution of 30 m (GADM, 2015) is used to refine urban boundaries. Because of the large number of cities, only cities with a minimal population of 250,000 residents are selected. For China and India this number was set on 1 million, as it would be a too large number of cities to process. These maps are derived by Nootenboom (2015) and were available for our purpose.

Now, the link between exposed area and damage should be made. In economic damage assessment, depth damage, or stage damage, functions are generally used to calculate the share of the damages to the exposed area. Stage-damage functions show the percentage of exposed assets that would suffer damage for different flood depths (Ward et al. (2013); Merz et al. (2010)). To translate urban population exposure to a potential damage value, two things are needed; a depth-damage function for the damage to urban areas and a maximum country-specific damage value per unit area. The latter one is based on the gross domestic product per capita (GDP/capita) - or product purchasing power, which is a measure very suitable for comparison purposes between countries. Maximum damage value for the urban dense and peri-urban area are first obtained from the Damage Scanner (Klijn et al., 2007). After that, the maximum damage value is adjusted based on the GDP per capita value of the country, where is it assumed that GDP/per capita values are uniform on a country basis. This is done by making use of data from the World Bank, who has an up to date database of GDP/per capita value for every country in the world. Next to that, these value are corrected for inflation from the year 2007 (publication Damage Scanner) to the year 2015 using World Bank inflation data again, to make them representable for the current conditions. A depth-damage function is obtained from the same Damage Scanner (Klijn et al., 2007), which is the same for both the urban dense and peri-urban. The base value for 2007 are 9.65 M€/ha, or 965 €/m2 for urban dense areas and 400 €/m2 for peri-urban areas. The corresponding depth-damage function is shown in figure 5, where the line of interest is the solid black line ('Wonen average' in Dutch). The horizontal axis is the waterdepth in meters and the vertical axis is the damage fraction, which is dimensionless. These maximum damage values are assigned for the Netherlands. Using GDP/capita values of other country, maximum damage values are scaled. This yields the following calculation for economic risk, which we will further defines as ER:

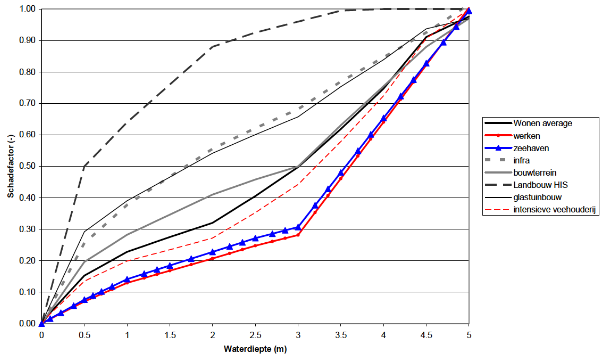


figure 5: Depth-damage function for the urban-dense and peri-urban area (Klijn et al., 2007)

$$ER_{now}[€/yr] = p_i * D_i * \frac{GDP/capita_{country,i}}{GDP/capita_{NL}} \tag{4}$$

4.2 FATALITY RISK

4.2.1 PROBABILITY

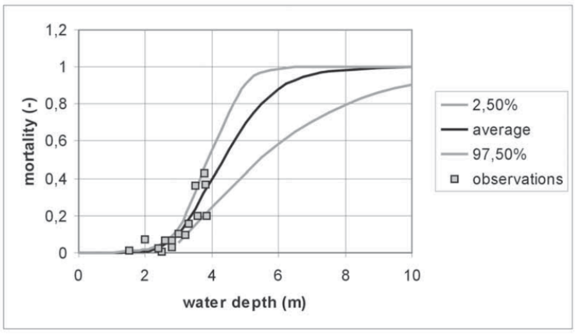
Same as in section 4.1.1.

4.2.2 CONSEQUENCES

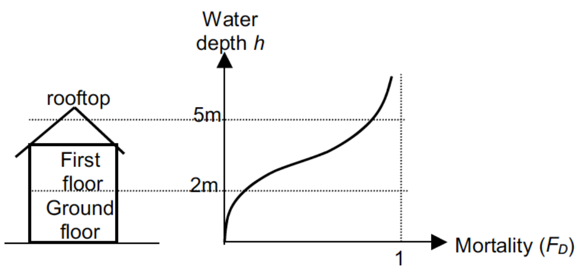
The consequences for the fatality risk assessment shows some similarities and some differences compared to the economic risk assessment. The fatality rate of the exposed population is difficult to predict, but is determined by a flood fatality function, quite similar to a depth-damage function. In general, the total number of fatalities is estimated from the fatality rate multiplied by the size of the exposed population, whereas this fatality rate is hard to derive (Boyd et al., 2005). In mathematical form the number of fatalities is a function of the fatality rate, number of exposed people and the evacuation fraction. (Jonkman (2007); Maaskant et al. (2009))

$$N = F_d(1 - F_E)N_{PAR} \tag{5}$$

F_d It is the ratio between the number of people killed and the number of people exposed in the floodzone. This number is approximately 1% Maaskant et al. (2009). We can further define this by using a depth-mortality function with a maximum mortality of 1 procent by using the function proposed by Jonkman (2007) as shown in figure 6a. In figure 6b, in indication of the water depth is given by the comparison of standard two story house.



(a)



(b)

figure 6: a) Depth-Mortality function proposed by Jonkman (2007) b) Depth-mortality function relative to building height for indication (Boyd et al., 2005)

N_{PAR} is the number of exposed people, which can be derived from population density data as we will do in this case. However, we have to keep in mind that people will not always be present at any time of the data and a flood event happening over night will have higher potential mortality. Last of all, there is the evacuation fraction F_E, defined as the fraction of the number of the exposed people evacuation from the later inundation area. As mentioned before, this value is dependent on a large number of variable and because of the complexity and uncertainty in this value, is it often assumed a standard value or neglected in case of a first approximation. The latter will be done in our assessment, just to express the maximum potential people affected.

For the land cover, again the land-cover maps for urban-dense and peri-urban are used. Also, the same global administrative boundaries are used (GADM, 2015). However, the two land-types are now not scaled to potential economic damage but to the population density to represent the number of exposed people. Next to that, instead of a maximum damage value, a maximum mortality value should be defined. In the economic damage assessment, this was given in unit €/m2, so in case of loss of life this should be # fat/m2. First we assign an average population density value (# /km2) to the peri-urban and urban-dense areas. This value is multiplied with the maximum mortality 1%, and divided by thousand to get to the required format. We used average population density for the urban-dense and peri-urban areas in the Netherlands, which were respectively 5000 people/km2 and 3000 km/m2. Consequently, maximum mortality is therefore 50 people/km2 and 30 people/km2. To include deviations in maximum values worldwide, because of population density differences, the maximum mortality for every city will be corrected with a global population density map using the map based on UN-database values. This yields for the fatality risk (FR):

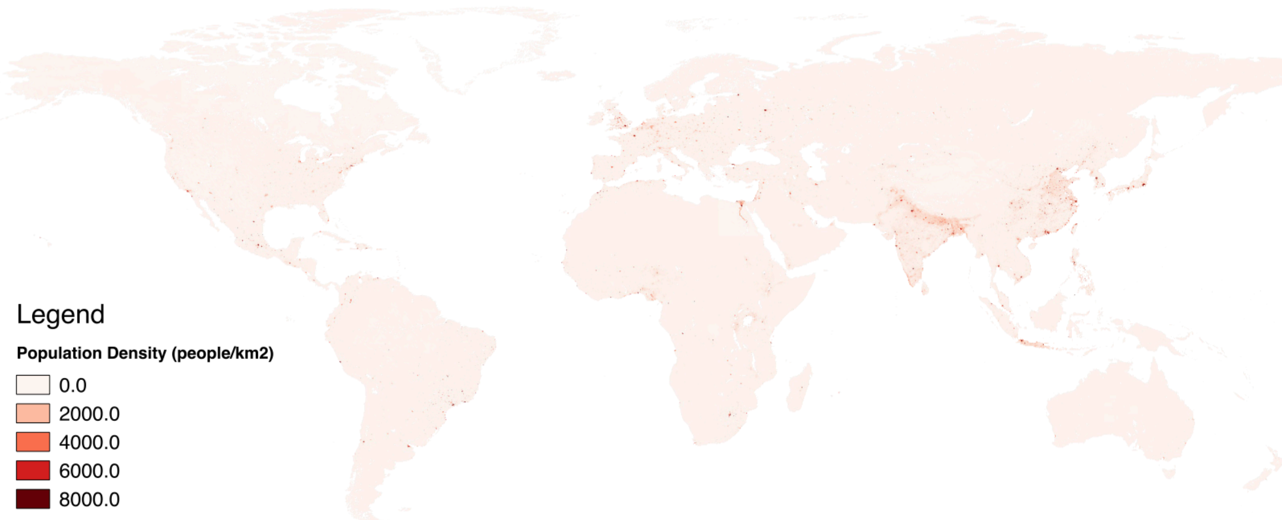


figure 7: Global population density values on subnational scale

$$FR_{now}[\#/yr] = p_i * D_i * \frac{Populationdensity_{Country,i}}{Populationdensity_{NL}} \tag{6}$$

In the end, we want to add economic risk and fatality risk to come up with the total risk. Therefore, we need to transform fatalities to an economic value. By not going into depths if a human life can ethically be expressed as an economic value, we do this in the way this is usually done for assessment of protection standards in the Netherlands. This is done using the so-called 'Value of Statistical Life (VoSL)' determined by Bockarjova et al. (2009), who conducted a survey in Dutch flood prone areas measuring the willingness to pay for the risk reduction to human life. Result of this is a value of 6.7 million Euro to reduce the statistical incidence of premature death in the population by one (Kind, 2014). This value can be seen as the initial conversion rate, but for other countries this value will be corrected based on the preliminary determined GDP/capita, which again raises some ethical objectives if human life in developed countries are 'worth more' than human life in developing countries. The formula for calculating this is:

$$FR_{now}[€/yr] = FR_{now}[\#/yr] * VoSL_{NL} * \frac{GDP/capita_i}{GDP/capita_{NL}} \tag{7}$$

4.3 TOTAL RISK

The final, total risk measure is simply determined by adding the economic risk together with the (in monetary value translated) fatality risk. In this way, we can better distinguish to what extent a city is dominated by fatality or economic risk and where most benefit in terms of risk reduction can be made. Also, it can say something about appropriate measures. For example, in case of low economic risk and high fatality risk, measures given under the emergency layer of the multi-layer safety ideology seems most appropriate. Another advantage is a better comparison of cities worldwide in terms of total risk, which is now not mainly determined by being a developed country with high potential economic damages. Fatality risk is often ignored in global flood risk assessment, but can be of even or greater importance as we can see later.

$$TR_{now}[€/yr] = ER_{now} + FR_{now} \tag{8}$$

4.4 FLOOD RISK 2030

In order to make a projection of the increase of both the economic and fatality risk for the year 2030, several climate and socio-economic scenarios are included in the risk calculation. This assessment can be used to see future increase in risk and one can say something about the urgency to react to this future increase, identify the main drivers on a city scale and distinguish the global variety.

4.4.1 CLIMATE CHANGE

It is important to know the potential increase in flood losses due to the effects of climate change developments. The report of Intergovernmental Panel of Climate Change (IPCC) concluded that it is *likely* that the frequency of heavy precipitation or the proportion of total rainfall from intense events will increase in the 21st century over many areas of the globe, with an increasing magnitude and frequency of flood events as results (Field et al., 2014). However, there is no conformity which future scenario to use in practise, and many countries conduct research to develop their own country specific climate projections. In this research project, data from an ensemble of five global climate models (GCM) is included in the PCR-GLOBWB hydrological hazard component as climate forcing for the year 2030. These five climate models were selected to span the space of global mean temperature change and relative precipitation changes as best as possible (Warszawski et al., 2014), resulting projections of new daily average river discharges to model climate enforced inundation probabilities. Each of the GCM is run for two of the well-known representative concentration pathways (RCP) scenarios describing projected atmospheric CO2 concentrations. The two pathways considered are respectively the RCP 4.5 and RCP 8.5 scenarios. In terms of RCPs, the RCP 4.5 (4.5W/m2) is a moderate-low emission scenario. In the long term, the global emission of greenhouse gasses stabilizes to 4.5 Watt per square meter in the year 2100 without exceedence of this value over the year. To reach this, it is assumed that climate policies are invoked to achieve the goal of goal of limiting emissions (Thomson et al., 2011). The RCP 8.5(8.5 W/m2) is the highest emission scenario of the RCPs. Main underlying assumptions are high population with relatively slow income growth together with modest technology and energy intensity improvements, resulting in high energy demand with corresponding high emission concentration (Riahi et al., 2011). Stabilization of the radiating forcing is expected to be after 2100. Global hydrological models run with climate forcing of GCMs is often biased due to errors in the input, in particular precipitation (Kundzewisz et al., 2013). Part of this bias is already corrected before implementation in the hydrological model used, but still some residual bias is expected in the final results, since no comprehensive method to remove this residual bias exists (Winsemius et al., 2013). Including climate forcing of different scenarios yield different flood risk values. The climate forcing is only applied to the economic risk and not to the fatality risk, since both are added up later on and more direct impact is expected for the economic risk. The probability remains unchanged and the new values are simply the average values of the various climate forcing models. In mathematical form, the new risk formulas for economic risk are as followed:

$$ER_{RCP4.5}[€/yr] = p_i * \sum \overline{D_{RCP4.5}} \tag{9}$$

$$ER_{RCP8.5}[€/yr] = p_i * \sum \overline{D_{RCP8.5}} \tag{10}$$

4.4.2 SOCIO-ECONOMIC DEVELOPMENT

To account for the development in socio-economic changes for both the expected increase in economic damages and number of fatalities, two economic growth scenarios and one global population scenario are currently being implemented to address this. In many flood risk assessments, the only way to include socio-economic development to exposed assets is by means of a scaled GDP per capita method. To adjust future exposed assets the ratio between the future period GDP per capita and the baseline asset values is used (Rojas et al., 2013). This adjusted GDP per capita value is assumed to be uniform for a country, whereas it can be expected that this increase is higher in the urban delta areas were the largest part of the economic activity takes place. Projected GDP/capita data is derived from the International Institute for Applied Systems Analysis, from which two shared socio-economic pathways (SSP) are taken (IIASA, 2016). The SSP pathways describe plausible alternative trends in the evolution of society and natural systems over the 21st century at the level of the world and large world regions (O'Neill et al., 2014). In line with the climate change pathways, we have selected one low-moderate pathway (SSP 2) and one more extreme pathway (SSP 5). The SSP 2 pathway is based on a "business-as-usual" scenario in which socio-economic development is based on the trend of recent decades. The SSP 5 scenario expects an rapid economic development, which is driven by by high investments in human capital and high energy demand (O'Neill et al., 2014).

To include projections of future fatality risk for the year 2030, insight is needed in the urban development over time. The world has undergo a rapid process of urbanization over the last decades and it is expected that this grow will continue leading to a global urban population of two-third by the year 2050 (WUP, 2014). As Africa and Asia are considered front-runners in rapid urbanization, by the year 2050, 89 countries distributed over all continents will become more than 80% urban. This number will significantly affected the potential number of exposed people, especially if this urbanization is uncontrolled and settlements in flood-prone areas are formed. To account for this development in the fatality risk assessment, projected population data of urban agglomeration over 300,000 inhabitants from the World Urbanization Prospects (WUP, 2014) initiative of the United Nations is used. This database contains a projection for all urban agglomerations with a population of over 300,000 inhabitants for the year 2030. Although the definition of an urban agglomeration is rather ambiguous and not heterogeneous across countries. Despite this, we can still say something about the increase of the number of exposed people for the cities considered in our assessment.

The information above is now included in a scenario for 2030. SSP-scenarios are economic growth values expressed in percentage per year. This affects the maximum damage value of the cities, because this value grows together with the growth of the economy. For 2030, under the assumption that the current risk is for 2015, a 15 year power is taken for every city. For the urbanisation, simply the increase of the agglomeration population over the year 2030 and 2015 are taken. This increase also affects the population density of the cities directly, therefore the fatality risk can be multiplied with this increase. We obtain the following expressions:

$$ER_{SSP2}[€/yr] = p_i * (D_i * (1 + \%_{i,SSP2})^{15}) \tag{11}$$

$$ER_{SSP5}[€/yr] = p_i * (D_i * (1 + \%_{i,SSP5})^{15}) \tag{12}$$

$$FR_{2030}[€/yr] = p_i * D_i * \left(\frac{WUP_{2030}}{WUP_{2015}}\right) \tag{13}$$

4.4.3 LAND COVER CHANGE

Because of urbanisation, land cover that is now considered peri-urban (PU) area will be transformed to urban-dense (UD) area. Main consequences of this is that the economic value of these areas will be higher and therefore the maximum damage will be higher. Including this in the future scenario is done in the following manner. First, the damage distribution between urban-dense and peri-urban is calculated, from which the percentage of total area affected by the flood event for both classes can be determined. After that, by making use of the urban expansion numbers (as will be treated into more details later) (Angel et al., 2016a), we can make a prediction about the future land cover under the assumption that the urban growth inside the boundaries are uniform. The damage distribution changes, as the percentage of peri-urban area will decrease and the percentage of urban-dense will increase, with an increase in damage as result of this. This procedure is followed for both scenarios. In a formula forms, this yields:

$$\%UD_{2030} = \%D_{UD} * (1 + \%_{urbangrowth})^{15}) \tag{14}$$

$$\%PU_{2030} = 100\% - \%UD_{2030} \tag{15}$$

$$ER_{landcover,2030}[€/yr] = \%UD_{2030} * max€_{UD} + \%PU_{2030} * max€_{PU} \tag{16}$$

4.4.4 2030-LOW AND 2030-HIGH

Climate change, social-economic and population scenarios can be combined to establish a certain bandwidth indicating how the future risk can develop. Although both the climate change and socio-economic pathways are modelled by making assumptions of drivers like emissions, land-use, economic growth, technological development and climate policies, they are independent of each other and are therefore suitable for combining purposes. In general, all combination can be combined with each other, it is most interesting to create two extreme scenarios for the both the economic risk and fatality risk, to illustrate the uncertainty. For an economic risk assessment for the year 2030, the upper bound scenario is a combination of the RCP 8.5 climate change pathway together with the SSP 5 socio-economic pathway. The lower bound consists of a combination of the RCP 4.5 and SSP 2 pathways. Land-cover change can be included in both. For the fatality risk assessment, we make use of the aforementioned WUP-projection. For the total risk, all four changes are incorporated in two future scenario's for 2030, namely the 2030-low and the 2030-high. These include:

- 2030-low: RCP 4.5, SSP2, Land Cover Change, and WUP
- 2030-high : RCP 8.5, SSP5, Land Cover Change, and WUP

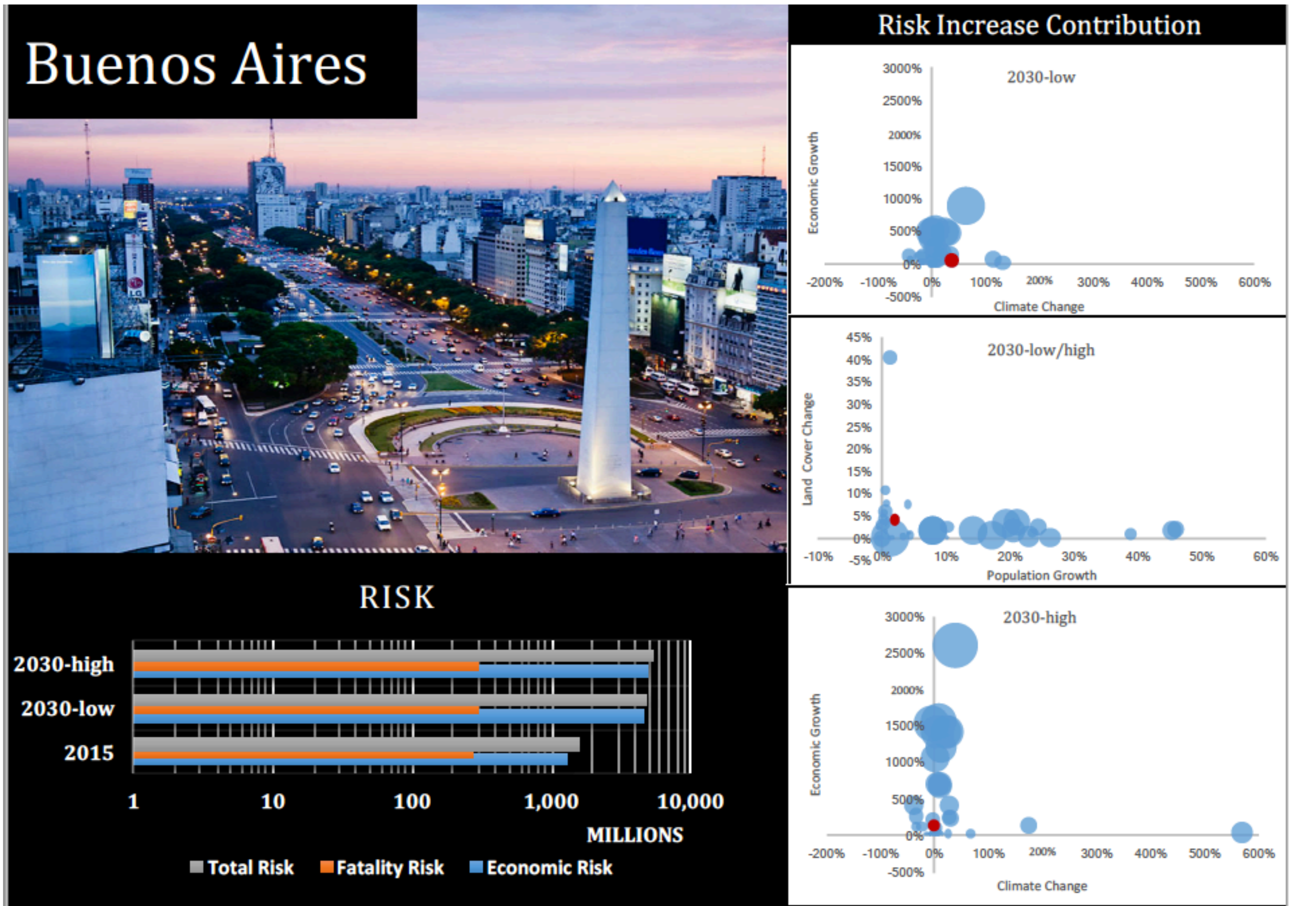
In mathematical form, the earlier formulas can be added up:

$$TR_{2030-low}[€/yr] = FR_{now} + \frac{FR_{2030}}{FR_{2030}} + ER_{now} * \frac{ER_{RCP4.5}}{ER_{now}} * \frac{ER_{SSP2}}{ER_{now}} * \frac{ER_{landcover,2030}}{ER_{now}} \tag{17}$$

$$TR_{2030-high}[€/yr] = FR_{now} + \frac{FR_{2030}}{FR_{2030}} + ER_{now} * \frac{ER_{RCP8.5}}{ER_{now}} * \frac{ER_{SSP5}}{ER_{now}} * \frac{ER_{landcover,2030}}{ER_{now}} \tag{18}$$

4.5 EXAMPLE: BUENOS AIRES

In the figure below (figure 8), all parts of the risk assessment are included in the risk component of the index, which will be expanded later on with the two other components. At the bottom, the position of Buenos Aires in the risk ranking is shown for the situation now and the situation in 2030. These values follow from the graph above in the black box, from where can be identified if fatality risk or economic risk is the biggest contributor. Mind the **logarithmic scale** in this graph. Although the fatality and economic risk look quite similar, the values of both are in the order of 300 and 1300, still a factor >4. In the right panel, the main drivers of the future risk can be identified. The radius of the sphere is determined by the magnitude of the increase. The sphere in red is the city if interest, whereas the blue spheres are the other cities. Based on this, not only the drivers in absolute sense can be determined, but also how the city is affected relative to the other cities. For the 2030-low situation, climate change contribution to the increase in risk, whereas this climate change is diminished in the high scenario. Land-cover change and population increase are expected to not give high increase to the risk. At last, something can be said about the uncertainty of the future projections. Despite the fact that the increase in risk will be three times the risk now based on these two scenarios, both values are in a similar range leading to a small uncertainty bandwidth for the city. As we will see later for the other cities, this is not always the case. Small uncertainty bandwidth generally makes it easier for deriving plans to tackle this risk increase, not only for 'knowing what to expect', but also for cost-benefit analysis.



Now

Rank	*City*	*Risk(Million€/yr)*
1	**Buenos Aires**	**1600.2**
2	Tianjin	893.4
3	Sao Paulo	721.6
4	Tokyo	501.6
5	Taipei	390.1

2030-low

Rank	*City*	*Risk(Million€/yr)*
1	**Buenos Aires**	**4837.1**
2	Tianjin	3512.7
3	Taipei	2648.1
4	Shanghai	2503.9
5	Guangzhou	1556.4

2030-high

Rank	*City*	*Risk(Million€/yr)*
2	Taipei	6295.5
3	Shanghai	6107.0
4	**Buenos Aires**	**5341.8**
5	Guangzhou	3761.3
6	Jinan	2261.9

figure 8: Risk section of the Buenos Aires index

5 FLOOD INDEX

In the section, the flood index with parameters are shown with their representation in a radar chart. The parameters are divided into four categories following the MLS layers and a general layer for comparison purposes. The normalization method for all parameters is shortly described as well as the axis used. An example is given for the city of Buenos Aires. In appendix D more extensive definitions of the parameters are shown together with source. Furthermore, some ideas are given for improvements of the parameters and how cities can provide better information in a self-assessment.

The flood index with parameters is the second component of the index. It is composed of 13 parameters represented in a radar chart. The parameters are already summarized in table 2 and will therefore not be repeated for convenience. The three layers of the MLS-ideology can be recognized, respectively 1) preventive (blue) 2) emergency (yellow) and 3) land-use (green). In orange some general characteristic parameters are included, mainly for comparison purposes. In defining the parameters, a choice had to be made between simplicity and complexity, and by making use of openly available data. Both criteria made it difficult to find adequate parameters and some simplifications and assumption are made. Also, the data sources from which the data is obtained should be updated in a repeating time manner, so updated value can be incorporated in the future. Given all this, improvements can be made for nearly all parameters. Especially if cities are contributing by doing a self-assessment, better and more reliable data can be obtained and more cities could be included. In appendix D, a detailed description of all parameters are given with data sources. Moreover, some ideas are given for improvements of the parameters and how cities can provide better information in a self-assessment. Some parameters are directly related to the flood risk assessment (preventive, land-use), whereas the rest is not directly related. This relation gives more insight how the flood risk is composed. For example, two cities with identical flood risk values can have different consequences. City A can be have a large flood cover with low damage value, whereas city B can have a small cover with high damage value. Obviously, for both cities, the consequences can be mitigated by means of different approaches.

5.1 PREVENTIVE

The preventive layer is focused on the probability of flooding , in other words the protection standards in place. The flood cover shows the percentage of city area covered in case of the flood event. The city boundaries are again the administrative boundaries as was used in the flood risk assessment. The properties at risk and loss of life potential says something about the potential economic damages and fatalities. Properties are directly related to the density of the buildings showing the number of properties hit. The loss of life potential is related to the fatality risk of a city divided by its population. In this way, becoming a victim of drowning can be compared relative to each other. Now, a high score, showing higher vulnerability is not only determined by the size of the city, but small and big cities can be compared.

5.2 ECONOMIC

The economic category consist of three parameters; population density, GDP-capita and economic impact. These three parameters are mainly included to compare cities with similar population density and GDP. It is somewhat ’unfair’ to compare a high GDP city with a low GDP city, because the ability to prevent flooding is mainly determined by economic power. The economic impact relates to the percentage of the national economy produced in the city itself. This says something about the impact of a flood event on a national scale, which are related to the indirect damages.

5.3 EMERGENCY

Emergency describes the parameters related to the evacuation possibilities. Because data for awareness is not available and difficult to predict, flood history is used, because it is assumed to be highly correlated to awareness. When experienced a large number of flood event, awareness is higher. The vulnerable people are the people below 15 and above 65, who are most likely to become victim of drowning. Preventive evacuation is determined by the number of people per km that has to be moved. High values have a high likelihood of congestion and ineffective evacuation. ICT-infrastructure determines the number of people that can be reached. At last, the shelter capacity represent the number of shelters in place. However, only very high rise buildings are taken into account, which is of course not representable for shelter possibilities.

5.4 LAND-USE

The only parameter is the vulnerable urbanization. This parameter is more related to the next component of the index, the ’adaptive capacity of cities’, however for convenience it is included here. It indicates the approximate percentage of urbanization over the last 15 years towards to flood-prone areas. It is therefore more or less related to the natural expansion over the cities, where it could be that urban expansion away from the flood prone area is because of prohibited settling in these areas. Nevertheless, it can also just be that the city is expanding ’naturally’ away from the flood prone areas.

5.5 APPROACH

In the end, cities will be get a score for each parameters between 1 and 10, where 0 represent no data. The orientation of the parameters are from a risk perspective, where a higher score means a higher vulnerability. Therefore, some parameters are inversely scaled, for example a high population density means a low vulnerability, so high population density means a higher score. For nearly all parameters, except for 'flood cover' and 'vulnerable urbanization', a min-max normalization is used. First the minimum and the maximum value are determined. In case of big difference in several orders, a log-operator is used to transform the values. After that the value are scaled to 1-10 following the min-max normalization:

$$X_{i,normalized} = 9 * \frac{X_i - Xmin}{X_{max} - X_{min}} + 1 \tag{19}$$

Figure 9, shows the extreme values for all parameters and the normalization approach. In some cases, a maximum value if applied to avoid skewness of the data. The given axis are shown in figure 10

Table showing orientation axis and normalization methodology

Category	Min	Max	Unit	Meaning 10	Meaning 1	Transformation	Normalization	Note
Probability	5	1000	/yr	Low standards	High standards	log	min-max	
Flood Cover	0.50%	76.90%	%	100% cover	0% cover		/100	
Properties at Risk	0.30%	54.06%	%	Almost all properties	Few Properties		min-max	
Loss of Life Potential	6.0E-09	3.4E-05	/yr	High probability dying	Low probability dying	log	min-max	
Population density	910	28,508	#/km2	High population density	Low population density	log	min-max	
GDP-capita	1800	67811	$/capita	Low GDP/capita	High GDP/capita		min-max	
Economic Impact	0.2%	30.7%	%	High disruption	Low disruption		min-max	
Flood History (Awareness	0.1	15.0	#/yr	Low flood awareness	High flood awareness		min-max	
Vulnerable People	34.0%	34.1%	%	High Percentage	Low Percentage		min-max	
Evacuation Road Capacity	471.4	17980.3	people/km road	High likelihood congestion	Low likelihood congestion		min-max	
ICT-infrastructure	17.6	270.4	#/300	Low percentage reached	high percentage reached		min-max	num is taken to be 100, whereas maximum is set to be 300
Shelter capacity	1	5963	#	No highrise	A lot of highrise	log	min-max	
Vulnerable Urbanization	2	10	%	80-100 % expansion to flood prone	0-20 % expansion to flood prone		*2	

figure 9: Table showing parameters, units, and orientation of the axis with given normalization methodology

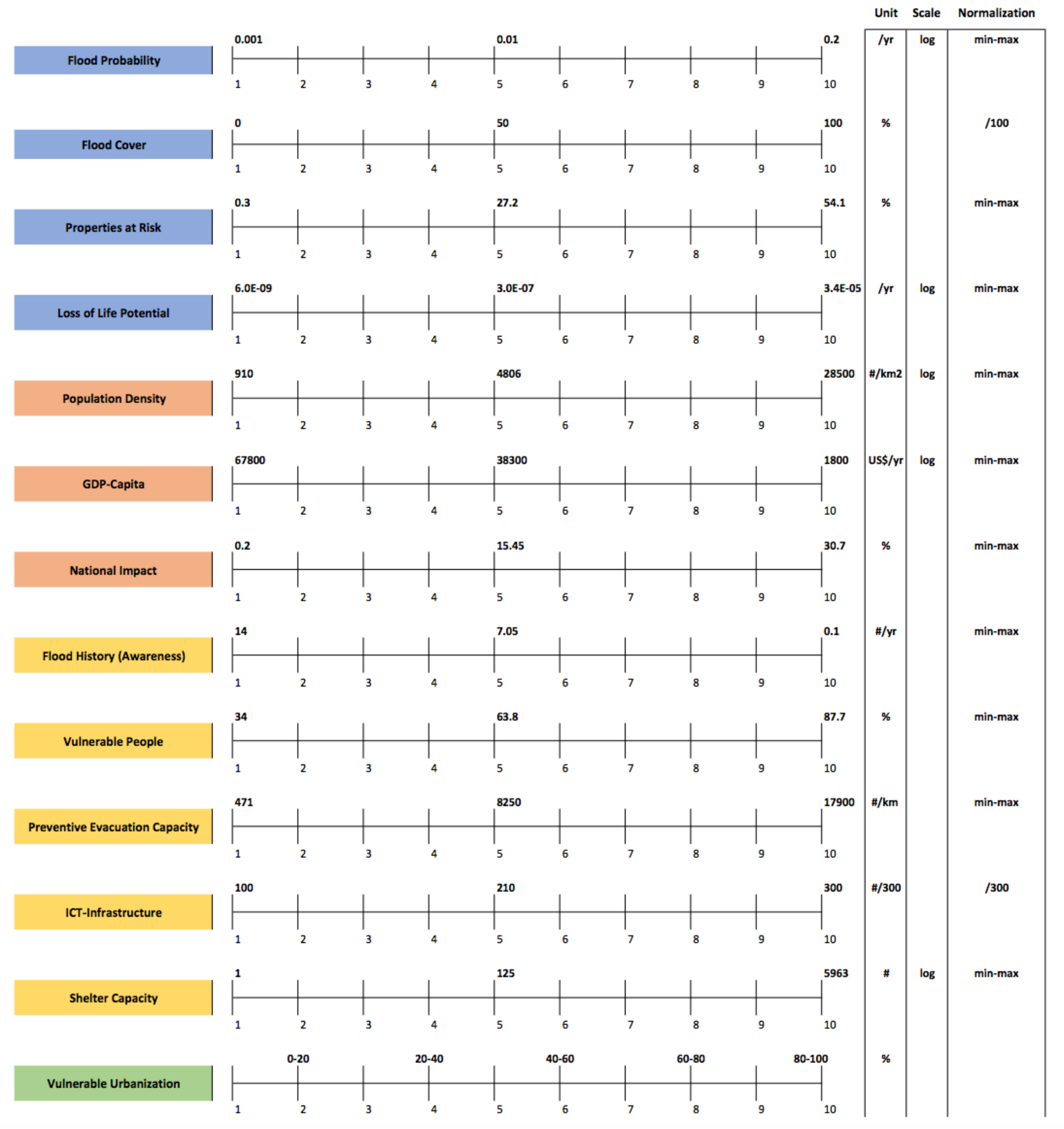


figure 10: Axis with value for 1, 5 and 10 together with units and normalization

5.6 EXAMPLE: BUENOS AIRES

We will discuss one example index for Buenos Aires, especially showing the strengths and weaknesses. The overview is given in figure 11, where again a higher score indicates a higher vulnerability. Interestingly, the loss of life potential is the highest of all cities. This could already been seen from the fatality risk, which contributes to the total risk. In addition, dividing that number over the population in the city gave the highest average probability of dying a year. Also, flood events are happening almost never in Argentina, from which can be assumed that the flood awareness among the inhabitants is low. GDP/capita and Population Density are moderately high in the city, which is comparable with cities like Sao Paulo and Osaka. What is also noticeable is the vulnerable urbanization parameter. 60-80 % of the historical urbanization has moved to potential flood prone areas, which is high compared to most cities. Flood cover and properties at risk are low. Furthermore, economic impact is low meaning that a low percentage of the national economy is produced in Buenos Aires. Vulnerable people, ICT-infrastructure and Shelter Capacity are on average relative to the other cities.

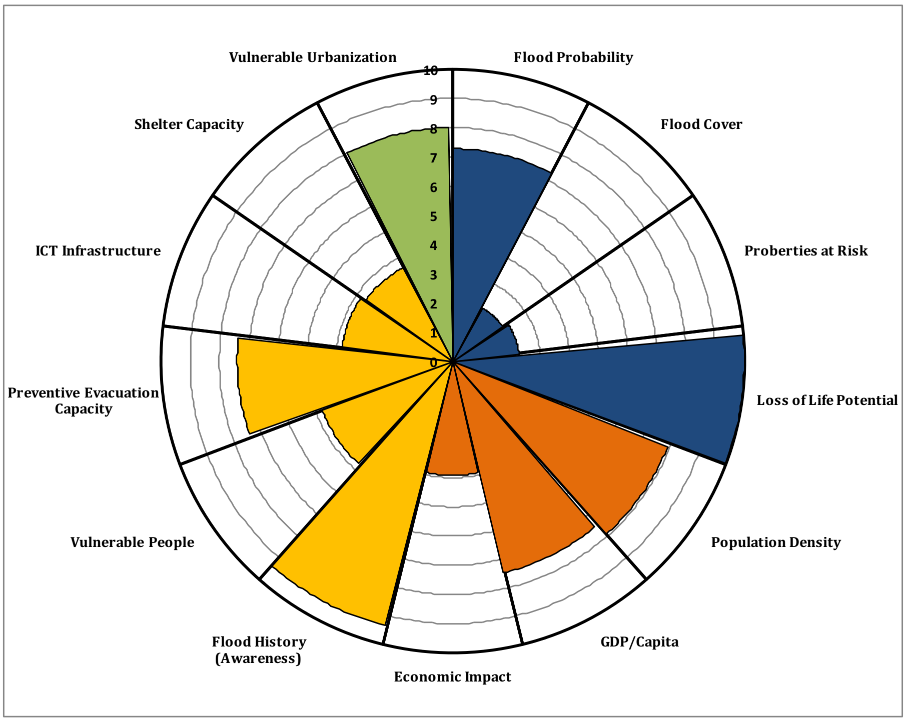


figure 11: Flood Index of Buenos Aires

6 ADAPTIVE CAPACITY OF CITIES

In this section, we will discuss the 'Adaptive Capacity of Cities' component of the index. This measure links the urban expansion to the increase in flood risk for the two scenarios to give insight in the adaptation possibilities of cities. The method is explained and an example for Buenos Aires is given.

As was already discussed, we can not treat a city as a static system over time but a constantly changing system. The urban expansion in combination with the risk increase gives insight if the city 'keeps up' with the increase. The adaptation of a city includes the transition from recognizing the risk increase and linking this to the recurring infrastructural urban investment, where these moments in time can be used to tackle the risk increase in a time and cost effective way. This degree of adaptation is mainly determine by the degree of expansion of a city, where this is easier done in rapidly evolving cities that have shorter investment cycles. In such cities, simple shifts in the policies can be carried out to assure a smooth transition between the risk now and the risk over several years. However, it can be imagined that especially static cities with less development over time puts a limit effective implementation of measures. Result of this could be that only preventive measures like dyke and levee enhancements are feasible given the spatial situation.

6.1 METHOD

Defining the urban development of cities in a quantitative way is difficult, because no uniform consensus exist how to define the urban part of a city. In order to say something about the expansion of the future, looking at the past expansion can say something about the expected future expansion, assuming it grows with approximately the same rate. To measure the degree of expandability, the increase of the urban extent over the period 2000-2014 for cities analysed by the Atlas of Urban Expansion (Angel et al., 2016a) is taken. We have used this annual expansion rate and assumed that this trend will progress until 2030. Note to this is that urban extent is something different than the administrative boundary of a city, where the extent may surpass the administrative boundary.

6.2 ALARM

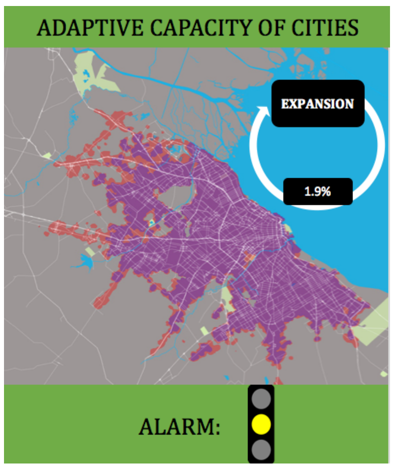
We would like to link the urban expansion to the increase of the flood risk to determine if the risk grows faster relative to the grow of the city. As was mentioned before, adapting new urban environment is easier than adapting existing urban environments to risk increase. If a city grows faster than its risk, it will be relatively easy to make the transition between the situation now and in 2030. If the risk increases more than the city grows, risk will increase in the whole city and the situation becomes riskier over time. Because it is hard to come up with an adequate way to define if 'bridging the gap' possibilities are easy or not, we have come up with a simple method with color indication. The city is assigned a color varying from green (adaptation is relatively simple) to red (adaptation is hard). For both scenarios, 2030-low and 2030-high, the risk increase is divided by the expected urban expansion for 2030 based on the historical urban expansions rates as described above. Three various groups are identified, respectively ratio's of >1, 1-2 and >2, whereas the first one is obviously the best ratio to have. This is done for both scenario's and by combining them, a color indication is assigned. Although 5 colors are indicated, the two greens are just a green color and the light red and dark red are simply indicated as red in the final index. Yellow is just yellow. In the figure below, the combinations are shown in figure 12a.

6.3 EXAMPLE: BUENOS AIRES

As can be seen below, the urban areas of Buenos Aires are expanding with 1.9% a year, not a very high number. However, the risk increase is also not so high, so relative to eachother risk increase is slightly higher. This means that for both the 2030-low and 2030-high scenario, the city can not keep up and ratio's in the range 1-2 are found corresponding with the yellow alarm. Therefore, Buenos Aires can only limitedly benefit from the expansion possibility to adapts it city to the increase in flood risk. What is also interesting to note is that the city is growing towards the delta region in the north as was shown in the parameter for the 'vulnerable expansion'. Therefore, the vulnerable expansion is more or less related to this adaptive capacity as well, because the city has to take measures to make these new urban areas flood-proof with the development towards the delta.

2030low/ urban development			2030high/urban development			Alarm
0-1.0	1.0-2.0	>2.0	0-1.0	1.0-2.0	>2.0	color
x			x			
	x		x			
x				x		
	x			x		
	x				x	
		x		x		
		x			x	

(a)



(b)

figure 12: a) Color indication b) Adaptive Capacity of Cities for Buenos Aires

6.4 RESULTS

The results for the three components are given for a first sample of 38 'delta' cities. These cities are chosen on the basis of data availability and location near a coast and river, which can be interpreted as a delta cities in the broadest sense of the definition. First, the risk ranking for the risk assessment is given. Also, the results for the alarm encoding of the 'adaptive capacity of cities' is given. Finally, these two components are combined with the flood parameter index ending up with the final indices of the cities. The results is shown for one example cities, Buenos Aires, whereas the indices of the other cities can be found in the appendix E.

7 FIRST GLOBAL SAMPLE OF CITIES

To make a first assessment for a selection of cities based on open data to illustrate the use of the index, some selection criteria must be set. The different parameters are already discussed in combination with the quantitative flood risk assessment. Because we make use of a number of parameters based on one study, namely the Atlas of Urban Expansion study (Angel et al. (2016a); Angel et al. (2016b)), we need to restrict ourselves in the first assessment on the cities considered in this specific study. This is also because the urban expansion data are obtained from this source. This study encompasses a global sample of 200 urban agglomerations. However, not all of these cities are relevant in the context of our research. First, is the city considered in flood risk assessment, in other words, does the city have at least 300,000 [1] inhabitants? Furthermore, because we are focusing on delta cities in general, coastal cities are selected. In the end, the number of cities is downsized to a number of 38 cities, where it is doubtful in some case of these cities can be considered a delta city. Although they are not located in a delta in most general definition, these cities are vulnerable for both coastal and river flooding. In figure 13, the names of the positive identified cities are depicted together with a world map, showing the distribution of the cities over the continents. It is clear that majority of cities are located in Asia, with China as main contributor with 6 cities (considering Taipei as a Chinese city). Europa and Africa are represented with three cities each followed by Australia with only Sydney in the list.

