Assessing the Resiliency of Urban Environments to Climate Change

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Abstract

Many areas of the world are experiencing large inflows of people from rural areas into urban areas. In some areas of the developing world, this is giving rise to "megacities," cities with 10 million inhabitants or more. The growth of some of these megacities is not in response to the promise of economic opportunity (i.e., a surplus of jobs), rather, it is a matter of basic survival prospects and often results in people merely swapping rural poverty for urban poverty.

Many of the major urban environments around the world are in areas where the potential impacts from climate change are predicted to be severe. For urban environments in coastal areas, sea level rise may threaten the very existence of these cities. In addition, the costs of developing adaptive or mitigation solutions will be considerable and may be beyond the means of countries in the developing world.

In this paper we examine approaches that can be used to assess the resiliency of urban environments to climate change. These approaches can be used by decision makers to assess risks and develop mitigation strategies. We discuss both internal "self-assessment" type approaches and the use of complementary external independent approaches to evaluate the capability to respond to and reduce risks from natural disasters and climate change. We then give examples of analyses of both approaches, done at the country level, with examination of the issues associated with applying within a nation to specific urban areas. Finally, we discuss various strategies that urban environments can utilize to mitigate or adapt to climate change impacts, including relocation which could be the only choice for some coastal areas.

Key Words: Resiliency, urban environments, climate change, decision support

1. Introduction

Many areas of the developing world are experiencing a massive inflow of people from rural areas into urban areas. In some countries, this is giving rise to "megacities," cities with 10 million inhabitants or more. In 2014, there were 33 megacities around the world in both developed and developing countries and there a number of areas that are growing quickly and could become future megacities. According to the United Nations, 1 out of every 2 children born in the future will grow up in an urban environment (United Nations, 2014). The growth in some of the megacities is often not in response to the promise of economic opportunity (i.e., a surplus of jobs), but is a matter of basic survival prospects and simply results in people swapping rural poverty for urban poverty.

Table 1 gives an example of megacities from around the world, selecting at least one from each major region of the world (the Americas, Europe, Africa, Asia, and Oceania) and compares them using data elements from the United Nations (UN) Human Development Index (HDI) project (UNDP, 2014). The HDI rankings, which are a composite statistic of four indicators used to rank countries, in the second column are for the 198 countries assessed in the UN data and the qualitative developmental categories used by the UN of "very high", "high", "medium", and "low". The HDI data noted in Table 1 are country level summaries and are presented for comparative purposes only as they may not necessarily be representative of the conditions in the noted cities.

Table 1. Representative Megacities and Human Development Index Data (UNDP, 2014).

City, Country	HDI Ranking (Out of 198)	Life Expectancy at Birth (Years)	Under 5 Years Mortality Rate*	Maternal Mortality Rate*	Gross National Income Per Capita ($)
Tokyo, Japan	17 Very High	83.6	3	5	36,747
Jakarta, Indonesia	108 Medium	70.8	31	220	8,970
New York City, USA	5 Very High	78.9	7	21	52,308
Karachi, Pakistan	146 Low	66.6	86	260	4,652
Dhaka, Bangladesh	142 Medium	70.7	41	240	2,713
Sao Paulo, Brazil	79 High	73.9	14	56	14,275
Lagos, Nigeria	152 Low	52.5	124	630	5,353

*Per 1,000 live births

The purpose in presenting the data in Table 1 is to point out that there are significant differences between urban environments and that there cannot be a "one-size-fits-all" solution to how to make them more resilient to extreme perturbations, such as impacts from climate change. Further, many of the major urban environments are in areas where the potential impacts from climate change are predicted to be severe. For urban environments in coastal areas, sea level rise may threaten the very existence of cities. In addition, the costs of developing mitigation or adaptive solutions may be beyond the means of the developing world.

2. Defining Resiliency

It is acknowledged that the literature abounds with numerous definitions for resiliency and that they can vary depending upon the system under study. For the purposes of this work, we are defining resiliency as "the ability of an entity (e.g., asset, organization, community or region) to anticipate, resist, absorb, respond to, adapt, to, and recover from either natural or man-made events." This definition is based on one used by Argonne National Laboratory in its analyses of the resiliency of infrastructure systems (Hummel, 2014).

In this paper, we will be focusing on community resilience of urban environments. In our discussions, a "community" can be represented at many functional levels, from a national level to individual cities to neighborhoods. This is consistent with the fact that there is no universal definition of what level of population density and degree of features constitutes an urban environment. However, in adopting our broad view, we do not mean to imply that analyses done at a national level will by definition apply to smaller demographic levels within a nation or region. In fact, analyses at differing scales will elucidate challenges inherent to those granularities, and therefore, indicate appropriate actions that could be initiated.

Figure 1 shows the basic concepts that contribute to community resiliency as used by Argonne researchers (Hummel, 2014). Again, the literature contains different terms and definitions for the resiliency characteristics, but they all generally share common themes: being able to meet the basic needs of the community; having the will to improve the quality of life; having the services and functionality to make the improvements; and being able to maintain and secure the improvements. The degree to which a secure environment is maintained can also be considered to be a measure of the stability in a community.

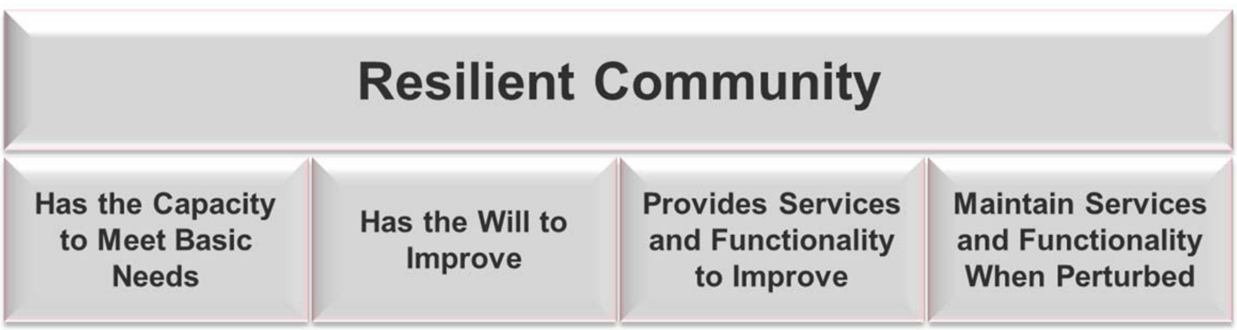


Figure 1. Characteristics that contribute to community resiliency.

Efforts to build community resilience require a system wide perspective. For example, making a public health system more resilient requires improvements to more than just the public health facilities. The public health system also needs a robust educational system to supply the necessary staffing, a financial system to provide needed funding and operating expenses, a governing system to provide appropriate regulatory guidelines, industry and businesses to provide the necessary supplies and supply chains, etc.

Figure 2 gives a conceptual view of the systems that are required in a resilient community. The elements shown are high level representations of the systems that contribute to a resilient community and can be broken down in to a finer level of sub-systems and/or combined with other systems to represent more complex concepts, such as an "economy." The result of these contributing systems is that any analysis of resilient communities must be done as a "system-of-systems" problem.

The systems in Figure 2 are fairly obvious in their contribution, but a comment is warranted for the "human landscape" system shown at the bottom. This system represents the human players that must be engaged in order to make any activities happen as well as the human elements that will be impacted by the activities - they represent where some measures of effectiveness would be assessed.

Figure 2. A conceptual view of the systems that contribute to community resiliency.

All of the systems shown in Figure 2 will require adaptation and mitigations strategies to respond to climate change. For example, public health systems in temperate locations have begun to observe diseases normally only associated with tropical environments. Utilities and public infrastructure in many coastal areas are being hardened to respond to more occurrences of severe weather. New building codes are being developed for the construction industry to incorporate anticipated future environmental conditions so that the developments can be insured by the insurance community. Finally, the financial community is developing new financial mechanisms that incentivize developments that incorporate "green" technologies and do not locate in or further impact environmentally sensitive locations, like flood plains and coastal areas that can be impacted by major sea level increases.

3. Self-Assessing Regional Resiliency to Climate Change

As confidence in the predictions from climate models increases, numerous efforts have begun to enable regions, countries, and urban environments to assess their plans and the resources necessary to respond to climate impacts. While there are many assessment approaches available, we will focus on just one in this paper – the Hyogo Framework for Action (HFA). The HFA (UNISDR, 2005) began in 2005 as a 10-year plan with the goal of assisting countries in reducing their risks to natural disasters and climate change. In 2015, the HFA was superseded with a new 15-year activity, the Sendai Framework for Action. (UNISDR, 2015). As with the original Hyogo effort, the Sendai effort involves voluntary participation by the signatory countries. Since food security is critical to our ability to respond to impacts from climate change, the United

Nation's (UN) Food and Agriculture Organization has also developed a food security framework that is based on the HFA (FAO, 2014).

The HFA involved 5 priorities that represented the goals for each country to achieve, with each priority broken down further into a set of core indicators. The HFA priorities are:

- **Priority 1 –** Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.
- **Priority 2 –** Identify, assess and monitor disaster risks and enhance early warning.
- **Priority 3 –** Use knowledge, innovation, and education to build a culture of safety and resilience at all levels.
- **Priority 4 –** Reduce the underlying risk factors.
- **Priority 5 –** Strengthen disaster preparedness for effective response at all levels.

During the original 10-year span of the HFA, the signatory countries conducted self-assessments of their progress in meeting the 5 priorities of the HFA. The self-assessments were made using a 1 – 5 Likert rating scale in which 5 denoted that substantial progress had been made and 1 very little progress had been achieved. All responses involved whole number values.

The 86 countries shown in Figure 3 prepared self-assessments of their progress in meeting the HFA priorities for the years 2009 – 2011. The responses were analyzed by Argonne as part of the efforts to prepare for the negotiations leading to the final approval of the Sendai Framework.

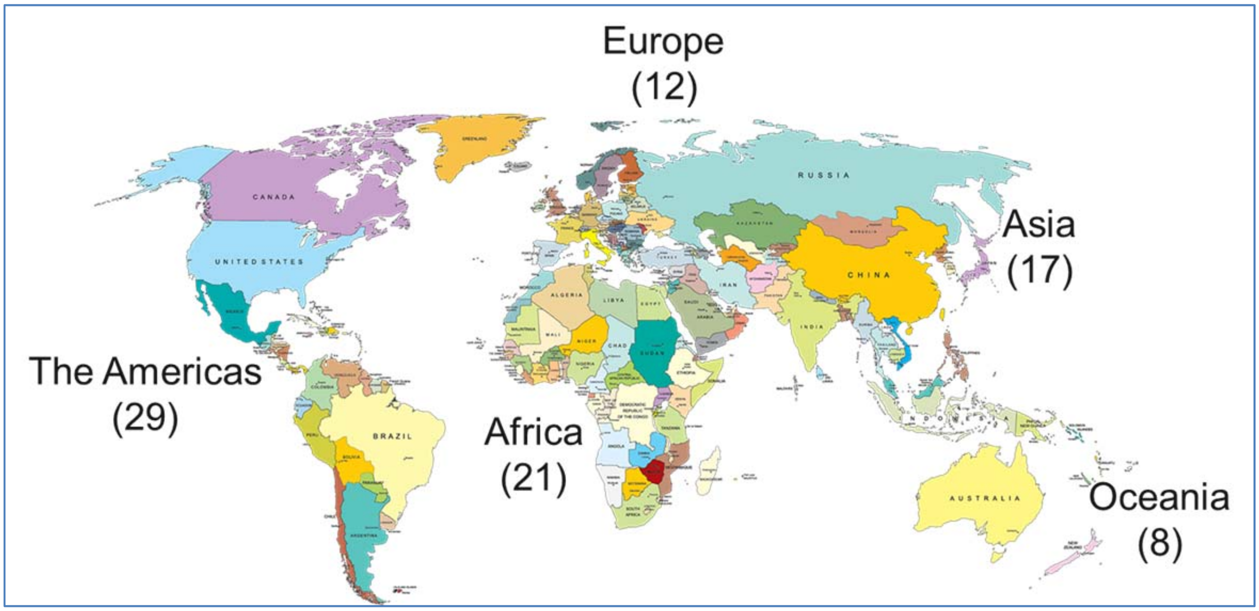


Figure 3. Regional distribution of countries that provided self-assessments to the Hyogo Framework for Action for the years 2009-2011.