[1] This threshold value is 1,000,000 for Asian countries to limit the amount of cities

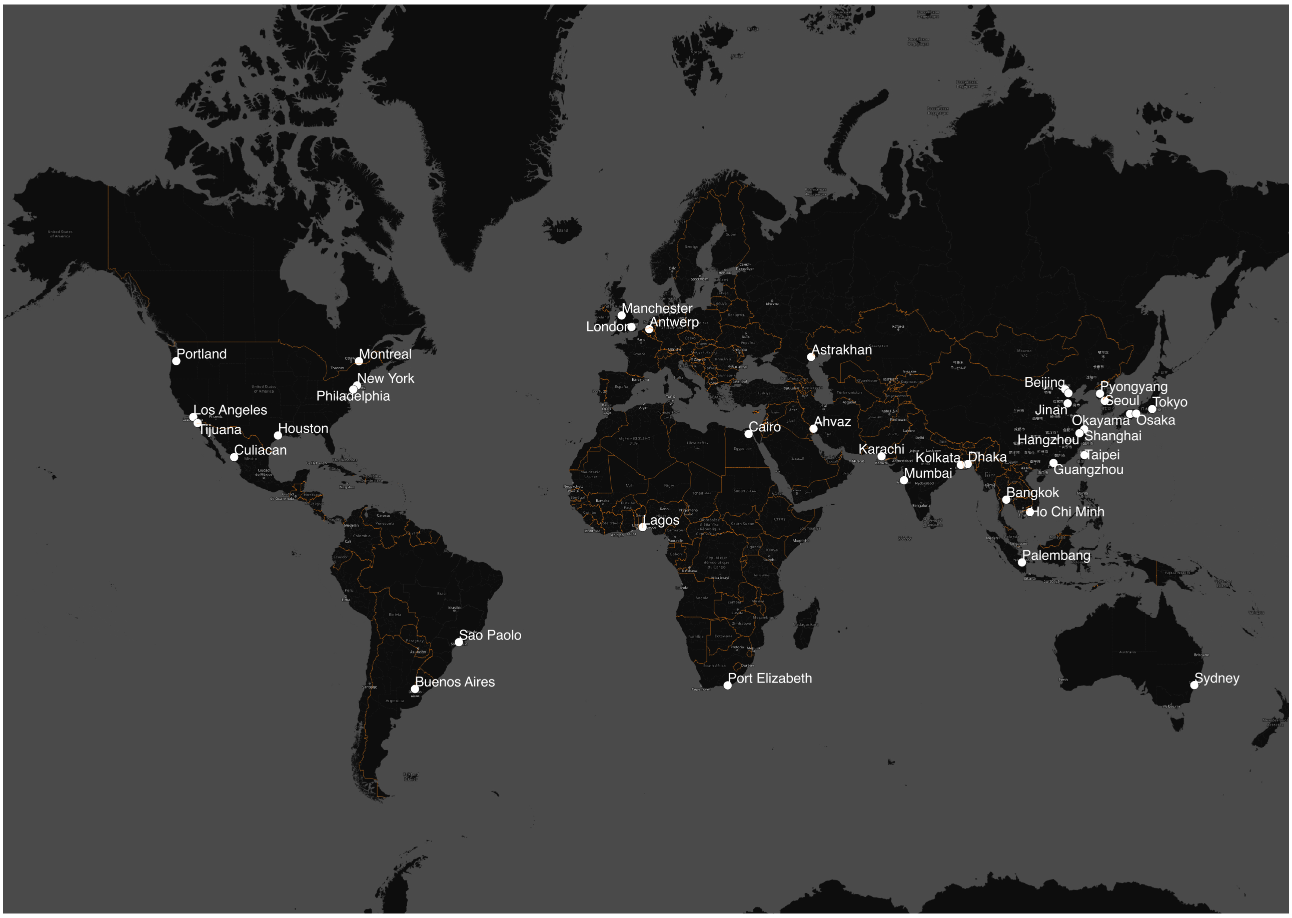


figure 13: List of cities eligible for our research scope and their geographical location

7.1 RISK ASSESSMENT

In the figure below, the ranking for the total risk now and 2030 under two scenarios, as we have determined them now, is shown. Because quite some steps are followed as described in the risk assessment approach, it can be difficult to imagine how the total risks are calculated. Therefore, in appendix E, detailed results of the economic, fatality and total risk are summarized with risks values, external development characteristics and uncertainty bandwidths.

The top of the ranking now is being dominated by the megacities worldwide, led by the city of Buenos Aires in Argentina. More importantly, the fast growing, mostly Chinese cities, are getting more on top of the ranking, because of high ongoing urbanization rates and economic growth, which is also the case in Indian cities and in Bangladesh. This in contrast with the cities in Japan, which will encounter a more stagnated increase leading to a less significant impact. From this figure, we can not distinguish if the risk is mainly determined by the economic contribution or the fatality contribution, but this can be in the indices for every city. Also interesting is to look at the size of the cities, compared to the risk. If we look for example to the city of Tijuana, an one million city along the Mexican coast, risk estimates are in the same order as for cities like Shanghai and New York, where the latter two cities have significantly larger areas. In a relative sense, Tijuana would be affected more severely in case of an actual flooding. This same applies to the city of Ahvaz (Iran), located in the middle region of the ranking, also a small city relative to its neighbour ranked cities.

Whereas Buenos Aires is still on top in the lower scenario for 2030, the coastal cities of Tianjin, Taipei and Shanghai will surpass Buenos Aires as being most at risk if we consider the extreme scenario. In the lower region of the ranking, cities like Antwerp and Manchester will barely being affected by climate and socio-economic changes as their projections predict slow growth in both urbanization rates and economic development. Cities who will face the most difficulties between now and 2030, are the cities with explosive increase of risk. Examples are the city of Dhaka, which will experience a future risk between 4 and 9 times its risk now, or the city of Kolkata with expected risk multiplication of 4 to 11 times. It seems almost impossible to cover the huge risk increase rates, keeping in mind that both cities have relatively low GDP/capita and extremely high population density rates. Interesting is that both cities are located in the same delta area, the Ganges-Brahmaputra delta. Therefore, delta interventions in this delta, could positively affect both cities. This exponential increase also indicates that it is quite difficult to make decisions in such cities, because of the fact that a huge uncertainty bandwidth is present in future risk increase. This in contrast with the aforementioned barely risk changing cities Manchester and Antwerp, who are better able to make decisions, because it is more certain how their future risk will look like.

Ranking Total Risk

	Now		2030-low		2030-high	
Rank	City	Risk(Million€/yr)	City	Risk(Million€/yr)	City	Risk(Million€/yr)
1	Buenos Aires	1600.21	Buenos Aires	4837.12	Tianjin	7579.69
2	Tianjin	893.40	Tianjin	3512.73	Taipei	6295.50
3	Sao Paulo	721.64	Taipei	2648.05	Shanghai	6107.02
4	Tokyo	501.58	Shanghai	2503.93	Buenos Aires	5341.77
5	Taipei	390.12	Guangzhou	1556.36	Guangzhou	3761.29
6	Osaka	297.77	Tokyo	941.69	Jinan	2261.94
7	Bangkok	282.10	Sao Paulo	935.83	Bangkok	1259.35
8	Guangzhou	233.74	Jinan	933.37	Kolkata	1187.39
9	Cairo	232.35	Bangkok	861.47	Tokyo	1029.03
10	Los Angeles	216.91	Osaka	560.70	Sao Paulo	1011.24
11	Shanghai	215.09	Cairo	484.96	Osaka	611.56
12	Tijuana	141.94	Los Angeles	455.37	Cairo	604.86
13	New York	137.24	Kolkata	412.51	Beijing	572.88
14	Jinan	128.77	Tijuana	361.17	Los Angeles	446.36
15	Philadelphia	128.42	Philadelphia	294.96	Tijuana	403.44
16	Seoul	98.33	New York	282.83	Mumbai	340.23
17	Kolkata	97.33	Beijing	235.81	New York	293.53
18	Ahvaz	52.68	Ahvaz	205.93	Philadelphia	276.94
19	London	51.99	Seoul	142.48	Ahvaz	274.35
20	Houston	39.86	Mumbai	129.39	Dhaka	233.07
21	Mumbai	39.39	Astrakhan	113.57	Palembang	232.95
22	Astrakhan	37.42	London	97.90	Lagos	175.97
23	Beijing	35.66	Palembang	94.05	Astrakhan	175.78
24	Portland	33.00	Dhaka	92.48	Seoul	163.16
25	Lagos	30.76	Lagos	90.20	Karachi	108.63
26	Karachi	27.67	Houston	83.56	Houston	101.56
27	Dhaka	26.54	Portland	76.46	Portland	98.01
28	Culiacan	18.30	Karachi	64.21	London	95.00
29	Okayama	17.10	Ho Chi Minh City	42.12	Ho Chi Minh City	73.88
30	Palembang	13.65	Culiacan	39.70	Montreal	72.41
31	Ho Chi Minh City	12.06	Sydney	39.54	Hangzhou	59.71
32	Sydney	11.01	Okayama	36.67	Culiacan	54.79
33	Pyongyang	10.33	Hangzhou	25.16	Okayama	42.36
34	Montreal	9.02	Pyongyang	22.49	Sydney	27.29
35	Antwerp	6.41	Montreal	19.97	Pyongyang	27.07
36	Manchester	5.48	Antwerp	13.24	Antwerp	13.81
37	Hangzhou	4.27	Manchester	11.94	Manchester	11.87
38	Port Elizabeth	0.29	Port Elizabeth	0.90	Port Elizabeth	1.25

figure 14

7.2 ADAPTIVE CAPACITY OF CITIES

Based on the easy method described, all cities are assigned an alarm color indication representing their adaptation possibility, shown in figure 15. Some interesting results show up. First of all, although Chinese Cities are growing rapidly and expected to grow further like this, the exceptional increase of the risks causes that the cities cannot catch up with this. Surprisingly, the cities of Sydney, Astrakhan and Port Elizabeth pop up as potential problematic cities, even though their place in the ranking is fairly at the bottom. For these cities, it is even more important to focus on their urban flood management and derive adequate plans for urban settling and spatial planning. On the other side of the spectrum, some cities are located higher in the risk ranking, but their urban development catches up with the increase of the risk. Cities in this category are for example Cairo, Los Angeles, Seoul and very surprisingly Tianjin. For these cities, risk increase can for a large extent be managed by means of effective urban flood risk management.

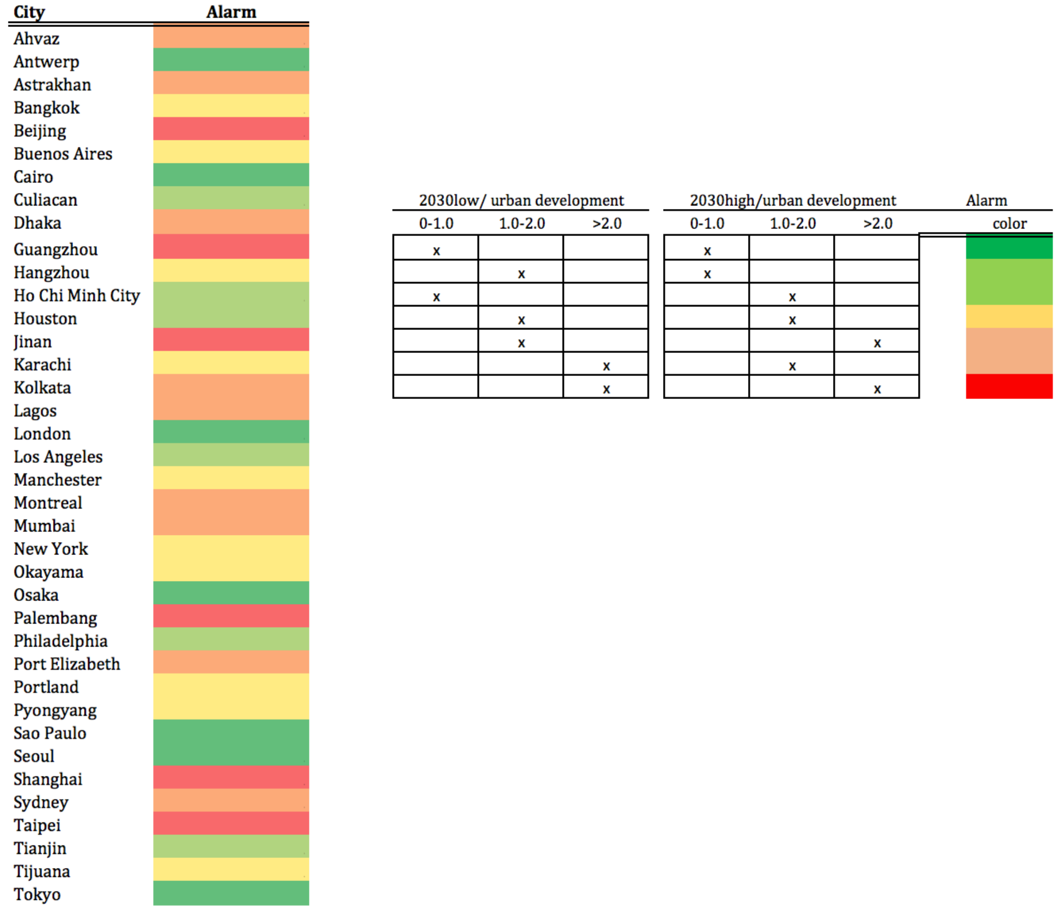
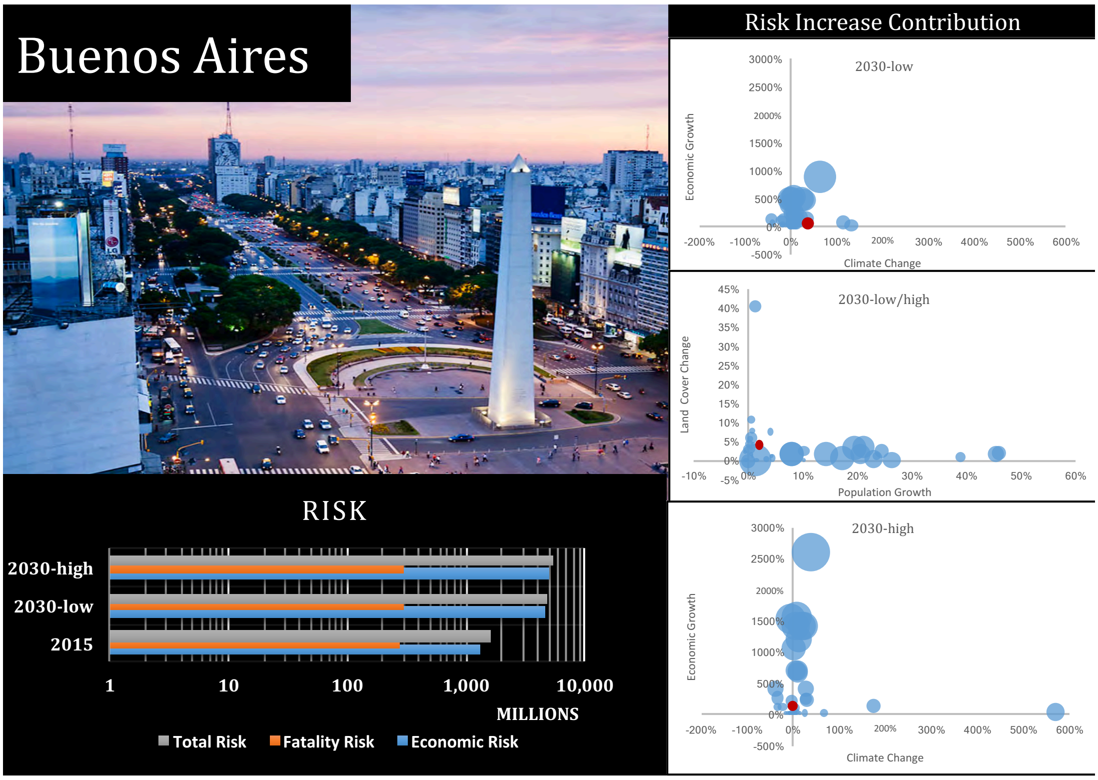


figure 15: Alarm decoding 'adaptive capacity of cities'.

7.3 FLOOD DELTA CITY INDEX: EXAMPLE OF BUENOS AIRES

Now all three components; flood risk assessment, flood index en the adaptive capacity of cities, are incorporated in the final index. An example is shown for the city of Buenos Aires (16), whereas the other indices are included in the appendix (E).



Now

Rank	City	Risk(Million€/yr)
1	**Buenos Aires**	**1600.2**
2	Tianjin	893.4
3	Sao Paulo	721.6
4	Tokyo	501.6
5	Taipei	390.1

2030-low

Rank	City	Risk(Million€/yr)
1	**Buenos Aires**	**4837.1**
2	Tianjin	3512.7
3	Taipei	2648.1
4	Shanghai	2503.9
5	Guangzhou	1556.4

2030-high

Rank	City	Risk(Million€/yr)
2	Taipei	6295.5
3	Shanghai	6107.0
4	**Buenos Aires**	**5341.8**
5	Guangzhou	3761.3
6	Jinan	2261.9

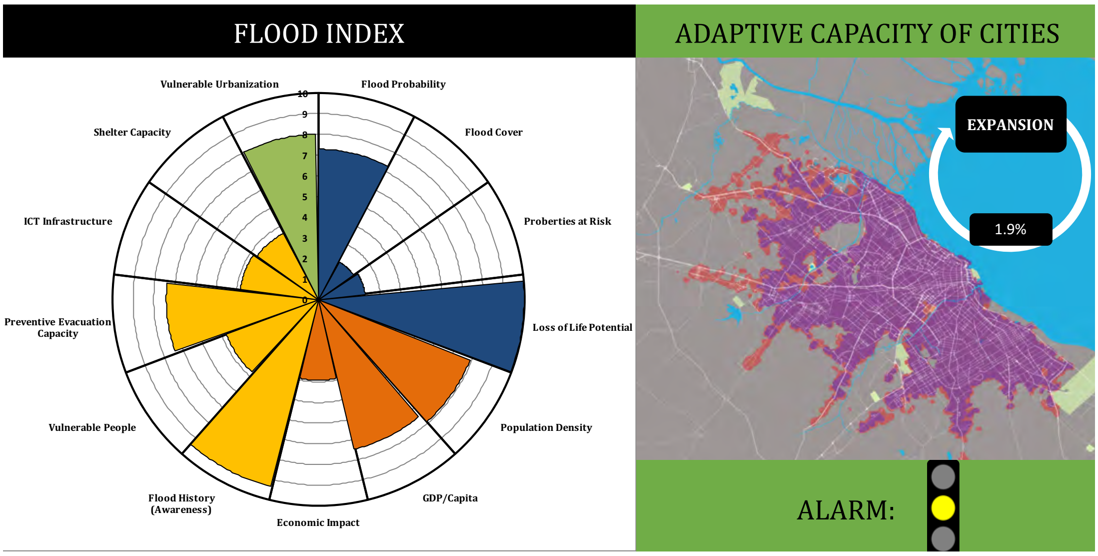


figure 16: Flood Delta City Index of Buenos Aires

8 CONCLUSION

In this report, a start is being made to establish a Smart Delta City Index to identify the most vulnerable urban areas in a first global assessment of 38 cities. More importantly, cities have a quick and readable overview of their current risk, future risk and main risk drivers. In addition, a city can identify their strong points in the first try to make a flood index covering the concept of the multi-layer safety approach. We are not presenting this as our final concept, but more as a first initiative to come up with ways to improve the risk assessment, flood index and to determine the urban expansion in a more appropriate and detailed way. Especially the index should be red as the 'best we can get' index right now based on open-data and models. Despite this, 38 cities worldwide can now look at this concept and really identify the added value of having an overall index like this that could be published ones every few years.

Further conclusions:

- Based on a literature review of existing flood index concepts, some opportunities are recognized. Flood risk assessments are not new, and several flood indices are already developed. However, most of them lack quantitative parameters making it hard to make the index reproducible. Also, because qualitative parameters are usually based on research, they are time-consuming and 'expensive'. Result of this is that it is difficult to cover too many cities and reproducing it every few years would be difficult. Moreover, parameters are often based on expert judgement making it a subjective interpretation of the researcher. Doing the same research again conducted by someones else may yield different results. Therefore, a quantitative index has the benefit that it is easier to reproduce, objective and can include more cities in a more time and money consuming way. However, opportunities for quantitative parameters are hampered by lack of data or appropriate models.

- Most flood risk assessments are a picture of the risk at a certain moment. However, most cities are not interested how high their risk is because they have difficulty interpreting this number, but are more interested in the drivers of change and how this will influence the future risk of the city and consequently the long-term projections of the city. This will help them in the allocation of resources and will trigger cities to react as well seeking way to collaborate and communicate with cities facing similar problems. On a city scale, flood risk management should also be linked to the urban characteristics and developments as these concepts are strongly interdependent. Therefore, adding urban expansion and ultimately aiming to create this link between flood and urban management creates a more sophisticated way to look at the flood risk increase and how to bridge this.

- Most indices are not focusing on one specific problem, but are more broadly orientated. They are for example focused on the overall water problem including next to flooding aspects of water scarcity and water quality. Or they focus on resilience of cities in general, which combines water-related topics with healthcare, food supply, economic, infrastructural and governmental characteristics of a city. By trying to get ahold of the overall resilience of cities, they loose the in-depth problematic of the individual aspects. Therefore, we distinguish ourselves by focusing more specifically on the flood-related problems in city making it more tangible for cities.

- Cities are now able to compare their situation with other cities in the same continent or at the other end of the world. They can set ambitions and keep track on their ambitions. Moreover, it also triggers some sort of competition to stay ahead of other cities or to share best practises of effective risk management. In this way, the impact of the index can be more than only an overview of a city, but can really be a stepping stone towards a more flood-proof initiative.

9 FURTHER RESEARCH AND SUGGESTIONS

As said before, a lot of additional work and research can arise from this work all aiming to improve the whole concept by using better data sources, more models and improved and refined urban footprints to make global flood risk assessment on a better resolution. This will asks for more computer power as well and more complicated models. A balance should therefore be made between reproducibility and complexity. During a first information session with representatives from Unesco-IHE, Deltares and PBL, support for the further development is being expressed as well as possibilities to improve the models or to use a model currently being developed at their institute. Also, the Delft University of Technology showed interest how to improve the concept and new research initiatives are proposed. Throughout the report, some remarks are already made in what way a parameter could be improved. The main points on the research agenda will be:

Risk Assessment: Three ways to improve the flood risk assessment are identified.

- **Subsidence**: First of all, subsidence is not yet included in the future risk calculation, although many cities worldwide and especially in groundwater depleting deltas are prone to subsidence. Efforts are made to make a global subsidence model based on groundwater depletion data, which can possibly be implemented in the flood risk model and consequently in the assessment of the flood risk. Deltares and Utrecht University are developing this model and therefore further contact with them is necessary.
- **Urban growth modelling** Another additional feature would be an urban expansion model to get more specific insights in urban expansions trends to better predict how economic and human development are spatially spread in the cities and if cities are expanding towards flood-prone areas or not. Economic development should go hand in hand with urban expansion, as well as the land cover change from rural to urban areas. In addition to that, city boundaries should be defined more carefully or should be defined in such a way that they grow together with the urban expansion as cities are generally speaking not only determined by their administrative boundaries, but city boundaries more or less change as a result of urbanisation. A promising method could be by implementing an urban development tool based on a genetic algorithm to map urban land cover change, as being developed at UNESCO-IHE (Veerbeek et al., 2015). If this could be used in combination with more accurate urban footprint, more detailed assessment could be done.
- **Multi-Flood Hazard**: For now, we have only included riverine flooding in the assessment. However, some cities are less prone to riverine flooding, but more prone to coastal or/and pluvial flooding. On the one hand, including multiple flood sources can give a better overall picture of the complex flood problem of a city. On the other hand, including these two

other types of flood sources asks for more and different parameters to include in the index. For example, for pluvial flooding, the discharge capacity of the sewage network is important and the amount and availability of storage basins. For coastal flooding, the sea defences are important in a similar way as the protection standards along the river. Therefore, we should carefully look how to include these types in our assessment.

Flood Index The index proposed now is the best we can get right now based on the available open data sources. However, to achieve the objective of getting a reproducible index, which is right now not entirely the case, better data sources should be found or extra models should be developed. In the section that describes all parameter, improvements are already suggested but they will be repeated here for convenience.

- Flood Probability: Detailed information on city scale. In the current database, mainly regional data is available and data on city scale only in limited cases.
- Flood Cover: //
- Properties at Risk: A more detailed urban footprint in combination with a GIS spatial analysis can give more insight in the amount and type of buildings at risk. Often the most vulnerable population of a city lives close to the flood-prone areas, whereas the more luxurious neighbourhoods are located on the higher elevated parts of the city.
- Probability of Dying: Same as above, a better spatial analysis of the distribution of the population over the city can give better insight in the probability of dying. However, the population density map included in the flood model already includes a spatial spread over the city, however in a quiet course resolution.
- Population Density: Better definition of city boundaries. Sometimes not clear if data is for the city or the municipality.
- GDP/capita: GDP-capita estimates on city level for all cities. Now only for OECD-country members
- Economic Disruption: Same as above
- Flood History: Country estimates are used, because it is often unclear where the flooding occurred in the country. Therefore, it would be better if we know cities were affected by the flooding or not. Also, a link can be made to flood awareness.
- Vulnerable People: //
- Preventive Evacuation Capacity: GIS analysis to better able to predict evacuation fraction in flood prone areas.
- ICT-infrastructure: //
- Shelter Capacity: A method is proposed to assess the shelter capacity based on LIDAR satellite data in this report and tested for two places in London. The number of buildings can be calculated as well as the average building height or the number of houses below or above 5 meter (height of inundation of an average two story house). However, this data

is not yet available globally but it is expected that this will happen in the (near) future.

- Vulnerable Urbanization: The percentage of vulnerable urbanization is now based on an approximation if the vulnerable urbanization is 0-20, 20-40, 40-60, 60-80 or 80-100 %. This can however measured in more detail to really show the differences between cities, whereas cities now are often in the first two groups.

Cities In this assessment, only 38 cities are considered. Since this is mainly dependent on the data sources we used, this number can greatly be improved if data sources are improved. The flood risk models is able to calculate all cities worldwide with a number of inhabitants of 300,000 or more (1 million in Asia). If the shift is being made from direct information from cities, in fact all cities that are willing to participate are able to in this way.

Link between urban management and risk reduction Urban expansion and risk reduction are two terms with a strong interdependent relationship hand in hand with a better model to predict urban expansion is to create the possible link between urban expansion and risk reduction as was extensively discussed in the report. A methodology need to be derived to really show how cities can see urban growth not only as a difficulty, but more like a window of opportunity to make cities climate-proof now they have the possibility in new to develop parts of the city.

Link to cost-efficiency In interesting further expansions would be to seek the link between the flood risk assessment and cost-efficiency. As was already mentioned in the report, when large investment schemes are considered with limited budget, cost-efficiency is often the determining factor for lots of authorities worldwide. Developing a framework to assess the possibilities and come up with an initial proposal or indication for an appropriate cost-efficient strategy can really help cities in allocating their resources. This can again be linked to measures following the multi-layer safety approach to determine which layer should be the dominant investment one.

Positioning Next to the recommendation for further research, another important aspect is the partnering and further development of the index to the greater public. To achieve our ultimate goal to let cities participate and to create a way to communicate, so cities set ambitions or share best practises, funding and partnerships should established to make this jump from a concept version towards a real concept adopted on a global platform. This does not only asks for the need of a funding and networking partner, but also research collaborations to help improve the concept and to get it from the ground. The ideal partner should be the Rockefeller Foundation, and more specifically the 'Resilient Cities' initiative of this organization. Rotterdam and (recently) The Hague are part of the network of cities and a possible partnership with the municipality of The Hague can help the project to get support and adoption by the Rockefeller Foundation. Another possible partner would be the World Bank, which may enhance the possibility of global adoption. New concepts can be tested in a case study for the city of The Hague or a Delta Alliance partner city for example.

Graphical representation In order to show the results in an easy and informative way, a graphical viewer should be made. This viewer should contain a world map with the cities currently being assessed from which the city of interest can be selected leading the user to an additional page where the in-depth results will show up. This viewer is not only necessary for illustrating purposes, but also to make the possible end-users and partners enthusiastic about the project and convince them to participate.

SELF-ASSESSMENT

The next step in reaching the objective to form a communicative platform for cities, delivery of better information and a way to include more cities is by creating a way to let cities self-assess the parameters. Importantly, we need to find a way to reward cities for their efforts taken to reduce the risk or vulnerability of their city. How can city influence parameters and how can they assess this? This should be done in a practical way, not making it to complex to make it achievable for all cities. For example, cities can assess the percentage of people they have reached to inform them about flood safety in their neighbourhood. This self-assessment should form a second layer that influences and determines the first layer of parameters. The easiest thing to do this is by means of an online portal to upload information. In a similar fashion, ARUP and the Rockefeller Foundation started the Resilient City project. Cities who want to contribute and participate in this can easily apply via the internet page. After applying, the are guided through similar steps where they have to assess themselves by means of score indicators. We could use a similar approach, but cities can upload information sources or just fill in a number based on their own information sources. This makes it easier for the developers of the index, because they do not have to search for all the information themselves, but just get an overview of the input of the cities, which can be easily post-processed. Furthermore, participation in this initiative can be done in a comparable approach as the 'MERCER Quality of Living' [2] index. In this index, where cities assessed for aspects related to the quality of living in these cities, 231 cities worldwide are included. This is possible by asking for a fee for participation in the ranking by the city governments. By using a similar approach for our project, we can already cover some costs made by the project and it can stimulate cities to actively participate, because they want something in return for their fee.

[2] see https://www.imercer.com/content/mobility/quality-of-living-city-rankings.html

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A EXISTING INDICES

Over the years, several flood risk and other water-related indices are developed by various institution worldwide all trying to rank cities based on their own parameters set. By looking at these methods, we can identify different methodologies, parameters, sources and way to present the results. These indices can be used as inspiration for our index and useful sources can be picked out from these indices. More importantly, we can identify shortcomings of these indices and how we can distinguish ourselves from these existing methods. Analysing these methods by assessing the compatibility with our main criteria 'reproducible', 'universal' and 'quantitative' gives us the necessary insight in usefulness of these methods as basis for our new to develop method. The following methods are discussed; City Blueprint Index (CBI), Coastal City Flood Vulnerability Index (CCFVI) , Sustainable Cities Water Index (SCWI), Resilience Wheel, Global Competitive Index (GCI) and the Notre Dame-Global Adaptation Index (ND-GAIN). The choice is based on a literature review and the thesis work of Winkel (2016), who already did a literature study to look into the methods. Four relevant criteria can be distinguished for this assessment:

- How is the data obtained?
- What methodology is used to make the ranking?
- Which parameters are used?
- Relevance towards our three main criteria.

A.1 CITY BLUEPRINT INDEX

The City Blueprint Index (CBI) is an index showing the implementation of sustainable urban water cycle services in cities (UWCS). The City Blueprint is an interactive quick scan that generates a baseline assessment of the sustainability of UWCS in a municipality or other dominantly urban region (van Leeuwen et al., 2016). 24 parameters are used divided over eight broad categories: water security, water quality, drinking water, sanitation, infrastructure, climate robustness, biodiversity and attractiveness as well as governance. Score are scaled from 0 to 10, where the score zero is only assigned in case of no data availability. Data is obtained by means of a questionnaire with 24 questions distributed and carried out by the developers of the index and other stakeholders. Identified shortcoming by the authors are data quality of sources, scaling method and aggregation method. 45 municipalities and regions took part in the research with mainly European cities represented (only 7 cities or re-

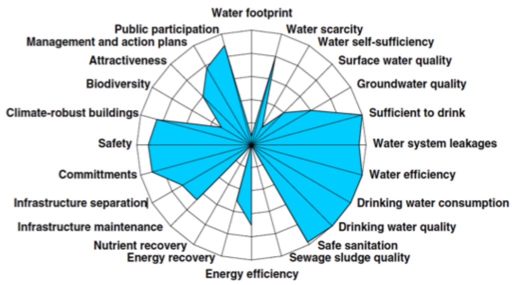


figure 17: City Blueprint with used parameters obtained from van Leeuwen et al. (2012)

gions outside Europe). In the overview in figure 17, all 24 parameters are shown. Reference is made to van Leeuwen et al. (2012) for with description, scale and source used for determining every parameter. The ratio quantitative data versus qualitative is 1:1, whereas most parameters are given for local scale (21 out of 25). Some interesting parameters are collected under the headings 'Climate Robustness' with parameters 'Local authority commitments', 'Safety' and 'Climate-robust buildings'. However, all three parameters are based on qualitative data making them less compatible with our scope. The way of illustration the City Blueprint is a radar chart consisting of the 24 parameters. From our point of view, this representation is a little bit to chaotic, where a radar chart with the eight categories was maybe a better option. Data sources for quantitative data are own research, The European Commission, Global City Indicators Facility, United Nations databases like the FAOAquastat, and other indexes like the European Green City Index.

A.2 COASTAL CITY FLOOD VULNERABILITY INDEX

The Coastal City Flood Vulnerability Index (CCFVI) is developed to create the link between the concepts of flood vulnerability and the day-to-day decision-making process (Balica et al., 2012). The index focuses on the exposure, susceptibility and resilience against coastal flooding. Raking is based or a normative score from 0 to 1, where higher scores represents higher coastal vulnerability. The developers of the index link the vulnerability against coastal flooding to a system of three components; hydro-geological, socio-economic and politico-administrative. What makes this index especially interesting is the way they included climate change to show the impact of this on the vulnerability of the cities. By doing this, the effect of possible adaptation options can be considered making it a useful tool for decision makers and guidance towards in-depth investigation of the most promising strategies. In total 19 parameters are used for scoring the cities for the three components. The total CCFVI index is the summation of the three components. The following parameters are used with given units as shown in table **??**. Until now, nine cities are assessed based on these parameters by using online data sources. Interesting and useful data sources are: 'World Factbook', 'World Bank', 'Highbeam research', 'Bnamericas' (business information South America), 'Water Resource eAtlas' and 'UNESCAP'. Despite the fact that this index is focused on coastal flooding, by changing certain parameters, this index can be transformed to an index for other flood phenomena or flooding as an overall theme, which is more the focus of our index. As mentioned before, the impact of future changes on the vulnerability can also be assessed with the methodology. Only selected parameters are changing by the consideration of climate change projections for the year 2100. In the hydro-geological component, the following indicators are affected by climate change projections: sea level rise, increasing number of cyclones, higher river discharges, increased storm surge and soil subsidence. In the social-economic component, only the indicator 'popu-

Category	Parameter	Unit
Hydro-geological	Sea-level Rise	mm/year
	Storm Surge	m
	# of Cyclones	#
	River discharge	m3/s
	Foreshore slope	%
	Soil subsidence	mm/year
	Coastal line	km
Socio-economic	Cultural heritage	#
	Population close to coastline	People
	Growing coastal population	%
	Shelters	#
	% of disabled persons (<14 and >65)	%
	Awareness and Preparedness*	-
	Recovery time	days
	km of drainage	km
Politico-Administrative	Flood Hazard maps **	-
	Institutional organisations	#
	Uncontrolled planning zone	%
	Flood protection	-

table 4: *Experience of floods in last 10 years. **Availibility of flood hazard mapping. Overview of categories, parameters and units used in Coastal City Flood Vulnerability Index based on Balica et al. (2012)

lation close to coastline' is affected. Scenarios for the impact of climate change are based on IPCC reports and the SRES scenarios. Impact values are assigned to the cities considered dependent on their location and taking into consideration the values assumed in the literature. To create a bandwidth in the climate change impact, a 'best-case scenario' and a 'worst-case scenario' are considered. Representation of the index is done by means of a bar chart with the relative contribution of the hyro-geological, social, economic, and politico-administrative components adding up to the total CCFVI index score. What makes this index a good source for the derivation of our index is the use of mainly open-data and the including of a climate change scenario. Some remarks regarding this methodology pop up. First of all, some parameters are difficult to quantify (Awareness and preparedness, Recovery time, and the Politico-Administrative parameters). If quantified in an appropriate way, these parameters can be a big additive to the index. Secondly, only climate change impact is considered in this index, whereas changes in socio-economic developments like urbanization and increase in economic value at risk are other future projections that could be included in a vulnerability projection of a city or delta. Also, more scenarios can be included like a most probable scenario next to the extreme scenarios. Another limited factor is the use a many different sources, what can be time consuming. On one hand, it makes the scoring objective, because quantitative data is obtained. On the other hand, questions rise about the comparability of these different data sources. These databases may work properly in their own domain with specific reason, but may not work properly outside this domain. For example, are the numbers derived in the same way or is a different method used for the same parameter. A single database, if available, is therefore preferred for every single parameter but problems with data availability will be expected to meet this requirement.

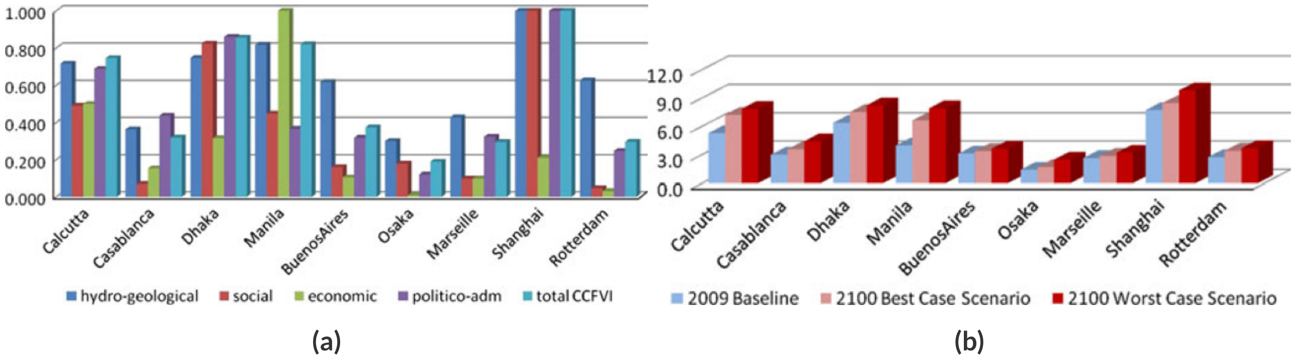


figure 18: a) Result of the CCFVI for every category and total CCFVI b) Change of CCFVI index under climate change conditions for a best case scenario and a worst case scenario for the year 2100 Balica et al. (2012)

A.3 SUSTAINABLE CITIES WATER INDEX

The Sustainable Cities Water Index (SCWI) made by Arcadis in collaboration with the Centre for Economics and Business Research is maybe the most well-known water related ranking, because it is published every year. The index consists of 17 parameters distributed in three elements 'Resiliency', 'Efficiency' and 'Quality', and cities are able to score up to a maximum of 100. In the latest published work, the 2016 raking, 50 cities worldwide are examined. The definition of an sustainable water city according to Arcadis (2016) is given as:

"The way in which cities manage their water has a lot to do with their ability to attract and retain businesses and residents, to encourage economic growth, and to compete on the global stage. Top cities understand and address their water in a sustainable manner. This means efficiently providing safe, reliable, and easily accessible water to residents and businesses; reliable access to sanitation, and protecting waterways from pollution. It also means being resilient and adaptable to extreme weather events and climate change that may contribute to issues such as flooding and scarcity"

The appendix of the report gives a useful overview of all indicators used, description and sources considered. After an inspection of the parameters, it can be concluded that only the 'Resilience' elements has some relevant parameters related to flood risk. In contrast with other indices, flood risk on itself is included in this ranking by looking at past flood experiences. This was used on the CCFVI to say something about flood preparedness and awareness. Another potentially interesting parameter is the green space of a city defined as the percentage of city area covered with green space. The relevance of this parameter in the given context is the storage of rain water, added value to the urban ecosystem and fight against urban heating. However, this parameter could also be used as indicator of retention area in case of a flooding. Databases used for the two relevant parameters are the Economist Intelligence Unit and the Siemens Green Cities index for the green coverage and the World Resources Institute to obtain data about past flood experiences. These parameters show that the same parameters can be used in a different context. What makes the index inspiring is that fact that they managed to make the index reproducible every year, what is the aim of our index as well.

RESILIENCY INDICATORS AND DESCRIPTIONS

INDICATOR NAME	DESCRIPTION	SOURCE
Water stress	Freshwater withdrawn as a percentage of the total available locally	World Resources Institute
Green space	Percentage of city area covered with green space	Economist Intelligence Unit, Siemens Green Cities Index
Water-related disaster risk	Number of different types of water-related natural disasters a city is exposed to, including floods, storms, droughts and mud flows.	EM-DAT International Disasters Database
Flood risk	Number of floods experienced between 1985-2011	World Resources Institute
Water balance	Monthly deficits and surpluses of rainfall,	Terrestrial Water Balance Data Archive (Willmott and Matsuura, University of Delaware)
Reserve water	Reservoir capacity within 100km of city, relative to total city water supply	GRanD Global Reservoir and dam database of the GSWP

EFFICIENCY INDICATORS AND DESCRIPTIONS

INDICATOR NAME	DESCRIPTION	SOURCE
Leakage*	The proportion of water lost in transit. Includes unbilled consumption, apparent losses and physical leakage.	Smart Water Networks Forum, municipal water utilities, World Bank
Water charges	Average cost per cubic meter of water to consumers, relative to average income in city.	International Water Association, World Bank IB-NET, municipal water utilities
Metered water	Percentage of households whose water consumption is metered.	Municipal water utilities, World Bank
Reused wastewater	Wastewater reuse compared to total wastewater produced.	FAO-Aquastat, Water Reuse Association
Service continuity	Continuity of service, average hours per day over the whole network.	World Bank, municipal water utilities
Sanitation	Percentage of households with access to improved sanitation.	WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation
Drinking water	Percentage of households with safe and secure drinking water.	WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation

QUALITY INDICATORS AND DESCRIPTIONS

INDICATOR NAME	DESCRIPTION	SOURCE
Sanitation	Percentage of households with access to improved sanitation.	WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation
Drinking water	Percentage of households using an improved drinking-water source.	WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation
Treated wastewater	Percentage of wastewater treated.	FAO Aquastat
Water-related disease	Incidence of water/sanitation related disease per capita.	WHO/Global Health Observatory Data Repository
Threatened freshwater amphibian species	Percentage of freshwater amphibian species classified by the International Union for Conservation of Nature as threatened in an area.	World Resources Institute
Raw water pollution	Concentration of phosphorus and sediment yields from source	International Water Association
Drinking water	Percentage of households with safe and secure drinking water.	WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation

figure 19: Used indicators, descriptions and sources for creating the Sustainable Cities Water index Arcadis (2016)

A.4 RESILIENCE WHEEL

In the framework of the master thesis of Haitsma (2016) in close collaboration with the Delta Alliance, a new concept is derived to operationalize a method enabling to monitor flood resilience of delta cities. This led to the development of the Resilience Wheel: a framework based on 5 dimensions and 19 indicators of flood resilience which structure what needs to be measures for flood resilience monitoring in delta cities. By conducting a literature review in existing articles and methods, an overview is made of indicators covering most dimensions of what we know as flood resilience. Five main categories are identified; Recovery, Resistance, Adaptability, Vulnerability of population and Organizational capacity. These categories are further subdivided in several indicators completing the Resilience Wheel showed in figure 20. This framework focuses on a whole different side of flood risk, more closely related to our research question. This Resilience Wheel forms a valuable basis for the derivation of our own framework. The Wheel is originally derived from the Adaptive Capacity Wheel, which is a tool to assess if institutions stimulate the adaptive capacity of society to respond to climate change. However, the general idea of the wheel can be applied in various contexts. Colour differences are used to scale the individual parameters and fill in the wheel. In an eye contact, end users can identify weak and strong points in the given context. In the flood resilience context of Haitsma (2016), for every indicator a grading system is made defining how to assign values from 1 to 5. The framework and indicators looks very promising, but applicability and suitable data sources are concerning factors. Despite this, two case studies are conducted, Rotterdam and Dhaka, to show how the Wheel can be used. Some parameters are still based on judgement, where a quantitative approach is maybe more suitable. For example, the 'Flood Barriers' indicator for Rotterdam is given a score of 5 based on interpretation of sources with "very high flood barrier" as conclusion. A better approach is to use a more universal definition like the protection standards expressed in a given exceedance probability (1/1000 years) for example. Another issue is the focus on plans of a city versus the execution of the plans given the fact that this is very hard to check in reality. The 'preparedness' indicator illustrates this uncertainty. Because several plans and scenarios for the city Rotterdam were the developed, the preparedness of the inhabitants is assumed to be very high. In reality, it is uncertain how these plans led to effective awareness translating in preparedness of the inhabitants. Next to some critical points, useful parameters are also recognized. Especially the 'Vulnerability of Population', consisting of population density, population composition, household assets and income level looks like a promising set of indicators, which can easily be based on quantitative data. Moreover, this category is the only quantitative one of the five categories. One weird thing about the grading procedure is the scoring based on availability of data. When a certain subject could be found in multiple sources, or multiple reports were available, indicator scores were assumed to be higher. This is an unusual way of scoring, because data availability should not be influencing the score.