The responding countries covered the full spectrum of developed countries as measured by the UN HDI program, with the majority of the countries being in the categories of "medium" to "low" human development. Seven of the countries had at least 1 current "megacity" within their borders while all of the others had at least 1 major growing urban area. Table 2 lists the countries in each region and the average degree of urbanization and annual rate of growth in urbanization in each region based on estimates for the years 2010 - 2015(CIA World Fact Book, 2013). Figure 4 shows the results for the HFA priorities self-assessments averaged over the countries in each region.

Table 2. Summary of the regions that provided HFA self-assessments and the average level of urbanization and annual rate of increase in urbanization.

HFA Region	**Countries**	**Degree of Urbanization (% of Population)**	**Annual Rate of Increase (%)**
Africa	Algeria, Botswana, Burundi, Cape Verde, Comoros, Cote d'Ivoire, Ghana, Guinea-Bissau, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Morocco, Mozambique, Nigeria, Senegal, Sierra Leone, Tanzania, Zambia	40.3	3.4
The Americas	Anguilla, Antigua and Barbuda, Argentina, Barbados, Bolivia, Brazil, British Virgin Islands, Canada, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, Saint Kitts and Nevis, Saint Lucia, Turks and Caicos Islands, United States of America, Venezuela	68.3	1.6
Asia	Bangladesh, Brunei, Georgia, India, Indonesia, Japan, Laos, Lebanon, Malaysia, Maldives, Mongolia, Nepal, Pakistan, Sri Lanka, Syria, Thailand, Yemen	51.9	2.4
Europe	Armenia, Bulgaria, Czech Republic, Finland, Germany, Italy, Norway, Poland, Romania, Sweden, Switzerland, Macedonia*	70.9	0.4
Oceania	Australia, Cook Islands, Fiji, Marshall Islands, New Zealand, Samoa, Solomon Islands, Vanuatu	55.0	1.6

*Former Yugoslavian Republic

As shown in Figure 4, there is not an important difference between the regions that would enable one to draw any regional conclusions, nor should one try to because of the large disparity in the capabilities of the countries, at least in terms of their levels of development as expressed by the UN HDI data. (The full analysis of the HFA data for all 86 countries is contained in the supplemental report that accompanies this paper, *Analysis of HFA Assessment Results 2009-2011.doc*.)

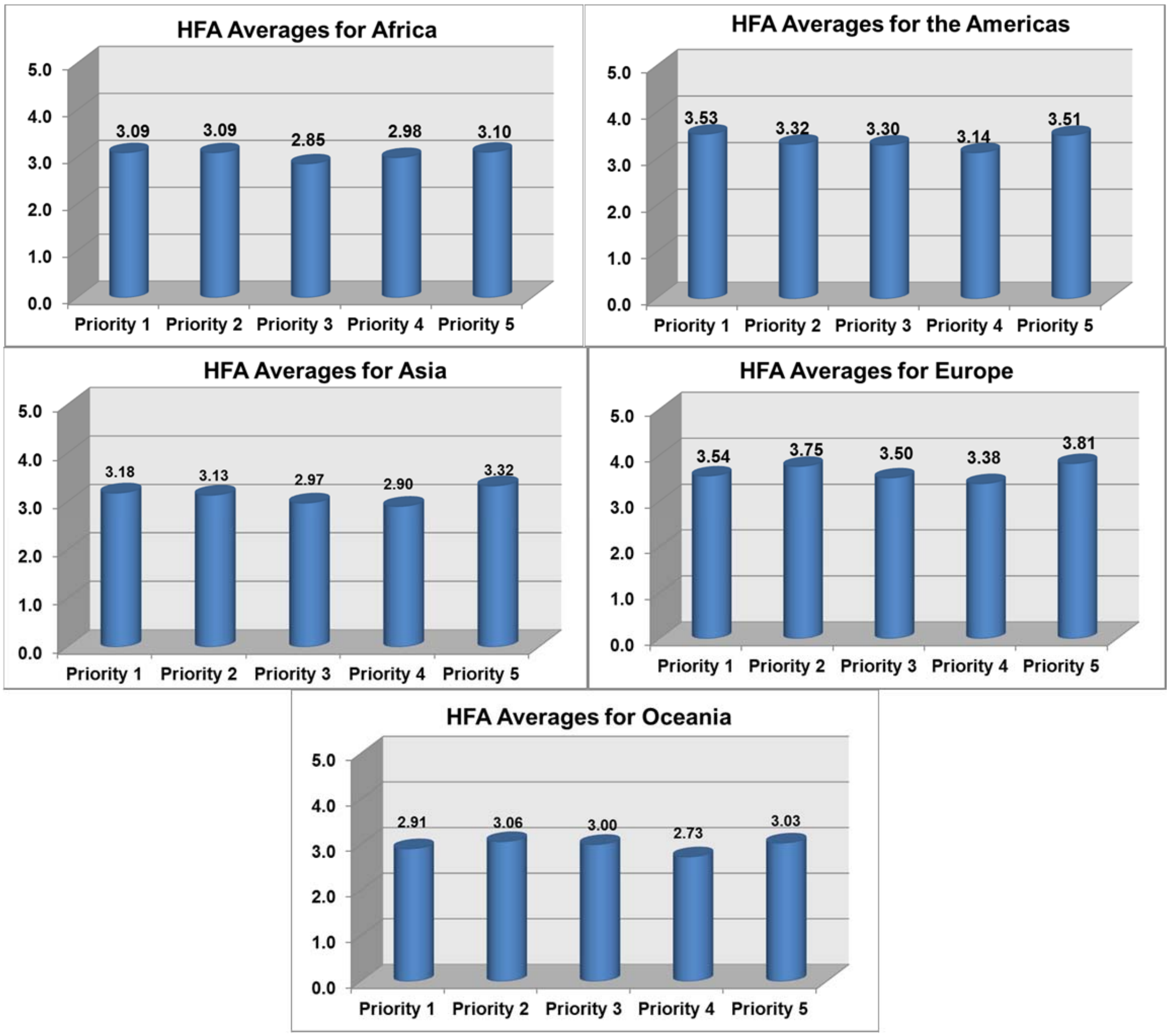


Figure 4. High level summary of the progress achieved in meeting the goals of the HFA priorities. The results are averaged over the countries in each region.