Dimensions	Indicators			
Recovery	Emergency management	Resourcefulness	Protection of critical infrastructures	
Resistance	Flood barriers	Absorption capacity	Strength of build environment	Building codes
Adaptability	Self-organization	Learning capacity	Preparedness	
Vulnerability of population	Population density	Population composition	Household assets	Income level
Organisational capacity	Stakeholder cooperation	Access to information	Institutional capacity	Public participation

Score	Description
1	Absent
2	Low
3	Medium
4	High
5	Very high
	No data

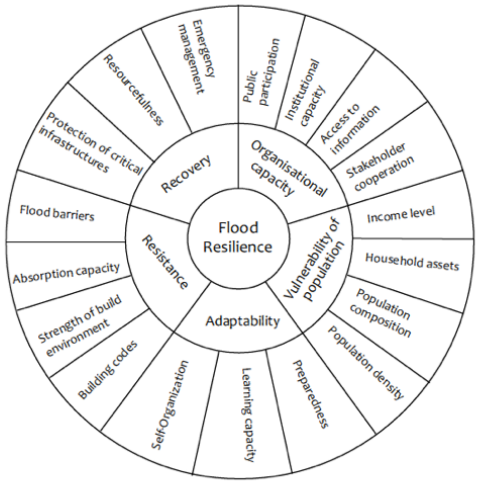
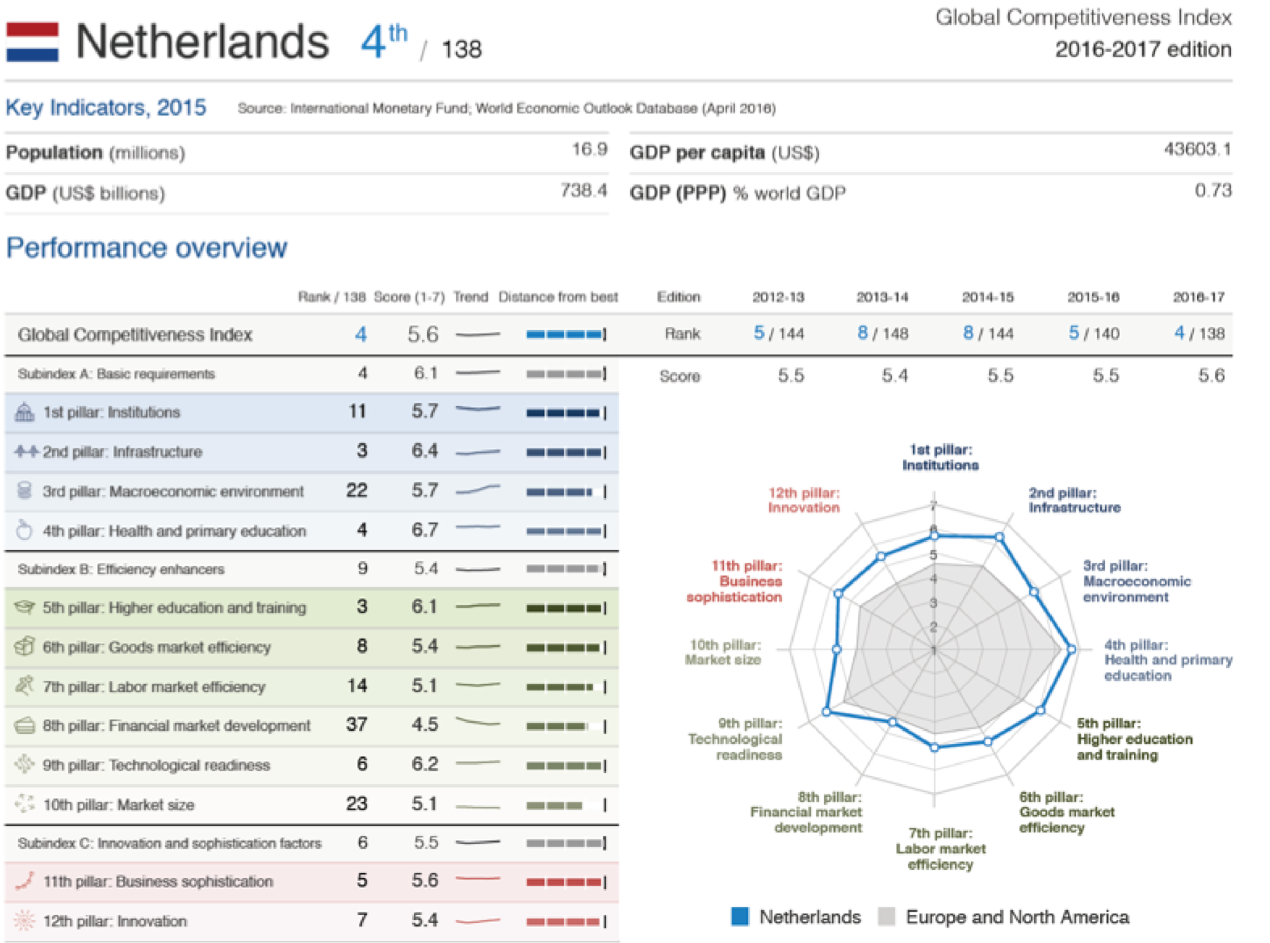


figure 20: Indicators, scoring scale expressed in colours and graphical representation of the Resilience Wheel of Haitsma (2016)

A.5 GLOBAL COMPETITIVE INDEX

The Global Competitive Index (GCI) is not directly related to flood risk, but can be an inspiration for data and parameter inputs. The GCI is published every year and is a measure of competitiveness of economies worldwide based on 118 parameters clustered in 12 categories (WEF, 2016). These 12 categories are presented in a radar chart scaled from 1 to 7. The 12 categories, or pillars, are defined as; (1) Institutions, (2) Infrastructure, (3)Macroeconomic environment, (4)Health and education, (5)Higher education and training, (6)Goods market efficiency, (7) Labour market efficiency, (8)Financial market development, (9)Technological readiness, (10)Market size, (11)Business sophistication and (12)Innovation. Most parameters are scored based on open data obtained from the big databases like the ones maintained by the International Monetary Fund, United Nations, World Health Organization and so on. Most parameters are focused on business and economy and are therefore not relevant for our research interest. Nevertheless, some parameters could be extremely useful. The parameters of the 'Infrastructure pillar' could be used if we want to include evacuation measures into our framework. Also, Macroeconomic environment, 3rd pillar, could be used as indicator for social disruption after a flooding or as indicator for the ability to recover after a flood. An example of the GCI is given for the Netherlands in the figure below.



Netherlands 4th / 138

Global Competitiveness Index
2016-2017 edition

Key Indicators, 2015 — Source: International Monetary Fund; World Economic Outlook Database (April 2016)

Population (millions)	16.9	GDP per capita (US$)	43603.1
GDP (US$ billions)	738.4	GDP (PPP) % world GDP	0.73

Performance overview

	Rank / 138	Score (1-7)
Global Competitiveness Index	4	5.6
Subindex A: Basic requirements	4	6.1
1st pillar: Institutions	11	5.7
2nd pillar: Infrastructure	3	6.4
3rd pillar: Macroeconomic environment	22	5.7
4th pillar: Health and primary education	4	6.7
Subindex B: Efficiency enhancers	9	5.4
5th pillar: Higher education and training	3	6.1
6th pillar: Goods market efficiency	8	5.4
7th pillar: Labor market efficiency	14	5.1
8th pillar: Financial market development	37	4.5
9th pillar: Technological readiness	6	6.2
10th pillar: Market size	23	5.1
Subindex C: Innovation and sophistication factors	6	5.5
11th pillar: Business sophistication	5	5.6
12th pillar: Innovation	7	5.4

Edition	2012-13	2013-14	2014-15	2015-16	2016-17
Rank	5 / 144	8 / 148	8 / 144	5 / 140	4 / 138
Score	5.5	5.4	5.5	5.5	5.6

figure 21: Global Competitive index for the Netherlands showing the scores for every pillar relative to the Europe and North America average WEF (2016)

A.6 NOTRE DAME-GLOBAL ADAPTATION INDEX

The last index considered is the Notre Dame Global Adaptation Index (ND-GAIN) published by the university of Notre Dame. The index aims to represents a country's current vulnerability to climate disruptions. Next to that, it assesses a country's readiness to leverage primate and public investment for adaptive actions (Chen et al., 2015). In total, 45 indicators are used based on a wide variety of sources. Especially the vulnerability indicators can be of valuable use, because they include some water and urban related parameters. The following vulnerability indicators are recognized as shown in figure 22. The university tries to update the ranking as much as possible, because they recognize adaptation as an evolving concepts. Especially the use of a lot of different sources, with different updating time frames makes it difficult to reproduce the ranking every year. This is also an important observation to keep in mind for deciding upon suitable parameters for our index. Interesting indicators for the vulnerability of a city or country in the scope of our research are 'Urban concentration', 'Quality of trade and transport-related infrastructure', 'Age dependency ratio' and 'Paved roads'. Where the first one is obvious, the latter three indicators need some explanation. These three indicators can be used as indicators for efficiency of evacuation in case of a flooding. The parameter 'Disaster Preparedness' can be used as to reflect a country situation and governance risk attitude towards disaster preparedness. In the readiness assessment (not included in the figure), we find the indicator 'ICT infrastructure', which includes the percentage of phones, mobile cellular subscription and internet users in a given country. This can in fact say something about how fast and how many people can be reached via the usual channels in case of an emergency. Although these indicators are mainly on country scale, an assumption can be made saying that these percentages reflect city or delta region scale as well.

Sector	Exposure component	Sensitivity component	Adaptive Capacity component
Food	Projected change of cereal yields	Food import dependency	Agriculture capacity (Fertilizer, Irrigation, Pesticide, Tractor use)
	Projected population change	Rural Population	Child malnutrition
Water	Projected change of annual runoff	Fresh water withdrawal rate	Access to reliable drinking water
	Projected change of annual groundwater recharge	Water dependency ratio	Dam capacity
Health	Projected change of deaths from climate change induced diseases	Slum population	Medical staffs (physicians, nurses and midwives)
	Projected change of length of transmission season of vector-borne diseases	Dependency on external resource for health services	Access to improved sanitation facilities
Ecosystem services	Projected change of biome distribution	Dependency on natural capital	Protected biomes
	Projected change of marine biodiversity	Ecological footprint	Engagement in International environmental conventions
Human Habitat	Projected change of warm period	Urban concentration	Quality of trade and transport-related infrastructure
	Projected change of flood hazard	Age dependency ratio	Paved roads
Infrastructure	Projected change of hydropower generation capacity	Dependency on imported energy	Electricity access
	Projection of Sea Level Rise impacts	Population living under 5m above sea level	Disaster preparedness

figure 22: Overview of indicators for every sector used to come up with the ND-GAIN Chen et al. (2015)

A.7 CONCLUSION AND REMARKS

Concluded can be that many different methods are already developed in the framework of flood risk but also in many others fields like economic competitiveness and climate change adaptation. These existing methods form a great source of inspiration and show the available data sources. If we look at the methodology of ranking, quantitative and qualitative methods are used. Quantitative methods are mainly based on data from the big database sources like the United Nations Database, IMF or the World Bank, whereas qualitative methods are based on expert judgment or questionnaires. Only the quantitative indexes are able to reproduce their index yearly or with some larger intervals. Picking the right parameters is therefore important, because updating is only possible if the data source used is updated in the same time manner given the parameter represent a time evolving principle. The amount of parameters is varying widely from 17 up to 118 looking more closely at a certain field like flood risk or looking more broadly into different fields. Looking at too many parameters out of different fields creates the idea of comparing things which cannot be compared easily. There must be an idea behind the selection of the parameters instead of finding as much parameters related to the subject. Also, sometimes a parameter is chosen in a qualitative way, where a quantitative way is more appropriate. An example is the 'Flood Barriers' indicator in the Resilience Wheel index which is scored based on judgement of the type and state of the flood structure, where data is available for return periods of these protective structures making comparison easier. Next to that, a judgement based ranking method makes ranking sometimes too subjective and dependent on the interpretation of the author, where a quantitative ranking will lead to a less ambiguous interpretation. Qualitative ways of scoring may also lead to conclusions or estimations, which may not be supported by data. An example is measuring the awareness and preparedness of inhabitants based on the number of reports of policy makers under the assumption that inhabitants are aware of these report and plans and react in the expected and appropriate way. Another remark is the observation that most indexes, more related to the flood risk, do not include the general definition of flood risk (probability x consequences). In the Arcadis ranking, the flood risk is defined as the experiences of flood event in the last 30 years. Notable detail is that flood experiences are used in another ranking (CCFVI) to represent the flood awareness and preparedness. This shows that definition of the parameters can be difficult and influenced by the authors perception. Last remark is the often static use of the ranking. All rankings are a static representation of the situation at a certain time, whereas an iterative and dynamic representation is more valuable showing the difference between the situation now and the situation in 2050 under climate, socio-economic and geological scenarios. The CCFVI tries to do this by changing specific parameters under climate change scenarios, but does not manage to achieve the full potential of this by only focusing on climate change and considering the impact of only two scenarios. Despite these remarks, some good ideas about parameters and valuable sources are identified by this review. For qualitative parameters is it however the question if data sources can be found to represent this.

Parameter	Method	Definition	Source
Local Authority Commitment	CBI	Assessment of how ambitious and comprehensive strategies and actual commitments are on climate change	Questionnary
Public Participation	CBI	Proportion of individuals who volunteer for a group or organization as a measure of local community strength and the willingness of residents to engage in activities for which they are not remunerated.	Questionnary
Sea Level Rise	CCFVI	How much the level of the sea is increasing in 1 year (mm/y)	Various, city dependent
Storm Surge	CCFVI	A storm surge is the rapid rise in the water level surface produced by onshore hurricane winds and falling barometric pressure (cm)	Various, city dependent
Soil Subsidence	CCFVI	How much the area is decreasing? (m2)	Various, city dependent
% of disabled people (<14 and >65)	CCFVI	% of population with any kind of disabilities, also people less 12 and 65 years	Various, city dependent
Awareness and Preparedness	CCFVI	Are the coastal people aware and prepare for floods? Did they experience any floods in the last 10 years?	Various, city dependent
Kilometer of drainage	CCFVI	km of canalisation in the city	Various, city dependent
Flood Risk	SCWI	Number of floods experienced between 1985-2011	World Resources Institute
Green Space	SCWI	Percentage of city area covered with green space	Economist Intelligence Unit, Siemens Green City Index
Population density	RW	Average residents/km2 in the city	CityLab, National Databases
Population composition	RW	Proportion of the city population above the age of 65 and below the age of 14 as percentage of the total population in the city	World Bank, National Databases
Household assets and income level	RW	Percentage of the city population owning a radio, mobile phone and car	National Databases
Income Level	RW	The average annual household disposable income in a city in $	National Databases
Infrastructure	GCI	Included more measures of connectivity, ICT, energy, and water infrastructure	WorldBank, IMF, World Economic Outlook
Macroeconomic environment	GCI	Added measures of external and foreign currency debt and improved conventional indicators	WorldBank, IMF, World Economic Outlook
Urban concentration	ND-GAIN	Urban concentration measures both concentration of a country's population within cities and concentration of the urban population within a small number of large population centers via the Herfindahl Index	WDI, United Nations
Quality of trade and transport-related infrastructure	ND-GAIN	Logistics professionals' perception of country's quality of trade and transport related infrastructure	WDI
Age dependency ratio	ND-GAIN	An indication of the size of the vulnerable population in terms of ages. This indicator considers the population under 14 or above 65 as the vulnerable group.	WDI
Paved roads	ND-GAIN	Proportion of the total length of the roads that are paved.	WDI
Disaster Preparedness	ND-GAIN	An indication of capacities to deal with climate-related nature disasters. This indicator uses monitoring from the Hyogo Framework Action (HFA	HFA National Progress
ICT Infrastructure	ND-GAIN	A composite indicator from 4 sub-indicators that consider both the access to and the use of ICT infrastructure: mobile phone subscription per 100 persons, fixed phone subscription per 100 persons, fixed broad-band subscription per 100 persons, and percent of individuals using internet.	ICT Development Index

table 5: Summarizing table given all relevant indicators, method, definition and used source which can be used a basis for our index

B SUMMARY DISCUSSION SESSION

In the section, a short summary of the discussion session, which was held on the 7th of February 2017, is given (in Dutch).

Aanwezig: William Veerbeek (IHE), Tom Bucx (Deltares), Joost Knoop (PBL), Jasper Verschuur (TUDelft), Bas Kolen (TUDelft, HKV)

In dit bespreekverslag zijn de discussiepunten opgenomen zoals besproken in het overleg met de begeleidingsgroep.
- Instemming met het concept. Het idee kan op draagvlak rekenen. Wat met name aanspreekt is:

- De kwantitatieve onderbouwing en dat het gebaseerd is op open data en modellen. Hierdoor ben je niet afhankelijk van inschattingen gemaakt in de studies en kwalitatieve inschattingen door experts. Het toevoegen van een self assessment en opties tot maatwerk (en onderzoeksvragen) biedt goede kansen. De basis aan informatie uit het Aqueduct-model is een goede keuze.
- De focus op overstromingsrisico. Er bestaan al bredere indices in de wereld die meer op resilience focussen

- Alle betrokken partijen werken in projecten al aan aanpalende thema's. De delta monitor kan hiermee gevoed worden en extra kansen opleveren voor toepassing van de risicobenadering en diverse onderzoeksvragen opleveren.
- Focus: De naam van de monitor bevat het woord delta. Omdat de monitor zich (terecht) richt op steden (hier vinden de ontwikkelingen plaats) is het belangrijk om niet het woord delta te gebruiken maar het woord city. Smart Flooding City Index is een betere term. Deze index zou dan gepositioneerd kunnen worden onder bredere indices. Afgesproken om niet het woord delta te gebruiken in de naam maar city.
- Positionering. Er zijn twee niveaus van toepassing voorzien:

- In de stad zelf. Het kan hier leiden tot vaststellen van ambities voor verbetering en vergelijkingen met andere steden (in de wereld of in een delta).
- Een wereldwijde organisatie die samen met de ontwikkelaars de lijst publiceert. Te denken valt aan Rockefeller foundation, OECD of Wereldbank of een krant als the economist.

- Thematiek. De focus ligt nu op rivieroverstromingen. Het zou mooi zijn om kustoverstromingen en neerslag ook toe te voegen. Het concept is gelijk, de toepassing wordt dan breder.
- Parameter adaptive capacity. Hierover is veel discussie geweest. De consensus was om deze parameter anders vorm te geven. Het idee achter deze parameters is dat er een doorkijk wordt

gegeven of op basis van de verwachte groei de risico's in 2030 onbeheersbaar worden. Het toevoegen van meer informatie over adaptiviteit is onwenselijk omdat enerzijds het lastig is te onderbouwen en anderzijds er veel meer informatie nodig is. Geadviseerd is om zowel de naam van deze parameter aan te passen als de uitwerking. De parameter zou een 'alarmwaarde' moeten geven (rood, geel, groen) in welke mate de snelheid van het ontwikkelen uit het verleden mogelijkheden biedt om het verschil in risico tussen nu en 2030 te overbruggen. Op basis van onderliggende aannames: stel dat de helft van de groei gedaan kan worden zonder extra schade en slachtoffers en dat bestaande bouw met een bepaald iets kan worden gereduceerd, is het verschil dan te overbruggen. Groen is dan makkelijk, geel om het even en rood zeker niet. De onderliggende parameters in het spinnenwebdiagram komen dan te vervallen (de databases zijn landelijk en de informatie is zeer zacht). Afgesproken is de parameter aan te passen op basis van bovenstaand advies.
- Onderzoeksvragen. Tijdens de discussie zijn al diverse onderzoeksvragen benoemd die opgenomen kunnen worden in een onderzoeksagenda (die we opstellen naast de uitwerking nu):

- Schatten van wereldwijde groei van steden uitgedrukt in kaarten waaruit het grondgebruik blijkt. IHE doet hier al onderzoek na voor een aantal steden waarbij ze voorspellingen maken op basis van ontwikkelingen uit het verleden.
- Opnemen van de indirecte schade van overstromingen.
- Opnemen van ook neerslag en kustoverstromingen

Op basis van de aanbevelingen wordt de monitor nu aangepast. We werken hierbij een ranking uit van ongeveer 30 steden (waarvoor de data voorhanden is). Deze ranking gaan we dan bespreken met de Delta-Alliance waarin de focus ligt op de mogelijkheden voor gebruik. In een tweede begeleidingsgroep bespreken we dan onze voortgang, de (eind)resultaten en de verdere kansen.

C FLOOD RISK ASSESSMENT: BACKGROUND INFORMATION

HYDROLOGICAL MODEL

Over the years, several global hydrological models are developed to simulate river discharges as a consequences of extreme rainfall. This model distinguishes itself in particular for the addition of new and advanced schemes for sub-grid parametrization of surface runoff, interflow and baseflow and added explicit routing of surface water flow using the kinematic wave approximation, dynamic inundation of floodplains and a reservoir scheme. These added features, and especially the dynamic routing component (DynRout) make it suitable for the use in flood risk assessments. The model is coded in Python-based software environment PC-Raster using a raster based approach. PCR-GLOBWB calculates for each grid cell (0.5 degree x 0.5 degree) on a daily time step the water storage in two vertically stacked soil layers and an underlying groundwater layer, as well as the water exchange between the soil layers and between the top layer and the atmosphere (Van Beek and Bierkens, 2009). Next to that, the model also calculates canopy interception and snow storage. In short, the specific discharge consist of three layers; saturation excess of the groundwater layer (base ow QBf), runoff from the second soil layer (interflow, QSf) and direct runoff (QDR) (Nootenboom, 2015) . The PCR-GLOBWB extension for dynamic routing (DynRout) converts the sum of specific discharge and the direct gains and losses from PCR-GLOBWB in river discharge by using the Saint-Venant kinematic wave approximation, as well as overland flow in flood plain areas outside the river banks, resulting in a temporally variable inundation extent. The overland flow is calculated by means of a Digital Elevation Model available in a 1x1 km spatial resolution. To make the all maps compatible with the later derived exposure and flood protection maps, the spatial resolution is scaled down to 30-arc second, or 1x1 km ,which gives reasonable flood risk estimates on city scale. For more information how this is done, further reading of the article of (Winsemius et al., 2013) is suggested. In figure 23 a graphical overview of the aspects mentioned above is shown. On the right, the numerous discharge components and interactions are displayed and the left maps is the final map including all river basins with average discharge and soil moisture used for the interaction between water and soil. To derive the flood extremes, the PCR-GLOBWB and DynRout models were run for a 30 year time domain from 1961- 1990 using gridded monthly in situ observations of the Climate Research Unit together with climate data obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF).

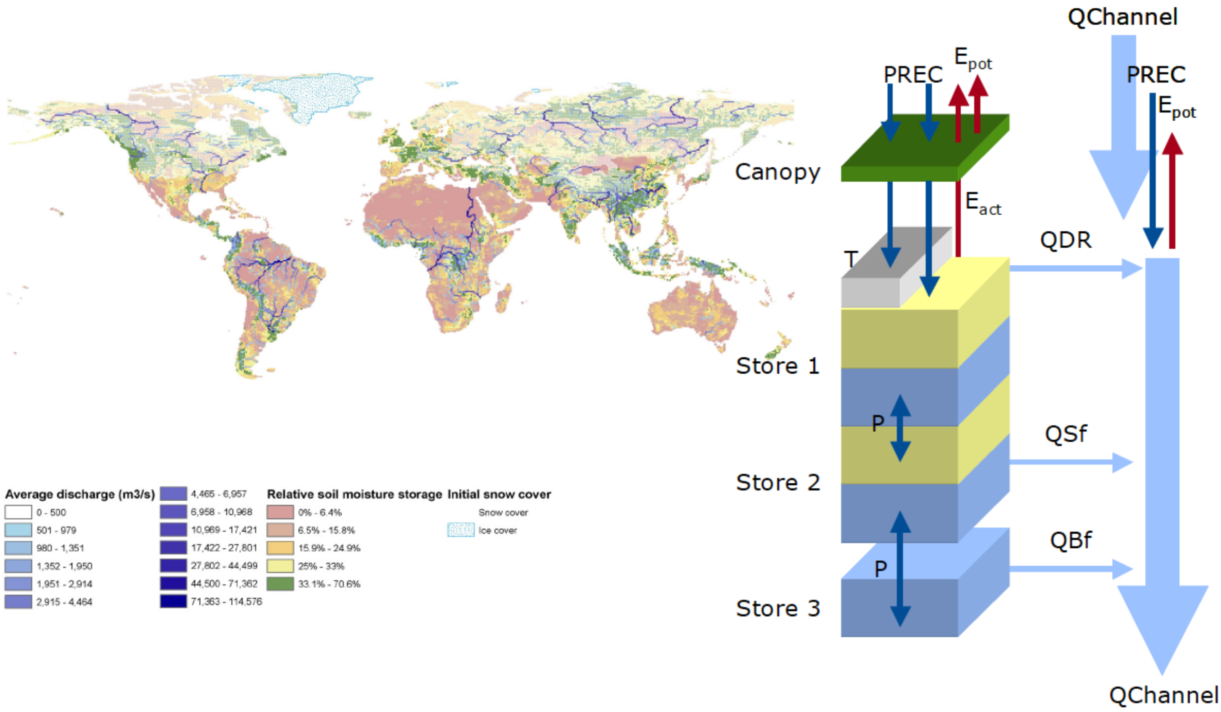
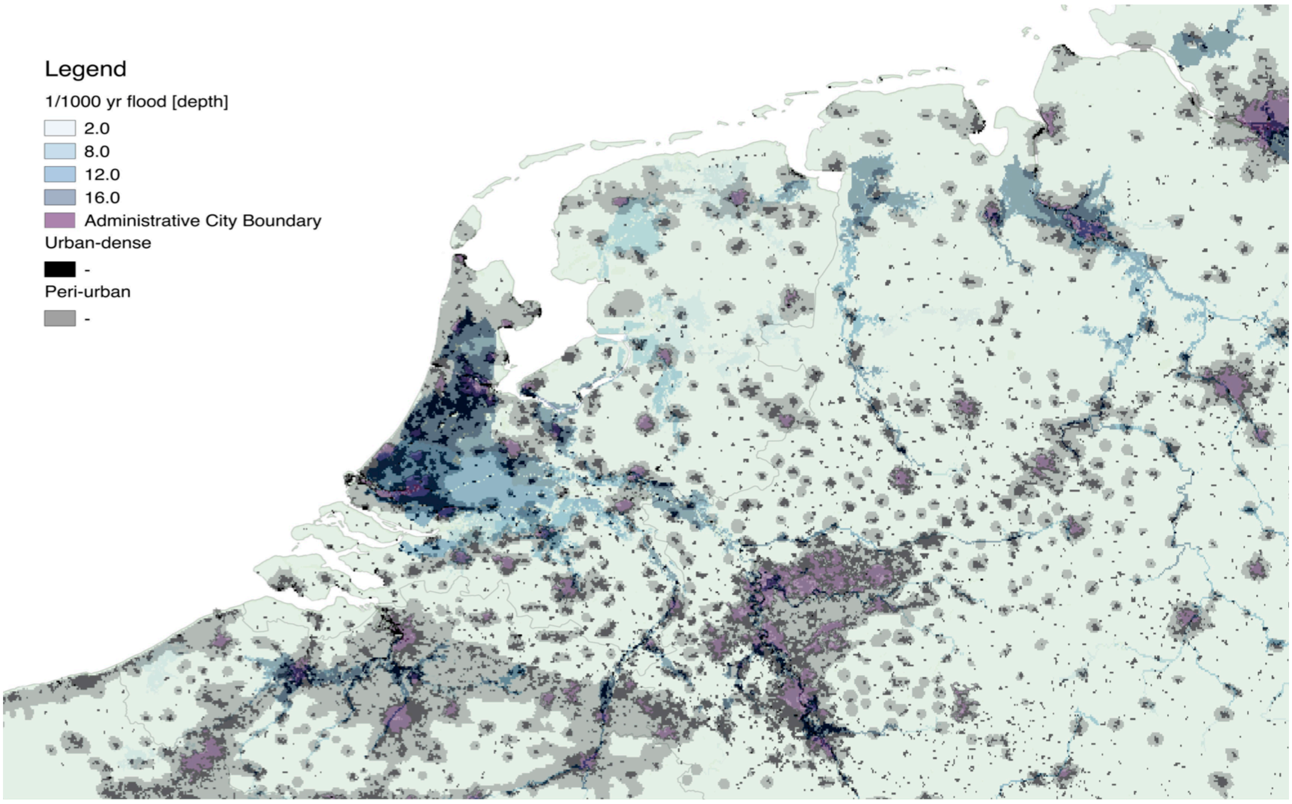


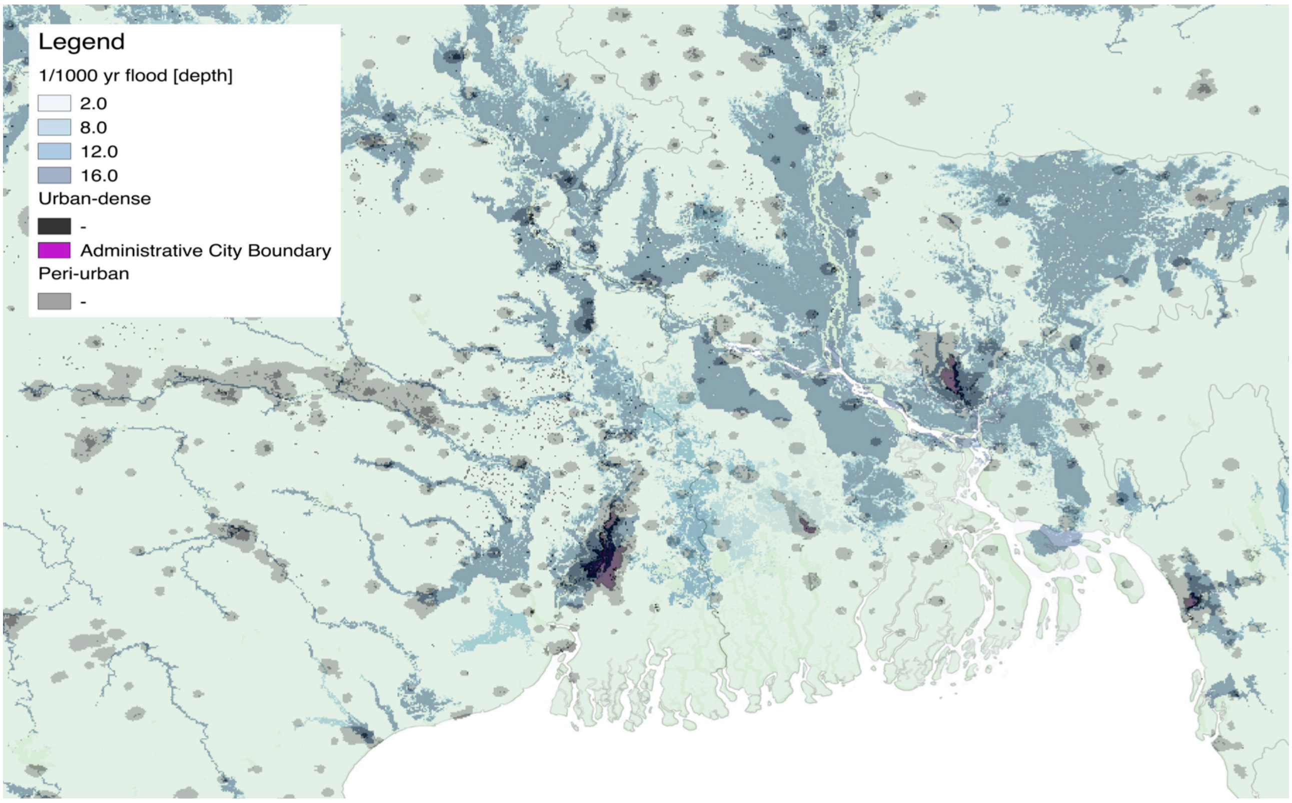
figure 23: a)Final map included all river basins with average discharge and soil moisture used for the interaction between water and soil. b) The numerous discharge components and interactions used to calculate and simulate discharges (Van Beek and Bierkens, 2009).

GRAPHICAL IMPRESSION

To illustrate how the several map components come together, a map from the Netherlands and from Bangladesh are derived. This map shows the flood inundation of a 1/1000 yr flood event, the urban-dense and peri-urban areas, and the administrative boundaries of the cities for which the risk can be calculated.



(a)



(b)

figure 24: a) A map of the Netherlands and Bangladesh showing the 1/1000 yr flood event (Van Beek and Bierkens, 2009) with given depths (m), urban dense (black) and peri-urban extent (grey) and the administrative boundaries (purple) (GADM, 2015)

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D FLOOD INDEX: PARAMETER DESCRIPTIONS

FLOOD PROBABILITY

The occurrence of a flood event from a statistical view is described by the probability that a certain water level occurs in the river, which finds its way over the river banks and flood prone areas. Stated otherwise, the probability is determined by the protection standards in place that withhold the city from flooding. The database including these protection standards, FLOPROS, is already discussed extensively in the flood model describing chapter. This database aims to have a open character, where cities and country can contribute by delivering information to update the database and to refine the resolution to smaller scales even on city level. In the database now, standards are available on regional level and in exceptional cases on city level. The flood probability is being expressed as a return period, for example an one in 100 year event, or a one in 10 year event.
Source: FLOPROS (Scussolini et al., 2016)
Latest years: 2016
National/Regional/City-scale: Regional/City
Self-Assessment: Cities can provide information about there protection levels, which may deviate from regional protection levels. Also, cities can decide to investment in flood protection, for example dykes or levees, with higher standards as a result. These two developments can both update the index as well as the database.
Improved model /

FLOOD COVER

Indicating what percentage of the city will be flooded in case of a flood event provide valuable information not only about the direct impact that households and companies face, but also difficulties with evacuation possibilities. In this way, we can focus more on the vulnerable areas and eventually collecting information about these areas only. For example, it could be the case that the urban slums are located in these areas, meaning that this can even have more disastrous consequences for these people if their properties are being flooded. The flood cover is determined by overlapping the flood event of the most probable event discussed above with the administrative boundaries of the city covered in the 'Global Administrative Boundaries' database. This database is however not frequently updated, therefore asking for additional tools to characterize the dynamic expansion of city boundaries. Flood cover may change due to expansion of the city or change in flood probability and is therefore directly related to the parameters above. Eventually, it is the percentage of the city flooded by dividing the flooded area with the total area of the city. Keeping in mind that the model only provides information on a 1x1 km scale, which is somewhat scarce on a city scale, this value is therefore a first ap-

proximation.
Source PCR-GLOBWB (Van Beek and Bierkens, 2009) | Global Administrative Boundaries (GADM, 2015)
Latest Years 2016 | 2015
National/Regional/City-scale City
Self-Assessment Parameter can be refined if probability estimates, same as above, are provided by cities.
Improved model This parameters asks for an assessment with an hydrological model able to predict inundation area on a smaller scale.

PROPERTIES AT RISK

The number of properties at risk does tell us something about the affected area, if the densely populated and therefore densely build parts of the city are flooded or the less densely populated. To determine this parameter, we make use of the percentage of damage contributed by densely populated areas (urban-dense) and less densely populated areas (peri-urban). We add a factor for the built-up density for urban areas provided by the 'Atlas of Urban Expansion' indicating the average density of built-up in a city. Because the peri-urban area is characterized by a urban coverage of one third of urban dense areas, we assume that the built-up density is also one third of built-up density of urban areas. Multiplying the shares with built-up density and with the approximate flooded areas gives a number of the area of built-up properties at risk.
Source PCR-GLOBWB (Van Beek and Bierkens, 2009) | Global Administrative Boundaries (GADM, 2015) | Atlas of Urban Expansion (Angel et al., 2016a)
Latest Years 2016
National/Regional/City-scale City
Self-Assessment City have often more detailed maps of built-up distribution of the city giving more information about the properties at risk.
Improved model High resolution satellite image, for example LIDAR data, can give high resolution urban footprint showing the built-up of cities, from which a more detailed estimation can be made.

LOSS OF LIFE POTENTIAL

The people at risk estimate follows directly from the FIAT risk calculation. In the total risk estimate, fatality risk is converted to an economic value, but people at risk is the number of people being potentially drowned per year. To be better able to compare between cities, the probability of dying is used by dividing the fatality risk (# /yr) by the population.
Source Flood Risk Assessment (see H4) | Citypopulation (CityPopulation, 2016)
Latest Years 2016
National/Regional/City-scale City
Self-Assessment /
Improved model /

POPULATION DENSITY

Population density is simply the number of people living per square kilometre. High population densities are more vulnerable for flooding, which can give high fatality risk value and major contribution to the total risk of cities. The Citypopulation website collects population information for almost all cities worldwide, where statistics are available for most recent years. In case a population density estimate was not available for the year 2016, the value from the year 2015 was given. Estimates can sometimes be confusing, for example the Beijing population density value, which is relatively low. This because, the great area of Beijing covers high density areas in the middle of the city as well as more agricultural areas with low population density on the city sides.
Source Citypopulation (CityPopulation, 2016)
Latest Years 2015, 2016
National/Regional/City-scale City
Self-Assessment Data need to be checked with cities, because sometimes it is not clear if the data is for city boundary or for a urban agglomeration. Also, definitions of city boundaries may differ globally.
Improved model /

GDP/CAPITA

GDP/capita values are obtained from the OECD-database, containing regional GDP-capita estimates for OECD-member. GDP/capita, or Purchasing Power Parity per capita, are expressed in US dollars with constant 2010 prices. 2014 is the latest updates year, but it can be expected that deviation for the upcoming years are small. In case no regional data could be found, mostly for non-OECD member, country GDP/capita values are obtained from the IMF-database.
Source OECD Regional GDP/capita (OECD, 2015) | IMF-Database

Latest Years 2012, 2013, 2014
National/Regional/City-scale National/Regional/City
Self-Assessment City specific GDP/capita is usually available in a city statistics database, which provides more reliable values and may include city statistics of non-OECD countries.
Improved model /

ECONOMIC IMPACT

Because large cities established in deltas are often the main drivers of national economies, damage to this city can not only affect the city, but the indirect damages can spread far outside the city boundaries potentially affecting the whole country. An example is the flooding in Bangkok in 2011, which led to an economic disruption of the whole Thai economy, because a lot of large manufacturing companies, which were the driver of the Thai economy, were out of business for a long time. In essence, a country's economy depending heavily on the economic production in a certain city has a greater potential on a nationwide economic disruption. Measuring this dependency is therefore essential, which could be defined as the city produced GDP divided by the national GDP.
Source OECD Regional GDP/capita (OECD, 2015) | United Nations National GDP (UNdata, 2015)
Latest Years 2012, 2013, 2014
National/Regional/City-scale National, Regional, City
Self-Assessment City specific GDP/capita is usually available in a city statistics database, which provides more reliable values and may include city statistics of non-OECD countries.
Improved model /

FLOOD HISTORY (AWARENESS)

Measuring flood awareness is a difficult and although data about flood awareness is scarce, it can be expected that awareness is correlated by the history of flood events happening in the vicinity of the city you live. People who are experiencing flood events on a yearly basis are expected to react in a less chaotic and more appropriate way and may even have adapted their life to this. Therefore, the number of flood events happened over the past 30 years can positively influence the ability of city inhabitants to respond to floods. The Dartmouth Flood Observatory is the most comprehensive flood event database, and this will be used to estimate the number of floods. In most cases, some extra information is given about the more exact location of the flood event in a country, but it is rather difficult to know if a city is included or not.
Source Dartmouth Flood Observatory (Brakenridge, 2017)

Latest Years 2017
National/Regional/City-scale Country
Self-Assessment Events are now assigned to cities based on their country statistics, so if countries experience flood events the last 30 years. However, it is more interesting to know how many of these events happened in the city or near the city.
Improved model /

VULNERABLE PEOPLE

Research has shown that some people are more vulnerable becoming a victim of drowning in case of a flood event, which are statically seen the older population (>65) and the young population (<15). The share of these people as part of the rest of the population can differ per country due to life expectancy and children born. The higher the share of these groups, the higher the vulnerability of the total population at risk. We measure this as the share of people older than 65 and young than 15 years old divided by the people have ages 15-65. The World Urbanization Prospects of the United Nations have made estimates of the variations of this number of time for the upcoming years until 2095. City data is used where available, otherwise country data is used under the assumption that demographic percentages are the same in city as well as in the whole country.
Source World Urbanization Prospects, United Nations (WUP, 2015)
| OECD (OECD, 2015)
Latest Years 2005, 2010, 2015
National/Regional/City-scale Country, City
Self-Assessment City can have more accurate demographic estimates of their city
Improved model

PREVENTIVE EVACUATION CAPACITY

In case of a large scale evacuation, people are usually taking there cars and leaving the flood prone area. However, roads are not designed for this kind of traffic leading to congestion and increased vulnerability. Especially in cities with high population density and low road density, congestion can be expected. Therefore, a measure for the evacuation road capacity is determined by dividing population density by road density, leading to a number which represents the number of people on the road per km. By looking at this number, it can easily be determined if this is above the design road capacity or not. Population density data was already given, whereas the road density of arterial roads in the city is obtained from the 'Atlas of Urban Expansion' database based on satellite info.

Source Atlas of Urban Expansion (Angel et al., 2016b) | Citypopulation (CityPopulation, 2016).
Latest Years 2016
National/Regional/City-scale City
Self-Assessment
Improved model

ICT-INFRASTRUCTURE

One of the determining factor in effective disaster management is the ability to reach people in potentially affected areas. With the tremendous grow of ICT-infrastructure over the past years, more and more people can be reached in a fast and effective way. However, this is not everywhere, and in every big flood event people drown because they were not informed or perceived the threat in the wrong way. To determine the amount of people that could be reached, the percentages of people fixed lines, broadband access and mobile cellular are added together and divided by 300. Because of data scarcity, a nationwide estimate is used, although a difference could be expected between urban and rural areas in a country.
Source UN Database (UNdata, 2015)
Latest Years 2015
National/Regional/City-scale National
Self-Assessment Estimate on city scale for all cities
Improved model

SHELTER CAPACITY

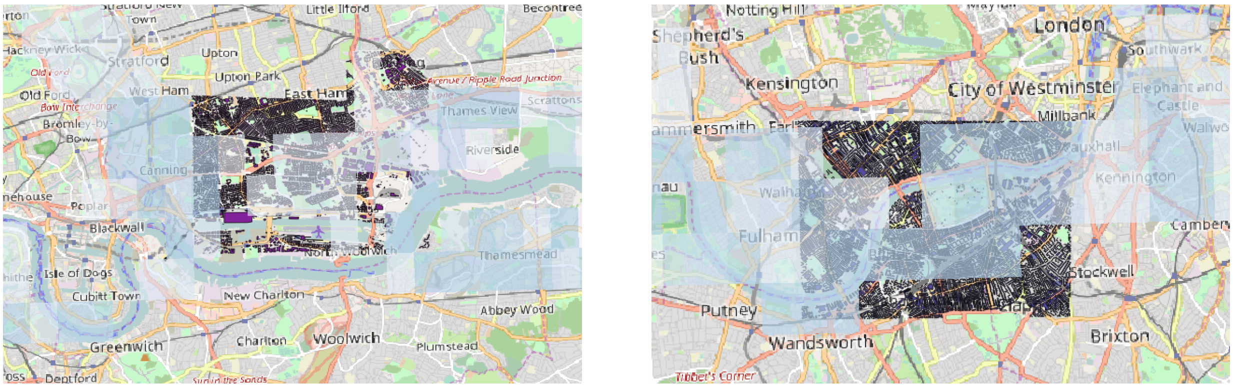
In case evacuation by car would lead to congestion or is even too late, finding shelter in your own building or a place nearby is in most cases the best thing to do. Especially when water levels are not so high, lets say 2 meters, finding shelter on the first floor of a house is already sufficient. In case higher water levels will occur and flow through the city, the number of high buildings can be a measure for the shelter capacity of a city. Where the normal two story house measures a height of approximately 5 meters, the density of higher buildings does say something about the shelter capacity during a large scale flood event. Because detailed information about building heights requires city scale assessment, the number of high rise buildings in a city could be correlated with the average high build up density. The skyscraper database includes information about high rise buildings in most major cities worldwide. In this database, a high rise building is defined as a building with at least 12 stories or a total height of at least 35 meters.
Source Skyscraper Database (Skyscraperpage, 2017)

Latest Years 2017

National/Regional/City-scale City

Self-Assessment

Improved model A potential valuable way of finding average building height information in flood prone areas is by making use of the newest satellite information, which will become more and more available. The latest high resolution satellite data is the LIDAR project. The United Kingdom published this data and can be downloaded for free in different resolutions for the whole country. A test side is used to look if building height data could be obtained from this. Two parts of flood prone areas among the Thames in London are being addressed. Using LIDAR data and urban footprint data including footprint of all buildings, the average building height and percentage of building higher than 5 meters is obtained. Only for these two small areas, information on building heights of over 11000 buildings was obtained. The average building height was 6 and 8.6 meter. The percentage of buildings higher than 5 meter was respectively 67% and 77%.



(a) (b)

figure 25: a) LIDAR data together with building data of coordinate grid TQ4080 in London. b) LIDAR data together with building data of coordinate grid TQ3070 in London.

VULNERABLE URBANIZATION

From a flood perspective, rapid urbanization does not need to be problem directly. However, it becomes a problem when rapid, unplanned or uncontrolled urbanization takes place towards the flood prone areas. This is often the cases in densely populated cities with trend of increasing house prices leaving only the inexpensive vulnerable areas left to settle. Looking at the urbanization trends shows insight in this, without knowing if spatial policy plans are in place. It could even be the case that cities without adequate policy plans face no problems when urban expansion evolves naturally away from the flood prone areas. Assessing this can be done by looking at the expansion trend over the last years, and what approximate share of the expansion is towards the vulnerable areas. This could be expressed in a fraction from 0-20, 20-40, 40-60, 60-80 and 80-100 per cent, or a score from 1 to 5.

Source PCR-GLOBWB (Van Beek and Bierkens, 2009) | Atlas of Urban Expansion (Angel et al., 2016a)

Latest Years 2016

National/Regional/City-scale City

Self-Assessment

Improved model

E RESULTS

This appendix gives some more in depth information about the risk assessment done. First of all, a detailed overview of the economic risk is given including the two scenarios. Furthermore the fatality risk assessment is given with number of people affected, population increase estimates and the 'Value of Statistical Life' values used. The last table of the risk results, shows the total risk results with the given bandwidth estimate, or the difference between the two pathways. The higher this bandwidth, the higher the uncertainty.

Furthermore, a table with detailed scores for every parameter is provided. These scores are scaled from 1 to 10, where 1 indicates a low score and 10 a high score. Some minimum and maximum values are taken, as was explained in the index chapter to prevent extremely skewed data.

F FLOOD DELTA CITY INDEX

The indices for all 38 cities are shown here. The order of the cities in the index is from the highest in ranking now until the lowest in the ranking.

Results Economic Risk

	Now	2030-SSP2/RCP4.5		2030-SSP5/RCP8.5		Uncertainty
City	Risk(€/yr)	Risk (€/yr)	Increase(%)	Risk(€/yr)	Increase(%)	Bandwidth(%)
Ahvaz	5.19E+07	2.05E+08	294.8	2.73E+08	426.6	131.8
Antwerp	5.58E+06	1.23E+07	121.4	1.29E+07	131.6	10.2
Astrakhan	3.59E+07	1.12E+08	211.9	1.74E+08	385.2	173.3
Bangkok	1.66E+08	7.17E+08	332.6	1.11E+09	572.8	240.2
Beijing	1.86E+07	2.13E+08	1040.4	5.50E+08	2847.8	1807.4
Buenos Aires	1.33E+09	4.54E+09	240.8	5.04E+09	278.7	37.9
Cairo	5.28E+07	2.51E+08	374.7	3.70E+08	601.8	227.1
Culiacan	1.55E+07	3.62E+07	133.0	5.13E+07	230.2	97.2
Dhaka	4.84E+06	5.87E+07	1112.8	1.99E+08	4015.7	2902.9
Guangzhou	1.24E+08	1.40E+09	1033.3	3.61E+09	2817.0	1783.6
Hangzhou	1.92E+06	2.19E+07	1040.4	5.65E+07	2838.3	1797.9
Ho Chi Minh City	4.65E+06	3.18E+07	583.3	6.35E+07	1266.3	683.0
Houston	3.85E+07	8.20E+07	112.7	1.00E+08	159.4	46.7
Jinan	7.50E+07	8.61E+08	1048.9	2.19E+09	2821.5	1772.6
Karachi	5.95E+06	3.18E+07	433.3	7.62E+07	1179.2	746.0
Kolkata	2.67E+07	3.22E+08	1107.1	1.10E+09	4014.3	2907.2
Lagos	1.41E+07	5.94E+07	322.0	1.45E+08	931.6	609.6
London	3.27E+07	7.65E+07	133.8	7.36E+07	125.0	-8.9
Los Angeles	1.97E+08	4.34E+08	120.5	4.25E+08	115.9	-4.6
Manchester	4.87E+06	1.13E+07	131.0	1.12E+07	129.5	-1.5
Montreal	9.02E+06	2.00E+07	121.4	7.24E+07	702.6	581.2
Mumbai	7.17E+06	8.68E+07	1110.7	2.98E+08	4050.6	2939.9
New York	1.25E+08	2.70E+08	115.7	2.81E+08	124.3	8.6
Okayama	1.65E+07	3.60E+07	118.3	4.17E+07	152.8	34.4
Osaka	1.99E+08	4.64E+08	132.4	5.15E+08	157.9	25.5
Palembang	1.01E+07	8.94E+07	789.3	2.28E+08	2171.3	1382.0
Philadelphia	1.23E+08	2.89E+08	135.2	2.71E+08	120.5	-14.7
Port Elizabeth	2.70E+05	8.75E+05	223.4	1.23E+06	354.4	131.0
Portland	3.21E+07	7.54E+07	135.0	9.69E+07	202.2	67.2
Pyongyang	7.88E+06	1.97E+07	149.9	2.43E+07	208.0	58.1
Sao Paulo	6.84E+07	2.09E+08	205.3	2.84E+08	315.5	110.2
Seoul	2.49E+07	6.76E+07	171.9	8.83E+07	255.0	83.1
Shanghai	2.07E+08	2.49E+09	1105.2	6.10E+09	2846.9	1741.7
Sydney	1.09E+07	3.94E+07	262.0	2.71E+07	149.4	-112.6
Taipei	2.06E+08	2.43E+09	1081.4	6.08E+09	2852.7	1771.3
Tianjin	2.28E+08	2.64E+09	1058.4	6.71E+09	2840.9	1782.5
Tijuana	1.18E+08	3.31E+08	180.4	3.73E+08	216.2	35.8
Tokyo	3.26E+08	7.69E+08	136.4	8.57E+08	163.2	26.8

figure 26: Detailed results of economic risk

Results Fatility Risk

	Fatality Risk in #people/yr				Fatality Risk in €/yr				
City	Fatality Risk now	Urbanization 2030(%)	Increase (factor)	Fatality Risk 2030	GDP/capita	GDP-correction	Value of Statistical Life	Fatality Risk now	Fatality Risk 2030
Ahvaz	0.33	29.5%	1.295	0.43	$ 17,388	0.35	€ 2,329,992	7.78E+05	1.01E+06
Antwerpen	0.09	7.5%	1.075	0.10	$ 67,811	1.36	€ 9,086,674	8.34E+05	8.96E+05
Astrachan	1.07	3.4%	1.034	1.11	$ 10,574	0.21	€ 1,416,916	1.52E+06	1.57E+06
Bangkok	57.20	24.4%	1.244	71.13	$ 15,192	0.30	€ 2,035,728	1.16E+08	1.45E+08
Beijing	5.23	35.9%	1.359	7.10	$ 24,295	0.49	€ 3,255,530	1.70E+07	2.31E+07
Buenos Aires	98.51	11.7%	1.117	110.03	$ 20,364	0.41	€ 2,728,776	2.69E+08	3.00E+08
Cairo	122.79	30.5%	1.305	160.27	$ 10,913	0.22	€ 1,462,342	1.80E+08	2.34E+08
Culiacan	1.61	27.2%	1.272	2.04	$ 12,917	0.26	€ 1,730,878	2.78E+06	3.54E+06
Dhaka	48.48	55.5%	1.555	75.41	$ 3,340	0.07	€ 447,560	2.17E+07	3.37E+07
Guangzhou	57.64	41.1%	1.411	81.31	$ 14,258	0.29	€ 1,910,572	1.10E+08	1.55E+08
Hangzhou	1.05	38.0%	1.380	1.46	$ 16,601	0.33	€ 2,224,534	2.34E+06	3.24E+06
Ho Chi Minh City	8.61	39.8%	1.398	12.03	$ 6,422	0.13	€ 860,548	7.41E+06	1.04E+07
Houston	0.17	19.3%	1.193	0.20	$ 57,147	1.14	€ 7,657,698	1.31E+06	1.57E+06
Jinan	28.21	34.2%	1.342	37.88	$ 14,235	0.28	€ 1,907,490	5.38E+07	7.22E+07
Karachi	32.34	49.5%	1.495	48.34	$ 5,011	0.10	€ 671,474	2.17E+07	3.25E+07
Kolkata	113.36	28.4%	1.284	145.59	$ 4,653	0.09	€ 623,502	7.07E+07	9.08E+07
Lagos	20.74	84.7%	1.847	38.32	$ 6,004	0.12	€ 804,536	1.67E+07	3.08E+07
London	2.33	11.2%	1.112	2.59	$ 61,823	1.24	€ 8,284,282	1.93E+07	2.14E+07
Los Angeles	2.72	7.7%	1.077	2.93	$ 55,687	1.11	€ 7,462,058	2.03E+07	2.18E+07
Manchester	0.11	12.2%	1.122	0.13	$ 39,825	0.80	€ 5,336,550	6.11E+05	6.86E+05
Montreal	0.00	13.5%	1.135	0.00	$ 34,260	0.69	€ 4,590,840	0.00E+00	0.00E+00
Mumbai	30.77	32.1%	1.321	40.65	$ 7,813	0.16	€ 1,046,942	3.22E+07	4.26E+07
New York	1.36	6.9%	1.069	1.46	$ 66,488	1.33	€ 8,909,392	1.21E+07	1.30E+07
Okayama	0.13	7.2%	1.072	0.14	$ 33,618	0.67	€ 4,504,812	5.92E+05	6.34E+05
Osaka	19.14	-1.3%	0.987	18.89	$ 38,327	0.77	€ 5,135,818	9.83E+07	9.70E+07
Palembang	3.86	29.7%	1.297	5.00	$ 6,971	0.14	€ 934,114	3.60E+06	4.67E+06
Philadelphia	0.88	10.2%	1.102	0.97	$ 48,458	0.97	€ 6,493,372	5.69E+06	6.27E+06
Port Elizabeth	0.01	17.9%	1.179	0.01	$ 12,354	0.25	€ 1,655,436	1.87E+04	2.20E+04
Portland	0.13	16.7%	1.167	0.16	$ 50,779	1.02	€ 6,804,386	9.13E+05	1.07E+06
Pyongyang	10.15	14.5%	1.145	11.62	$ 1,800	0.04	€ 241,200	2.45E+06	2.80E+06
Seoul	235.31	11.3%	1.113	261.87	$ 20,717	0.41	€ 2,776,078	6.53E+08	7.27E+08
Shanghai	14.86	1.9%	1.019	15.14	$ 36,886	0.74	€ 4,942,724	7.34E+07	7.48E+07
Soa Paulo	2.60	29.5%	1.295	3.37	$ 23,582	0.47	€ 3,159,988	8.22E+06	1.06E+07
Sydney	0.02	17.7%	1.177	0.03	$ 42,824	0.86	€ 5,738,416	1.35E+05	1.59E+05
Taipei	28.94	16.9%	1.169	33.83	$ 47,500	0.95	€ 6,365,000	1.84E+08	2.15E+08
Tianjin	219.15	30.7%	1.307	286.50	$ 22,653	0.45	€ 3,035,502	6.65E+08	8.70E+08
Tijuana	9.23	25.9%	1.259	11.63	$ 19,256	0.39	€ 2,580,304	2.38E+07	3.00E+07
Tokyo	20.53	-2.1%	0.979	20.09	$ 64,000	1.28	€ 8,576,000	1.76E+08	1.72E+08

figure 27: Detailed results of fatality risk

Results Total Risk

	Now	2030-low		2030-high		Uncertainty
City	Risk(€/yr)	Risk (€/yr)	Increase(%)	Risk(€/yr)	Increase(%)	Bandwidth(%)
Ahvaz	5.27E+07	2.09E+08	297.2	2.74E+08	420.8	123.6
Antwerp	6.41E+06	1.35E+07	110.9	1.38E+07	115.4	4.5
Astrakhan	3.74E+07	1.15E+08	206.9	1.76E+08	369.7	162.9
Bangkok	2.82E+08	8.69E+08	208.1	1.26E+09	346.4	138.3
Beijing	3.57E+07	2.36E+08	561.9	5.73E+08	1506.3	944.5
Buenos Aires	1.60E+09	4.91E+09	206.6	5.34E+09	233.8	27.2
Cairo	2.32E+08	4.88E+08	110.1	6.05E+08	160.3	50.2
Culiacan	1.83E+07	4.11E+07	124.7	5.48E+07	199.4	74.7
Dhaka	2.65E+07	9.30E+07	250.4	2.33E+08	778.2	527.8
Guangzhou	2.34E+08	1.56E+09	569.4	3.76E+09	1509.2	939.8
Hangzhou	4.27E+06	2.53E+07	493.5	5.97E+07	1299.4	805.9
Ho Chi Minh City	1.21E+07	4.24E+07	251.8	7.39E+07	512.7	260.9
Houston	3.99E+07	8.67E+07	117.5	1.02E+08	154.8	37.3
Jinan	1.29E+08	9.36E+08	626.8	2.26E+09	1656.6	1029.8
Karachi	2.77E+07	6.45E+07	133.0	1.09E+08	292.6	159.5
Kolkata	9.73E+07	4.14E+08	325.7	1.19E+09	1120.0	794.3
Lagos	3.08E+07	9.08E+07	195.3	1.76E+08	472.1	276.8
London	5.20E+07	9.85E+07	89.6	9.50E+07	82.7	-6.8
Los Angeles	2.17E+08	4.58E+08	111.2	4.46E+08	105.8	-5.4
Manchester	5.48E+06	1.22E+07	121.7	1.19E+07	116.4	-5.3
Montreal	9.02E+06	2.00E+07	121.4	7.24E+07	702.6	581.2
Mumbai	3.94E+07	1.29E+08	228.7	3.40E+08	763.8	535.1
New York	1.37E+08	2.88E+08	109.5	2.94E+08	113.9	4.3
Okayama	1.71E+07	3.77E+07	120.4	4.24E+07	147.7	27.3
Osaka	2.98E+08	5.62E+08	88.6	6.12E+08	105.4	16.8
Palembang	1.37E+07	9.43E+07	590.5	2.33E+08	1606.2	1015.7
Philadelphia	1.28E+08	2.97E+08	131.6	2.77E+08	115.7	-16.0
Port Elizabeth	2.89E+05	1.01E+06	250.6	1.25E+06	332.7	82.1
Portland	3.30E+07	8.00E+07	142.6	9.80E+07	197.0	54.4
Pyongyang	1.03E+07	2.26E+07	118.5	2.71E+07	162.1	43.6
Sao Paulo	7.22E+08	9.38E+08	30.0	1.01E+09	40.1	10.1
Seoul	9.83E+07	1.43E+08	45.4	1.63E+08	65.9	20.6
Shanghai	2.15E+08	2.50E+09	1064.6	6.11E+09	2739.3	1674.7
Sydney	1.10E+07	4.00E+07	263.6	2.73E+07	147.8	-115.8
Taipei	3.90E+08	2.65E+09	580.6	6.30E+09	1513.7	933.2
Tianjin	8.93E+08	3.52E+09	293.8	7.58E+09	748.4	454.6
Tijuana	1.42E+08	3.62E+08	155.2	4.03E+08	184.2	29.0
Tokyo	5.02E+08	9.53E+08	89.9	1.03E+09	105.2	15.2

figure 28: Detailed result of total risk including uncertainty bandwidth

Absolute Total Risk Increase per Risk Driver

City	2030-low				2030-high			
	Climate Change	Economic Growth	Population Increase	Land Cover Change	Climate Change	Economic Growth	Population Increase	Land Cover Change
Ahvaz	113.0%	78.9%	0.4%	6.3%	174.0%	147.8%	0.4%	6.3%
Antwerpen	3.2%	21.8%	1.0%	4.4%	565.4%	30.1%	1.0%	4.4%
Astrachan	547.9%	127.6%	0.1%	3.4%	29.6%	244.0%	0.1%	3.4%
Bangkok	16.7%	119.9%	10.1%	2.7%	27.6%	250.0%	10.1%	2.7%
Beijing	0.0%	491.8%	17.1%	0.6%	20.7%	1416.2%	17.1%	0.6%
Buenos Aires	37.0%	80.1%	2.0%	4.3%	567.1%	149.6%	2.0%	4.3%
Cairo	11.0%	51.4%	23.6%	1.4%	3.8%	110.2%	23.6%	1.4%
Culiacan	528.1%	67.9%	4.1%	7.7%	545.2%	133.3%	4.1%	7.7%
Dhaka	18.0%	166.8%	45.4%	1.9%	9.7%	704.8%	45.4%	1.9%
Guangzhou	564.3%	497.4%	19.3%	3.6%	4.6%	1432.3%	19.3%	3.6%
Hangzhou	0.0%	423.6%	20.9%	3.9%	13.6%	1219.9%	20.9%	3.9%
Ho Chi Minh City	32.8%	153.5%	24.4%	2.4%	26.6%	423.1%	24.4%	2.4%
Houston	556.1%	24.2%	0.6%	7.8%	25.9%	31.5%	0.6%	7.8%
Jinan	4.9%	547.4%	14.3%	1.9%	7.7%	1576.4%	14.3%	1.9%
Karachi	566.4%	73.4%	38.8%	1.0%	564.2%	236.1%	38.8%	1.0%
Kolkata	7.1%	268.7%	20.7%	1.9%	1.4%	1070.5%	20.7%	1.9%
Lagos	526.9%	142.7%	46.0%	2.1%	530.3%	418.1%	46.0%	2.1%
London	5.5%	15.7%	4.2%	1.2%	560.7%	23.0%	4.2%	1.2%
Los Angeles	563.9%	22.7%	0.7%	1.3%	552.9%	29.6%	0.7%	1.3%
Manchester	5.3%	22.2%	1.4%	4.0%	561.7%	32.5%	1.4%	4.0%
Montreal	566.3%	23.2%	0.0%	0.0%	568.1%	34.6%	0.0%	0.0%
Mumbai	5.4%	178.7%	26.3%	0.2%	7.5%	711.8%	26.3%	0.2%
New York	559.6%	22.8%	0.6%	3.5%	560.4%	29.7%	0.6%	3.5%
Okayama	550.5%	35.3%	0.2%	5.9%	567.3%	51.7%	0.2%	5.9%
Osaka	565.3%	24.5%	45.5%	0.3%	2.9%	35.9%	45.5%	0.3%
Palembang	27.2%	480.2%	7.8%	1.6%	5.0%	1529.4%	7.8%	1.6%
Philadelphia	9.8%	23.9%	0.5%	1.9%	556.5%	31.2%	0.5%	1.9%
Port Elizabeth	552.8%	130.6%	1.2%	40.5%	534.6%	271.4%	1.2%	40.5%
Portland	9.7%	24.3%	0.5%	10.9%	67.6%	31.7%	0.5%	10.9%
Pyongyang	550.8%	55.3%	3.4%	0.7%	4.6%	77.8%	3.4%	0.7%
Seoul	0.6%	9.4%	10.2%	0.3%	1.5%	19.0%	10.2%	0.3%
Shanghai	567.9%	18.3%	1.4%	0.5%	13.4%	25.8%	1.4%	0.5%
Soa Paulo	62.3%	904.5%	1.1%	0.4%	37.2%	2604.8%	1.1%	0.4%
Sydney	131.6%	28.4%	0.2%	4.6%	8.7%	40.1%	0.2%	4.6%
Taipei	21.6%	496.4%	8.0%	1.8%	23.4%	1429.5%	8.0%	1.8%
Tianjin	4.6%	240.2%	22.9%	0.6%	8.3%	691.7%	22.9%	0.6%
Tijuana	0.2%	66.7%	4.4%	0.8%	533.9%	130.8%	4.4%	0.8%
Tokyo	567.9%	23.7%	45.2%	2.2%	6.3%	34.8%	45.2%	2.2%

figure 29: Result of the risk increase per main driver expressed in percentage

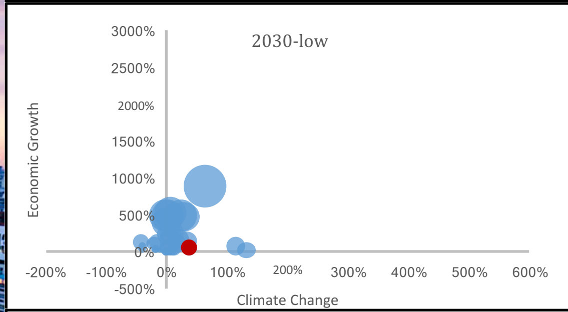
Overview of scores index normalized in range 1 to 10

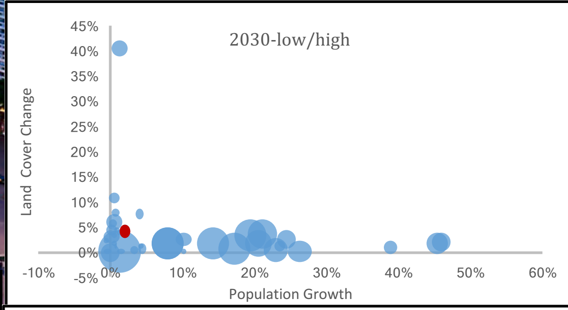
City	Probability	Flood Cover	Properties at Risk	Loss of Life Potential	Population density	GDP-capita	Economic Impact	Flood History (Awareness)	Vulnerable People	Evacuation Road Capacity	ICT-infrastructure	Shelter capacity	Vulnerable Urbanization
Ahvaz	7.3	3.7	3.9	5.1	2.9	7.9	2.3	8.4	2.0	9.7	6.6	0.0	6.0
Antwerp	3.4	1.9	1.8	4.5	3.3	1.0	3.2	10.0	4.3	9.5	3.7	5.4	4.0
Astrakhan	6.1	3.1	3.2	7.0	3.4	8.8	1.1	7.8	2.5	9.1	2.8	0.0	4.0
Bangkok	6.1	8.7	8.3	8.7	4.4	8.2	7.4	8.5	1.9	8.5	6.7	3.2	8.0
Beijing	7.3	1.6	1.5	5.1	1.7	6.9	2.0	2.6	1.4	9.8	7.3	4.0	2.0
Buenos Aires	7.3	2.1	2.3	10.0	7.9	7.5	3.9	9.4	4.8	7.4	3.8	3.6	8.0
Cairo	4.9	4.1	4.3	9.3	8.5	8.8	7.5	9.9	5.7	4.2	7.6	4.8	6.0
Culiacan	7.3	2.4	2.6	7.1	5.5	8.5	1.2	8.3	3.3	8.9	7.4	10.0	2.0
Dhaka	6.1	4.9	1.2	8.1	9.7	9.8	5.2	8.1	4.1	3.8	10.0	5.3	10.0
Guangzhou	6.1	4.1	4.9	8.1	2.4	8.3	1.3	2.6	1.4	9.8	7.3	3.9	4.0
Hangzhou	7.3	1.8	3.5	4.7	1.9	8.0	1.2	2.6	1.4	10.0	7.3	5.3	6.0
Ho Chi Minh City	8.8	3.6	1.7	6.4	4.5	9.4	8.9	7.7	2.4	9.5	6.0	4.8	4.0
Houston	2.2	1.4	3.6	2.8	1.4	2.5	1.4	1.0	2.1	9.9	4.2	3.6	2.0
Jinan	7.3	3.7	1.5	8.5	1.9	8.3	1.1	2.6	1.4	9.7	7.3	5.4	4.0
Karachi	8.8	1.8	4.4	7.0	9.3	9.6	10.0	8.6	6.2	6.3	10.0	6.3	2.0
Kolkata	4.9	6.7	1.7	9.7	9.3	9.6	1.2	5.0	4.1	2.6	9.7	5.5	8.0
Lagos	8.8	2.8	6.9	6.8	8.6	9.4	5.9	8.8	10.0	2.8	8.7	5.9	4.0
London	1.0	2.4	3.0	4.9	6.0	1.8	6.5	9.9	4.5	8.7	2.3	3.4	2.0
Los Angeles	2.2	1.4	2.7	5.9	4.1	2.7	1.3	1.0	5.8	9.4	4.2	3.5	2.0
Manchester	4.9	1.2	1.2	4.7	5.4	4.8	1.2	9.9	5.8	8.7	2.3	5.0	2.0
Montreal	6.1	1.3	1.2	20.7	5.1	5.6	2.1	8.9	1.0	9.2	4.8	3.3	4.0
Mumbai	4.9	2.0	1.3	7.3	9.7	9.2	2.3	5.0	4.1	1.0	9.7	3.9	6.0
New York	2.2	2.6	2.2	4.4	7.2	1.2	1.9	1.0	3.2	7.0	4.2	1.0	2.0
Okayama	3.4	3.8	2.6	4.5	0.8	5.7	1.1	8.7	3.5	10.0	2.4	6.7	2.0
Osaka	3.4	2.8	4.9	8.4	7.5	5.0	1.6	8.7	2.9	6.8	2.4	4.7	2.0
Palembang	4.9	5.2	2.9	7.3	5.0	9.3	1.3	5.8	3.5	7.6	7.2	8.6	4.0
Philadelphia	2.2	5.9	5.2	5.7	4.9	3.6	1.1	1.0	3.3	8.9	4.2	3.9	4.0
Port Elizabeth	4.9	1.2	5.1	1.8	3.5	8.6	2.0	8.9	5.7	9.0	4.6	7.1	6.0
Portland	2.2	2.1	1.2	4.7	2.6	3.3	1.0	1.0	3.8	9.8	4.2	4.8	4.0
Pyongyang	10.0	2.8	2.2	7.7	2.1	10.0	9.4	9.2	2.7	9.9	10.0	6.4	2.0
Sao Paulo	7.3	1.5	3.4	9.4	6.4	7.4	5.1	7.9	2.8	8.5	5.2	3.4	2.0
Seoul	2.2	3.3	1.5	6.7	8.4	5.2	9.1	9.4	2.8	6.8	2.5	3.7	2.0
Shanghai	3.4	5.4	3.5	4.0	4.5	7.0	2.5	2.6	1.4	9.1	7.3	2.6	8.0
Sydney	4.9	1.0	5.8	1.0	2.7	4.4	4.6	7.3	2.8	9.8	3.0	3.6	4.0
Taipei	3.4	4.2	1.0	8.8	7.0	3.8	8.2	9.4	1.4	9.1	7.3	3.7	6.0
Tianjin	7.3	8.0	4.4	9.6	1.7	7.2	1.5	2.6	1.4	10.0	7.3	5.2	10.0
Tijuana	7.3	2.5	10.0	8.3	5.6	7.6	1.6	8.3	3.2	8.7	7.4	5.9	4.0
Tokyo	3.4	2.2	2.6	7.1	8.0	1.5	4.9	8.7	2.8	7.5	2.4	2.6	8.0

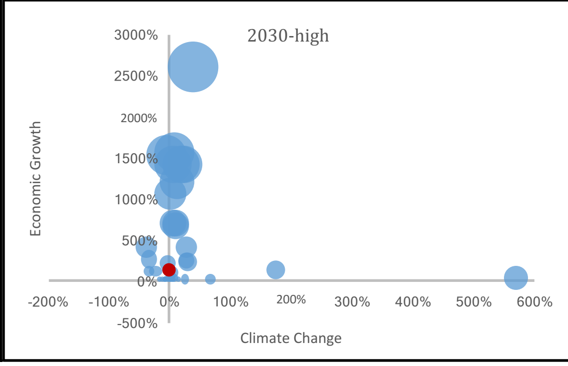
figure 30: Scores per parameters normalized on scale from 1 to 10

Buenos Aires

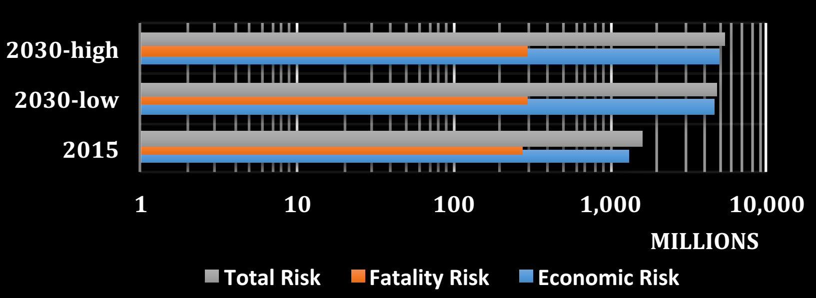
Risk Increase Contribution







RISK



Now

Rank	*City*	*Risk(Million€/yr)*
1	**Buenos Aires**	**1600.2**
2	Tianjin	893.4
3	Sao Paulo	721.6
4	Tokyo	501.6
5	Taipei	390.1

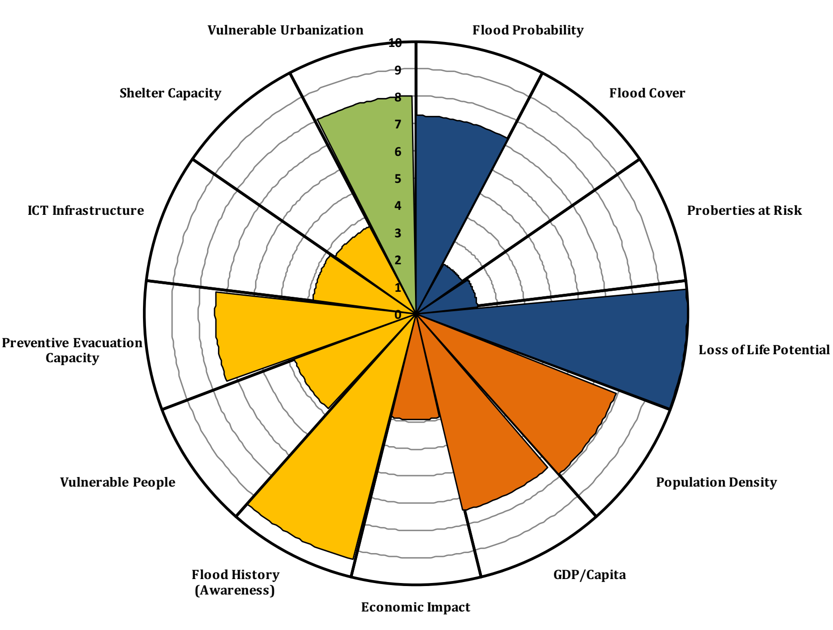
2030-low

Rank	*City*	*Risk(Million€/yr)*
1	**Buenos Aires**	**4837.1**
2	Tianjin	3512.7
3	Taipei	2648.1
4	Shanghai	2503.9
5	Guangzhou	1556.4

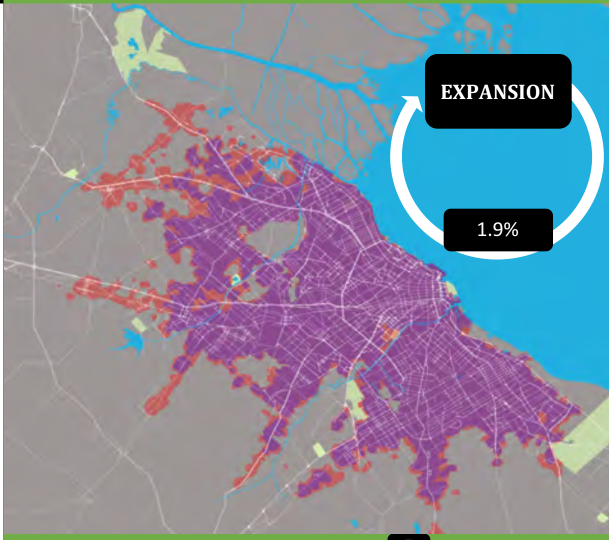
2030-high

Rank	*City*	*Risk(Million€/yr)*
2	Taipei	6295.5
3	Shanghai	6107.0
4	**Buenos Aires**	**5341.8**
5	Guangzhou	3761.3
6	Jinan	2261.9

FLOOD INDEX



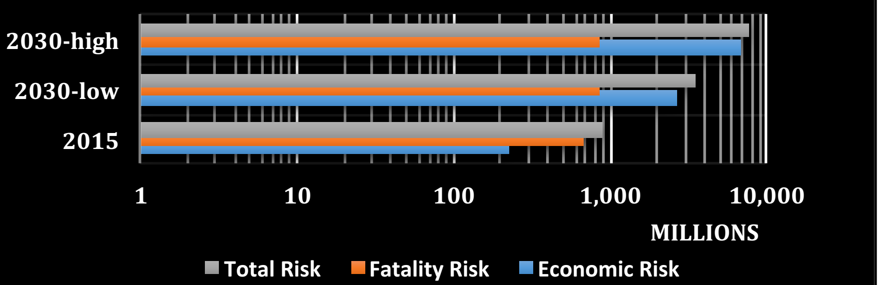
ADAPTIVE CAPACITY OF CITIES



ALARM:

Tianjin

RISK



Risk Increase Contribution

Now

Rank	City	Risk(Million€/yr)
1	Buenos Aires	1600.2
2	**Tianjin**	**893.4**
3	Sao Paulo	721.6
4	Tokyo	501.6
5	Taipei	390.1

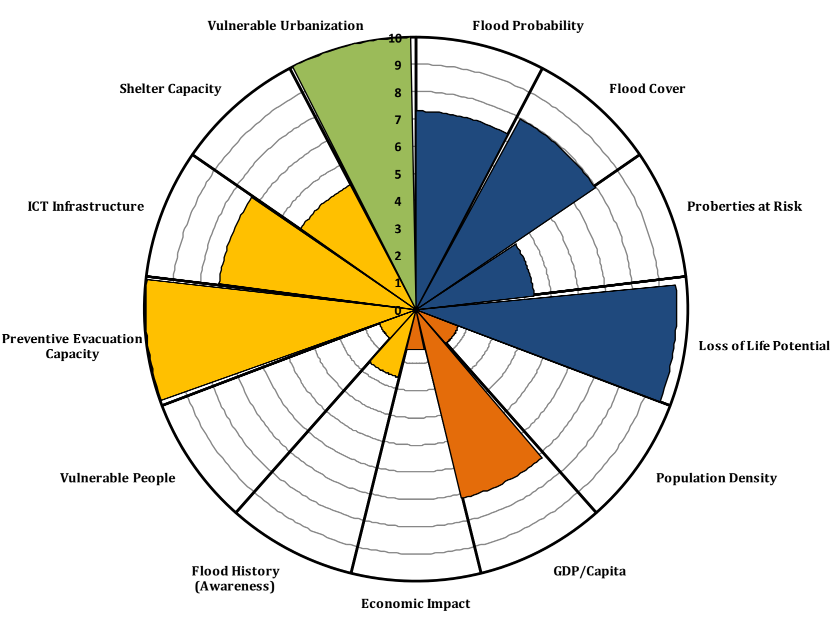
2030-low

Rank	City	Risk(Million€/yr)
1	Buenos Aires	4837.1
2	**Tianjin**	**3512.7**
3	Taipei	2648.1
4	Shanghai	2503.9
5	Guangzhou	1556.4

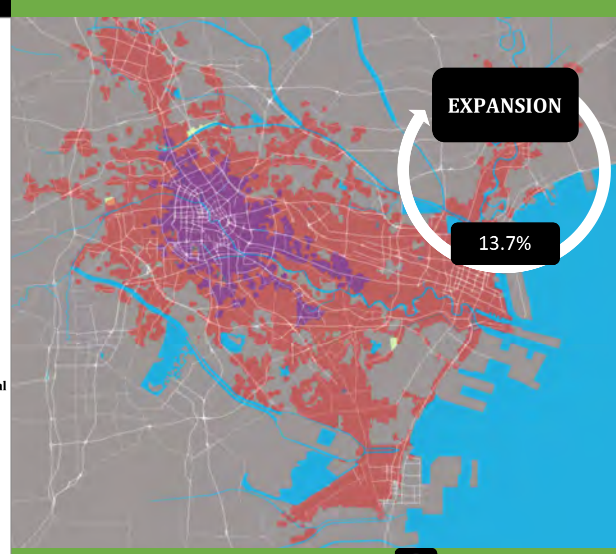
2030-high

Rank	City	Risk(Million€/yr)
1	**Tianjin**	**7579.7**
2	Taipei	6295.5
3	Shanghai	6107.0
4	Buenos Aires	5341.8
5	Guangzhou	3761.3

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

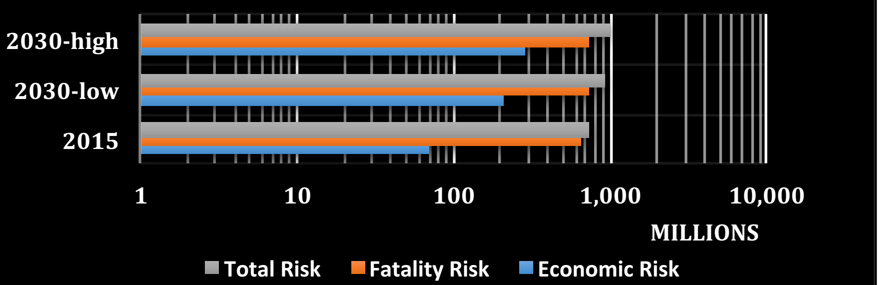


ALARM:

Sao Paulo

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
1	Buenos Aires	1600.2
2	Tianjin	893.4
3	**Sao Paulo**	**721.6**
4	Tokyo	501.6
5	Taipei	390.1

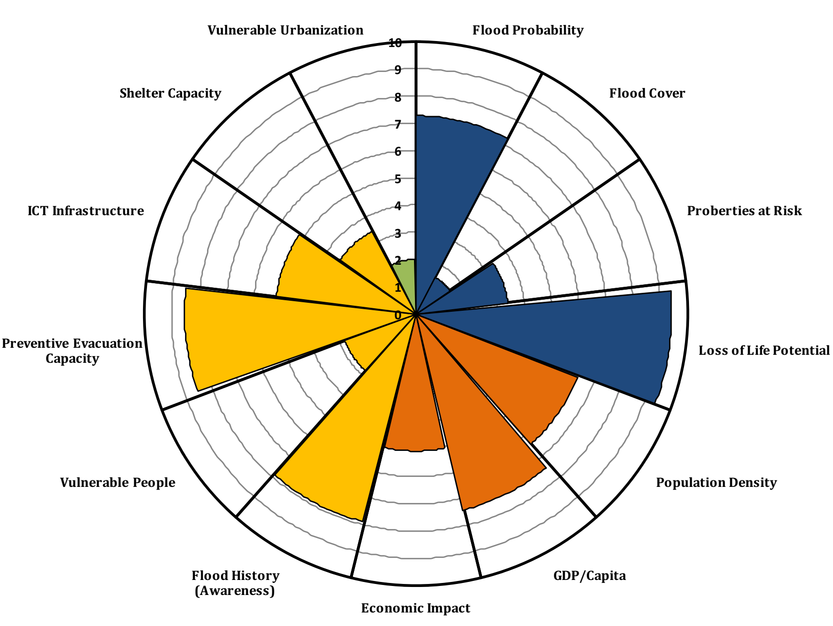
2030-low

Rank	*City*	*Risk(Million€/yr)*
5	Guangzhou	1556.4
6	Tokyo	941.7
7	**Sao Paulo**	**935.8**
8	Jinan	933.4
9	Bangkok	861.5

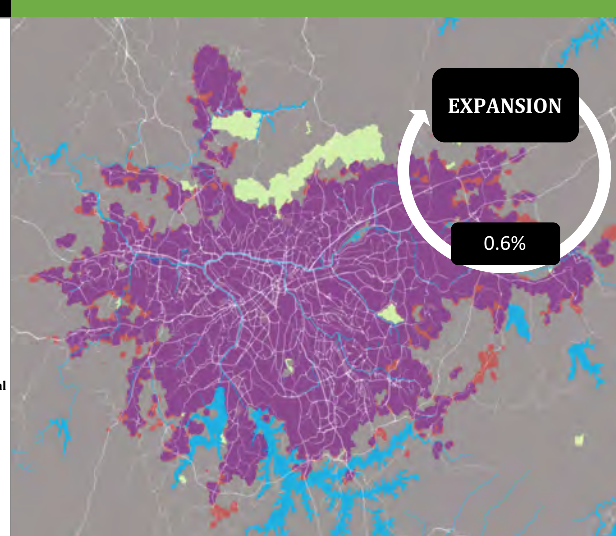
2030-high

Rank	*City*	*Risk(Million€/yr)*
8	Kolkata	1187.4
9	Tokyo	1029.0
10	**Sao Paulo**	**1011.2**
11	Osaka	611.6
12	Cairo	604.9

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

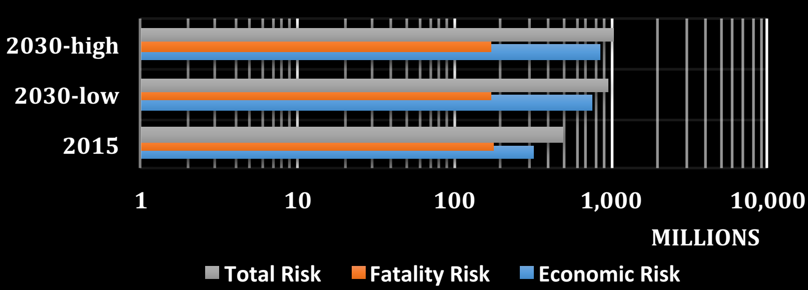


ALARM:

Tokyo

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
2	Tianjin	893.4
3	Sao Paulo	721.6
4	**Tokyo**	**501.6**
5	Taipei	390.1
6	Osaka	297.8

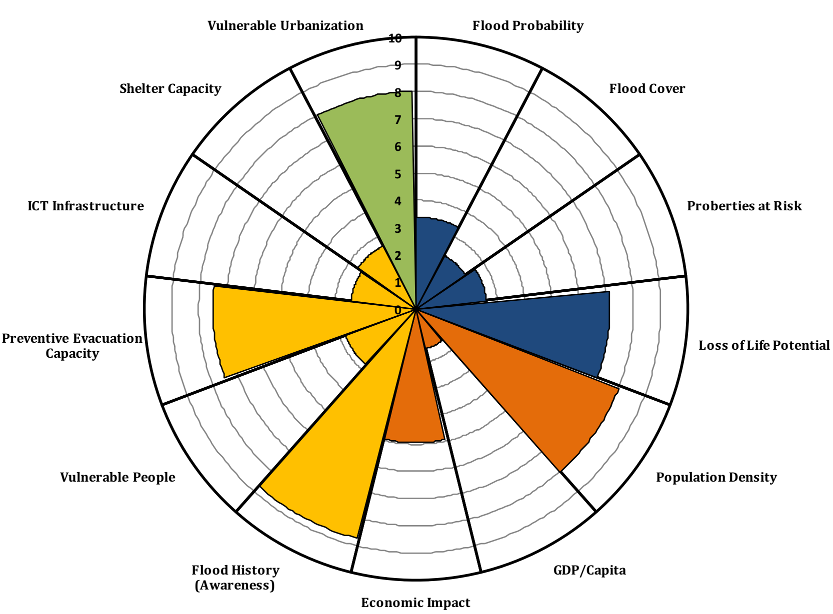
2030-low

Rank	City	Risk(Million€/yr)
4	Shanghai	2503.9
5	Guangzhou	1556.4
6	**Tokyo**	**941.7**
7	Sao Paulo	935.8
8	Jinan	933.4

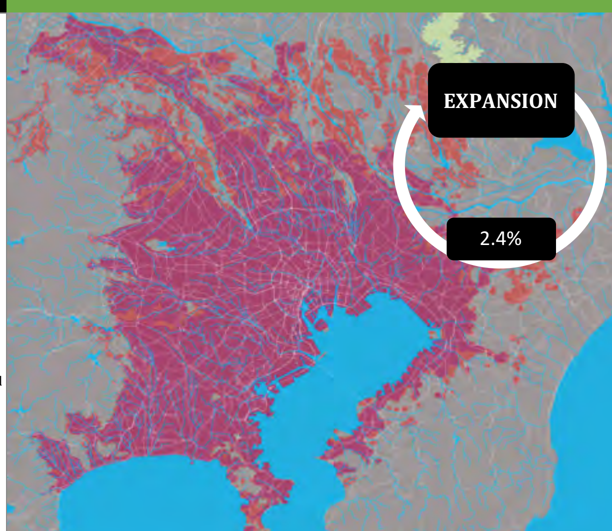
2030-high

Rank	City	Risk(Million€/yr)
7	Bangkok	1259.3
8	Kolkata	1187.4
9	**Tokyo**	**1029.0**
10	Sao Paulo	1011.2
11	Osaka	611.6