4. Assessing the Self-Assessments

In examining the country level results of the HFA self-assessments, there were some expected results. For example, countries that were considered to be "developing" countries according to the UN HDI efforts generally had lower reported results when compared against "developed" countries. However, there were some results that seemed to not be based upon representative data. The template provided by the UN for the HFA self-assessments did not require that the responding countries provide any supporting information for the self-assessments, such as who within the country generated the assessment or provide links to supporting documentation, therefore making it difficult for external evaluators (e.g., non-governmental organizations or potential donor countries) to perform any degree of independent analysis or verification of the results.

In support of an effort to provide recommendations to the groups participating in the negotiations on the language of the final Sendai framework language, we performed a detailed country-by-country analysis of the HFA results and a cross mapping with other developmental metrics. The cross mappings were made using World Bank governance assessments (Kaufmann, et. al., 2009), data from the UN HDI efforts (UNDP, 2014), and a subset of data from the UN FAO Food Security Indicators database (FAO, 2014.) Both the World Bank governance and the FAO food security results are given for the 2005 to 2012 time period to mirror the time period of the HFA timespan.

For the majority of the 86 reporting countries, it was concluded that the HFA self-assessments were a reasonable measure of the resiliency of a country to the risks associated with natural disasters and climate change. Countries reporting significant progress in meeting the goals of the HFA showed high values in the World Bank governance data and a high degree of development in the UN HDI data. They also showed a low degree of food insecurity as expressed by the FAO food security metrics (e.g., prevalence of undernourishment in the population, prevalence of inadequate food, and populations with access to improved water and sanitation sources.) Countries showing little progress in meeting the HFA goals had low values in the World Bank governance data that point to structural problems in their governing systems. They were also on the lower end of the development spectrum as measured by the UN HDI metrics and had higher levels of food insecurity as shown in the FAO data. Finally, there were many countries that reported that they were making progress in meeting the HFA goals, but have yet to achieve them. These countries were generally at moderate levels of development, had positive and improving values from the governance perspective, and were showing positive trends in addressing the food security issues. However, these countries would most likely require assistance from external sources, such as from donor countries or non-governmental organizations. There was a small group of countries in which it was not clear if the HFA results painted a clear picture of their resiliency. We will present results from two countries in which there are possible inconsistencies in the HFA self-assessments – Guinea-Bissau and Brazil.

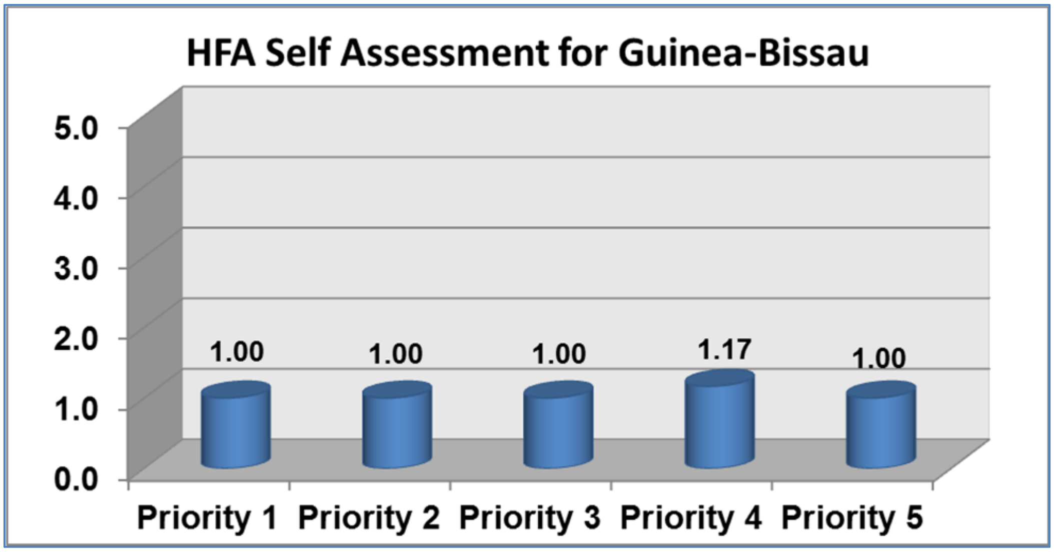
4.1 Guinea-Bissau

Guinea-Bissau, located on the West African coast between Senegal and Guinea is a former Portuguese colony that gained independence in 1974. It is a small country in both size and population. It is less than 3 times the size of the US state of Connecticut with an estimated July 2015 population of about 1.73 million inhabitants (CIA World Fact Book, 2013). The degree of urbanization in the country is 49.3% with an estimated 2010 – 2015 annual rate of urbanization change of 4.13%.

Figures 5 and 6 show the cross mapping of the HFA results against the WB governance assessments and a subset of the UN HDI and FAO food security metrics for Guinea-Bissau. The HFA results, in Figure 5 (a.), showed essentially no progress in achieving the HFA goals and the question was raised if these results were valid or if the country was just trying to attract funds from the international donor community.

The World Bank governance assessments in Figure 5 (b.) point to structural problems in the governing systems in Guinea-Bissau in all of the areas assessed and support the HFA self-assessments of little to no progress being achieved. The WB governance assessments are also supported by assessments in the CIA World Fact Book that detail the political instabilities that were occurring during the same time period. Finally, the UN HDI data in Figure 5 (c.) and the UN FAO food security assessment results in Figure 6 point to the inherent problems faced in the country in meeting basic developmental needs. To put the food security data in perspective, the percent of the population in the US with access to improved water sources and sanitation was about 99% for the years shown in Figure 6 and the depth of the food deficit for the developed countries ranged from 10 to 8 kcal/caput/day.

(a.)



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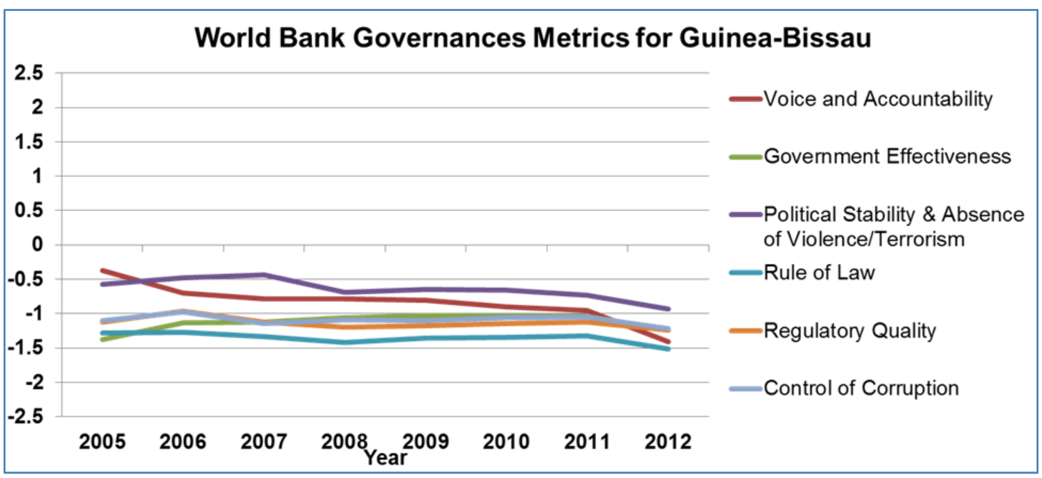
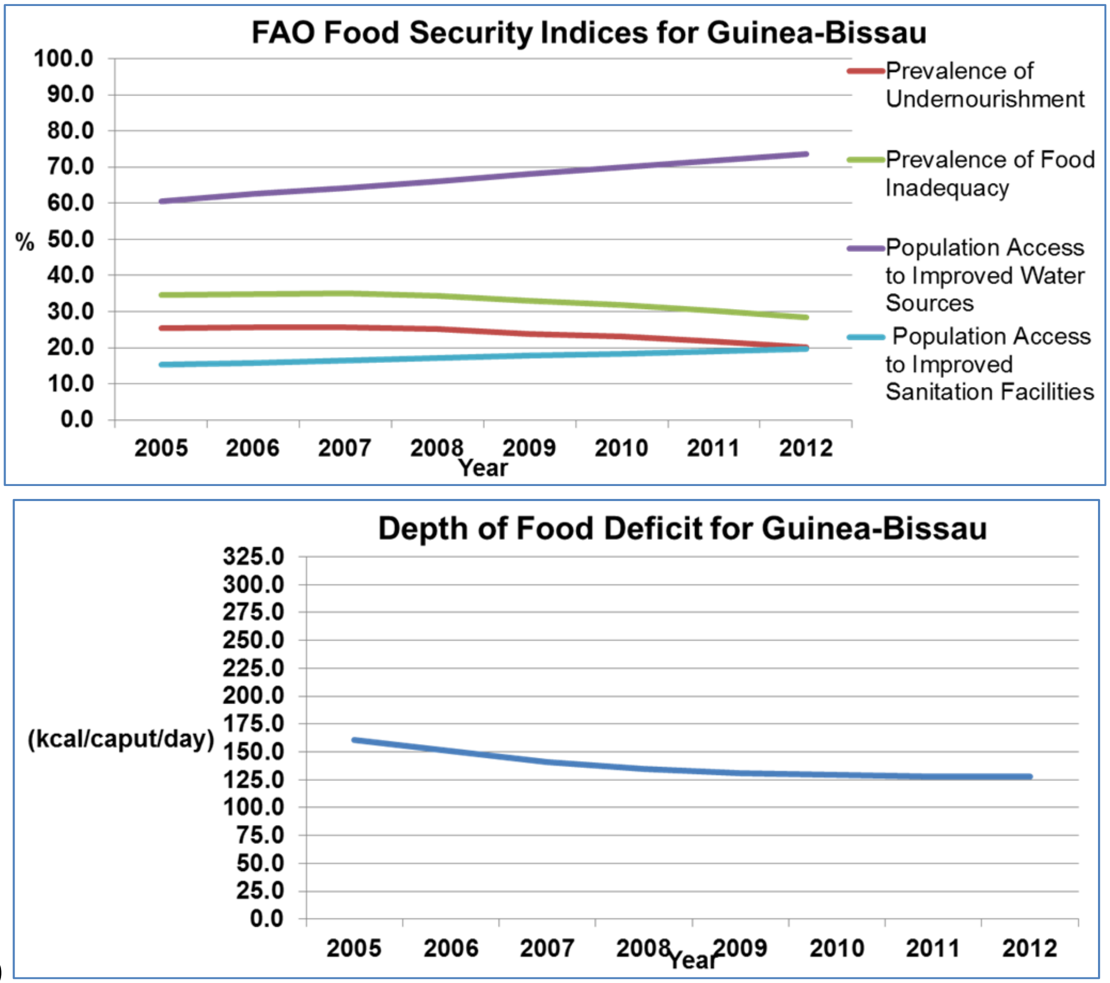


(c.)

HDI Ranking (Out of 198)	Life Expectancy at Birth (Years)	Under 5 Years Mortality Rate (per 1,000 live births)	Maternal Mortality Rate (per 1,000 live births)	Gross National Income Per Capita ($)
177 Low	54.3	129	790	1,090

Figure 5. (a.) HFA Self-Assessment Results for Guinea-Bissau, (b.) World Bank Governance Metrics, and (c.) UN Human Development Metrics.

(a.)



(b.)

Figure 6. Comparison of FAO food security indicators for Guinea-Bissau. (a.) The prevalence of undernourishment and food inadequacy and population with access to improved water and sanitation facilities and (b.) the depth of food deficit, a measure of the how many calories required to lift the undernourished from their status.

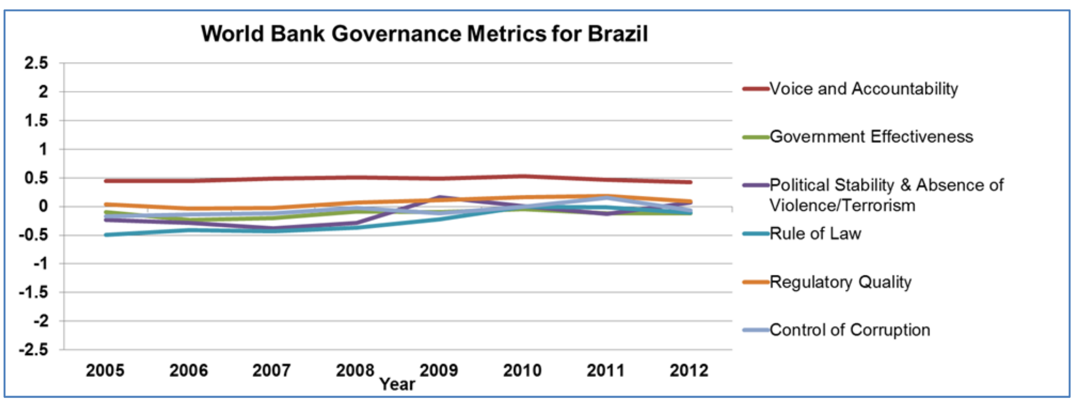
4.2 Brazil

The second example presented is for Brazil which in the UN HDI rankings is in the category of "medium" human development. Brazil is the largest country in South America with an estimated July 2015 population of 204.3 million. The degree of urbanization in the country is 85.7 % with an estimated annual rate of urbanization for the years 2010 – 2015 of 1.17%.

Figures 7 and 8 show the cross mapping of the HFA results against the WB governance assessments and a subset of the UN HDI and FAO food security metrics for Brazil. In the HFA self-assessments, Figure 7 (a.), Brazil had the highest value of 4.58 for all reporting countries. (In comparison, the United States, which is ranked third on the UN's list of developed countries, had an average HFA value of 3.75, which was the second lowest value in the category of "very high" human development countries.) When those results are compared to the WB governance values in Figure 7 (b.) a picture emerges of a country in which the government appears to be stable but still has perception issues from a strength perspective. Finally, when the UN HDI and food security data are examined, in Figures 7 (c.) and 8, it is clear that Brazil is a strong and growing country, but still facing some developmental issues. It was concluded from the analysis that Brazil provided a very optimistic picture of their progress in meeting the goals of the HFA priorities and it is has been presumed that they did not want to tarnish the image of a country that had recently been selected as the venue for the 2016 summer Olympics and would also be the host of the FIFA World Cup of soccer in 2014.

(a.)

(b.)

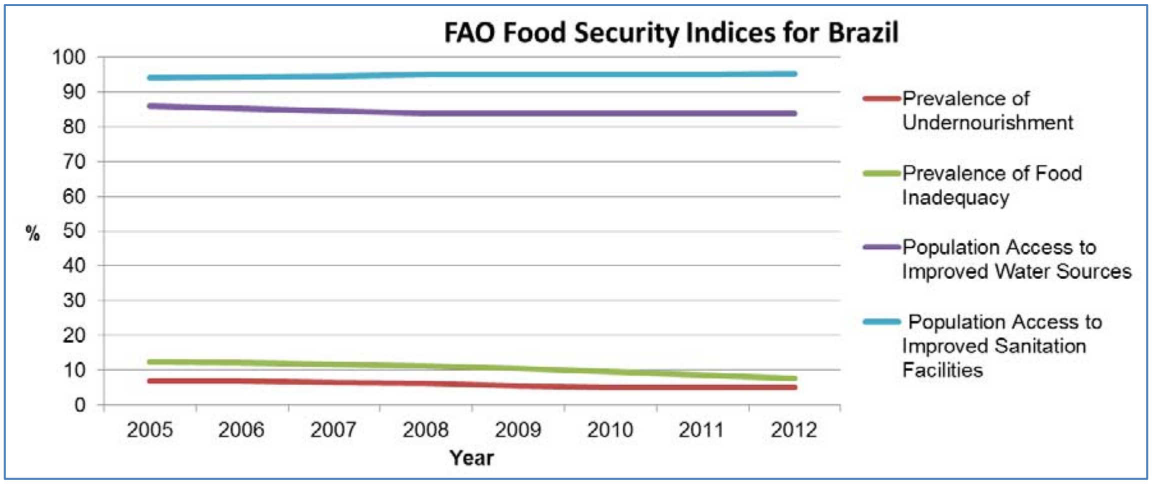


(c.)

HDI Ranking (Out of 198)	Life Expectancy at Birth (Years)	Under 5 Years Mortality Rate (per 1,000 live births)	Maternal Mortality Rate (per 1,000 live births)	Gross National Income Per Capita ($)
85 Medium	73.8	17	56	10,152

Figure 7. (a.) HFA Self-Assessment Results for Brazil, (b.) World Bank Governance Metrics, and (c.) UN Human Development Metrics.

(a.)



(b.)

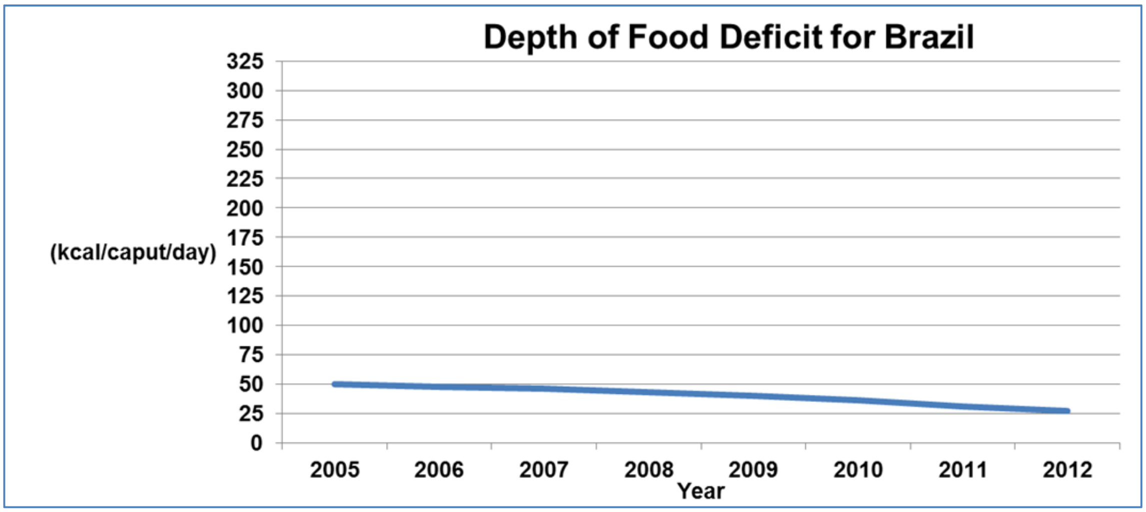


Figure 8. Comparison of FAO food security indicators for Brazil. (a.) The prevalence of undernourishment and food inadequacy and population with access to improved water and sanitation facilities and (b.) the depth of food deficit, a measure of the how many calories required to lift the undernourished from their status.

5. Addressing Organizational Challenges in Meeting the HFA Goals

As noted in the previous section, many regions have indicated that they are challenged by the goals of the HFA and this will likely continue as they adapt to the Sendai framework. The issues cannot simply be solved by greater financial support as many of them are rooted in systems-driven organizational issues that contribute to the overall resiliency of the region (see Figure 2.)

In examining the HFA priorities and their core indicators, a number of the systems noted in Figure 2 are required to achieve the goals of the HFA. We have decomposed the HFA priorities and core indicators into individual actions involving the high-level system elements described in Figure 2. Figure 9 shows an example of the postulated decomposed steps involved in meeting the first HFA priority, "ensure the disaster risk reduction is a national and a local priority with a strong institutional basis for implementation", and its first core indicator, "national policy and legal framework for disaster risk reduction exists with decentralized responsibilities and capacities at all level." Inherently, this involves the activities required for the development of the necessary plans (orange links) and the execution (blue links) of an HFA national disaster reduction plan. The example in Figure 9 is generic representation of the activities required, but by following a more formal system dynamics process (Sterman, 2000; Martinez-Moyano and Richardson, 2013), one can examine all of the specific steps and systems required by individual countries and use those decompositions to look for potential obstacles and assess strategies for addressing them.

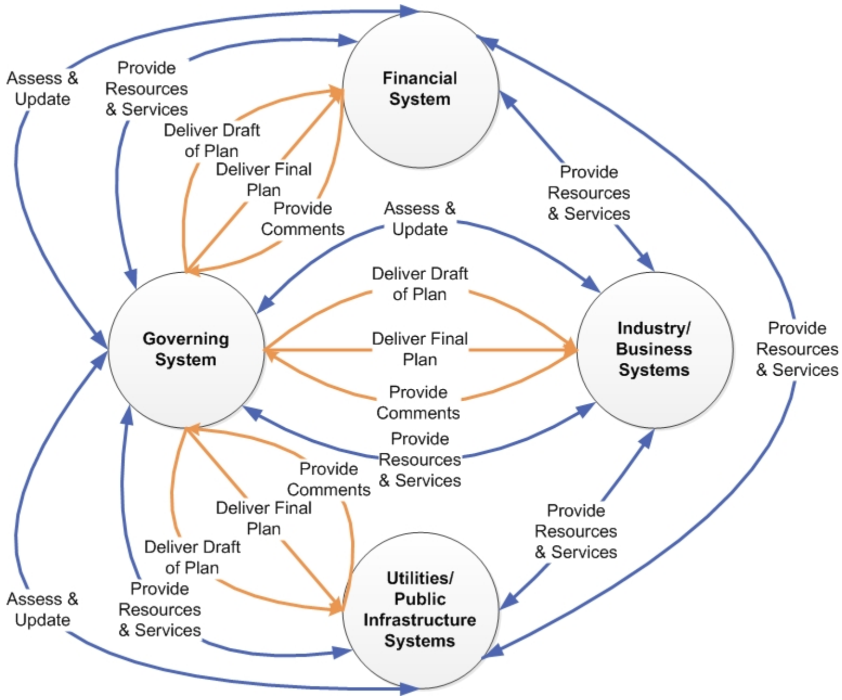


Figure 9. An Example of the Interactions Required for the Development (Orange Links) and Execution (Blue Links) of a National Framework for Risk Reduction in Response to the First HFA Priority.

6. The Extensibility of Country-Level Assessments to Specific Urban Environments

In the analyses examples presented in this paper, we have used country level data. In examining the language of the HFA priorities, it is clear that the tenets apply at both the national and local levels. Priorities 2 – 5 are more focused on implementation details and would have to be tailored to each specific locale. Each urban environment is different, therefore, climate change impacts and mitigation strategies required to address them will also differ. As the responses were generated by federal officials in each country, the assessments have a federal perspective, but the degree to which they represent actual local level response capabilities will depend upon the degree to which federal policies are implemented at local levels. In the United States, for example, there is Federal Emergency Management Agency, but it can only operate at local levels when formally invited in after the declaration of a national disaster. The development of specific response plans are all done at the state and local level. Therefore, we are treating the assessments provided in this paper as representative of the levels of response that could be found in the urban environments, but in order to assess specific capabilities, one would need to do specific analyses for each specific locale of interest.

7. Developing Climate Impact Mitigation and Adaptation Strategies

The development of climate impact mitigation and adaptation strategies must always be done on a case by case basis. Since the types and magnitude of the impacts will vary over time, the response strategies must consider both near and long term responses. As an example, numerous coastal areas in the United States are experiencing “nuisance flooding” (e.g., NOAA, 2014 and Cox and Cox, 2015) in which coastal flooding is occurring on a regular basis that is not associated with storm surges or extreme weather events. These flooding events are resulting in considerable inconvenience to inhabitants and unplanned maintenance and mitigation costs and are precursors of more significant impacts as sea levels rise in response to climate change.

It is a hope of city planners that that engineering solutions can be found for all of the proposed climate impacts. New building codes are being developed to account for anticipated changes in in heating and cooling as well as the development of new flood plain and storm surge maps for coastal areas. However, there are some areas where engineering solutions may not be feasible because of the basic characteristics of the terrain and geology. Much of Florida is built on porous limestone which results in sea water being able to seep up through the ground as well as from overland flooding. About 60% of Miami-Dade County is 6 feet or less above sea level and it is estimated that the sea level around the South Florida coast has already risen nine inches over the past century (Cox and Cos, 2015). The area routinely experiences “nuisance flooding” during high-tide events. Even with efforts to build higher sea walls and install more and stronger pumps, the area is facing multiple threats from the projected climate change impacts (e.g., more rainy day and high tide flooding, stronger storm surge events, sea level expansion from warmer sea waters, and salt water incursion into aquifers) that is forcing some municipal leaders to propose that relocation may be the only solution.

The Miami area currently has the highest amount of assets exposed to flooding for any city in the world – more than $400 billion. Based on growth projections for the area, it is expected that this value could increase to almost $3.5 trillion by the 2070s (Cox and Cox, 2015.) The magnitude of the property assets at risk to climate change has given rise to the concept of a “climate bubble” by the economic community that reflects the threat to the world’s economy because of the huge costs involved in developing mitigation solutions and the threat from the financial underwriting community to downgrade investments in environmentally threatened areas. The United States General Accounting Office (GAO) has reported that climate change creates a significant financial risk for the federal government which owns extensive infrastructure (civilian and military), insures property through the National Flood insurance program, and provides emergency aid for natural disasters (GAO, 2013.) The GAO report notes that the federal government is not well positioned to address the fiscal exposure and recommends that a government wide strategic approach be developed to manage the risks.

The international scientific community has developed an array of advanced modeling tools to estimate future environmental states and to assist world leaders and government planners in developing strategies to reduce impacts from climate change. While these tools can support country-level analyses, they are not sufficient to support local and regional planning activities for water and electric infrastructure. These global climate models cannot generate the necessary data at the smaller spatial scales required to support actionable decision making by local governments. However, the environmental modeling community has developed tools and approaches to “downscale” global-level climate data to spatial scales that can inform local planning. These tools and approaches are similar to those used by the weather forecasting community to downscale data products from the “synoptic” (continental scale) to “mesoscale” (regional scale) weather forecasting models. The downscaled regional climate models are used to reproduce past weather conditions (hindcasting), which can then be used for comparison purposes against future conditions (forecasting). An example of the additional detail provided by downscaled climate products is shown in Figure 10. Figure 10 shows an example of winter precipitation rates generated with a global scale climate model with 250 km resolution (left panel) and a high resolution regional climate model at 12 km resolution (right panel). The higher resolution in the regional climate model allows important environmental features like mountains and smaller bodies of water (e.g., the Great Lakes) to be resolved.

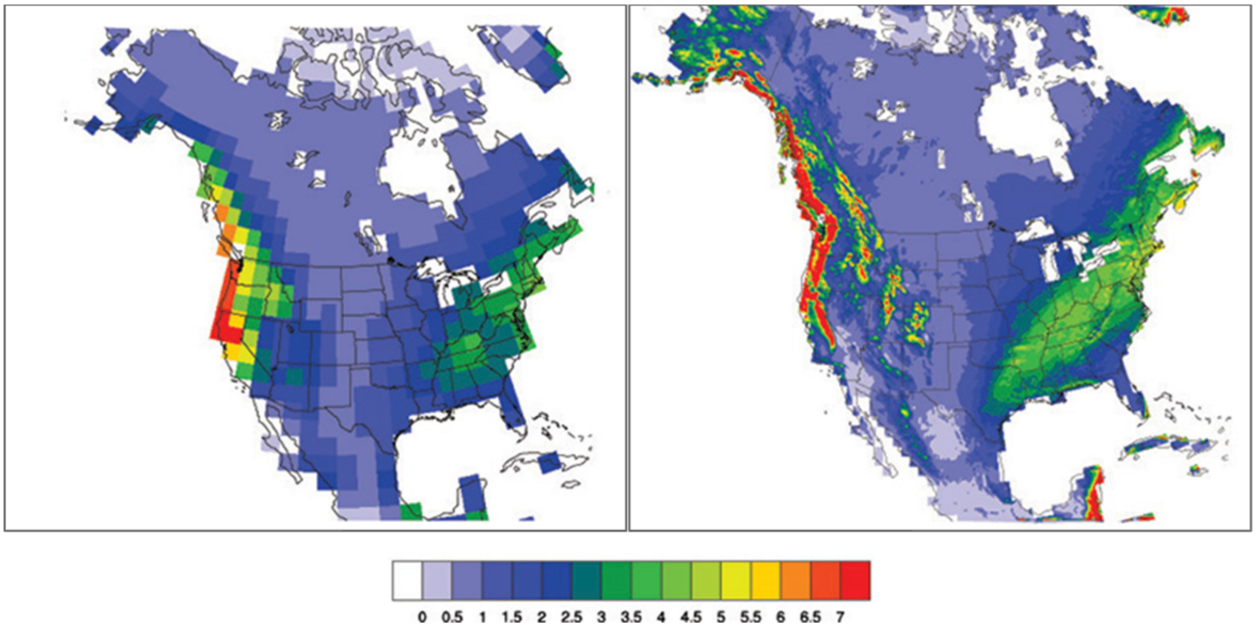


Figure 10. Winter precipitation rate (mm per day) for 1995 – 2004 calculated with a global climate model at 250 km (left) and a regional climate model at 12 km resolution (right

These approaches are being used by the U.S. Department of Defense to provide actionable data products to support the analysis of climate impacts on U.S. military bases and facilities. They are also being used to support regional analyses of climate change at various locations in the United States (e.g., DHS 2015 and Clifford et al., 2015.)

8. Summary and Way Forward Recommendations

The threats from climate change will have major impacts on urban environments around the world. In some coastal areas, the very existence of some urban environments is at risk. In order to develop and implement mitigation and response strategies, these urban environments need to increase their resiliency to environmental pressures. In this paper we have discussed the systems and relationships that contribute to community resiliency. We have also presented analytical methods that can be used to assess country level resiliency to disasters and climate change and how they can be applied to support assessments for specific urban environments. Finally, we have discussed how high resolution actionable climate products can be used to support urban planners.

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