FLOOD INDEX



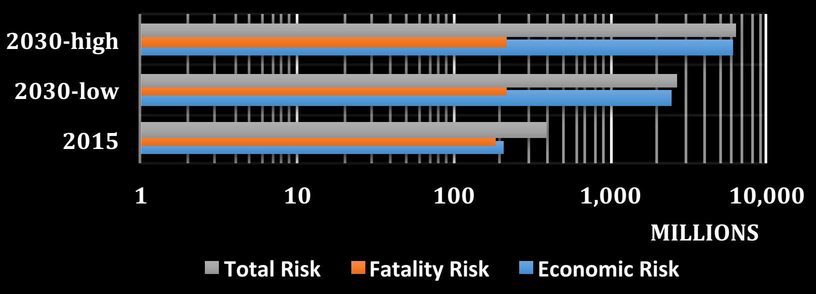
ADAPTIVE CAPACITY OF CITIES



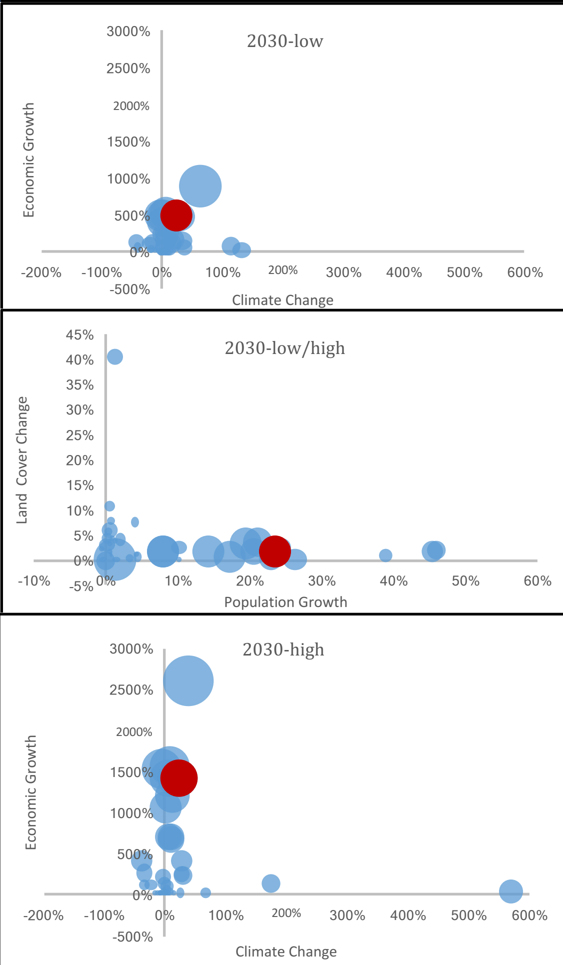
ALARM:

Taipei

RISK



Risk Increase Contribution



Now

Rank	*City*	*Risk(Million€/yr)*
3	Sao Paulo	721.6
4	Tokyo	501.6
5	**Taipei**	**390.1**
6	Osaka	297.8
7	Bangkok	282.1

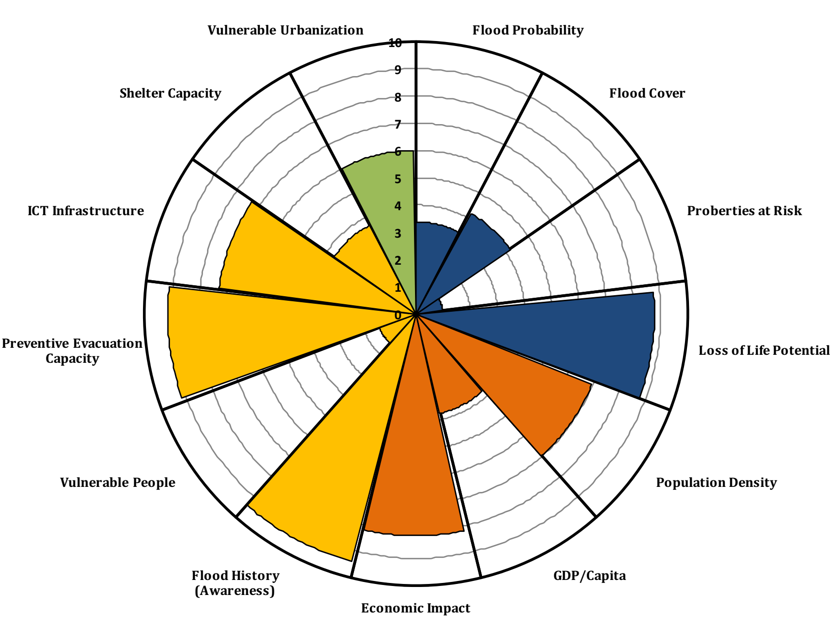
2030-low

Rank	*City*	*Risk(Million€/yr)*
1	Buenos Aires	4837.1
2	Tianjin	3512.7
3	**Taipei**	**2648.1**
4	Shanghai	2503.9
5	Guangzhou	1556.4

2030-high

Rank	*City*	*Risk(Million€/yr)*
1	Tianjin	7579.7
2	**Taipei**	**6295.5**
3	Shanghai	6107.0
4	Buenos Aires	5341.8
5	Guangzhou	3761.3

FLOOD INDEX



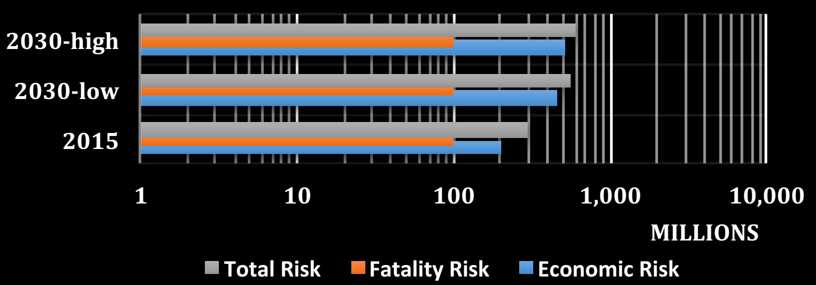
ADAPTIVE CAPACITY OF CITIES

ALARM:

Osaka

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
4	Tokyo	501.6
5	Taipei	390.1
6	**Osaka**	**297.8**
7	Bangkok	282.1
8	Guangzhou	233.7

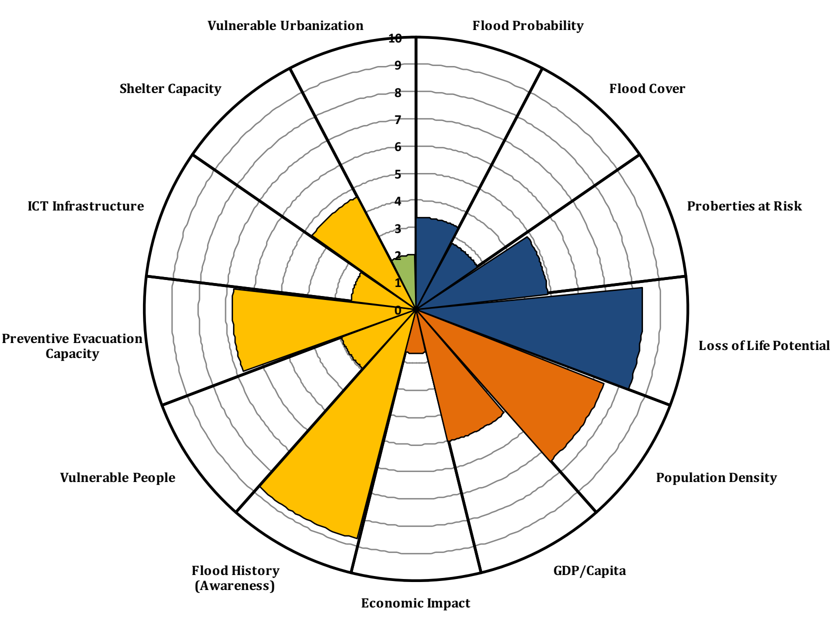
2030-low

Rank	*City*	*Risk(Million€/yr)*
8	Jinan	933.4
9	Bangkok	861.5
10	**Osaka**	**560.7**
11	Cairo	485.0
12	Los Angeles	455.4

2030-high

Rank	*City*	*Risk(Million€/yr)*
9	Tokyo	1029.0
10	Sao Paulo	1011.2
11	Osaka	611.6
12	Cairo	604.9
13	Beijing	572.9

FLOOD INDEX

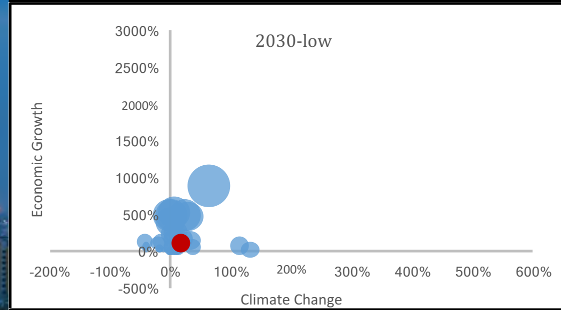


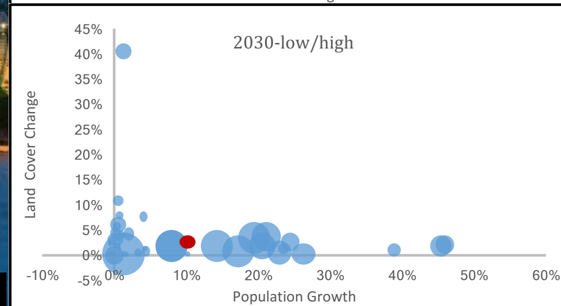
ADAPTIVE CAPACITY OF CITIES

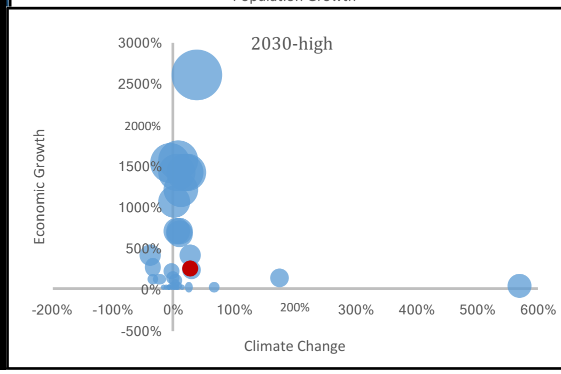
ALARM:

Bangkok

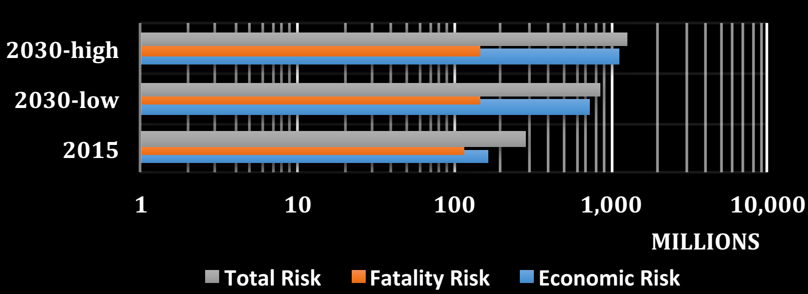
Risk Increase Contribution







RISK



Now

Rank	*City*	*Risk(Million€/yr)*
5	Taipei	390.1
6	Osaka	297.8
7	**Bangkok**	**282.1**
8	Guangzhou	233.7
9	Cairo	232.4

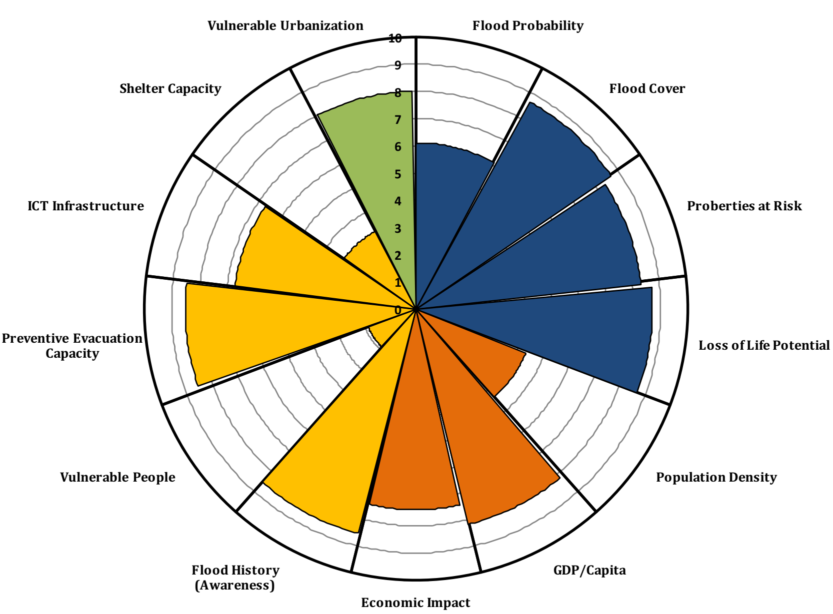
2030-low

Rank	*City*	*Risk(Million€/yr)*
7	Sao Paulo	935.8
8	Jinan	933.4
9	**Bangkok**	**861.5**
10	Osaka	560.7
11	Cairo	485.0

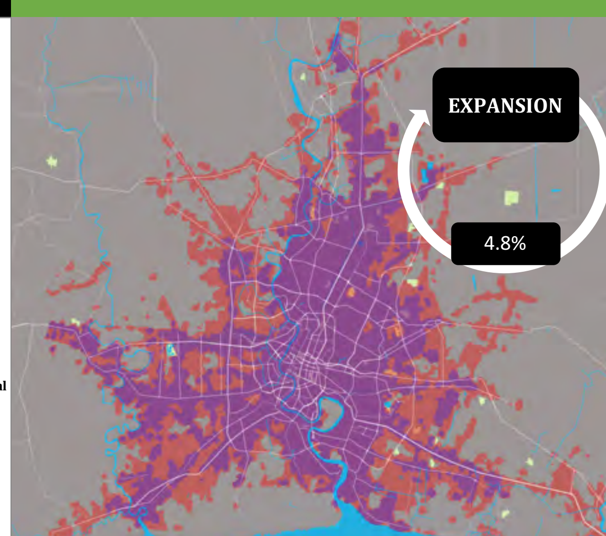
2030-high

Rank	*City*	*Risk(Million€/yr)*
5	Guangzhou	3761.3
6	Jinan	2261.9
7	**Bangkok**	**1259.3**
8	Kolkata	1187.4
9	Tokyo	1029.0

FLOOD INDEX

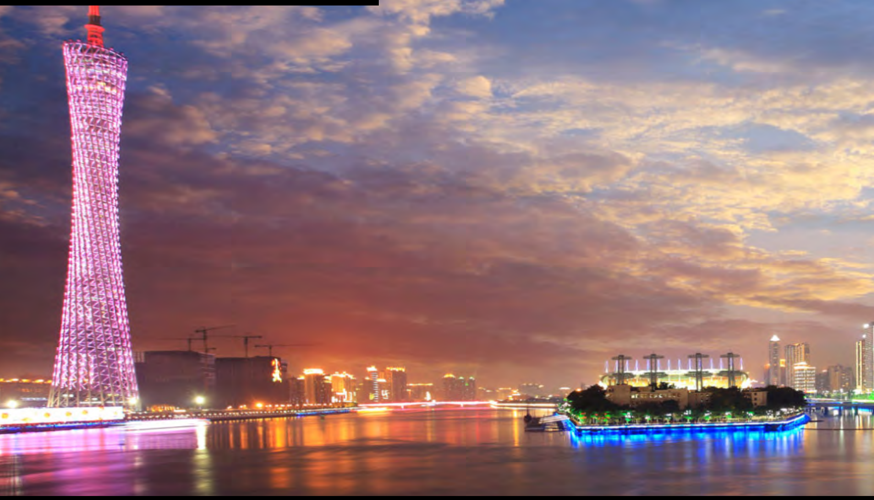


ADAPTIVE CAPACITY OF CITIES

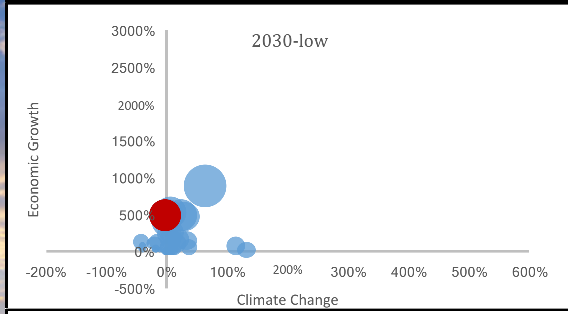


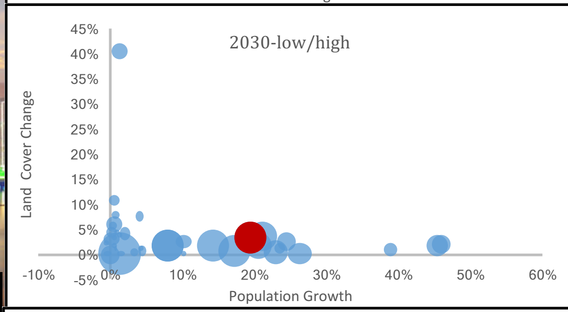
ALARM:

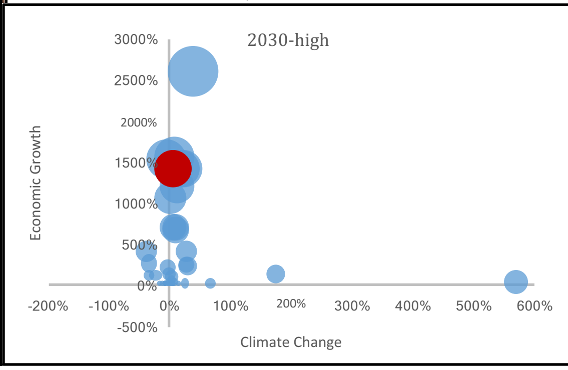
Guangzhou



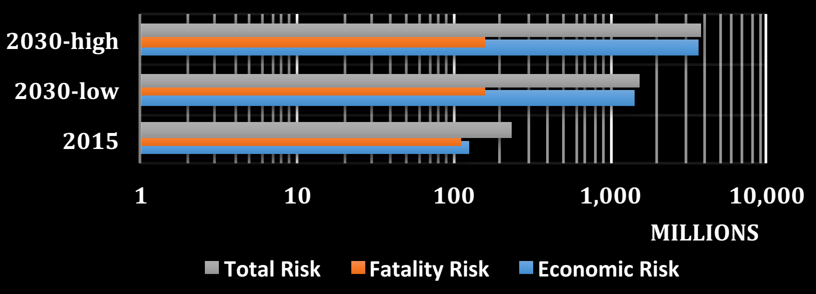
Risk Increase Contribution







RISK



Now

Rank	*City*	*Risk(Million€/yr)*
6	Osaka	297.8
7	Bangkok	282.1
8	**Guangzhou**	**233.7**
9	Cairo	232.4
10	Los Angeles	216.9

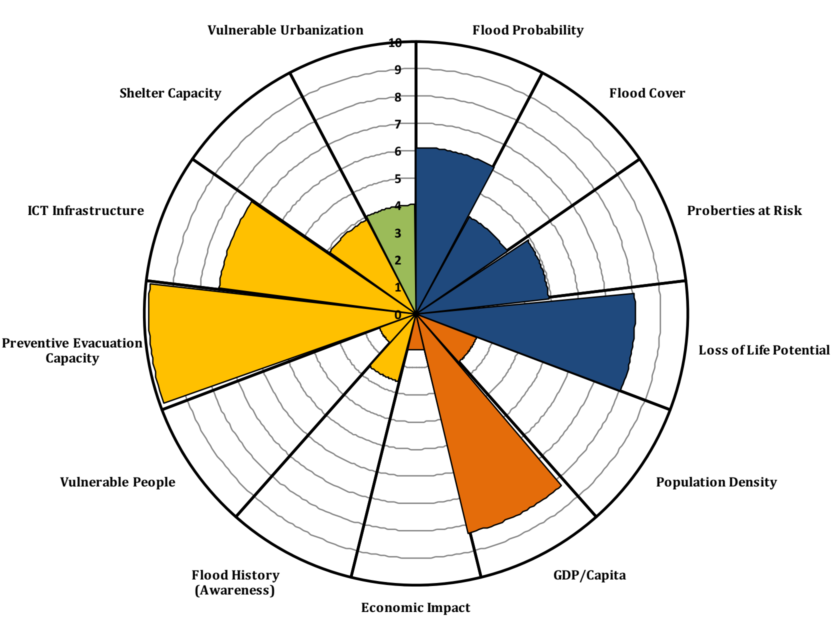
2030-low

Rank	*City*	*Risk(Million€/yr)*
3	Taipei	2648.1
4	Shanghai	2503.9
5	**Guangzhou**	**1556.4**
6	Tokyo	941.7
7	Sao Paulo	935.8

2030-high

Rank	*City*	*Risk(Million€/yr)*
3	Shanghai	6107.0
4	Buenos Aires	5341.8
5	**Guangzhou**	**3761.3**
6	Jinan	2261.9
7	Bangkok	1259.3

FLOOD INDEX

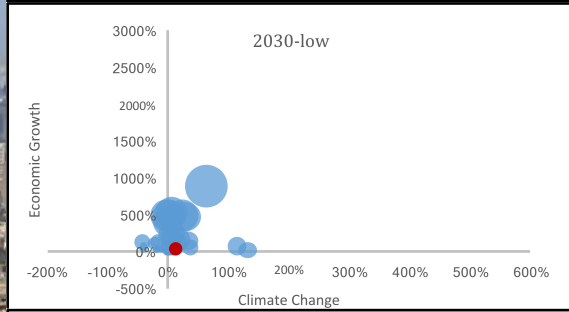


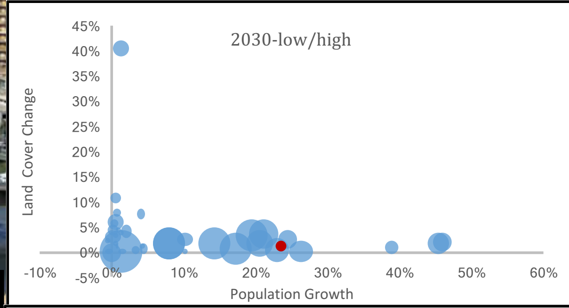
ADAPTIVE CAPACITY OF CITIES

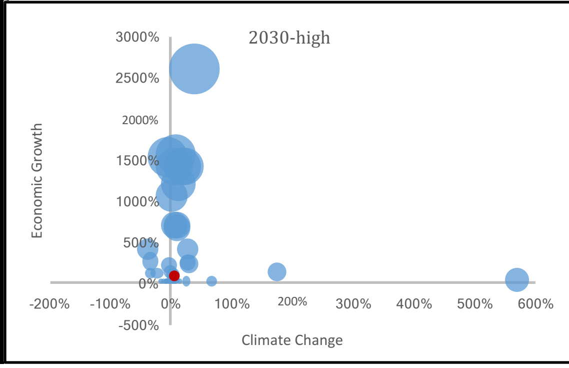
ALARM:

Cairo

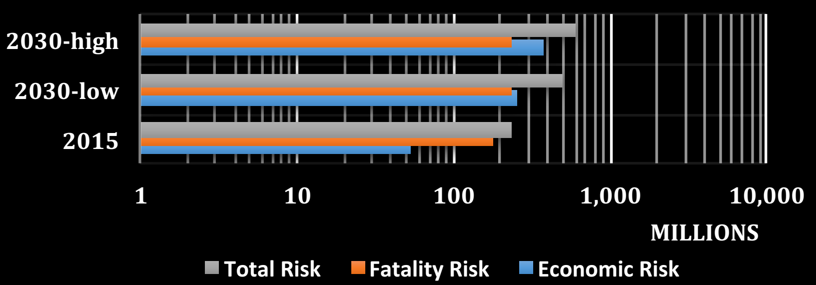
Risk Increase Contribution







RISK



Now

Rank	City	Risk(Million€/yr)
7	Bangkok	282.1
8	Guangzhou	233.7
9	**Cairo**	**232.4**
10	Los Angeles	216.9
11	Shanghai	215.1

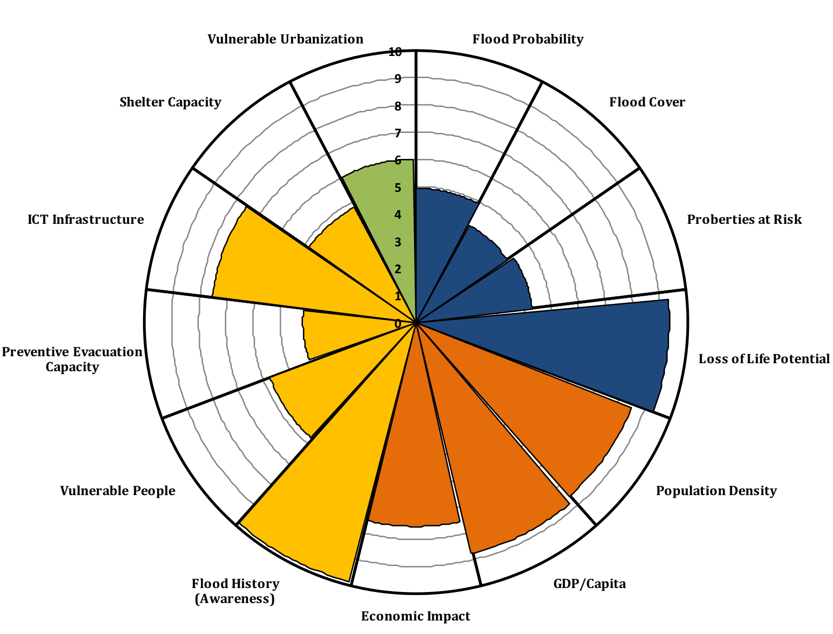
2030-low

Rank	City	Risk(Million€/yr)
9	Bangkok	861.5
10	Osaka	560.7
11	**Cairo**	**485.0**
12	Los Angeles	455.4
13	Kolkata	412.5

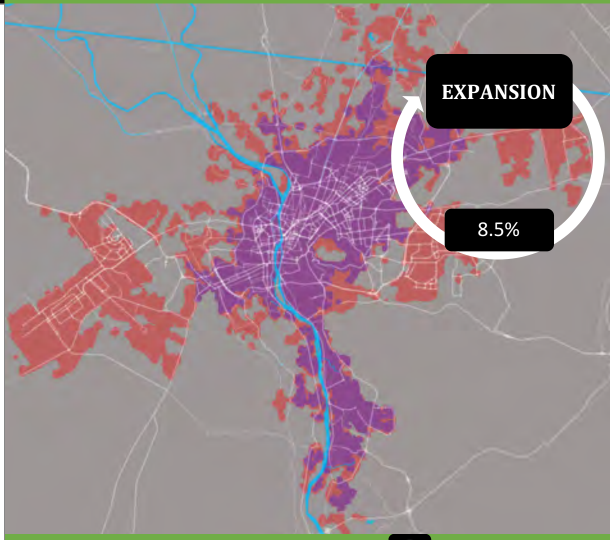
2030-high

Rank	City	Risk(Million€/yr)
10	Sao Paulo	1011.2
11	Osaka	611.6
12	**Cairo**	**604.9**
13	Beijing	572.9
14	Los Angeles	446.4

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

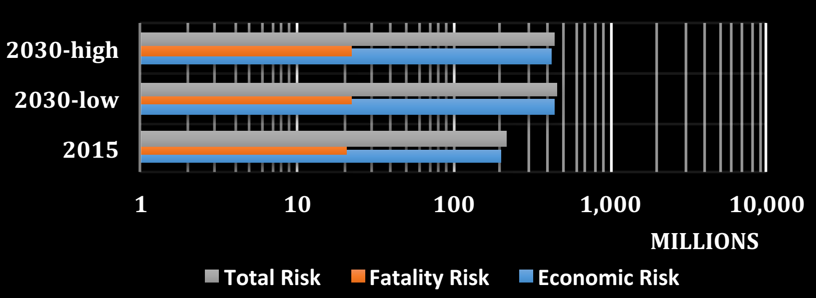


ALARM:

Los Angeles

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
8	Guangzhou	233.7
9	Cairo	232.4
10	**Los Angeles**	**216.9**
11	Shanghai	215.1
12	Tijuana	141.9

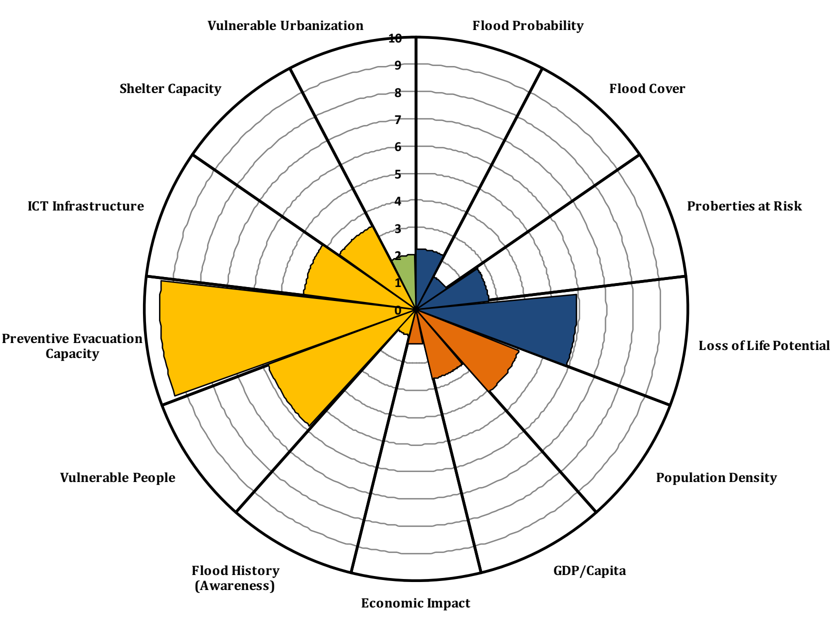
2030-low

Rank	City	Risk(Million€/yr)
10	Osaka	560.7
11	Cairo	485.0
12	**Los Angeles**	**455.4**
13	Kolkata	412.5
14	Tijuana	361.2

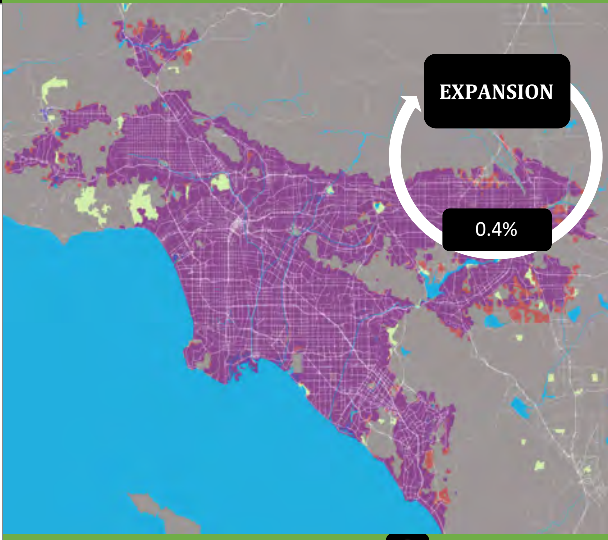
2030-high

Rank	City	Risk(Million€/yr)
12	Cairo	604.9
13	Beijing	572.9
14	**Los Angeles**	**446.4**
15	Tijuana	403.4
16	Mumbai	340.2

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

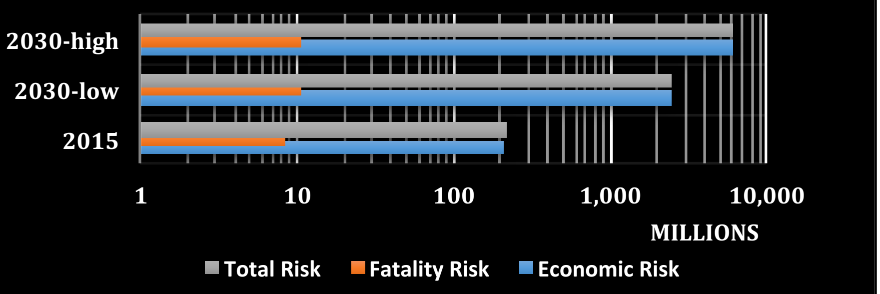


ALARM:

Shanghai

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
9	Cairo	232.4
10	Los Angeles	216.9
11	**Shanghai**	**215.1**
12	Tijuana	141.9
13	New York	137.2

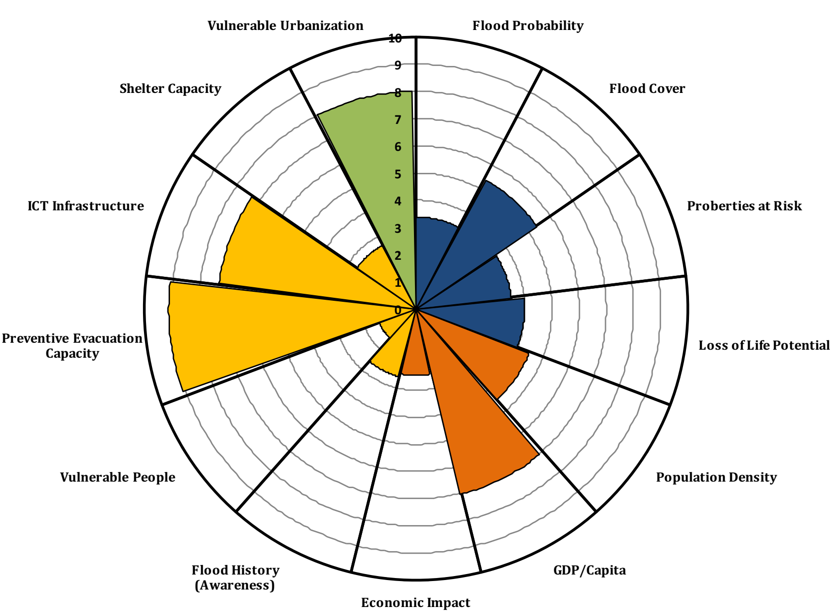
2030-low

Rank	*City*	*Risk(Million€/yr)*
2	Tianjin	3512.7
3	Taipei	2648.1
4	**Shanghai**	**2503.9**
5	Guangzhou	1556.4
6	Tokyo	941.7

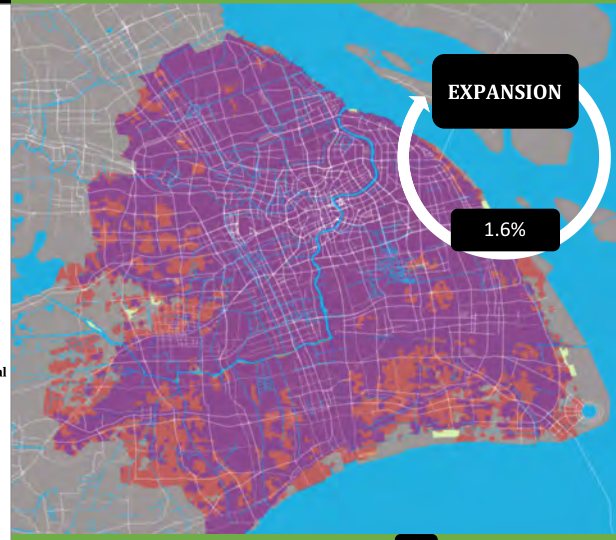
2030-high

Rank	*City*	*Risk(Million€/yr)*
1	Tianjin	7579.7
2	Taipei	6295.5
3	**Shanghai**	**6107.0**
4	Buenos Aires	5341.8
5	Guangzhou	3761.3

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

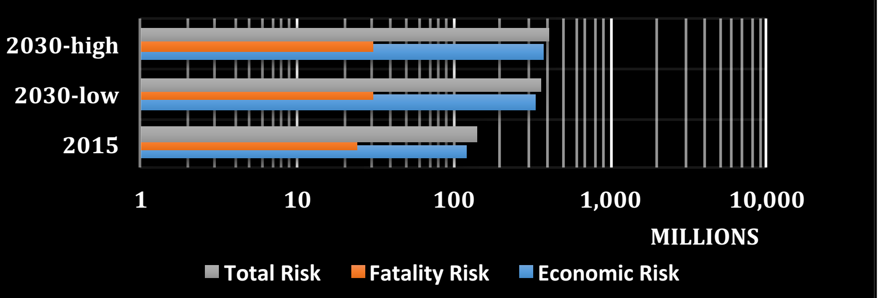


ALARM:

Tijuana

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
10	Los Angeles	216.9
11	Shanghai	215.1
12	**Tijuana**	**141.9**
13	New York	137.2
14	Jinan	128.8

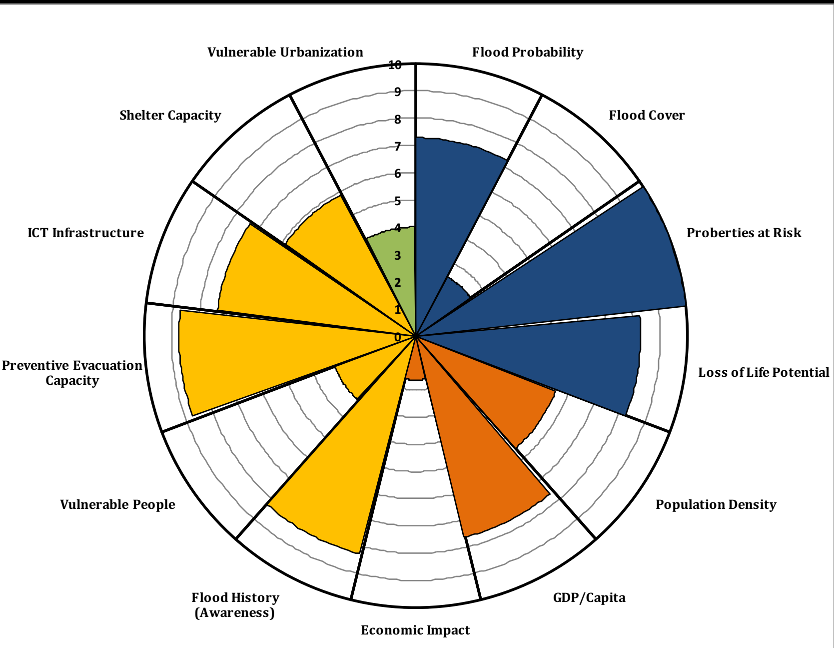
2030-low

Rank	City	Risk(Million€/yr)
12	Los Angeles	455.4
13	Kolkata	412.5
14	**Tijuana**	**361.2**
15	Philadelphia	295.0
16	New York	282.8

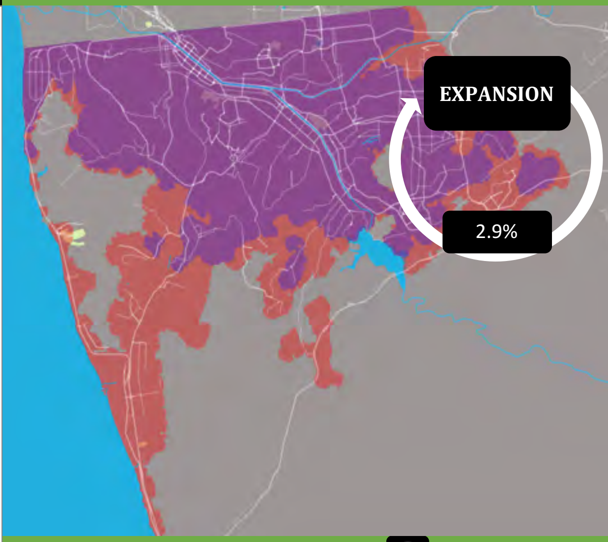
2030-high

Rank	City	Risk(Million€/yr)
13	Beijing	572.9
14	Los Angeles	446.4
15	**Tijuana**	**403.4**
16	Mumbai	340.2
17	New York	293.5

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

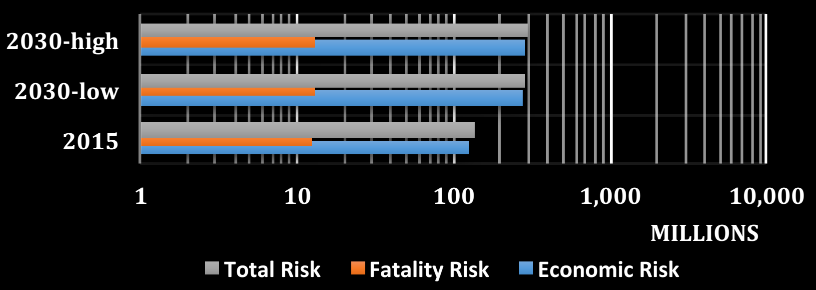


ALARM:

New York

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
11	Shanghai	215.1
12	Tijuana	141.9
13	**New York**	**137.2**
14	Jinan	128.8
15	Philadelphia	128.4

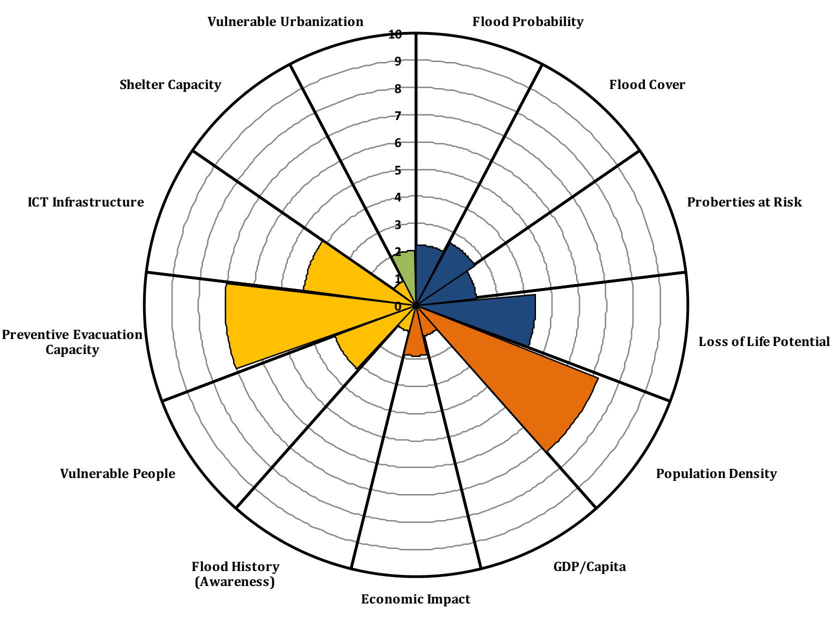
2030-low

Rank	City	Risk(Million€/yr)
14	Tijuana	361.2
15	Philadelphia	295.0
16	**New York**	**282.8**
17	Beijing	235.8
18	Ahvaz	205.9

2030-high

Rank	City	Risk(Million€/yr)
15	Tijuana	403.4
16	Mumbai	340.2
17	**New York**	**293.5**
18	Philadelphia	276.9
19	Ahvaz	274.3

FLOOD INDEX



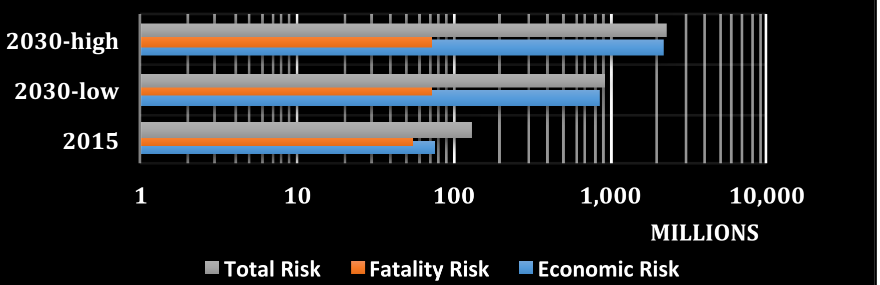
ADAPTIVE CAPACITY OF CITIES

ALARM:

Jinan

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
12	Tijuana	141.9
13	New York	137.2
14	**Jinan**	**128.8**
15	Philadelphia	128.4
16	Seoul	98.3

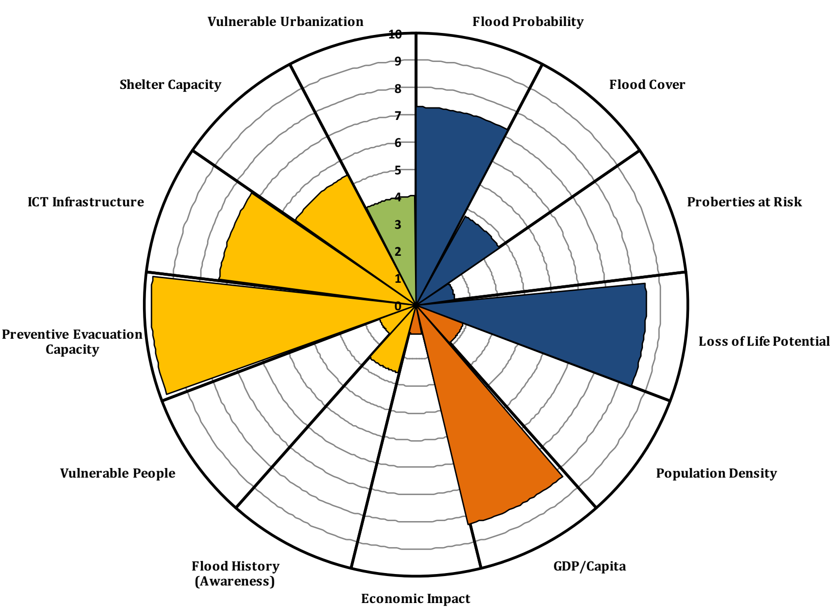
2030-low

Rank	City	Risk(Million€/yr)
6	Tokyo	941.7
7	Sao Paulo	935.8
8	**Jinan**	**933.4**
9	Bangkok	861.5
10	Osaka	560.7

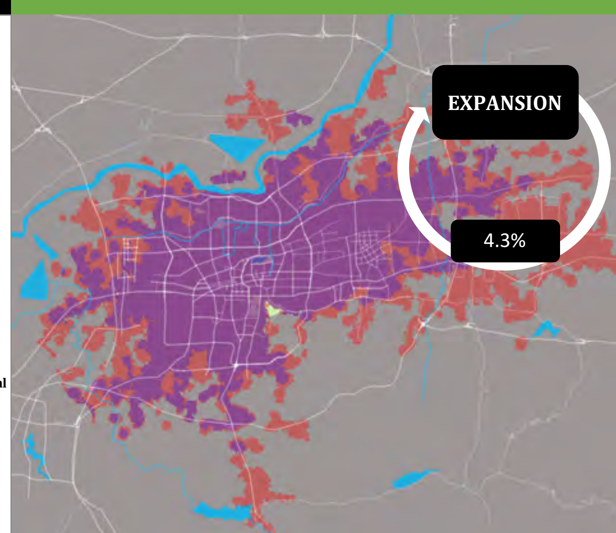
2030-high

Rank	City	Risk(Million€/yr)
4	Buenos Aires	5341.8
5	Guangzhou	3761.3
6	**Jinan**	**2261.9**
7	Bangkok	1259.3
8	Kolkata	1187.4

FLOOD INDEX



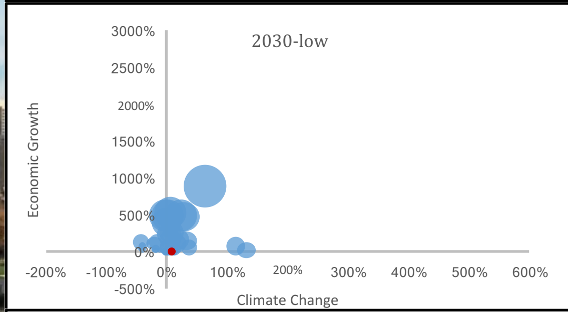
ADAPTIVE CAPACITY OF CITIES

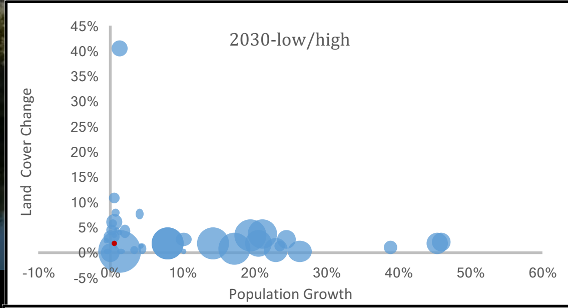


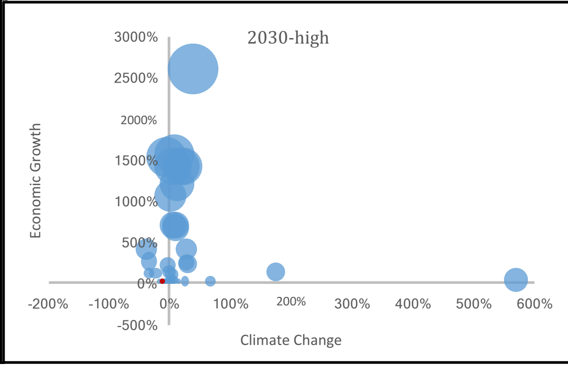
ALARM:

Philadelphia

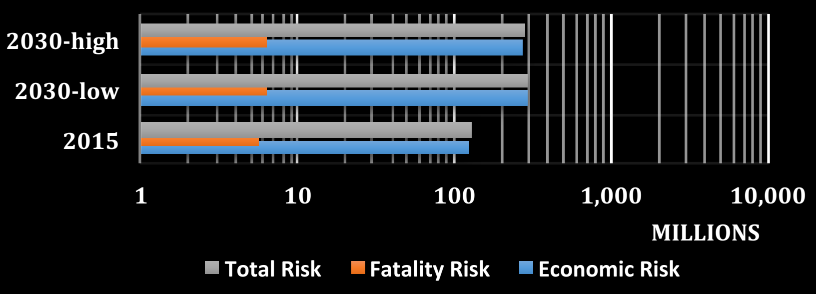
Risk Increase Contribution







RISK



Now

Rank	*City*	*Risk(Million€/yr)*
13	New York	137.2
14	Jinan	128.8
15	**Philadelphia**	**128.4**
16	Seoul	98.3
17	Kolkata	97.3

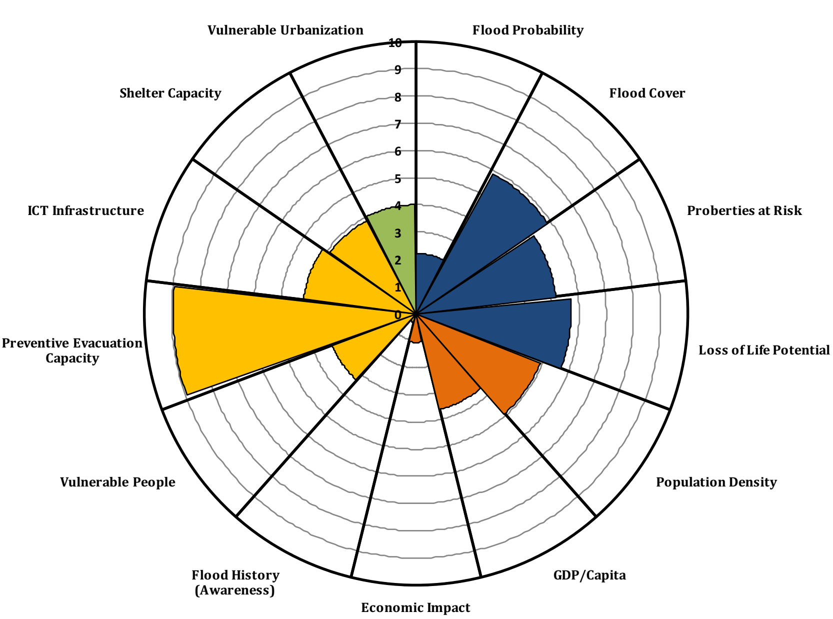
2030-low

Rank	*City*	*Risk(Million€/yr)*
13	Kolkata	412.5
14	Tijuana	361.2
15	**Philadelphia**	**295.0**
16	New York	282.8
17	Beijing	235.8

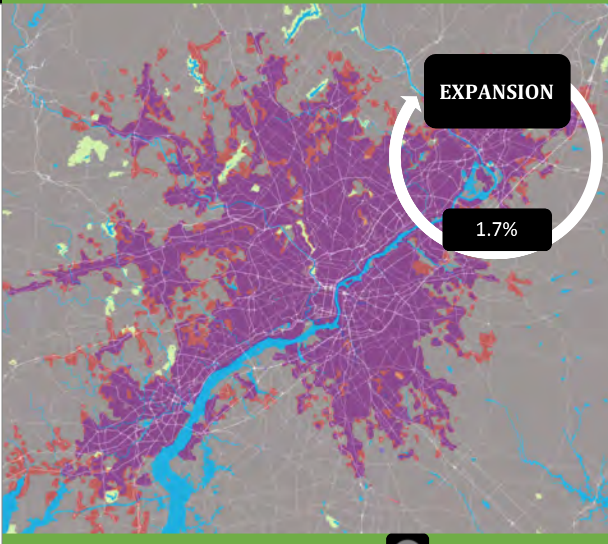
2030-high

Rank	*City*	*Risk(Million€/yr)*
16	Mumbai	340.2
17	New York	293.5
18	**Philadelphia**	**276.9**
19	Ahvaz	274.3
20	Dhaka	233.1

FLOOD INDEX



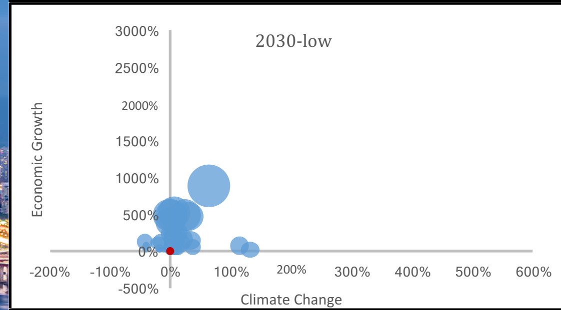
ADAPTIVE CAPACITY OF CITIES

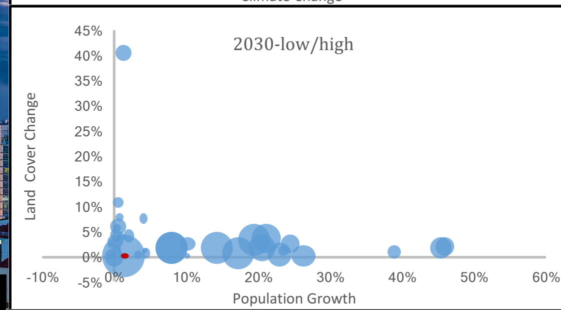


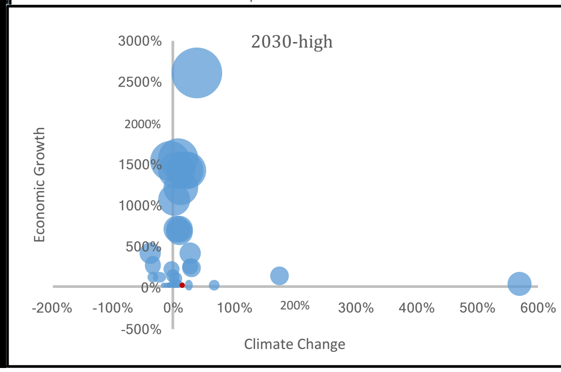
ALARM:

Seoul

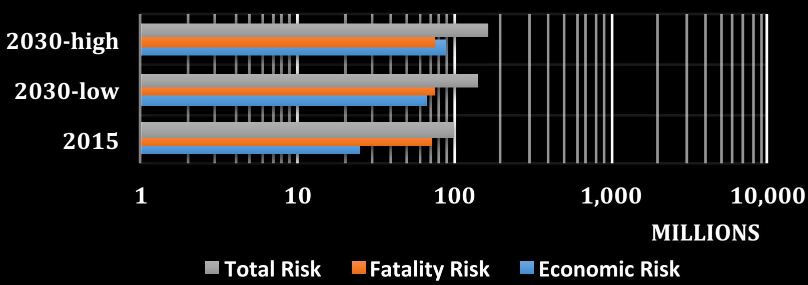
Risk Increase Contribution







RISK



Now

Rank	City	Risk(Million€/yr)
14	Jinan	128.8
15	Philadelphia	128.4
16	**Seoul**	**98.3**
17	Kolkata	97.3
18	Ahvaz	52.7

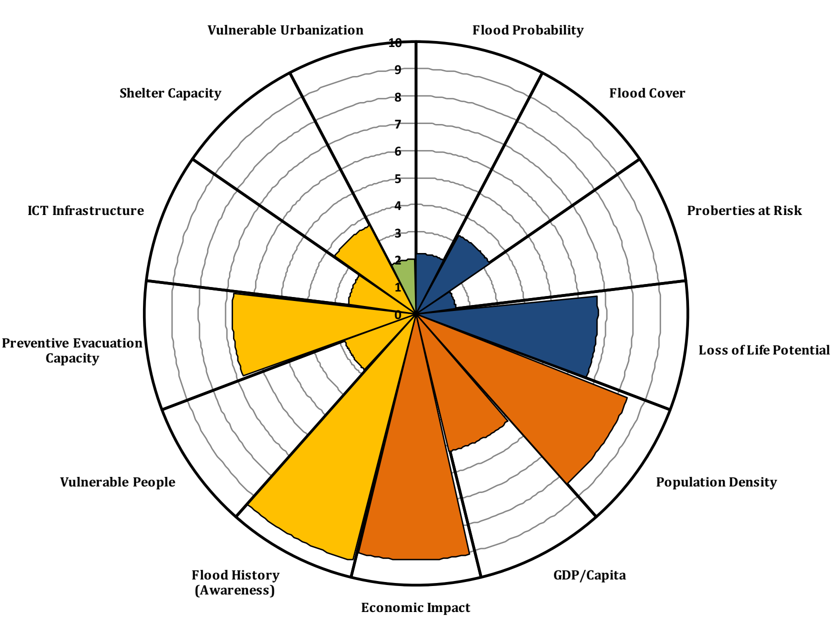
2030-low

Rank	City	Risk(Million€/yr)
17	Beijing	235.8
18	Ahvaz	205.9
19	**Seoul**	**142.5**
20	Mumbai	129.4
21	Astrakhan	113.6

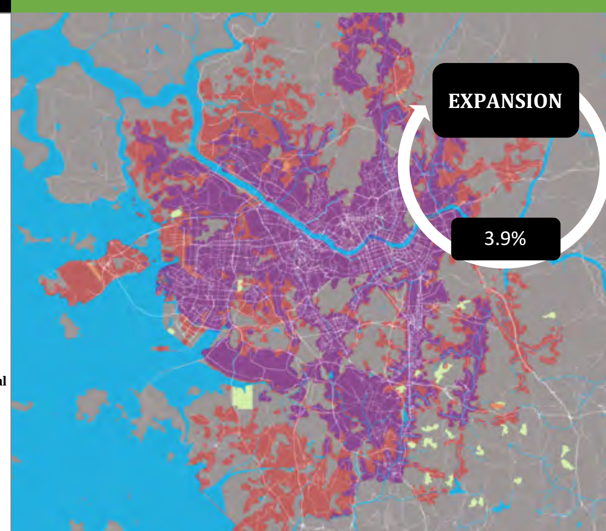
2030-high

Rank	City	Risk(Million€/yr)
22	Lagos	176.0
23	Astrakhan	175.8
24	**Seoul**	**163.2**
25	Karachi	108.6
26	Houston	101.6

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

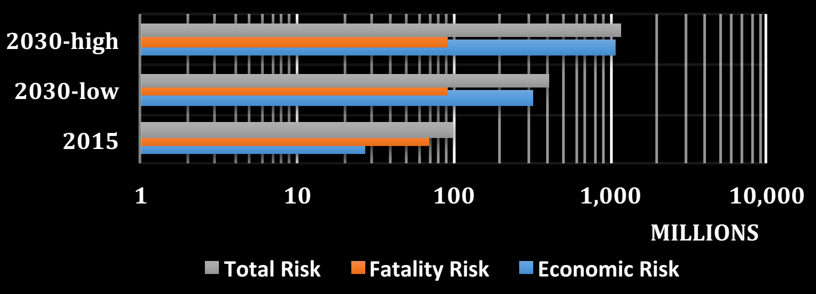


ALARM:

Kolkata

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
15	Philadelphia	128.4
16	Seoul	98.3
17	**Kolkata**	**97.3**
18	Ahvaz	52.7
19	London	52.0

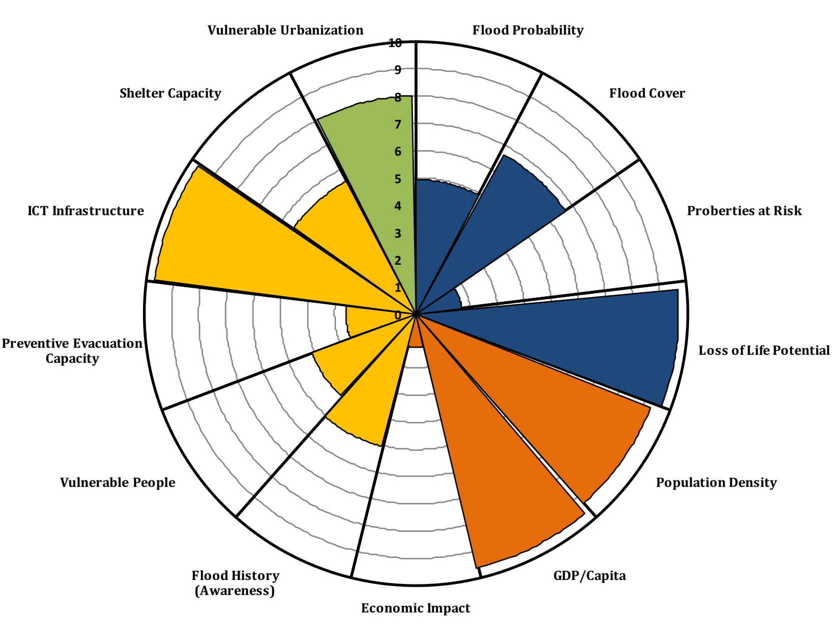
2030-low

Rank	*City*	*Risk(Million€/yr)*
11	Cairo	485.0
12	Los Angeles	455.4
13	**Kolkata**	**412.5**
14	Tijuana	361.2
15	Philadelphia	295.0

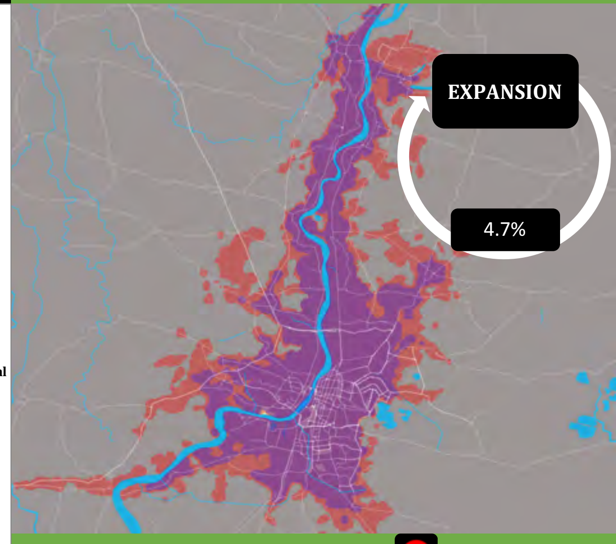
2030-high

Rank	*City*	*Risk(Million€/yr)*
6	Jinan	2261.9
7	Bangkok	1259.3
8	**Kolkata**	**1187.4**
9	Tokyo	1029.0
10	Sao Paulo	1011.2

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

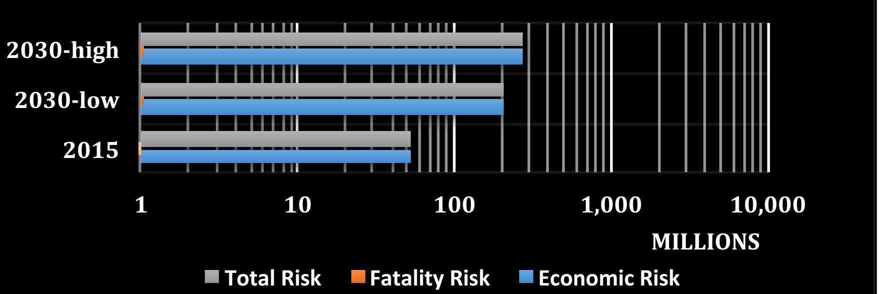


ALARM:

Ahvaz

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
16	Seoul	98.3
17	Kolkata	97.3
18	**Ahvaz**	**52.7**
19	London	52.0
20	Houston	39.9

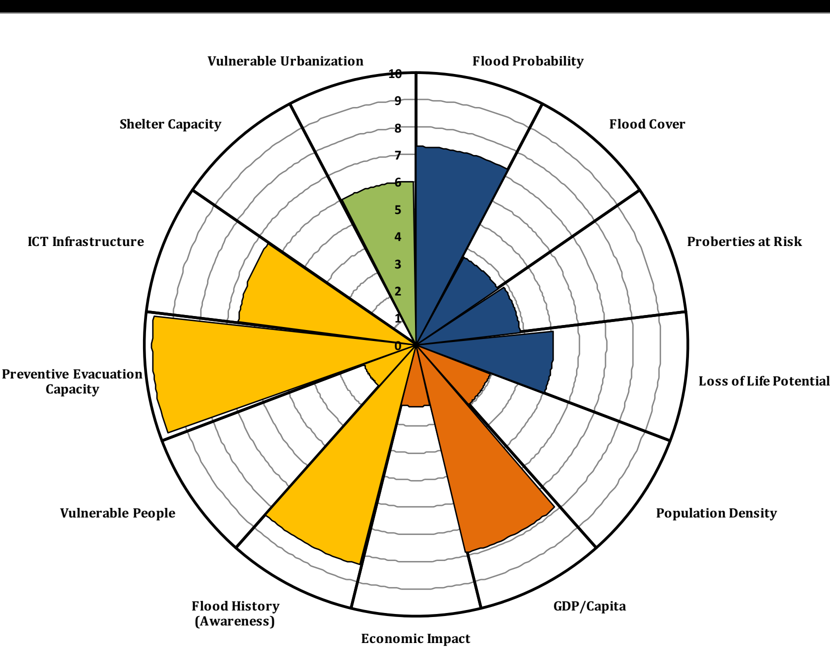
2030-low

Rank	City	Risk(Million€/yr)
16	New York	282.8
17	Beijing	235.8
18	**Ahvaz**	**205.9**
19	Seoul	142.5
20	Mumbai	129.4

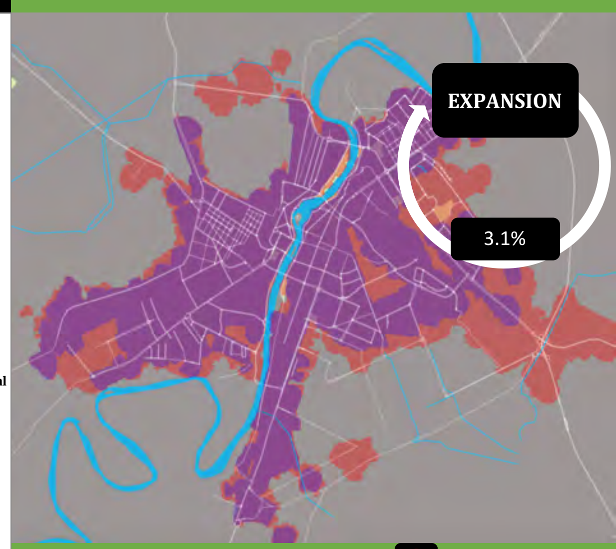
2030-high

Rank	City	Risk(Million€/yr)
17	New York	293.5
18	Philadelphia	276.9
19	**Ahvaz**	**274.3**
20	Dhaka	233.1
21	Palembang	232.9

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

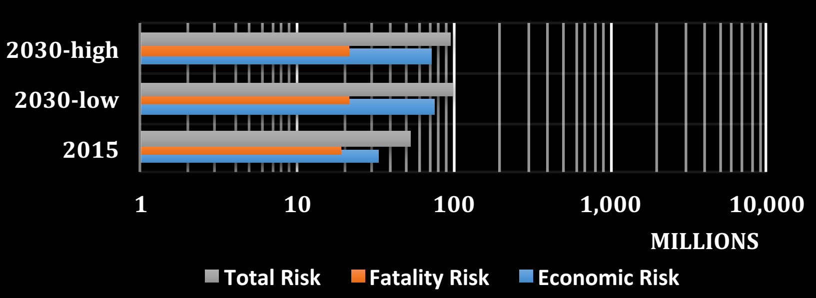


ALARM:

London

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
17	Kolkata	97.3
18	Ahvaz	52.7
19	**London**	**52.0**
20	Houston	39.9
21	Mumbai	39.4

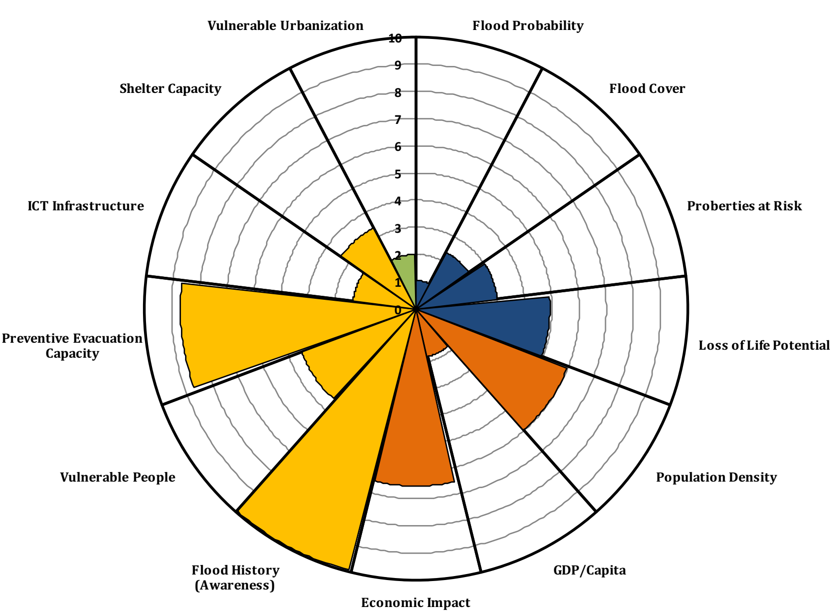
2030-low

Rank	City	Risk(Million€/yr)
20	Mumbai	129.4
21	Astrakhan	113.6
22	**London**	**97.9**
23	Palembang	94.1
24	Dhaka	92.5

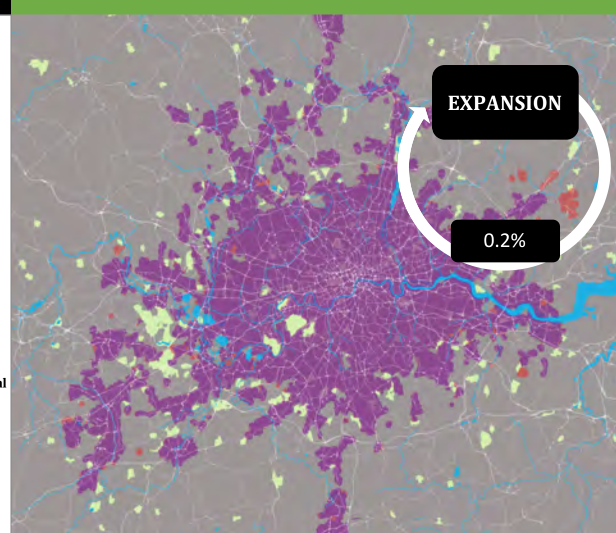
2030-high

Rank	City	Risk(Million€/yr)
26	Houston	101.6
27	Portland	98.0
28	**London**	**95.0**
29	Ho Chi Minh City	73.9
30	Montreal	72.4

FLOOD INDEX



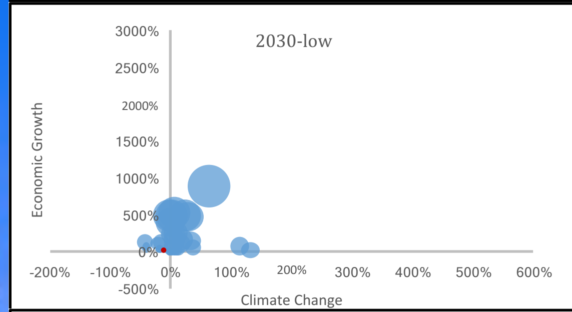
ADAPTIVE CAPACITY OF CITIES

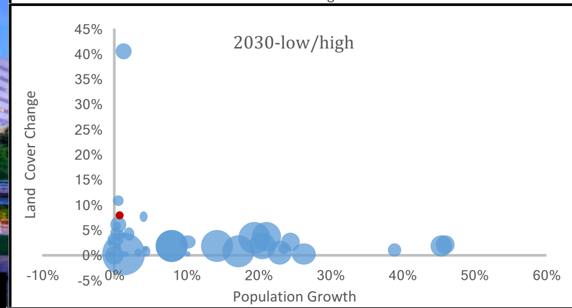


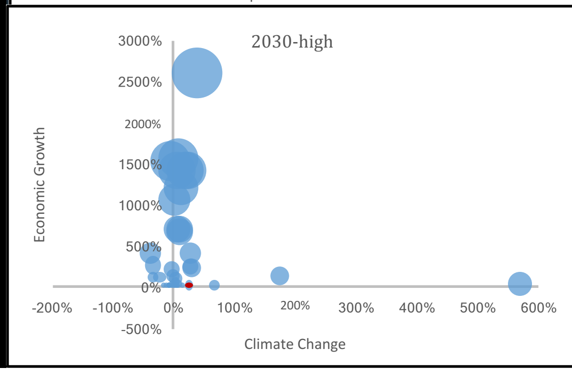
ALARM:

Houston

Risk Increase Contribution







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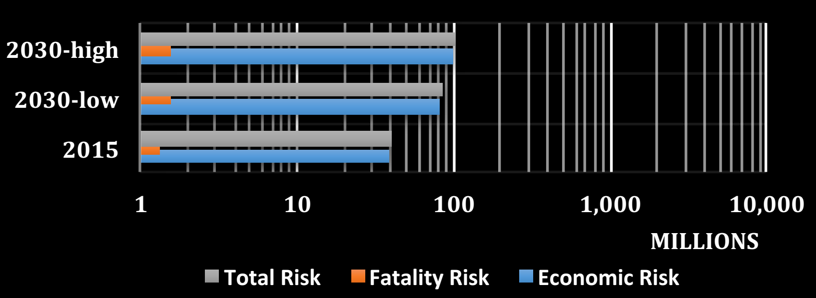


Now

Rank	*City*	*Risk(Million€/yr)*
18	Ahvaz	52.7
19	London	52.0
20	**Houston**	**39.9**
21	Mumbai	39.4
22	Astrakhan	37.4

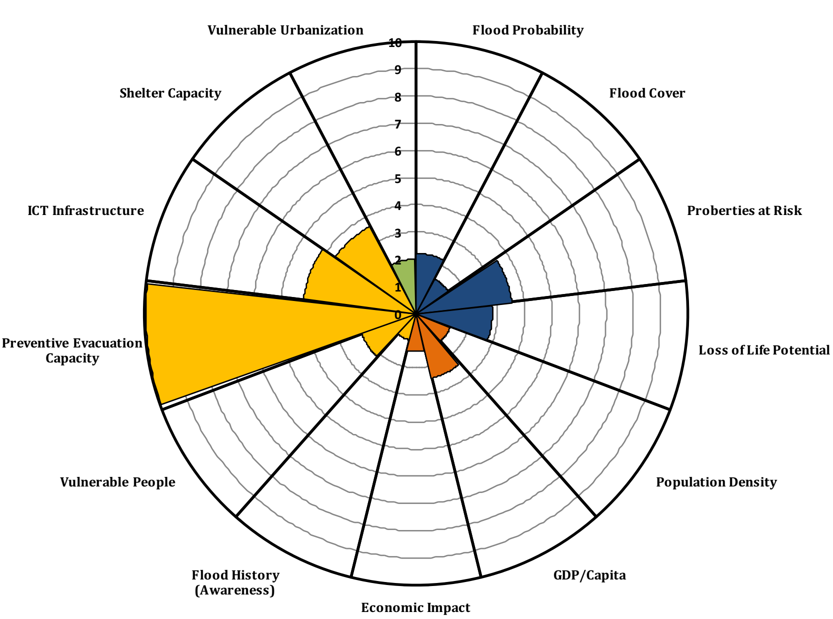
2030-low

Rank	*City*	*Risk(Million€/yr)*
24	Dhaka	92.5
25	Lagos	90.2
26	**Houston**	**83.6**
27	Portland	76.5
28	Karachi	64.2

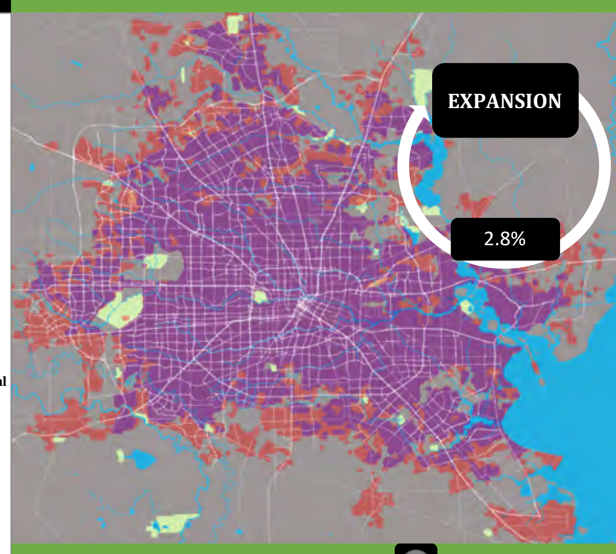
2030-high

Rank	*City*	*Risk(Million€/yr)*
24	Seoul	163.2
25	Karachi	108.6
26	**Houston**	**101.6**
27	Portland	98.0
28	London	95.0

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

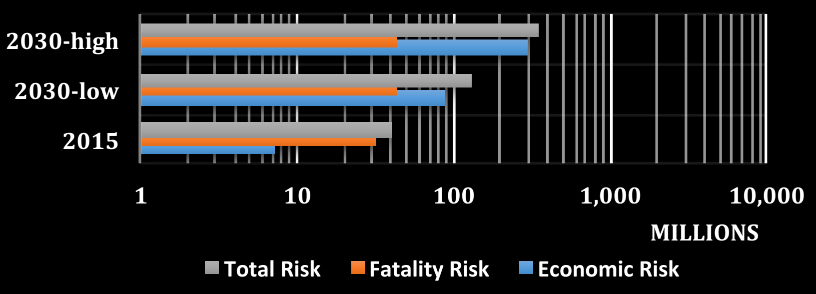


ALARM:

Mumbai

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
19	London	52.0
20	Houston	39.9
21	**Mumbai**	**39.4**
22	Astrakhan	37.4
23	Beijing	35.7

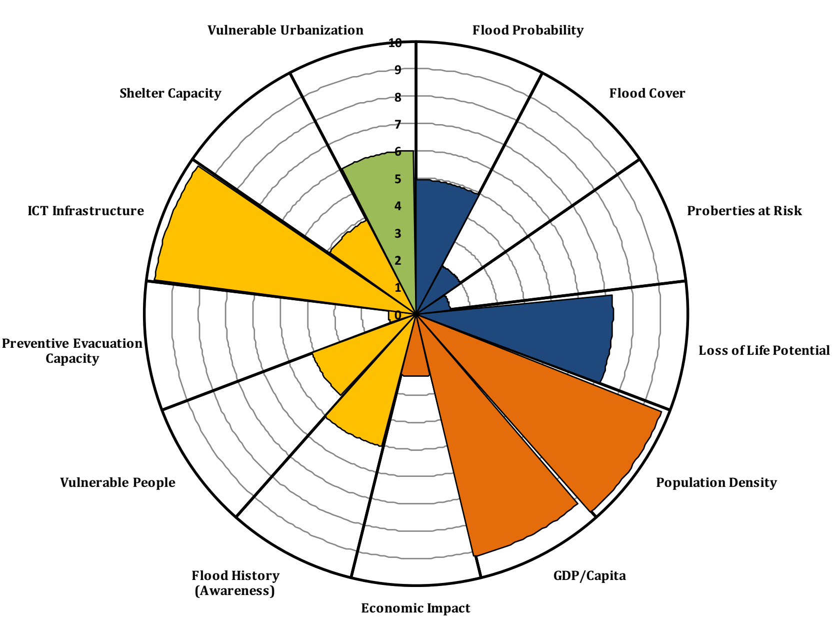
2030-low

Rank	*City*	*Risk(Million€/yr)*
18	Ahvaz	205.9
19	Seoul	142.5
20	**Mumbai**	**129.4**
21	Astrakhan	113.6
22	London	97.9

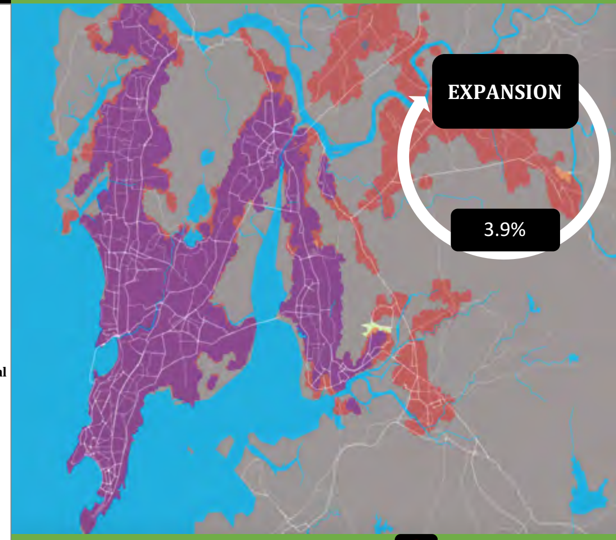
2030-high

Rank	*City*	*Risk(Million€/yr)*
14	Los Angeles	446.4
15	Tijuana	403.4
16	**Mumbai**	**340.2**
17	New York	293.5
18	Philadelphia	276.9

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

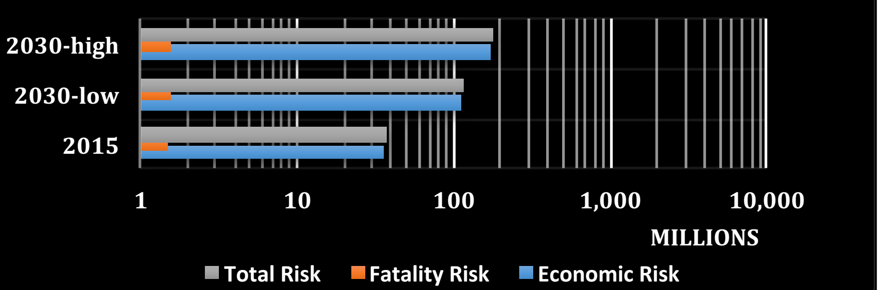


ALARM:

Astrakhan

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
20	Houston	39.9
21	Mumbai	39.4
22	**Astrakhan**	**37.4**
23	Beijing	35.7
24	Portland	33.0

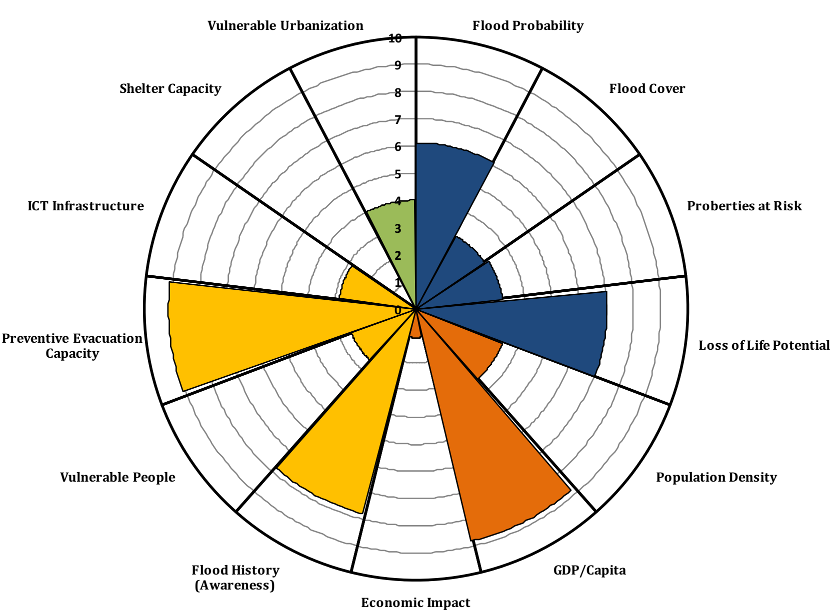
2030-low

Rank	*City*	*Risk(Million€/yr)*
19	Seoul	142.5
20	Mumbai	129.4
21	**Astrakhan**	**113.6**
22	London	97.9
23	Palembang	94.1

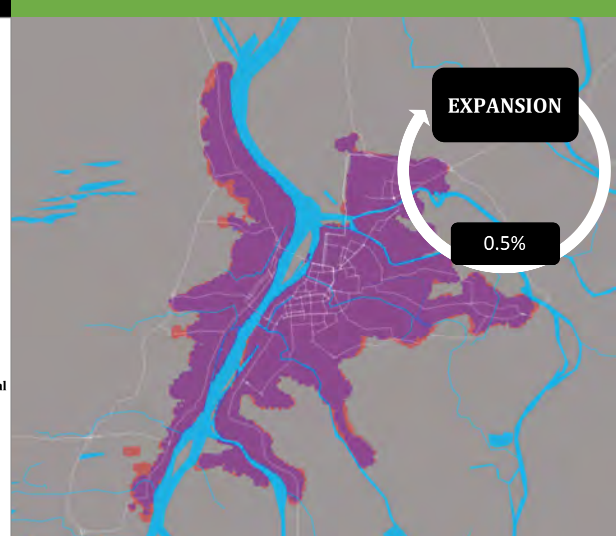
2030-high

Rank	*City*	*Risk(Million€/yr)*
21	Palembang	232.9
22	Lagos	176.0
23	**Astrakhan**	**175.8**
24	Seoul	163.2
25	Karachi	108.6

FLOOD INDEX



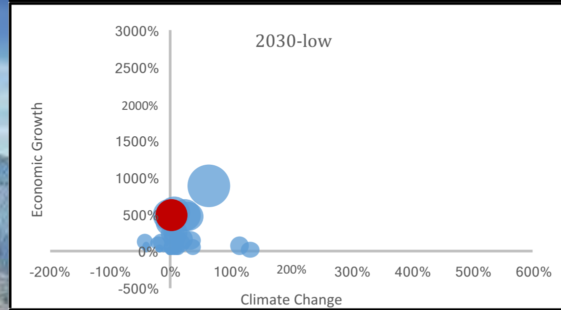
ADAPTIVE CAPACITY OF CITIES

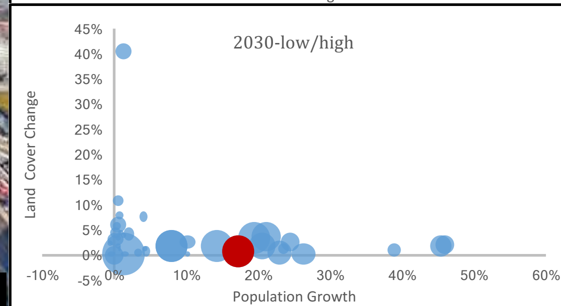


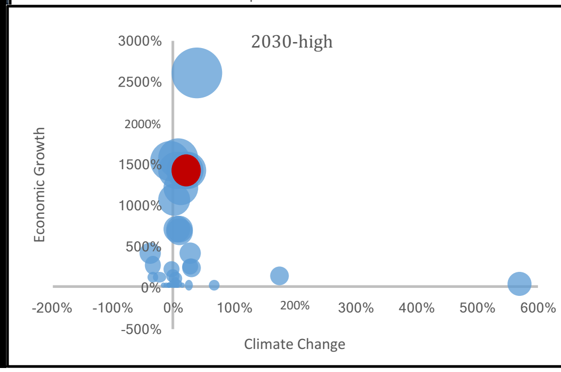
ALARM:

Beijing

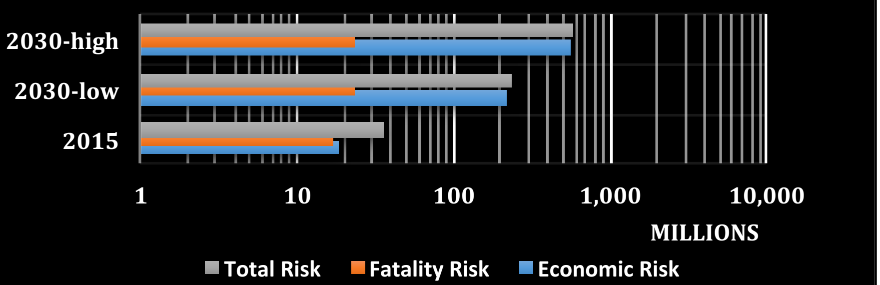
Risk Increase Contribution







RISK



Now

Rank	*City*	*Risk(Million€/yr)*
21	Mumbai	39.4
22	Astrakhan	37.4
23	**Beijing**	**35.7**
24	Portland	33.0
25	Lagos	30.8

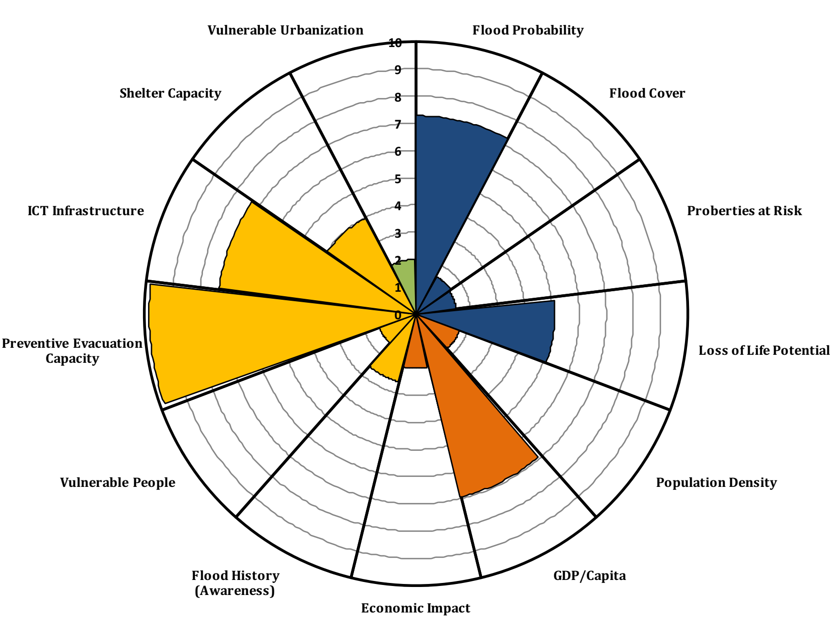
2030-low

Rank	*City*	*Risk(Million€/yr)*
15	Philadelphia	295.0
16	New York	282.8
17	**Beijing**	**235.8**
18	Ahvaz	205.9
19	Seoul	142.5

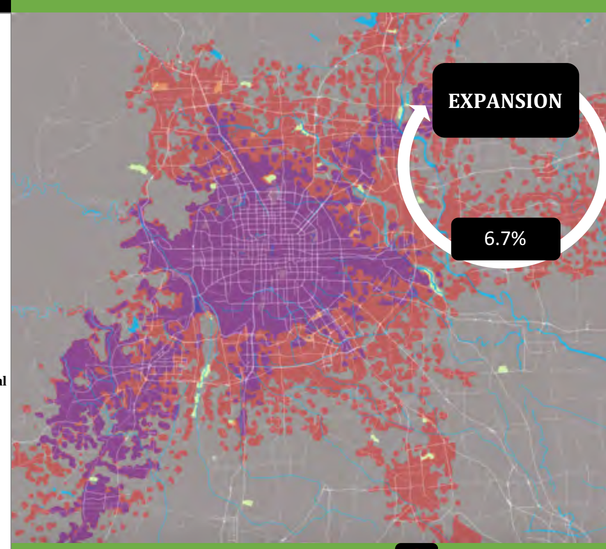
2030-high

Rank	*City*	*Risk(Million€/yr)*
11	Osaka	611.6
12	Cairo	604.9
13	**Beijing**	**572.9**
14	Los Angeles	446.4
15	Tijuana	403.4

FLOOD INDEX



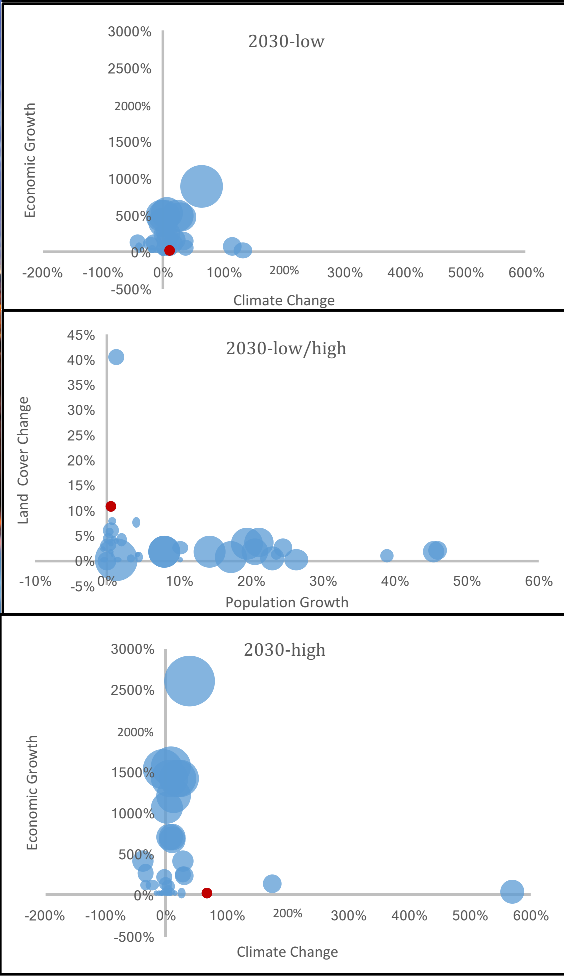
ADAPTIVE CAPACITY OF CITIES



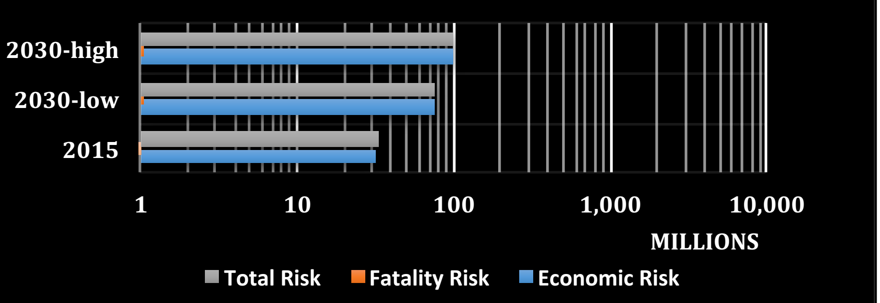
ALARM:

Portland

Risk Increase Contribution



RISK



Now

Rank	*City*	*Risk(Million€/yr)*
22	Astrakhan	37.4
23	Beijing	35.7
24	**Portland**	**33.0**
25	Lagos	30.8
26	Karachi	27.7

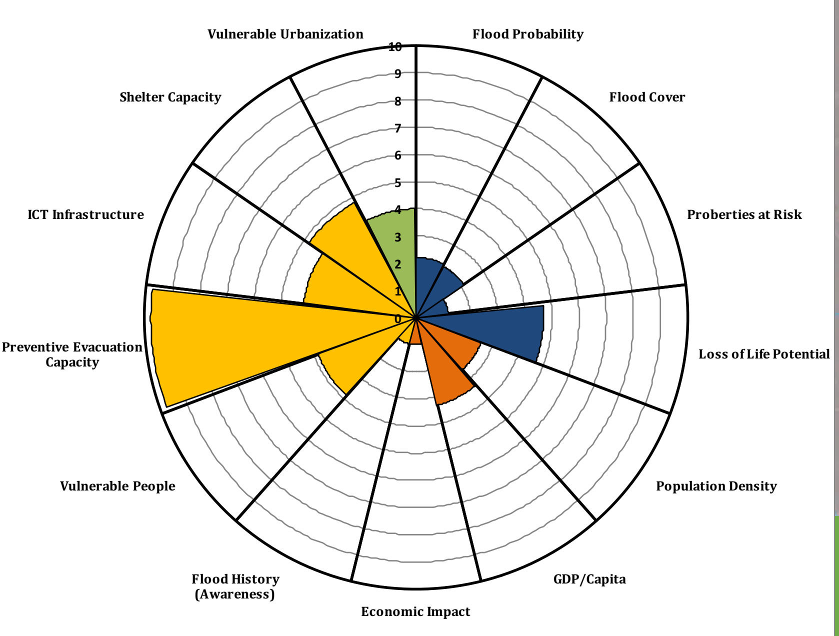
2030-low

Rank	*City*	*Risk(Million€/yr)*
25	Lagos	90.2
26	Houston	83.6
27	**Portland**	**76.5**
28	Karachi	64.2
29	Ho Chi Minh City	42.1

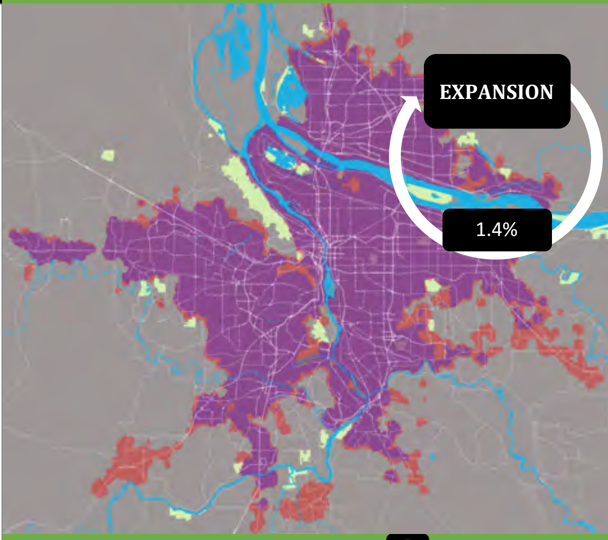
2030-high

Rank	*City*	*Risk(Million€/yr)*
25	Karachi	108.6
26	Houston	101.6
27	**Portland**	**98.0**
28	London	95.0
29	Ho Chi Minh City	73.9

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

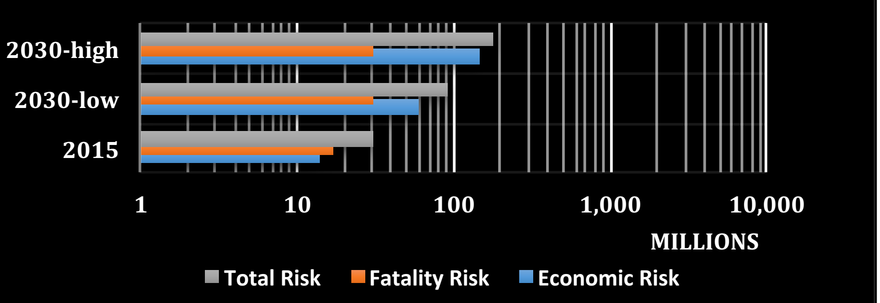


ALARM:

Lagos

Risk Increase Contribution

RISK



Now

Rank	City	Risk(Million€/yr)
23	Beijing	35.7
24	Portland	33.0
25	**Lagos**	**30.8**
26	Karachi	27.7
27	Dhaka	26.5

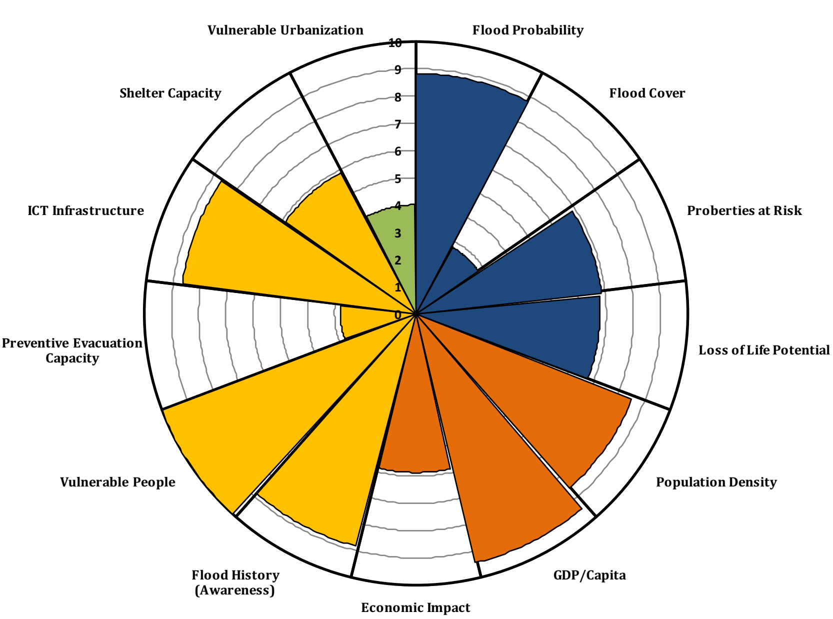
2030-low

Rank	City	Risk(Million€/yr)
23	Palembang	94.1
24	Dhaka	92.5
25	**Lagos**	**90.2**
26	Houston	83.6
27	Portland	76.5

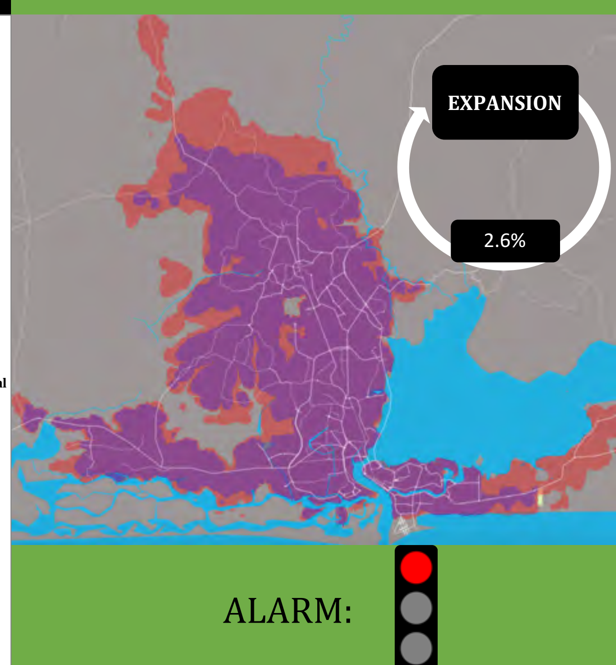
2030-high

Rank	City	Risk(Million€/yr)
20	Dhaka	233.1
21	Palembang	232.9
22	**Lagos**	**176.0**
23	Astrakhan	175.8
24	Seoul	163.2

FLOOD INDEX

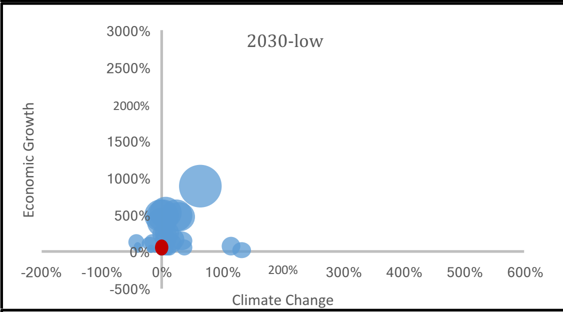


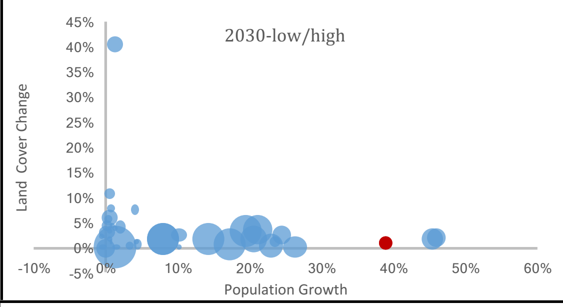
ADAPTIVE CAPACITY OF CITIES

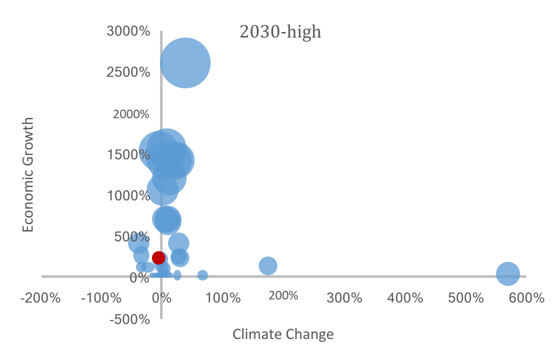


Karachi

Risk Increase Contribution







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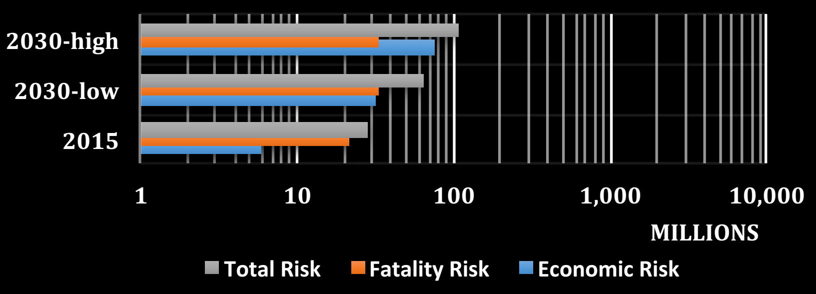


Now

Rank	City	Risk(Million€/yr)
24	Portland	33.0
25	Lagos	30.8
26	**Karachi**	**27.7**
27	Dhaka	26.5
28	Culiacan	18.3

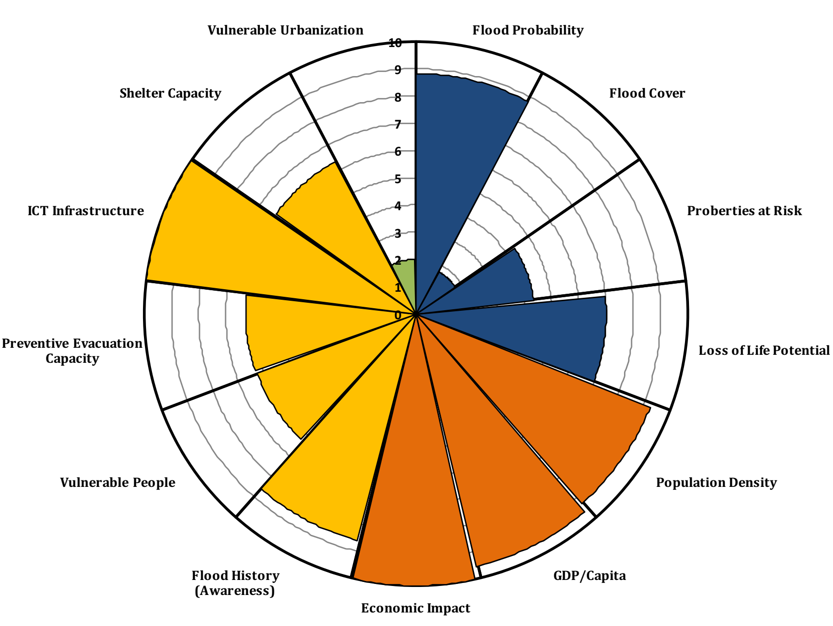
2030-low

Rank	City	Risk(Million€/yr)
26	Houston	83.6
27	Portland	76.5
28	**Karachi**	**64.2**
29	Ho Chi Minh City	42.1
30	Culiacan	39.7

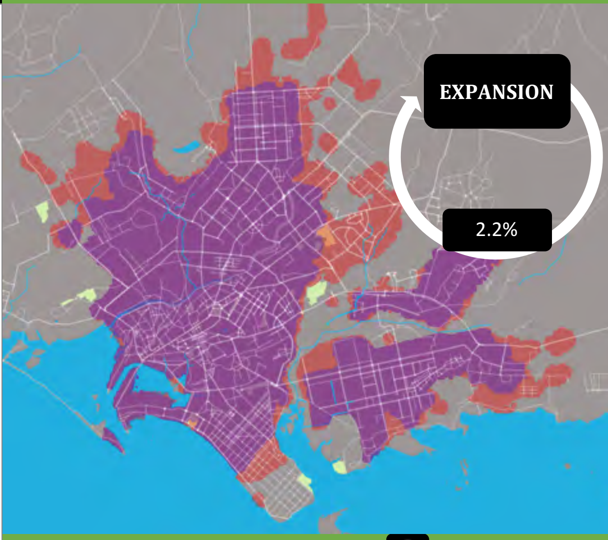
2030-high

Rank	City	Risk(Million€/yr)
23	Astrakhan	175.8
24	Seoul	163.2
25	**Karachi**	**108.6**
26	Houston	101.6
27	Portland	98.0

FLOOD INDEX



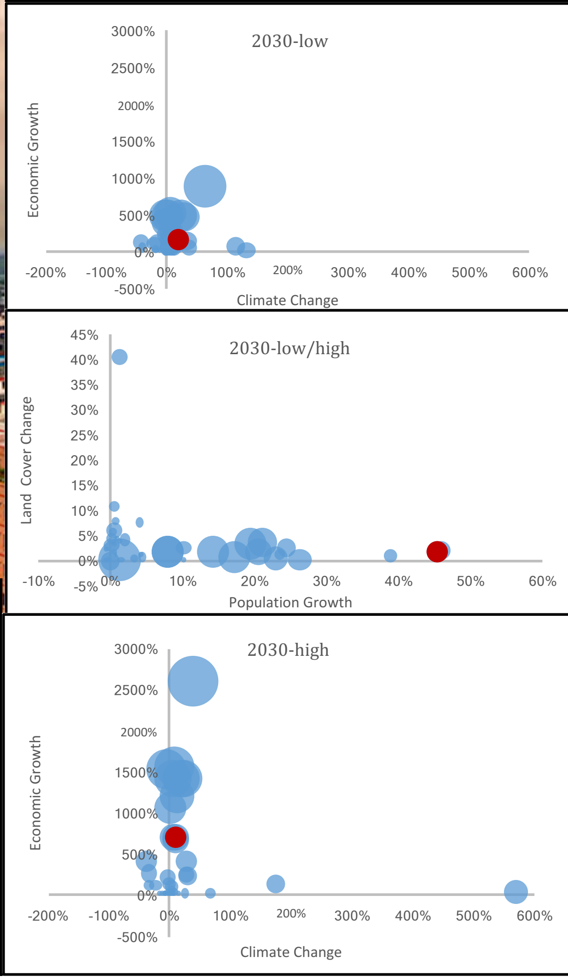
ADAPTIVE CAPACITY OF CITIES



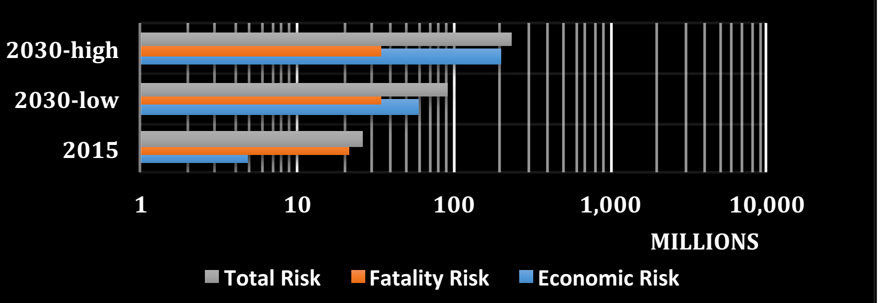
ALARM:

Dhaka

Risk Increase Contribution



RISK



Now

Rank	City	Risk(Million€/yr)
25	Lagos	30.8
26	Karachi	27.7
27	**Dhaka**	**26.5**
28	Culiacan	18.3
29	Okayama	17.1

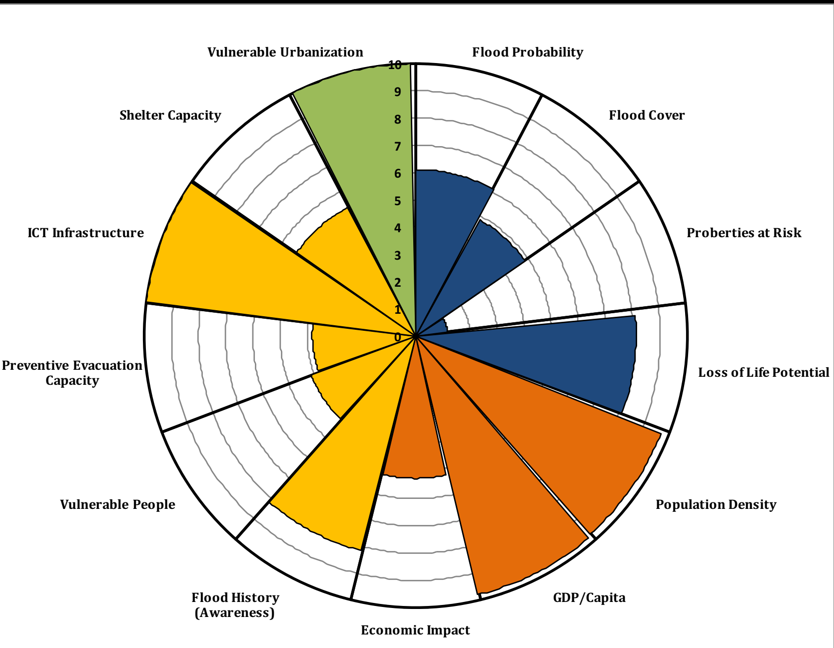
2030-low

Rank	City	Risk(Million€/yr)
22	London	97.9
23	Palembang	94.1
24	**Dhaka**	**92.5**
25	Lagos	90.2
26	Houston	83.6

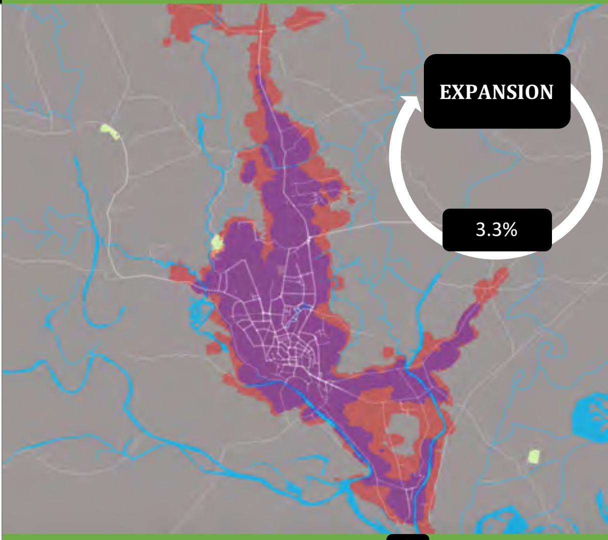
2030-high

Rank	City	Risk(Million€/yr)
18	Philadelphia	276.9
19	Ahvaz	274.3
20	**Dhaka**	**233.1**
21	Palembang	232.9
22	Lagos	176.0

FLOOD INDEX



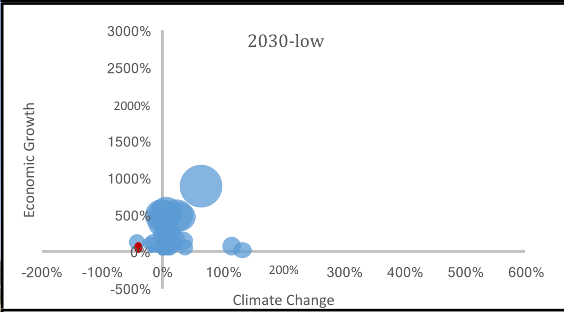
ADAPTIVE CAPACITY OF CITIES

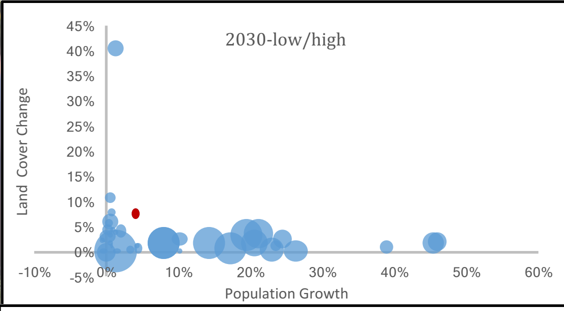


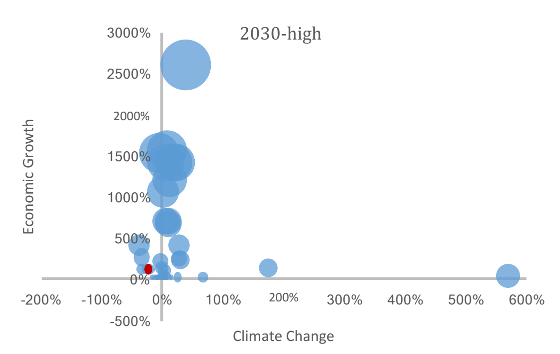
ALARM:

Culiacan

Risk Increase Contribution







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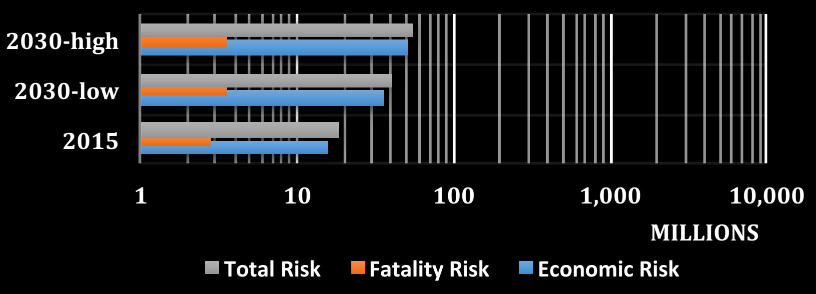


Now

Rank	*City*	*Risk(Million€/yr)*
26	Karachi	27.7
27	Dhaka	26.5
28	**Culiacan**	**18.3**
29	Okayama	17.1
30	Palembang	13.7

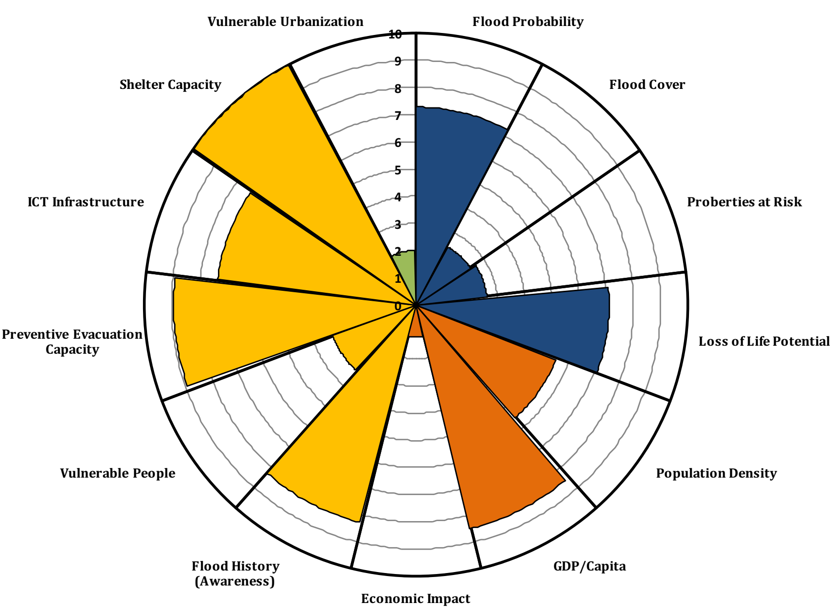
2030-low

Rank	*City*	*Risk(Million€/yr)*
28	Karachi	64.2
29	Ho Chi Minh City	42.1
30	**Culiacan**	**39.7**
31	Sydney	39.5
32	Okayama	36.7

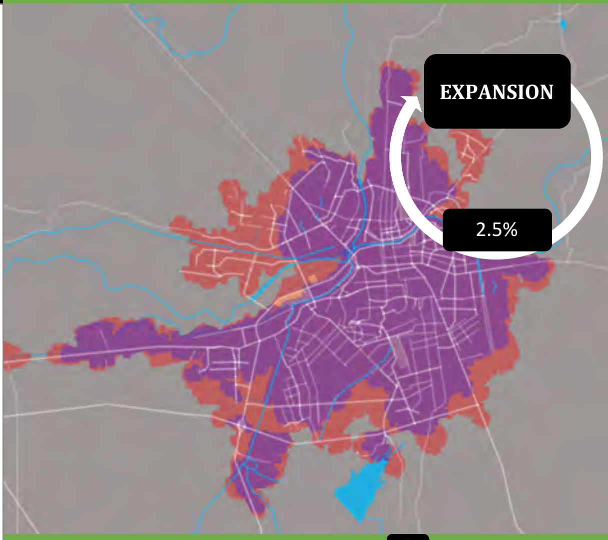
2030-high

Rank	*City*	*Risk(Million€/yr)*
30	Montreal	72.4
31	Hangzhou	59.7
32	**Culiacan**	**54.8**
33	Okayama	42.4
34	Sydney	27.3

FLOOD INDEX



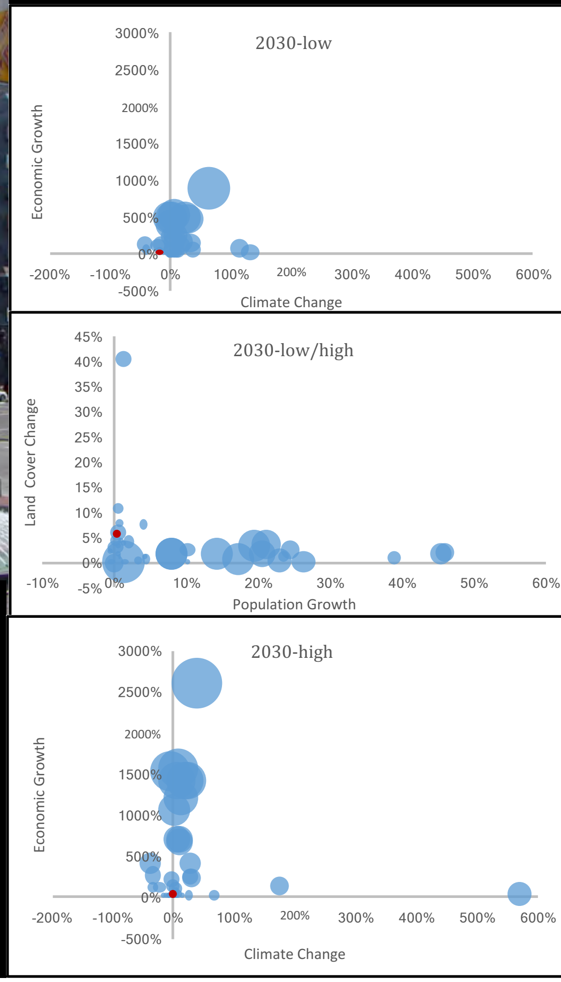
ADAPTIVE CAPACITY OF CITIES



ALARM:

Okayama

Risk Increase Contribution



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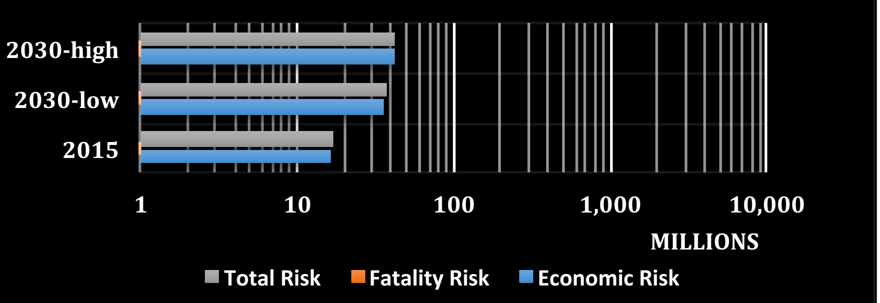


Now

Rank	City	Risk(Million€/yr)
27	Dhaka	26.5
28	Culiacan	18.3
29	**Okayama**	**17.1**
30	Palembang	13.7
31	Ho Chi Minh City	12.1

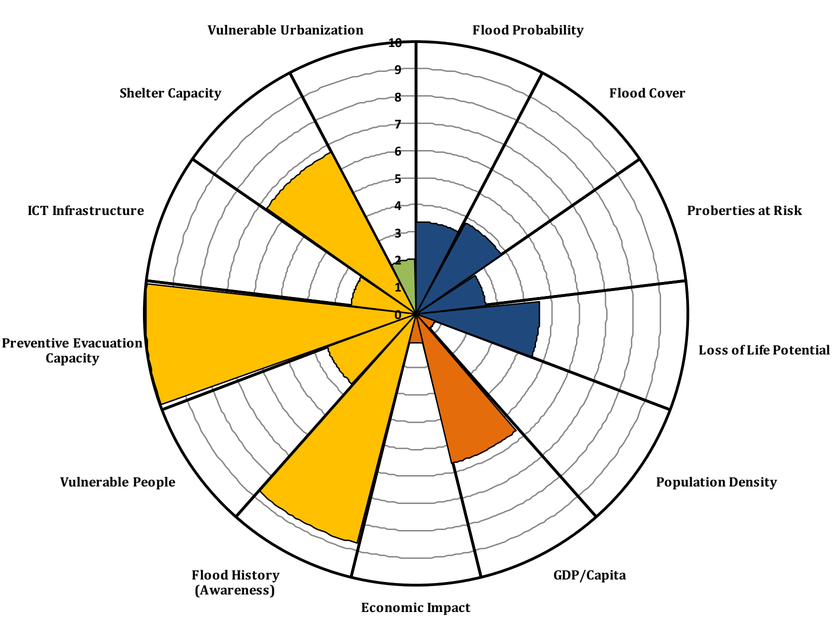
2030-low

Rank	City	Risk(Million€/yr)
30	Culiacan	39.7
31	Sydney	39.5
32	**Okayama**	**36.7**
33	Hangzhou	25.2
34	Pyongyang	22.5

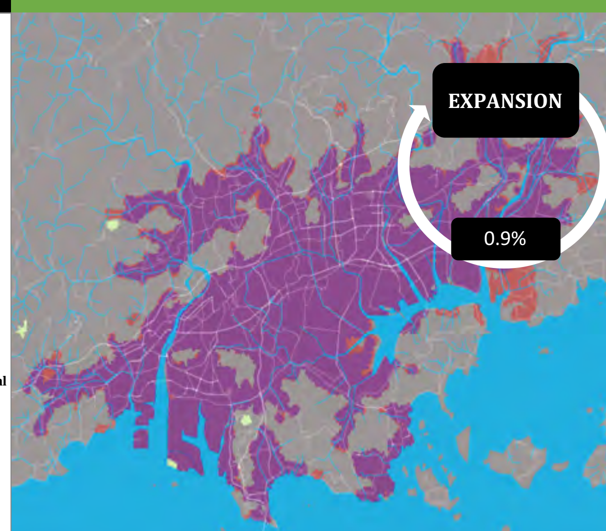
2030-high

Rank	City	Risk(Million€/yr)
31	Hangzhou	59.7
32	Culiacan	54.8
33	**Okayama**	**42.4**
34	Sydney	27.3
35	Pyongyang	27.1

FLOOD INDEX



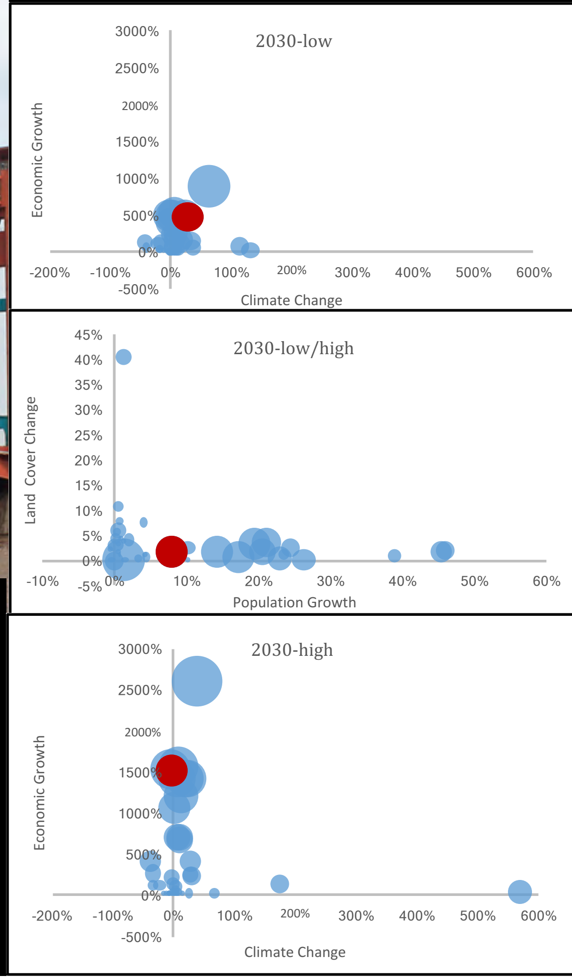
ADAPTIVE CAPACITY OF CITIES



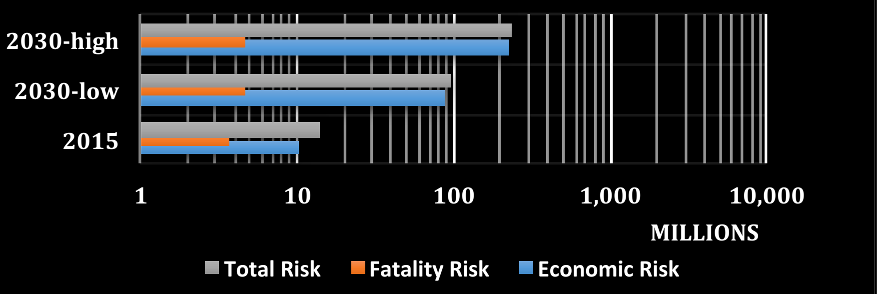
ALARM:

Palembang

Risk Increase Contribution



RISK



Now

Rank	City	Risk(Million€/yr)
28	Culiacan	18.3
29	Okayama	17.1
30	**Palembang**	**13.7**
31	Ho Chi Minh City	12.1
32	Sydney	11.0

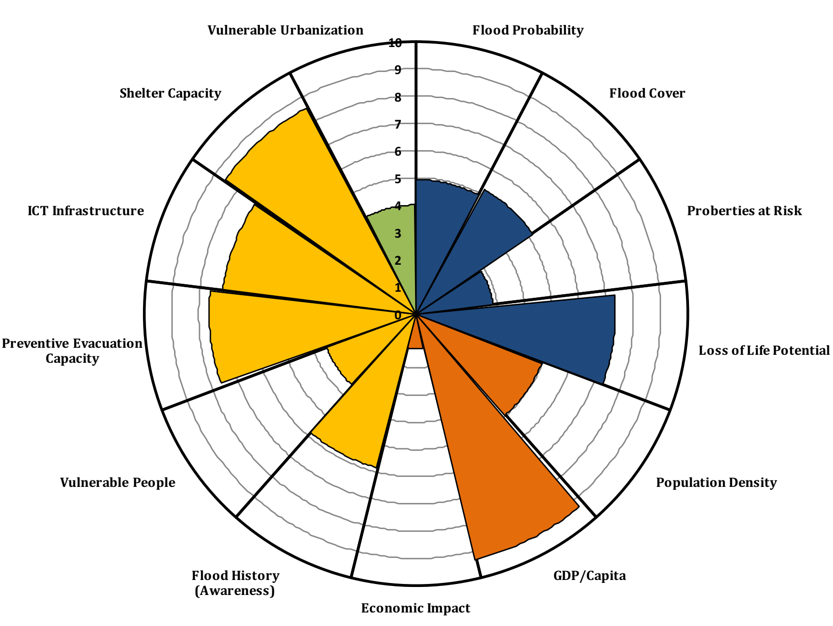
2030-low

Rank	City	Risk(Million€/yr)
21	Astrakhan	113.6
22	London	97.9
23	**Palembang**	**94.1**
24	Dhaka	92.5
25	Lagos	90.2

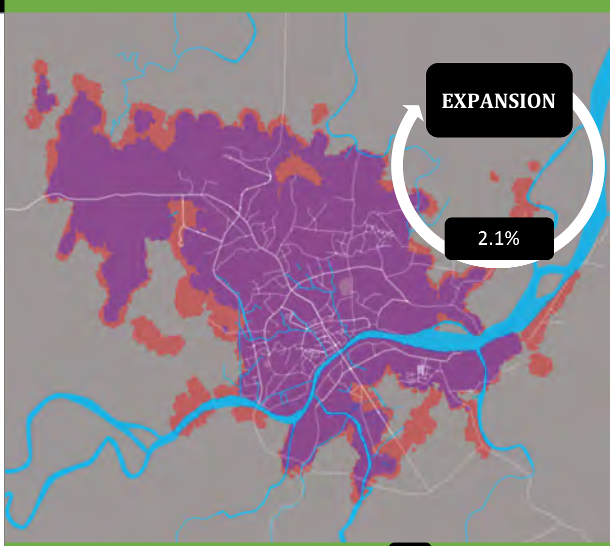
2030-high

Rank	City	Risk(Million€/yr)
19	Ahvaz	274.3
20	Dhaka	233.1
21	**Palembang**	**232.9**
22	Lagos	176.0
23	Astrakhan	175.8

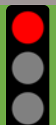
FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

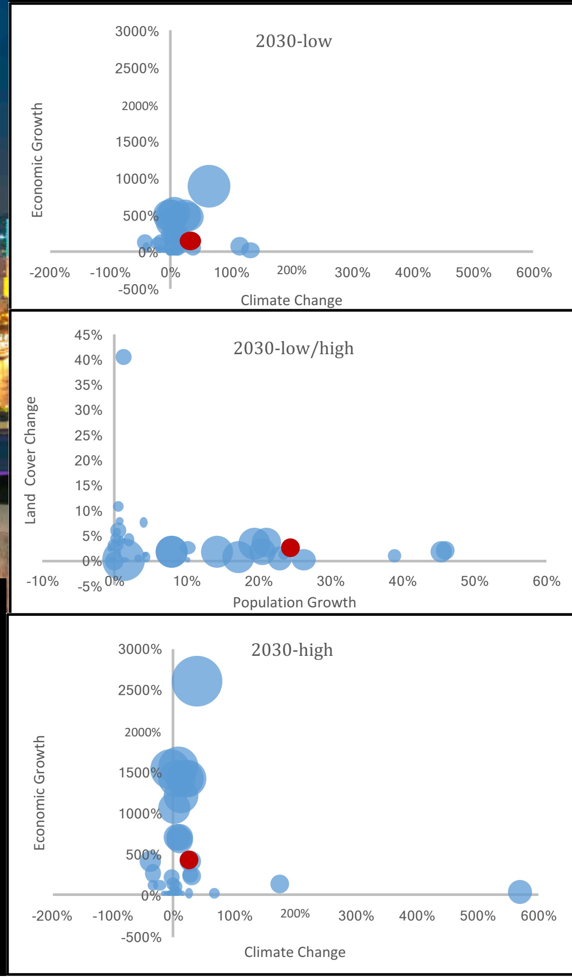


ALARM:



Ho Chi Minh City

Risk Increase Contribution



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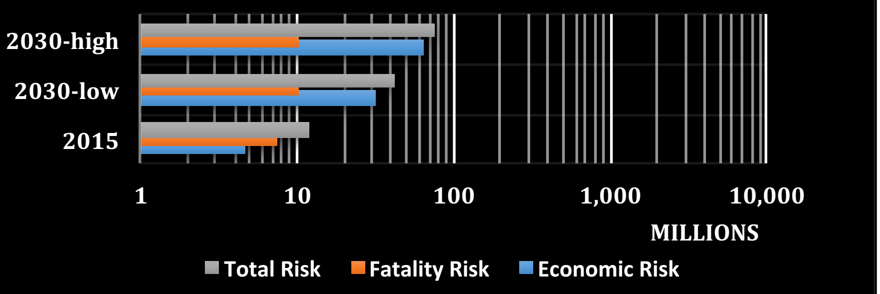


Now

Rank	*City*	*Risk(Million€/yr)*
29	Okayama	17.1
30	Palembang	13.7
31	**Ho Chi Minh City**	**12.1**
32	Sydney	11.0
33	Pyongyang	10.3

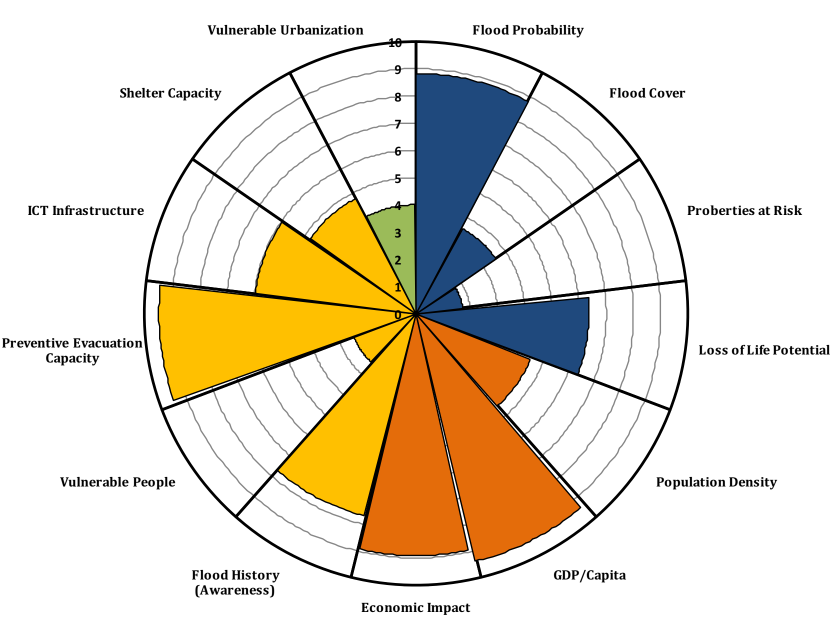
2030-low

Rank	*City*	*Risk(Million€/yr)*
27	Portland	76.5
28	Karachi	64.2
29	**Ho Chi Minh City**	**42.1**
30	Culiacan	39.7
31	Sydney	39.5

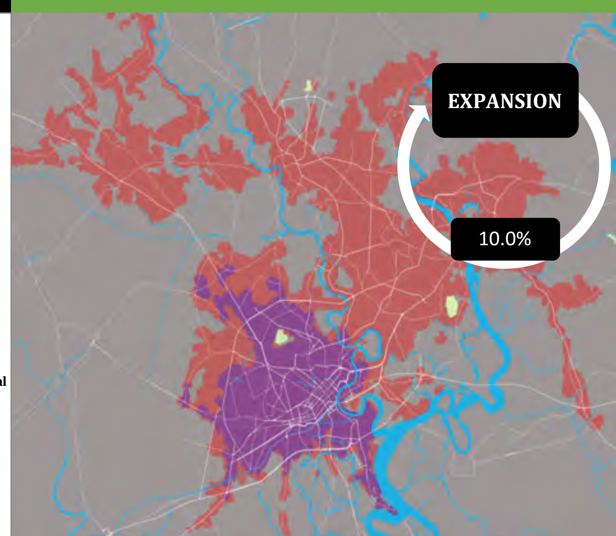
2030-high

Rank	*City*	*Risk(Million€/yr)*
27	Portland	98.0
28	London	95.0
29	**Ho Chi Minh City**	**73.9**
30	Montreal	72.4
31	Hangzhou	59.7

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

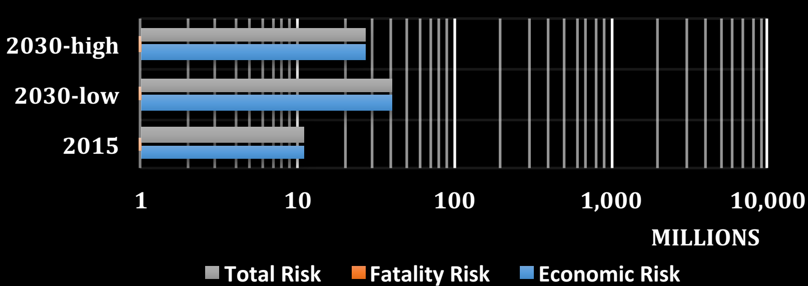


ALARM:

Sydney

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
30	Palembang	13.7
31	Ho Chi Minh City	12.1
32	**Sydney**	**11.0**
33	Pyongyang	10.3
34	Montreal	9.0

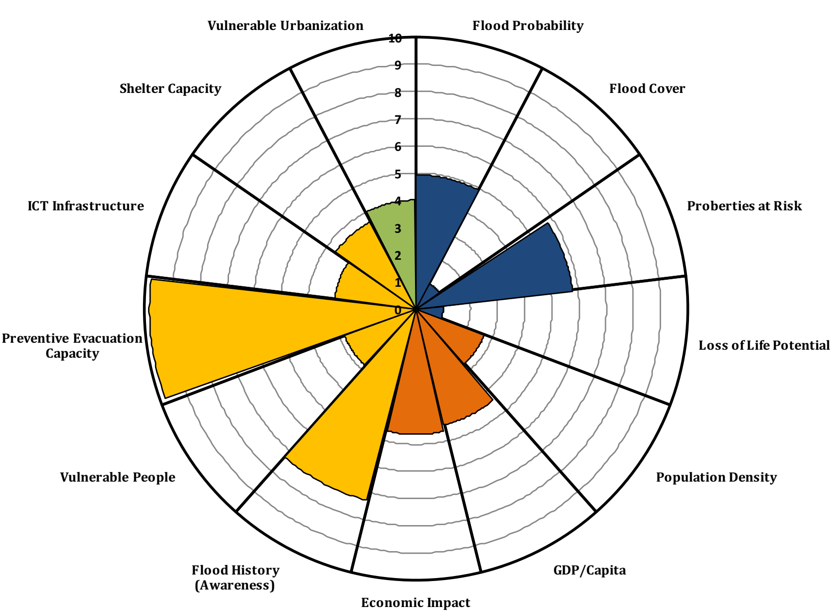
2030-low

Rank	*City*	*Risk(Million€/yr)*
29	Ho Chi Minh City	42.1
30	Culiacan	39.7
31	**Sydney**	**39.5**
32	Okayama	36.7
33	Hangzhou	25.2

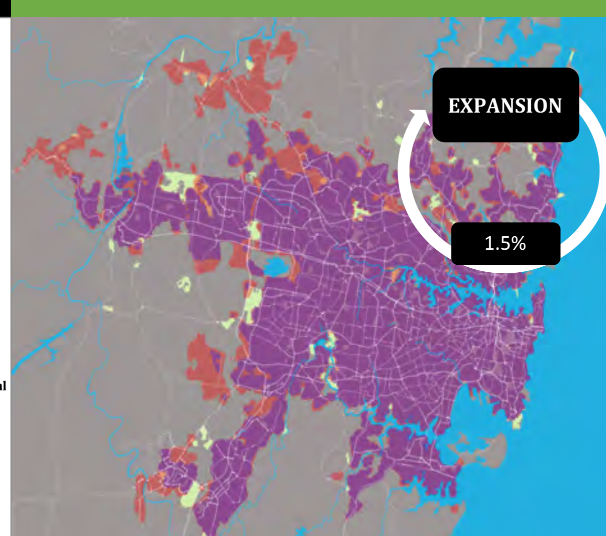
2030-high

Rank	*City*	*Risk(Million€/yr)*
32	Culiacan	54.8
33	Okayama	42.4
34	**Sydney**	**27.3**
35	Pyongyang	27.1
36	Antwerp	13.8

FLOOD INDEX



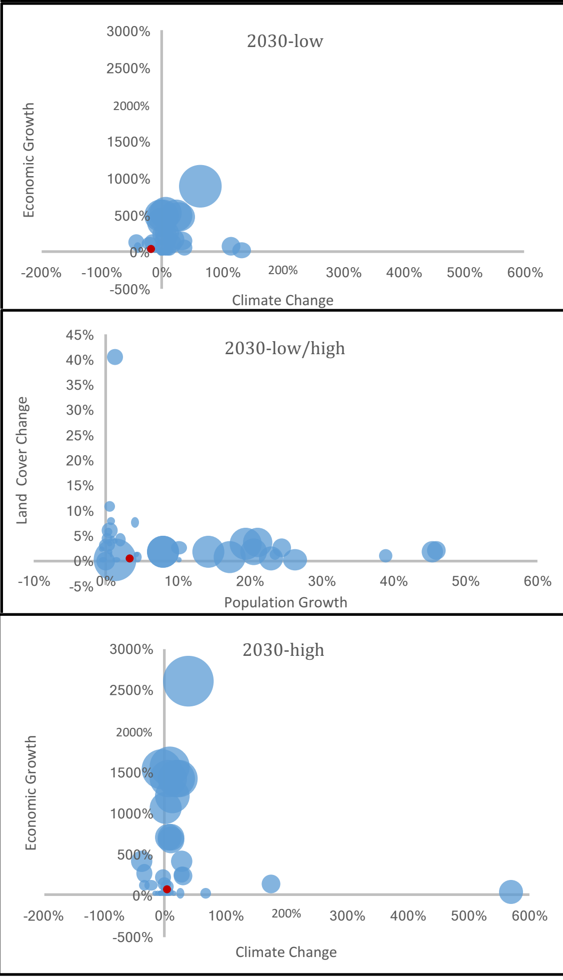
ADAPTIVE CAPACITY OF CITIES



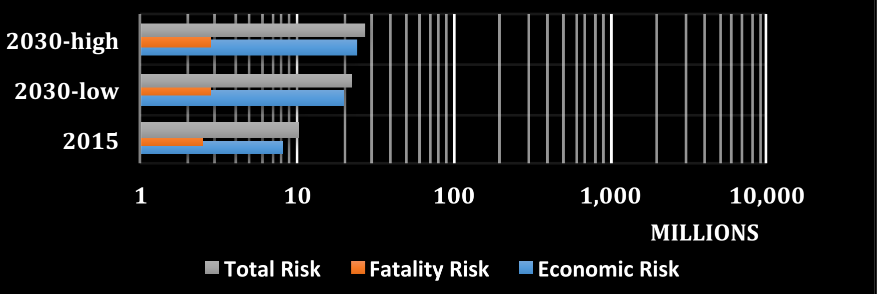
ALARM:

Pyongyang

Risk Increase Contribution



RISK



Now

Rank	City	Risk(Million€/yr)
31	Ho Chi Minh City	12.1
32	Sydney	11.0
33	**Pyongyang**	**10.3**
34	Montreal	9.0
35	Antwerp	6.4

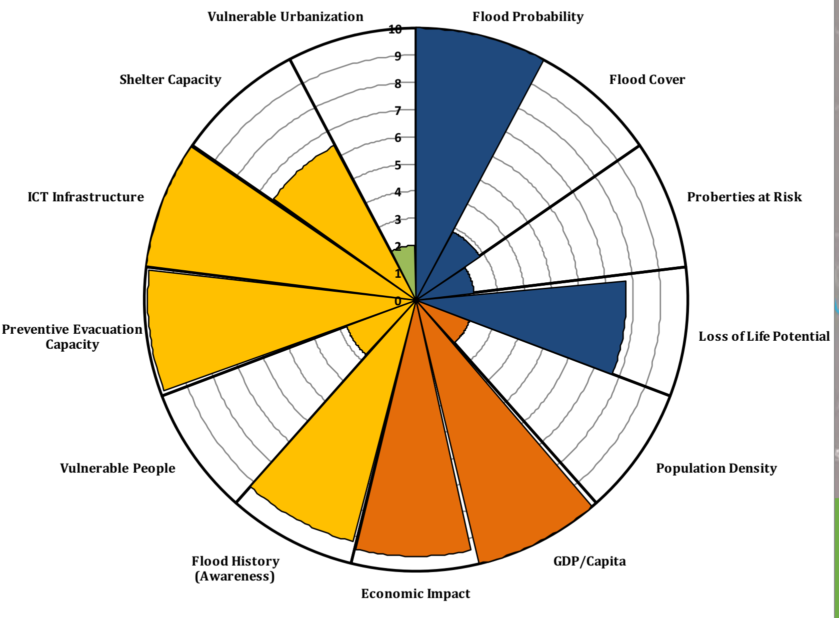
2030-low

Rank	City	Risk(Million€/yr)
32	Okayama	36.7
33	Hangzhou	25.2
34	**Pyongyang**	**22.5**
35	Montreal	20.0
36	Antwerp	13.2

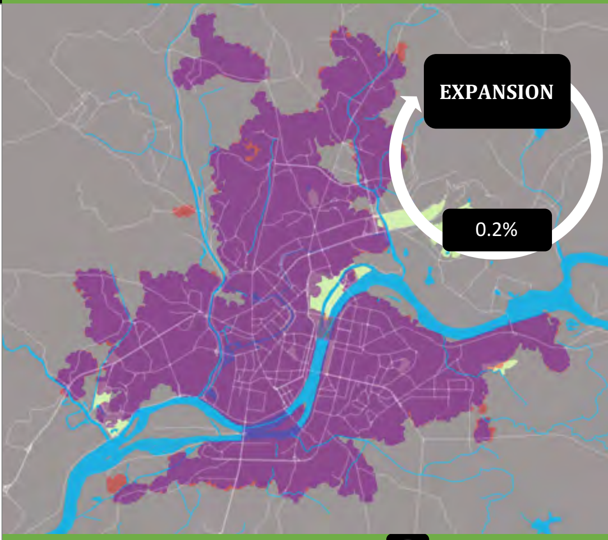
2030-high

Rank	City	Risk(Million€/yr)
33	Okayama	42.4
34	Sydney	27.3
35	**Pyongyang**	**27.1**
36	Antwerp	13.8
37	Manchester	11.9

FLOOD INDEX



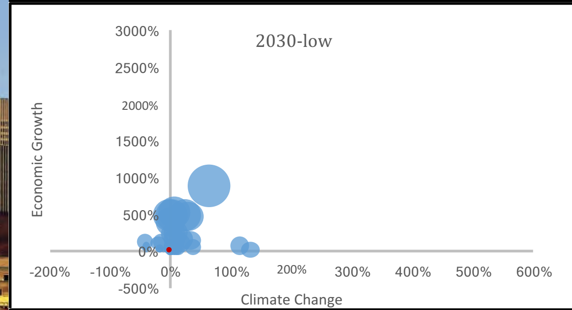
ADAPTIVE CAPACITY OF CITIES

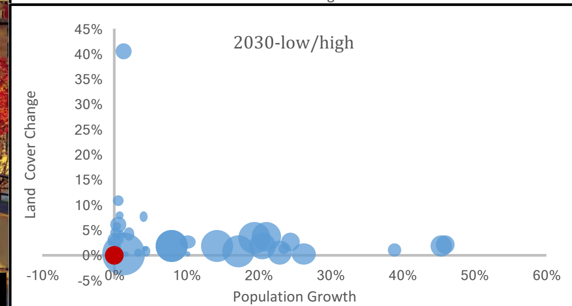


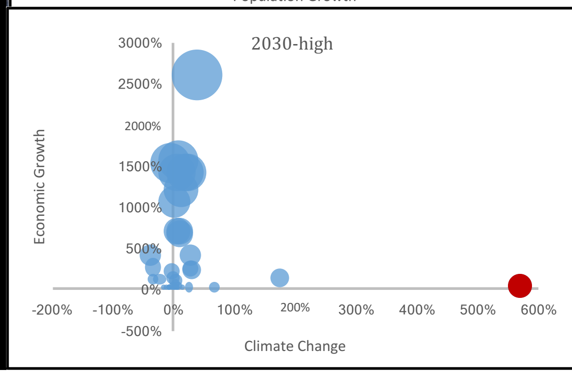
ALARM:

Montreal

Risk Increase Contribution







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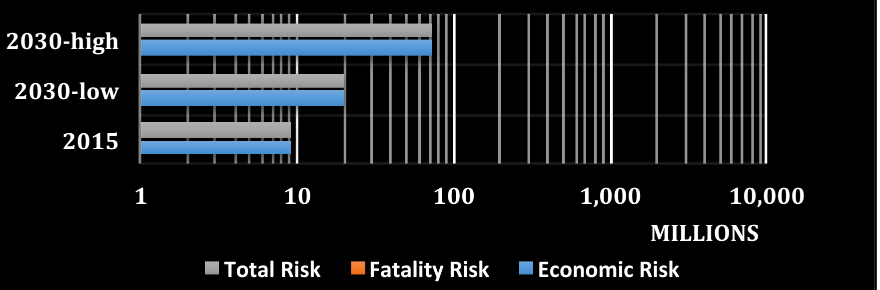


Now

Rank	*City*	*Risk(Million€/yr)*
32	Sydney	11.0
33	Pyongyang	10.3
34	**Montreal**	**9.0**
35	Antwerp	6.4
36	Manchester	5.5

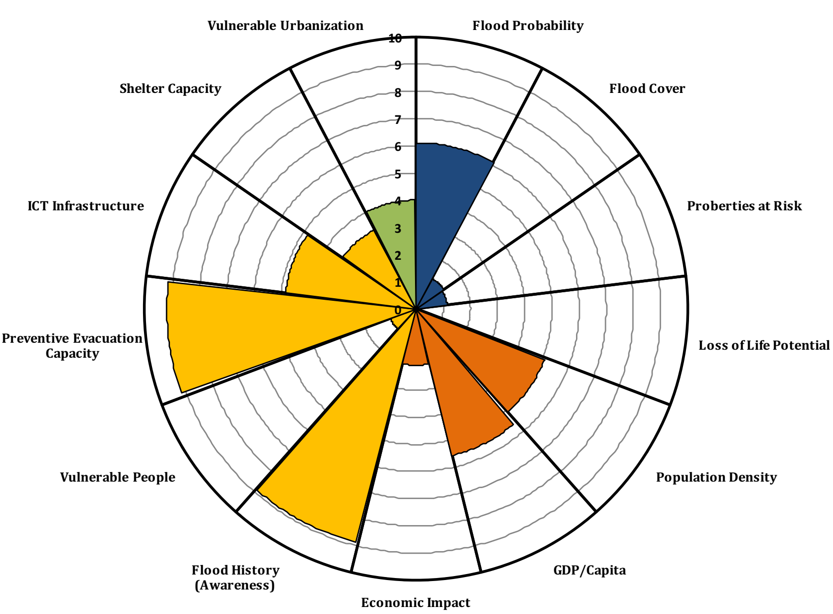
2030-low

Rank	*City*	*Risk(Million€/yr)*
33	Hangzhou	25.2
34	Pyongyang	22.5
35	**Montreal**	**20.0**
36	Antwerp	13.2
37	Manchester	11.9

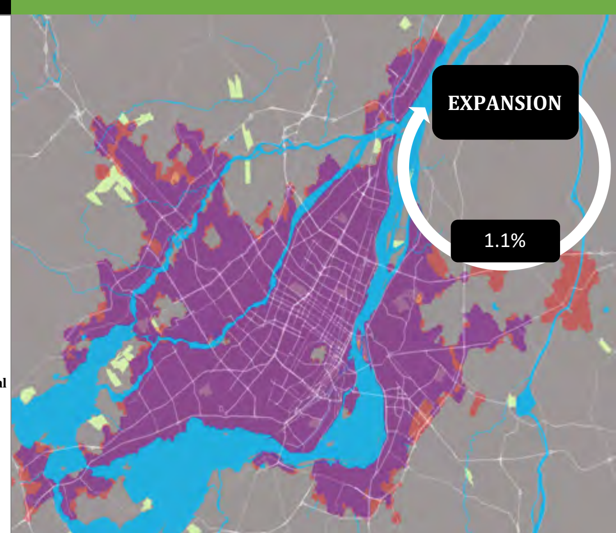
2030-high

Rank	*City*	*Risk(Million€/yr)*
28	London	95.0
29	Ho Chi Minh City	73.9
30	**Montreal**	**72.4**
31	Hangzhou	59.7
32	Culiacan	54.8

FLOOD INDEX



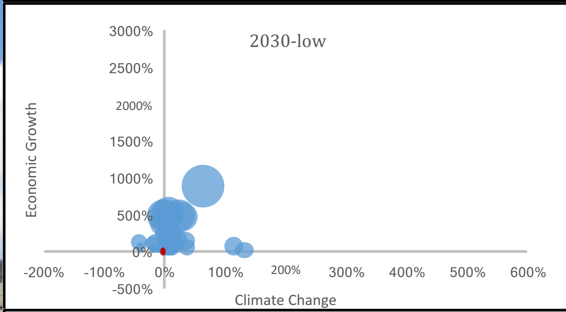
ADAPTIVE CAPACITY OF CITIES

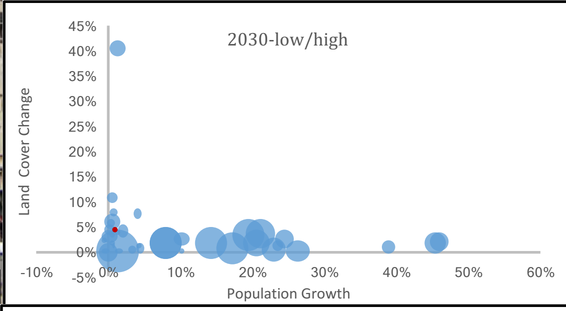


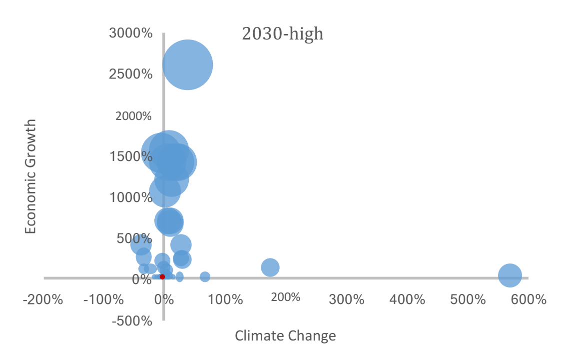
ALARM:

Antwerp

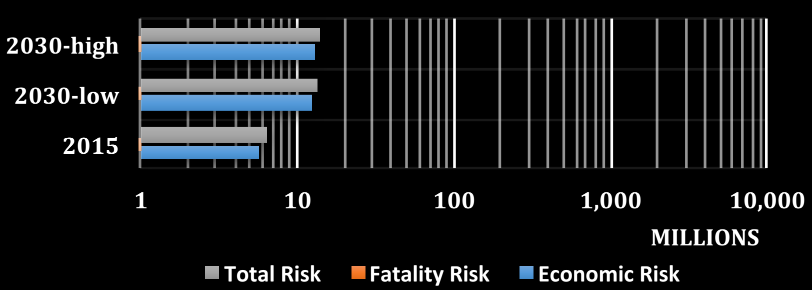
Risk Increase Contribution







RISK



Now

Rank	*City*	*Risk(Million€/yr)*
33	Pyongyang	10.3
34	Montreal	9.0
35	**Antwerp**	**6.4**
36	Manchester	5.5
37	Hangzhou	4.3

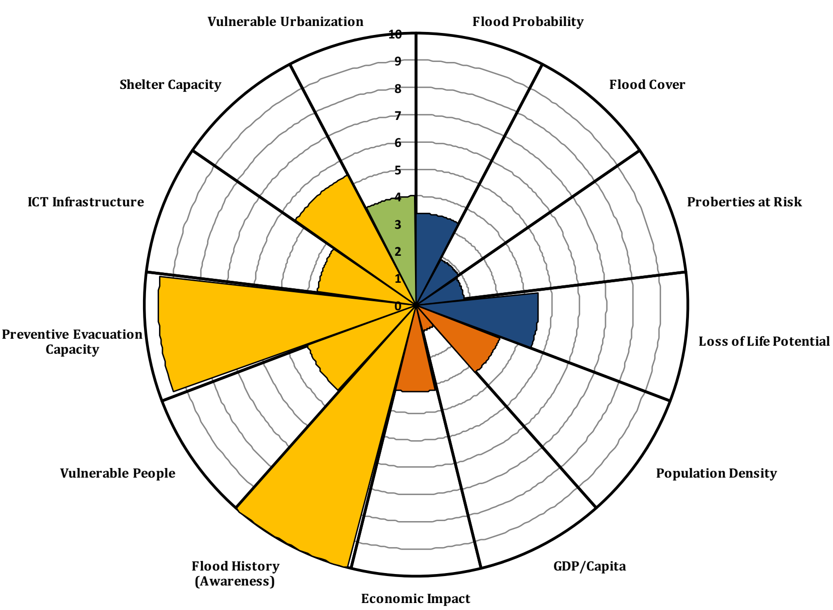
2030-low

Rank	*City*	*Risk(Million€/yr)*
34	Pyongyang	22.5
35	Montreal	20.0
36	**Antwerp**	**13.2**
37	Manchester	11.9
38	Port Elizabeth	0.9

2030-high

Rank	*City*	*Risk(Million€/yr)*
34	Sydney	27.3
35	Pyongyang	27.1
36	**Antwerp**	**13.8**
37	Manchester	11.9
38	Port Elizabeth	1.3

FLOOD INDEX

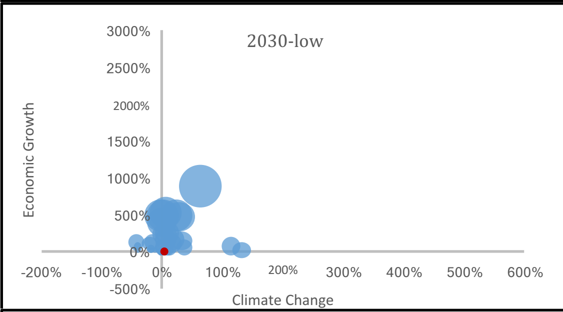


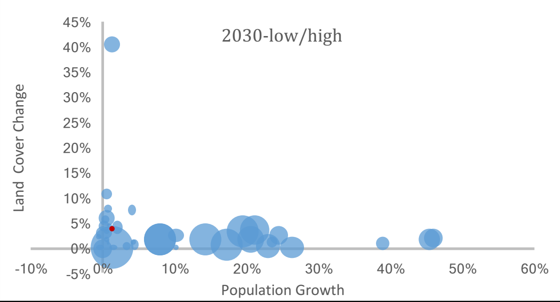
ADAPTIVE CAPACITY OF CITIES

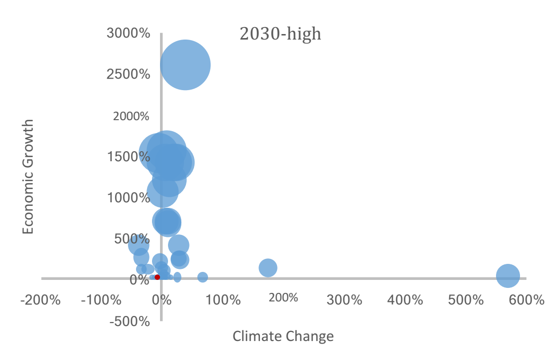
ALARM:

Manchester

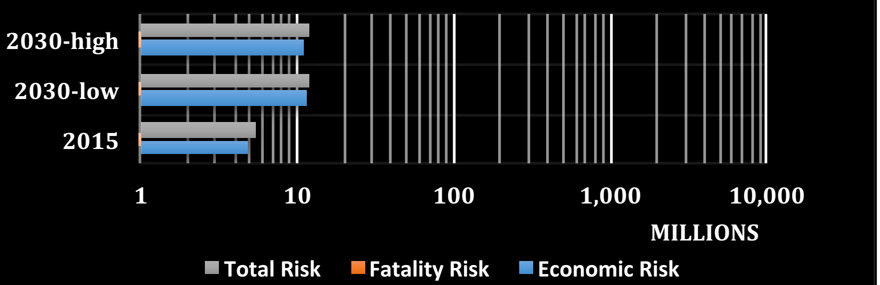
Risk Increase Contribution







RISK



Now

Rank	*City*	*Risk(Million€/yr)*
34	Montreal	9.0
35	Antwerp	6.4
36	**Manchester**	**5.5**
37	Hangzhou	4.3
38	Port Elizabeth	0.3

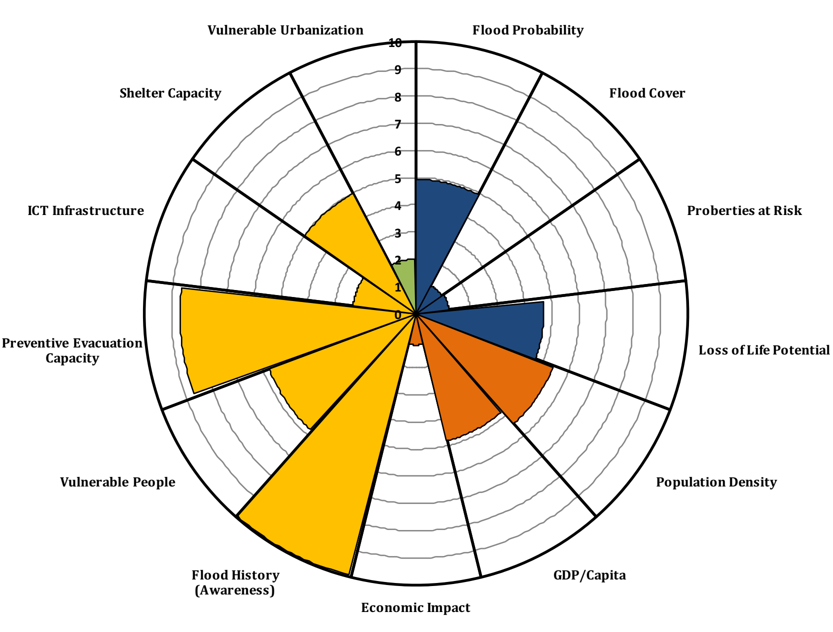
2030-low

Rank	*City*	*Risk(Million€/yr)*
34	Pyongyang	22.5
35	Montreal	20.0
36	Antwerp	13.2
37	**Manchester**	**11.9**
38	Port Elizabeth	0.9

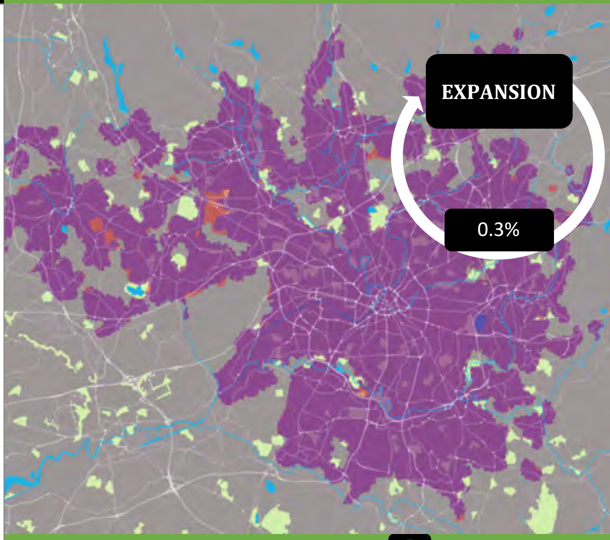
2030-high

Rank	*City*	*Risk(Million€/yr)*
34	Sydney	27.3
35	Pyongyang	27.1
36	Antwerp	13.8
37	**Manchester**	**11.9**
38	Port Elizabeth	1.3

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES

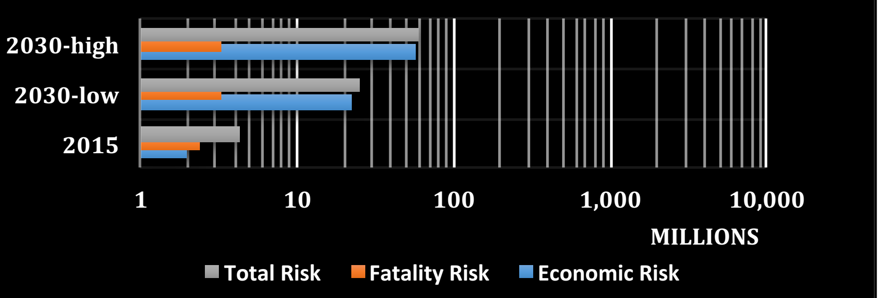


ALARM:

Hangzhou

Risk Increase Contribution

RISK



Now

Rank	*City*	*Risk(Million€/yr)*
34	Montreal	9.0
35	Antwerp	6.4
36	Manchester	5.5
37	**Hangzhou**	**4.3**
38	Port Elizabeth	0.3

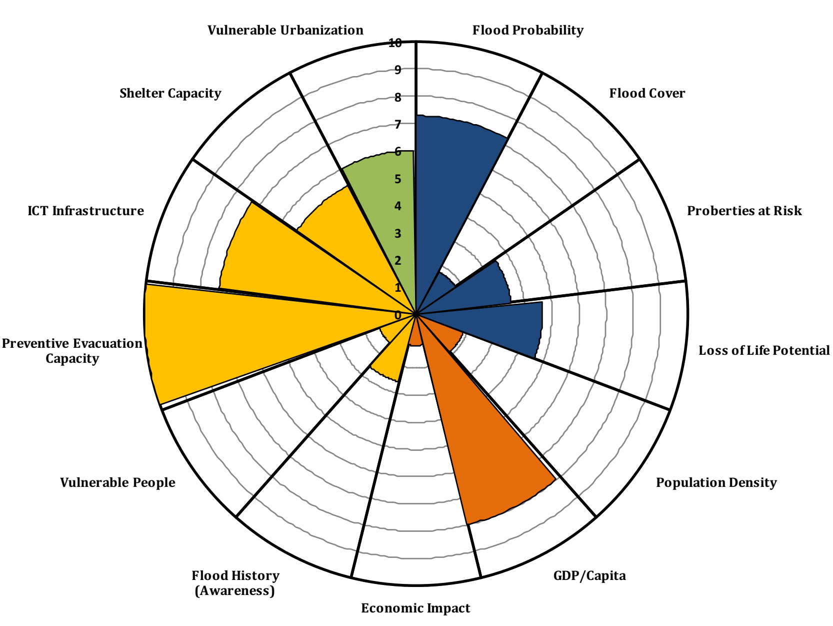
2030-low

Rank	*City*	*Risk(Million€/yr)*
31	Sydney	39.5
32	Okayama	36.7
33	**Hangzhou**	**25.2**
34	Pyongyang	22.5
35	Montreal	20.0

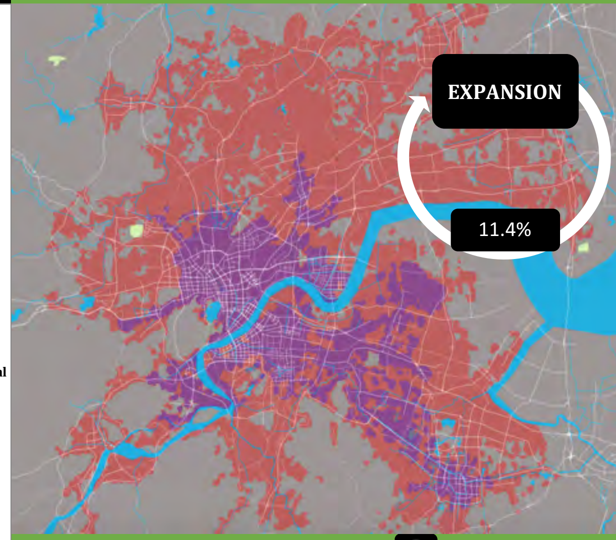
2030-high

Rank	*City*	*Risk(Million€/yr)*
29	Ho Chi Minh City	73.9
30	Montreal	72.4
31	**Hangzhou**	**59.7**
32	Culiacan	54.8
33	Okayama	42.4

FLOOD INDEX



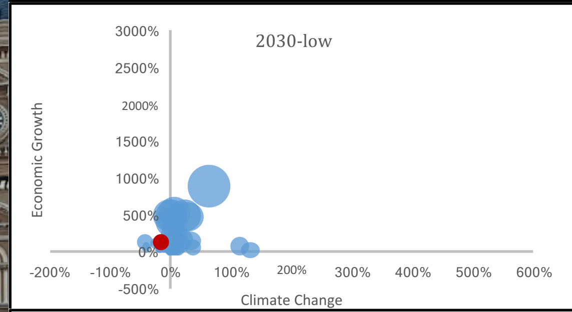
ADAPTIVE CAPACITY OF CITIES

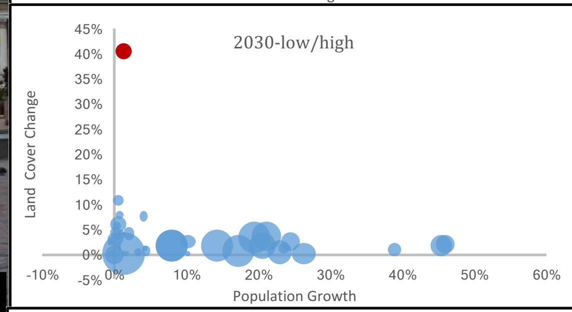


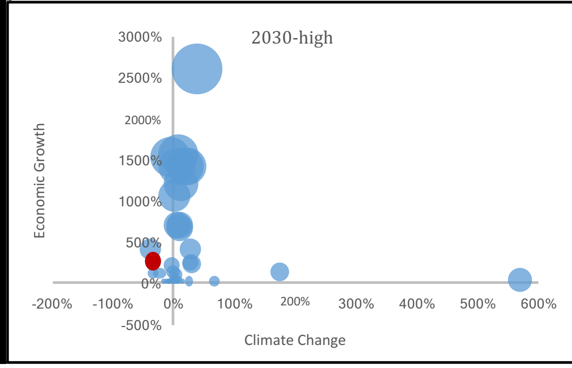
ALARM:

Port Elizabeth

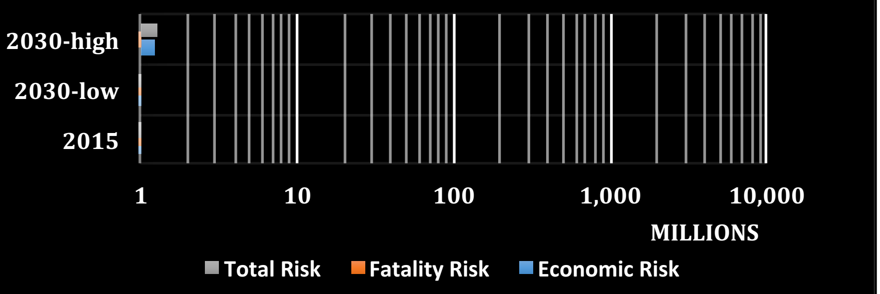
Risk Increase Contribution







RISK



Now

Rank	City	Risk(Million€/yr)
34	Montreal	9.0
35	Antwerp	6.4
36	Manchester	5.5
37	Hangzhou	4.3
38	**Port Elizabeth**	**0.3**

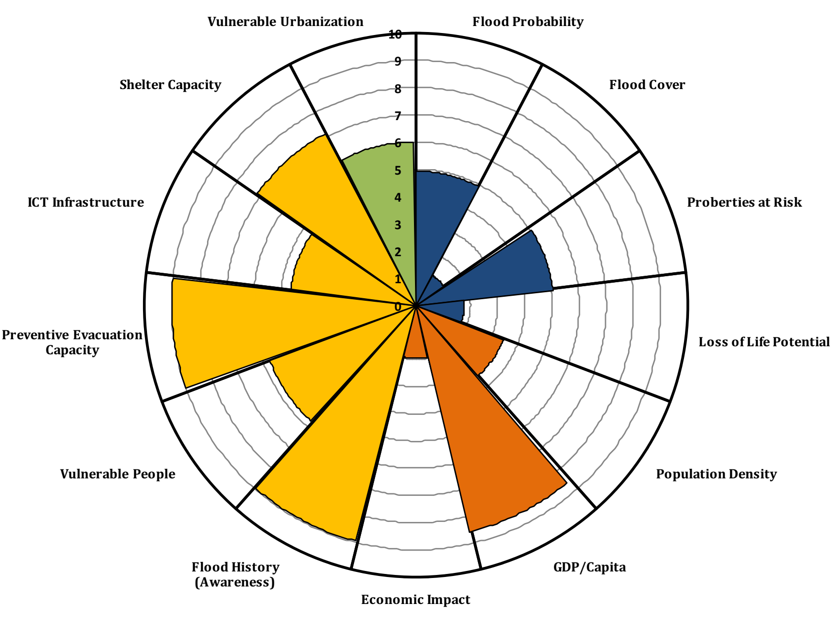
2030-low

Rank	City	Risk(Million€/yr)
34	Pyongyang	22.6
35	Montreal	20.0
36	Antwerp	13.5
37	Manchester	12.2
38	**Port Elizabeth**	**1.0**

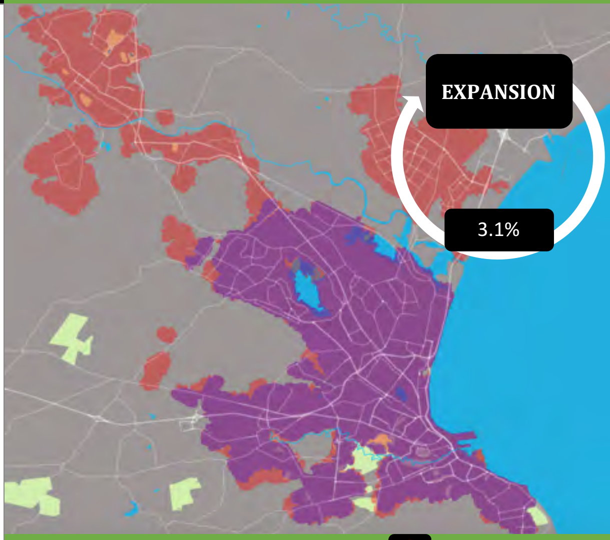
2030-high

Rank	City	Risk(Million€/yr)
34	Sydney	27.3
35	Pyongyang	27.1
36	Antwerp	13.8
37	Manchester	11.9
38	**Port Elizabeth**	**1.3**

FLOOD INDEX



ADAPTIVE CAPACITY OF CITIES



ALARM: