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Regional Environmental Change, 18, 1411-1426. doi: http://dx.doi.org10.1007/s10113-017-1269-3

Regional Environmental Change

Adapting to urban challenges in the Amazon: Flood risk and infrastructure deficiencies in Belém, Brazil

--Manuscript Draft--

Manuscript Number:	REEC-D-16-00551R1
Full Title:	Adapting to urban challenges in the Amazon: Flood risk and infrastructure deficiencies in Belém, Brazil
Article Type:	Original Study(max length 12pgs,figs./tabs.keep separate,e-supplements opt)
Keywords:	adaptation; Flood; Amazon; delta; vulnerability; urban growth
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Funding Information:	National Science Foundation (1342898) — Not applicable International Development Research Centre (106711) — Not applicable

Abstract:

Sustainable urban infrastructure transition is perhaps the biggest challenge confronting cities in the global south in a time of climate change. Fast growing cities are increasingly faced with deficiencies in the provisioning of public infrastructure, such as delivering water and sewage treatment, and mitigating the risk of flooding to large segments of the population. Problems such as flooding, encapsulate both structural and individual dimensions of adaptation. In this paper, we present a conceptual framework to analyze urban adaptation to increasing flood risk in the capital city of Belem in the Brazilian Amazon. Our analysis focuses on two domains of adaptive capacity to floods: generic capacity (provisioning of basic infrastructure and services) and specific capacity (effective flooding response, proactive strategies for risk reduction). We combined data from census sector and household semi-structured interviews, focus group discussions, observational and archival data, and photo documentation to analyze both capacities in the city of Belém. Our findings indicated deficiency and intra-urban variability of both generic (water supply, sanitation, waste management and adequate storm drainage) and adaptive capacities (specific individual and community and political actions for flood mitigation). However, significant inequalities exist across sectors of the population. Poorest urban sectors present higher deficits of generic adaptive capacity related to infrastructure. The expansion of vast areas of informal settlements, lack of basic infrastructure, and failed projects to reduce flood risk also challenge the specific adaptive capacity of households. A perception of corruption associated with public projects and high levels of violence also

	prevent cooperation and collective action among residents affected by flooding.
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Author Comments:	Dear Dr. Cramer, We are resubmitting a revised version of "Adapting to urban challenges in the Amazon: Flood risk and infrastructure deficiencies in Belém, Brazil" which we would like to have considered for publication as an original study in Regional Environmental Change. This is the first study to assess urban adaptation in the Amazon analyzing generic and specific capacities of adaptation in the capital city of Belém in the Amazon Delta. Our study is a contribution to efforts of the Belmont Forum Deltas Project to enhance our scientific understanding of urban vulnerability in deltas regions. In this paper, we analyze two dimensions of adaptive capacity in the capital city of Belém: generic capacity (provisioning of basic infrastructure and services) and specific capacity (effective flooding response, proactive strategies for risk reduction). For that, we present a conceptual framework for urban adaptation to flooding risk which was inspired by Eakin et al. (2014). Our results combine data from census sector and household semi-structured interviews, focus group discussions, observational, archival data, and photo documentation. Our findings indicated deficiency and intra-urban variability of both generic and specific capacities, indicating that extensive parts of Belém are now in a "poverty trap" configuration. We also present an example of a project has undermined effective risk mitigation in the city. In the review process, we made substantial changes in our manuscript to explore the specific and generic adaptive capacities and better explain our adaptation analysis through our conceptual model. I would like to thank the reviewers for their constructive and helpful suggestions that have helped us to improve the manuscript. The table "response to the authors" shows a breakdown of how the various comments that have been addressed. In the possibilities of a positive outcome from this review process, we would be happy to discuss further necessary edits to improve our manuscript. Sincerely, Andressa V. Mansur

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Adapting to urban challenges in the Amazon: Flood risk and infrastructure deficiencies in Belém, Brazil

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Abstract

Sustainable urban infrastructure transition is perhaps the biggest challenge confronting cities in the global south in a time of climate change. Fast growing cities are increasingly faced with deficiencies in the provisioning of public infrastructures, such as delivering water and sewage treatment and mitigating the risk of flooding to large segments of the population. Problems such as flooding, encapsulate both structural and individual dimensions of adaptation. In this paper, we present a conceptual framework to analyze urban adaptation to increasing flood risk in the capital city of Belem in the Brazilian Amazon. Our analysis focuses on two domains of adaptive capacity to floods: generic capacity (provisioning of basic infrastructure and services) and specific capacity (effective flooding response, proactive strategies for risk reduction). We combined data from census sector and household semi-structured interviews, focus group discussions, observational and archival data, and photo documentation to analyze both capacities in the city of Belém. Our findings indicated deficiency and intra-urban variability of both generic (water supply, sanitation, waste management and adequate storm drainage) and specific capacities (specific individual and community and political actions for flood mitigation). However, significant inequalities exist across sectors of the population. Poorest urban sectors present higher deficits of generic adaptive capacity related to infrastructure. The expansion of vast areas of informal settlements, lack of basic infrastructure, and failed projects to reduce flood risk also challenge the specific adaptive capacity of households. A perception of corruption associated with public projects and high levels of violence also prevent cooperation and collective action among residents affected by flooding.

Keywords: adaptation; flood; amazon; delta; vulnerability; urban growth

Length of the manuscript: 8,401 words

Introduction

The Amazon Delta-Estuary (ADE) is an important socio-ecological system characterized by a rapid urban expansion and accelerated environmental changes (Brondízio 2013; Brondízio et al. 2016). The urban population in the ADE has increased approximately 300 % in the last 40 years (Brondizio et al., 2016; IBGE 2010) and is expected to grow by more than 50% over a 10-year period, with projected impacts to the ecosystems services provided by the delta-estuary (Overeem and Syvitski, et al., 2009). About 60 – 90% of the urban population in the ADE live in conditions of moderate to high degree of vulnerability because of flood exposure, a deficit of services and infrastructure and poor socio-economic conditions (Mansur et al. 2016). The cities along the ADE have experienced similar trajectories of accelerated population growth, including an expansion of river margins and low-lying areas coupled with poor access to clean water and sanitation at the household level (Costa and Brondízio 2009, 2011). While the deficit in drinking water is shrinking, sanitation infrastructure continues to be highly deficient and unequal (Datasus 2013; CNI, 2014). As such, flooding is not only increasing in frequency, intensity and impact on people's displacement (Santos 2010; PBMC, 2016), but affecting water quality and health more broadly (Mansur et al. 2016).

Creating a transition to a sustainable urban infrastructure and promoting long-term mitigation and adaptation strategies to climate change in large cities is one of the greatest challenges of achieving progress towards sustainable development goals (Szabo et al. 2015; Sebesvari et al. 2016). We focus our attention to the municipality of Belém, the largest city of the ADE, with 1.5 million inhabitants and very high population density (about 1,315 inhabitants per km^2) (IBGE, 2016). Belém is part of a metropolitan area with a population of about 2.5 million. Currently, the majority of the population in this city lives in urban areas with poor or inexistent infrastructure, and this trend continues to increase. In a region in which adaptation highly depends on the quality of provision and coverage of infrastructure and services, municipal and state governments have been unable to address the growing adaptation deficit[1] to an expanding urban population (Mansur at al., 2016).

Various studies have illustrated the importance of assessing adaptation to reduce vulnerability to hazardous impacts (Adger et al. 2007; Kiunsi, 2013; Revi et al. 2014; Elrick-Barr et al. 2014; Eakin et al. 2014; Parry et al. 2017). Eakin et al. (2014) however, states that for critical and effective risk management related to climate and environmental change hazards, one needs to consider both generic and specific capacities at both household and community levels. In this paper, we assess generic and specific flood risk adaptation at the level of the city of Belém as a whole, as well as across sectors within the city. Our study aims to answer the following research questions related to adaptation to floods in the city of Belém: (1) Is there a deficit in generic and specific capacities to floods in Belem? (2) What is the spatial variability in the distribution of both types of capacities within the city? (3) To what extent the distribution of generic capacity is influenced by the average income of households?

To answer these questions, we use a conceptual framework for urban adaptation to flooding risk that includes two domains of adaptive capacity: generic capacities (e.g. risk reducing infrastructure, sanitation, and economic inequality) and specific capacities (e.g. traditional risk mitigation strategies, housing infrastructure and household capacity and risk perception). The framework draws on Eakin et al. (2014), which addresses the generic capacities associated with development goals and the specific capacities that are necessary for managing and reducing specific climate threats. In their analysis, they examine four different configurations of adaptation resulting from the relationship between generic and specific capacities. This is the first attempt to analyze generic and specific capacities to flood risk in the Amazon.

Our analysis indicates that extensive parts of Belém are now in a "poverty trap" configuration, represented by the lack of adaptive capacity for both generic (access to public infrastructure and services, low economic level, access to health and safety) and specific (effective flooding response, proactive strategies for risk reduction) capacities. The lack of adaptive capacities, however, is heterogeneous in the city. Provisioning of generic infrastructure, including domestic effluent collection, paved roads, and public water supply, is more concentrated in central and older neighborhoods, while scarce in subnormal occupations. Consequently, the level of risk and uncertainty varies significantly, creating an unequal spatial pattern of adaptive capacity within the city. Also, we discuss that frequent news about corruption associated with public projects and high levels of violence also prevent cooperation and collective action among residents affected by flooding, which together undermine both the provisioning of generic and specific capacities in the city. Finally, our findings indicate that with all these pressures, Belém is moving towards a scenario where flooding becomes hard to avoid, subjecting increasingly larger sectors of the population to flood insecurity.

To demonstrate that, first, we analyze the generic and specific capacities defined in the framework in the city of Belém. We then illustrate an example of an infrastructure project that has undermined effective risk mitigation and has disrupted organization and coping mechanisms of the local population. We combine data from public databases at the census sector level, which is the most disaggregated level of analysis of Brazilian census data, and a qualitative research based on household semi-structured interviews, observational data, focus group discussions, archival data, and photo documentation.

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Conceptual framework for flood risk adaptation in Belém

According to Adger et al. (2007), the adjustments to reduce vulnerability or enhance resilience in response to observed or expected changes in climate and associated extreme weather events are actions of adaptation to climate change. Levels and types of adaptive capacity vary significantly among geographical regions, communities and sectors (Adger et al. 2007, Revi et al. 2014, Elrick-Barr et al. 2014, Eakin et al. 2014). Regardless, climate change adaptation also depends on the socioeconomic development context (Eakin et al. 2014). Revi et al. 2014 highlight that adaptation in urban areas depends on the capacity of local government to provide a base for city resilience on which adaptation can be built and, the importance of local governments acting now to incorporate climate change adaptation into their development plans and policies and infrastructure investments (Revi et al. 2014).

Eakin et al. (2014) suggested that adaptation can be understood from the relationship between current levels of capacity for risk management (*specific capacities*) and levels of socioeconomic development (*generic capacities*), resulting in different configurations of adaptation. The combination of these two capacities can produce four configurations of adaptation for urban spaces. We adopted their concepts for urban systems. For example, the “safe development paradox” characterizes urban spaces of low specific and high generic capacities. Typically, here are cities in high-income nations with 80 to 100% of households served with risk-reducing infrastructure. The "sustainable adaptation" characterizes urban spaces with high generic and high specific capacities. We would expect to find high-developed cities with a strong basis for adaptation that has integrated their policies and investments within an understanding of the need for mitigation to all sectors of society. The "safety-first" characterizes urban spaces with low generic infrastructure but households with traditional risk mitigation strategies that can cope with environmental externalities. Finally, "low poverty trap" configuration characterizes urban spaces that lack in both generic infrastructure and specific capacities for climate change adaptation. Here are cities with vast deficits in both infrastructure and institutional capacity and households with very limited ability to cope and adapt.

To analyze the current configuration of the city of Belém, we present a conceptual framework for urban adaptation to flood risk based on the adaptive capacities proposed by Eakin et al. (2014) (Fig 1). In parallel, we used concepts and adaptive capacity variables for urban spaces that draw in particular on Revi et al. 2014. As well as in Eakin et al. (2014), our framework analysis the relationship between the levels of socioeconomic development (provisioning of generic infrastructure and services, economic level of households), and the current levels of capacity for risk management (specific actions based on traditional risk mitigation strategies, investment in housing infrastructure, community engagements and specific public policies and investments for flood risk mitigation). Supply of drinking water, sewage collection and treatment, surface drainage and macro drainage systems, as well as government maintenance of these services and systems, are considered elements of generic adaptive capacities because they are strongly linked to development objectives that reflect, among other indicators, the Human Development Index (HDI) (Parry et al. 2017). These infrastructure and services are also implemented vertically and unilaterally through universal policies of sanitation and drainage in which the technical and scientific rationality that guide the conformation of modern cities predominates (Scott 1998). They are generic capacities because they consist of the replication of public policy models and articulation between city and nature that disregard local tactics and strategies for adaptation to climatic extremes and urban infrastructure deficits. Specific capacities refer to spontaneous and immediate responses to floods and thus are situated on a micro-ethical level of social relations that happens independently and beyond the reach of State actions.

In Belém, adaptive capacities are heterogeneous and are subject to the degree of vulnerability that increases from the city center to peri-urban areas (Perz 2000; Lima 2001; Mansur et al. 2016). Additionally, the generic and specific capacities are mediated by multiple enabling factors (Fig 1). The level of generic infrastructure varies from the ones that are often available in the majority of neighborhoods, such as trash collection, to the infrastructure requiring large-scale investments costs, including domestic effluent collection, periodic dredging of sediments from river channels and paved roads, which are mostly restricted to older urban neighborhoods or to areas where the real estate market is highly valued. To capture these differences, we examine the distribution of generic capacity in different sectors of the city within which specific capacities take place.

The specific adaptation responses are dependent on the capacity and risk perception of the individual as a member of the household, the community as a group and the state as a provider of public actions (Brondizio and Moran 2008; Elrick-Barr et al. 2014; Mansur et al. 2016). For example, if the house is established in an area that is regularly flooded, residents are more likely to cope than residents who have never experience a flood. Likewise, for established residents, the memory of past events is part of inter-generational cultural knowledge that also make them cope more quickly and find practical solutions that are incorporated throughout their lives (Brondizio and Moran, 2008). Also, households have different economic levels, which allow them to take individual actions in their housing infrastructure.

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Also important to our framework is to consider the extent to which households engage in collective action related to flood risk, such as public manifestation to complain about flood risk and some other problems associated with it, such as disposal of solid waste in water channels. Besides that, it is also important to account for contextual factors such as perception of corruption influencing the improvement of public infrastructure (Adger and Kelly, 1999; Pelling and High, 2005; Duraiappah et al. 2014), and neighborhood violence that may limit individuals to organize (Barnett, 2003). Perhaps human insecurity caused in part by flood hazards may, in turn, lead more conventional security problems, undermining the design of effective adaptation strategies (Barnett and Adger, 2007). Consequently, our framework suggests that adaptive outcomes (generic and specific) are the result of these various types of interconnected mechanisms that in turns influence the respective adaptation choices.

--- Insert figure 1 here—

Characteristics of the city of Belém

Geographical setting and Climate: Belém is located in the northern Brazil, in the state of Pará. The city is positioned in the floodplain of the southern branch of the Amazon Delta Estuary (ADE), specifically on the edge of the Guajará Bay and the Guamá river mouth, in the Para River Estuary. The regional climate is tropical, warm and humid, with an average rainfall rate of above 3000mm. The city is based on an Intertropical Convergence Zone (ITCZ), which defines the seasonality of rainfall in two defined seasons: the wet season from December to May and the dry season from June to November (Figueroa and Nobre, 1990). The events of El Niño and La Niña also influence the rainfall variability in the region, where extreme precipitation become more likely during La Niña events (dos Santos et al. 2014).

The city is divided into thirteen watersheds encompassing an extensive network of interconnected channels that strongly influences the flood dynamics and daily life of population (Pinheiro et al. 2007). Topographically, about 40% of the city is situated in low-lying areas below sea level. The floodplain is influenced by tidal and seasonal floods subjected by rain regimes (Pinedo-Vasquez et al. 2011; Costa and Brondio, 2009, 2011).When the high tide coincides with heavy precipitation, population experiences severe floods, with localized events that vary in influence across a gradient of elevation (Mansur et al. 2016). The climate change effects, with changes in precipitation, are expecting to affect the severity of these tropical floods, with more frequent seasonal and stochastic events (Cohen et al. 2003; França et al. 2012; IPCC, 2014). In addition, the majority of the river channels are degraded and its riverbanks disorderly occupied, aggravating the severity of floods in the city (Pegado et al. 2012). Consequently, accelerated sea-level rise and enhanced human pressures in the city will exacerbate future flood impacts in this region (Tessler et al. 2015).

Human geography and socio-environmental changes: The city of Belém is the oldest capital in the Amazonian region and as such has experienced periods of growth and stagnation since its foundation to the 17th century (Online resource 1). The city has a very important geographical position from the social and economic point of view, providing easy access to the ocean and continent (Penteado, 1968). This strategic position has encouraged rapid development and urbanization, with the opening of the rivers for international merchant navigation after the colonial period. In the 1890s, the economic progress of the rubber commercialization attracted many people to the city, bringing foreign investments and private initiatives for public infrastructure development (Cardoso and Neto, 2013). With the end of the rubber cycle, the city suffered a period of economic decline followed by a slight decrease in population in the 1920s. From the 1970s to 1980s, the population has substantially increased in the city mainly driven by policies to stimulate regional economy and demographic development, with the construction of an important port and roads connecting the region to the center of the country (Cardoso et al. 2015). In the last 50 years, the population of Belém has increased by about 300%, reflecting the intensification of human activities and accelerated environmental changes in the region (Brondízio, 2013; Brondízio et al. 2016; City Mayors 2016). Still, at the end of 1990s, Belém lost its position as the largest city in the Amazonian region to the city of Manaus in the state of Amazonas (Browder and Godfrey, 1997).

Today, Belém remain as an important pole in the subregional network, maintaining a strong link with small cities and rural areas (Costa and Brondízio 2009, 2011; Guedes et al. 2009). The economy of the city relies on tertiary sector activities, informal employment with a high dependency on federal government cash transfer programs and subsidies (Lima, 2001; Costa and Brondízio 2009, 2011). As in other medium and large cities in the Amazon, Belém continues to grow because the city provides a base for rural families to access public services, education, economic opportunities and a sense of security, which they hardly find in smaller towns and rural areas (see Costa and Brondízio 2009, 2011; Brondízio, 2016).

The accelerated urban population growth has come with inadequate planning and management, contributing to the development of vast areas considered informal settlements or as in census terms, subnormal agglomerations (IBGE 2010). Since the 1970s, squatting became a major part of urban growth and the expansion of subnormal houses and agglomerations (Lima, 2001). These settlements have taken place mostly in low-lying floodplains, consequently subjected to high degrees of vulnerability and extensive exposure to flood impacts (Mansur et al. 2016).

Methodological approach

Our work relies mostly on the analysis of large demographic and socio-economic census datasets from 2000 and 2010 at the census sector[2] scale. This data was then complemented with field visits, interviews with selected households where specific generic adaptation could be observed, interviews with public officials and community leaders, and focus groups.

Data collection

We use the Amazon Delta-DAT[3] to collect socioeconomic data at the census sector scale, the most disaggregated level of analysis of census data for years 2000 and 2010 (IBGE 2000, 2010). We analyzed these data for household-level variables of infrastructure and services, income, and population. The assessment was conducted in 1183 and 1296 urban sectors of the municipality of Belém in 2000 and 2010 respectively, totalizing 294,532 and 365,633 households within the city. Urban sectors and data for variables at household-level were organized using GIS 10.2.2. A Spearman's correlation analysis was performed to explore the relationship between variables not normally distributed.

Field survey

We conducted a semi-structured interview with 34 households with the goal of observing or understanding examples of specific adaptation. We also applied an open-ended questionnaire to 16 local leaders of different flood-prone areas of Belém. We conducted unstructured interviews with stakeholders, including residents, civic leaders, local researchers and municipal representatives responsible for planning and disaster risk management in the city of Belém. We participated in three focus group discussions with residents of flood-prone areas and organized two consultation workshops with experts on topics including climate change hazards, exposure, vulnerabilities and development of adaptation initiatives. These workshops were part of the Belmont Forum Deltas Project and were held in the city of Belém in May 2015 and May 2016. Results from our interviews were complemented by observational data, archival data and photo documentation collected among residents of flood-prone areas of Belém. Results were also supported by a recent ethnographic study developed in the Una watershed, in Belém (Soares 2016). These documents were used as a qualitative data for the analysis and discussion of specific capacities and adaptation strategies in the city of Belém. Fieldwork visits occurred during 45 days of September and October 2015. The interviews were carried out in nine distinct neighborhoods in the city of Belém where flood exposure was reported, these include: Pedreira, Nazaré, Marco, Sacramenta, Marambaia, Cabanagem, Guamá, Terra-Firme and Jurunas.

Urban changes

Detecting urban changes is relatively complex with Landsat imagery over large periods of time, and the situation is fairly even more complex in areas with high probability of cloud cover. To resolve these issues, a series of methods were utilized to look at cloud free composites to understand decadal change. Google Earth Engine was used to create percentile reducers selecting only 10th percentile of the overall images within the time frame and then using the composite created from the percentile reducer. Panchromatic bands were selected for the base years from Landsat 7 collections, and then a pan sharpening was performed to allow for 15 meters resolution multispectral imagery. We used two thresholding for urban areas namely a combination function of the NDBI (Normalized Difference Built-up Index) and the NDVI (Normalized Difference Vegetation Index). The NDBI takes into consideration the higher reflectance in the shortwave infrared region (SWIR) and the near-infrared region (NIR) bands (Xu 2007, Zha 2003), like the following:

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NDBI = (SWIR-NIR)/ (SWIR+NIR)

The NDBI values vary between +1 to -1 and a positive value indicated urban reflective surfaces. In our case, a reducer function was applied based on known urban areas which calculate the median threshold for urban spaces. In the case of the NDVI, however, a negative index represents the urban area, and hence a simple and logical operator function was applied to the pan-sharpened imagery:

NDVI = (NIR-RED)/ (NIR+RED)

The images were then extracted along with the urban extracts and were overlaid with the subnormal agglomerations boundaries from 2010 (IBGE, 2010). While the combined thresholding allowed for the extraction of urban areas, it is important to mention that owing to the large population density of the area and the variation in terms of roof top materials in favelas, urban signatures are not always capable of capturing the full extent of areas where large chunks of the population maybe living.

Results

Accelerated urbanization changes

The intensification of the urbanization process in the Amazon region caused socio-spatial transformations in the urban configuration of Belém, as a result of socio-economic and political changes occurred in the region since the 1970s, with the expansion of transportation, industries and communication infrastructures and rural-urban migration due to better access to services and opportunities in the city (Carmo et al. 2015; Cardoso et al. 2015). In Belém, urban areas have expanded outwards through informal settlements usually located in low-lying areas, and upwards through high-rises, representing highly segregation of economic classes (Mansur and Brondizio 2017). This segregation has been aggravated since 2000, with the expansion process led by the real estate market supported by the local government to relocating the traditional riverside population to precarious urban neighborhoods far from the city center. This new pattern of urban sprawl has been causing urban fragmentation, socio-spatial segregation and transformation of the river margins into consumption spaces, which in turns illustrate the lack of sustainable planning and negligence with which these populations have been historically treated (Trindade JR, 2002; Cardoso and Neto, 2013; Trindade and Trindade JR, 2012).

Some of the basic observations this pattern of urbanization in Belém is that the urban area has almost doubled from 2000 to 2010, presenting an urban growth rate of about 82%. In this period, the area considered as subnormal agglomerations has increased by about 37% (Fig 2). In Belém, research has shown that population has expanded mostly to new areas of subnormal agglomerations and peripheries of the city, observing that the annual growth rate of households was about three times higher than the population rate during the years 2000 to 2010 (Carmo et al. 2015). As well as in other urban parts of the Brazilian Amazon (Costa and Brondízio 2011; Mansur et al. 2016; Parry et al. 2017; Marengo et al. 2013), this accelerated pattern of urban growth in Belém has come without provisioning of basic generic adaptation capacities, including sanitation infrastructure and services such as water and garbage collection.

Currently, the statistics show that the metropolitan region of Belém has the third biggest in the absolute population living in subnormal agglomerations, but the first in relative population of the country (IBGE 2011). When considered only the city of Belém, the majority of the urban residents (54.95% of the population) live in densely packed subnormal agglomerations many of which are violent and controlled by drug traffickers, presenting inadequate sanitation and low adaptive capacities to flooding.

In the next sections, we present different forms of generic and specific capacities in the city of Belém to analyze the relationship between these variables and recent urban growth.

--- Insert figure 2 here---

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The generic adaptive capacity and trends

Spatial analysis of Belém shows that the proportion of residents served with risk-reducing infrastructure and services indicates significant variability and considerable deficiencies across urban sectors of the city of Belém both in 2000 and 2010 (Fig 3). The analysis of 2010 shows very few improvements in water supply, domestic effluent collection and trash collection across urban sectors when compared to the year 2000, with services more concentrated in historical and older neighborhoods, a pattern also evidenced by other authors (Perz 2000; Lima 2001; Brondizio 2016; Mansur et al. 2016).

Although the majority of households (more than 60%) are located in areas that water supply is representative, yet there are areas in which households have no, or minimal, access to this service. Partial disruption of water provisioning, for hours or days at times, is very common across the city. For domestic effluent collection, the vast majority of the households in the city are not connected to this service, with exceptions of the households located in the historical city center. In fact, we observed some areas adjacent to the city center where the percentage of households connected to domestic effluent collection declined from 2000 to 2010, suggesting areas of increased population growth and subnormal occupation. While our analysis shows that trash collection is very representative in across urban sectors, the growth rate of this service from 2000 to 2010 points out to an increase in the proportion of households in areas with no, or minimal access to this service, indicative of new informal occupation in the city. However, neighborhoods with intermediate infrastructure (i.e., 40 to 80 % of households connected to water supply and domestic effluent collection), has also increased indicating improvements in the generic infrastructure in some parts of the city.

--- Insert figure 3 here---

Figure 4 shows sectors group with high and low probability of flooding and its relationship with storm drain in front of the house and household income. The percentage of households with storm drains varies considerably across the city. Box-plots show that this variation is high for both sectors group with high and with a low probability of flooding, with a median of about 55 - 60 % of the houses connected to storm drains. This suggests that the extent of storm drainage not necessarily influences the probability of flooding in Belém. Results show that the minority of households in all sectors of the city have an income higher than five minimum wage[4] (DIEESE 2015). The majority of households have an income lower than one minimum wage per month. These households tend to occupy areas with high probability of flooding.

A correlation analysis was performed to explore the relationship between household income and generic infrastructure according to sector's probability of flooding (Online resource 2). Results show that average income is positively correlated with access to a storm drain, domestic effluent collection and trash collection particularly in sectors with a low probability of flooding. This suggests that poorest urban sectors present higher deficits of generic infrastructure, including domestic effluent, storm drains and trash collection, in areas of higher probability of flooding. However, it also shows that households with better income and access to generic infrastructure may also be subjected to flooding. Contrary to what common sense approaches could suggest, in Belém the presence of storm drain itself often increases the incidence of flooding in areas that received investments regarding risk-reducing infrastructure. This can be explained by two causes that we observed during our field survey, also recognized in the literature (Pinheiro et al. 2007; Santos 2010; Pegado et al. 2012; Soares 2016; Brondizio 2016; Mansur and Brondizio, 2017). First, impervious surfaces increase the volume and timing of runoff, which carries large amounts of trash, which is then washed in the streets clogging storm drain systems producing flash floods in Belém. Second, storm drains constant need state-based maintenance to achieve its full functionality, when its maintenance is not performed, storm drains usually become another source of environmental hazards in the city.

--- Insert figure 4 here---

The specific capacity of urban dwellers

Overall, results indicate few specific adaptations at the household level. Adaptation measures in the housing infrastructure, such as raising entire or partially the floor level or raising the side walk, were reported as important and dominant adaptation measures (see illustrative examples fig. 5). Although raising the floor is a very common strategy, the majority of the households have financial limitations to carry out such change, especially in urbanized areas that have already been paved. This has motivated residents to value their real estate, replacing old houses made on wooden stilts for masonry houses. In other areas, most houses are still built on short stilts and to the ground in areas saturated with water. But, this type of housing construction has a short lifetime and high risk of collapsing.

--- Insert figure 5 here---

Both in interviews and in group discussions, another common adaptation measure at the household level reported as important was to raise the thresholds of the bathroom, doorway and shower enclosure. Such measures were reported as strategies to avoid a type of flood that comes from sewerage and storm water drainage. This type of flooding is very common in the city, and it happens when the pressure into the drainage system is reverse forcing contaminated water sludge back through toilets, drains, sinks and overflows into the rest of the house, causing serious damages and health hazards.

Interviewees and participants of focal group discussions also described problems with clogging of drainage and sewage pipes because of the heavy precipitation runoff that carries large amounts of sediments, leaves, and trash to the network systems. To solve this problem, households break the sewage network and connect the sewage collection to the drainage network. Sometimes this connection is not well done, and the sewage effluent is both mixed with the pipes for clean water supply and disposed in open-air ditches on the street, exposing residents to potential risks.

This type of solution to solve the absence of public infrastructure maintenance themselves reflects the attempts by residents of poor areas, but with a minimum of infrastructure. Many residents reported being too time-consuming waiting for the public service maintenance. On many occasions, individual actions are observed to solve practical problems, as usually, residents have empirical knowledge based on their technical professions, such as mason and plumber. One example is the case observed by Soares (2016) of a resident of the Telégrafo neighborhood, which for several times have had contact with contaminated water from the river channel to solve the problem of clogging of the sewage pipe. This situation has caused him an infection in his foot that has led to a loss of his leg. Cases like this, where individual actors take on a responsibility to maintain public infrastructure, are common in Belém.

Regarding collective actions, results of interviews, group discussions and field observations indicated nonexistence of collective actions aimed at risk mitigation in their neighborhoods. Although respondents stressed the lack of cooperation between residents and the lack of common interest to motivate local changes, we observed that in areas of more recent and precarious occupation, residents are more proactive to collaborate in solving immediate problems, such as joining efforts to move dirt, including material from landfills, to create street and ditches to facilitate the flow of storm and sewer water. In these cases, the absence of urban infrastructure, especially the absence of pavement, make the residents' agency on soil production a decisive factor in their specific adaptive capacities (Nelson and Finan, 2009).

Interviewed households also complained about the lack of community cooperation related to widespread trash and poorly maintained the river channels. Also, data based on our field survey indicated that public trash collection service is not regular and consequently, there is an informal economy based on collecting and selling trash. Often children or drug addicts, in exchange for some cash, collect solid waste from houses (construction remnants, pieces of wood, plastics and organic material) and dump it next to river channels or into watercourses. This situation increases pollution of land and water systems and creates spaces for disease, insects, rodents and drug consumption, which in turns increases violence and probability of floods in the city (Hardoy and Pandiella 2009, Costa and Brondizio 2011, Mansur et al. 2016).

While households reported that collaborative efforts are hard to organize and are even criticized by neighbors, individual actions for cleaning river channels are almost inexistent according to interviewees, group discussions, and field observations. “Most neighbors get offended when we ask to avoid dumping trash on the streets,” says a community leader of the Guama neighborhood, which tries to involve the community in the cleaning of the channels and streets. Other residents who care and try to raise awareness about the problems related to the trash on the streets are often repressed, as reported a resident of the Pedreira neighborhood “Some people collaborate, but many criticize those organizing collaborative efforts.” Discussants also pointed out that the responsibility for taking care of these problems and to mitigate flood risk, is of the government. However, pollution and garbage is easy ignored in the by decision-makers in Belém and other parts of the Amazon, as pointed by Brondizio (2016) "*The illusion that the mighty Amazon and its tributaries can absorb and dissolve almost all of the sewage and industrial pollution generated in the region offers a convenient excuse for not dealing with the problem".* Even though this is a very important issue in the context of specific adaptation measures, the daily attitudes related to the garbage disposal and trash in the streets are too complex to fit in this article and deserve further reflection.

Concerning individual perception and information, households rely on past individual and collective experiences of flood events to know if the excessive rainfall may cause flood impacts in their houses. For example, a resident of the Guama neighborhood mentioned an important local signal that makes her family aware if their house will be inundated "I see many land snails climbing in the house, and I know that the flooding is coming." Even though local signals are important early warning tools, as a whole, respondents reported remaining vigilant for any rainfall during the wet season. From interviews and focus group discussions, we observed that during rainfall periods households are highly apprehensive and psychologically impacted with the uncertainty of flooding in their houses. One of the residents in Pedreira neighborhood mentioned about being stressed out and in constant alert face a new episode of flooding in his house "I get concerned when there is a heavy rainfall, from December until April I am apprehensive and always thinking about to make a new investment in my house."

Regarding political actions and initiatives, a national survey on risk management strategies among city mayors indicated that the mayor of Belém at the time recognized floods problems as an important issue (IBGE, 2013). However, he indicated that the city lacks adequate plans for disaster risk management and mitigation, as well as contingency plans and early warning systems. Our interview data with the federal and municipal civil defense agencies corroborate these statements. These agencies are responsible for disaster risk management. Our data suggest that in spite of the efforts of different agencies, the city of Belem is unprepared to respond to direct or indirect impacts of hazardous events regarding the lack of early warning systems, immediate response actions, and post-disaster response. Our data also suggest that there is a lack of resources and qualified professionals to deal with flood mitigation, results in similar the ones found in other municipalities of the Brazilian Amazon (Pinho et al. 2014).

These limitations are perceived by all interviewees who complain about the lack of activities related to risk prevention and emergency plans in their neighborhoods, either from federal, state or municipal agencies or private institutions. Residents say that too often calls to the offices of the municipal civil defense are not answered, which was also our experience during fieldwork. Although interviewed residents demonstrated a good level of knowledge about flood events and its impacts, they unanimously pleaded for more information and instructions about flood risks, preventive measures, and diseases related to flooding or lack of sanitation in their neighborhoods.

Illustrative example: the case of the macro-drainage project of the Una watershed: promises and failures

Flood in Belem is not necessarily a new project. Because of the low topography of the city and its poor drainage capacity, flood problems have been recognized in Belém since the 1960s (Penteado, 1968). To mitigate this problem, during the 1980s to 2004, the Brazilian government started to invest in a major infrastructural project in Belem for risk-reduction and sanitation improvement to increase the generic capacity of part of the city. The project known as a Macro-drainage project of Una watershed was considered the biggest urban transformation of the Latin America. The aim of the project was: (i) to mitigate flooding risk through the construction of adequate drainage systems; (ii) restoration of the river channels and river embankment to avoid erosion and silting; (iii) increase sewage connections and water supply systems; (iv) enhance urban cleaning; and, (v) implement compatible road systems. Besides sanitation, the main goal of the project was to promote a socio-economic transformation in the city, enhancing the well-being of about 600 thousand people, approximately 120 thousand families (COSANPA, 2002).

The total cost of the project was estimated in US$ 312.5 million. The state government of Pará funded 54.2% of the project, and the Inter-American development Bank (IDB) financed the rest (CRBU, 2013). While the project brought some sanitation development to a part of the population, the effectiveness of such investment in improving disaster risk mitigation is contested. This is in part because of a history of poor management from its initial implementation to its partial conclusion in 2004. A significant part of the target investment was not accomplished. Although the project included a commission with representatives of different neighborhoods, it became widely known that members of the commission were also involved in corruption[5]. Based on group discussions and published and unpublished literature, some of the reasons that have contributed to undermining the quality and effectiveness of the project include (CRBU 2013; Soares 2016; Mansur and Brondizio 2017):

(1) Lack of control and monitoring in the construction phase;
(2) Lack of inspection of the construction sites and technical orientation from civil engineers to the relocated families;
(3) Low compensation for the relocation of about 2780 and about 4824 expropriated households (Pinheiro et al. 2007), many of which were relocated to areas with inexistent infrastructure and later became subjected to flooding
(4) Corruption schemes in all organizational levels, and in particular in the administration level;
(5) Lack of maintenance of river channels and infrastructure;
(6) Private appropriation of machinery and equipment destined to maintain the public works of the project by local politicians.

Around 2005, a group of residents submitted a class action through the state prosecutor's office against the agencies responsible for the project (CRBU, 2013). Among their claims is that of outstanding compensation for affected families. This lawsuit remains unsettled. Our field observations and some existing literature sources have shown that besides the ineffectiveness of the project in providing flood risk mitigation, the failure of the project has also created a series of other problems, including areas that serve as meeting places for drug addicts and criminals, exacerbation of poverty conditions in some areas. These in turns have caused the discredit of the population in the public sectors and in projects aiming at reducing flood risk in the city. These experiences have also contributed to undermining the ability of residents to collaborate and to engage in activities to minimize flooding. See online resources 3 for illustrative information.

Discussion and conclusion

We adopt the matrix of adaptation capacities proposed by Eakin et al. (2014) to describe the relationship between generic and specific capacities in the city of Belém. Our analysis shows the configuration of adaptation in Belém in two phases, before and after the 1980s (Fig 6). The "safety-first" configuration is the phase 1 of Belém, which is related to a period that took place before the 1980s. This period is characterized by low generic and high specific capacities at the individual level to floods (Penteado 1968; Fernandes Júnior 1989). Households occupied flood-prone areas and informal settlements, often economically marginalized and highly exposed to climatic variability. However, because many families came from riverine areas where stilt houses are a norm, they were better able to cope and adapt to floods. Also important to consider that population density was lower, trash less prevalent, and urban run-off less intensive. The more traditional style of houses, built on high stilts, were projected based on the highest possible flooding level during the year. These houses also had a smaller footprint on the river's shore.

During the late 1980s until the beginning of the XXI century, part of the city of Belém was subjected to a series of government projects of flood risk mitigation and infrastructure improvement (see illustrative example). Such projects partially enhanced the generic capacity in some areas of the city, but the overall demands on the urban infrastructure system changed dramatically, decreasing the specific capacity of the population. These large urban infrastructural projects have altered the traditional relations of the population with the water landscape in the city, especially due to the river channelization, street grounding, and pavement. If on the one hand, this process of urbanization has increased market prices of the properties and brought services previously non-existent in certain areas, this also brought a reduction of the specific adaptive capacities. Houses made of masonry are both difficult in raising from the contact with water and in recycling the material in their reconstruction. The project has also impermeable the natural floodplain areas, confining watercourses to channels that are unable to receive the large volume of Amazonian rainfalls. In sum, initiatives such as the Project of the Una watershed have disrupted traditional adaptation and mitigation strategies by reducing population agency[6] on land production and housing, while at the same time have turned the populations of the Una watershed dependent on State investments for generic adaptive capacities. Over time, the mechanisms of generic capacities failed as infrastructures constantly require investments and maintenance costs. Additionally, rapid population growth created more pressures in the socio-ecological environment, affecting the provisioning of generic infrastructure.

This situation has turned the configuration of adaptation of the city of Belém into what Eakin's framework defines as "poverty trap." Our analysis, however, shows that the current configuration of Belém is characterized by high degree of spatial variability regarding generic capacity, i.e., from higher and better conditions in historical sectors and consolidated neighborhoods to low or in some parts inexistent as one moves away from these sectors (see fig 6).

This is a postprint version of Mansur, A. V., Brondizio, E. S., Roy, S., Soares, P. P. M., & Newton, A. (2018).
Adapting to urban challenges in the amazon: Flood risk and infrastructure deficiencies in belém, brazil.
Regional Environmental Change, 18, 1411-1426. doi: http://dx.doi.org10.1007/s10113-017-1269-3

--- Insert figure 6 here---

The process of urban growth can have both positive and negative consequences for the overall adaptive capacity of cities, including impacts in basic ecosystem services (Peeling, 2003; McGranahan, 2005). For the city of Belém, our results suggest that accelerated urban growth has had negative implications for flood hazards and adaptation. Based on reports from residents, photographs, satellite imagery, and focus group discussions, our study indicates that the socio-environmental changes in river channels are creating a scenario where the overflow of contaminated water has become hard to avoid, generating constant insecurity. Rapid urban population growth in Belém has driven competition for land creating both areas of high density of skyscrapers and large more horizontal, but still dense, subnormal agglomerations. This growth has come with lack of urban planning and management. These drivers create pressures on the river channels through the increase of sewage inputs, waste disposal and river sedimentation, which allied with a lack of maintenance of river channels increases water level and pollution, decreasing carrying capacity of these systems. Illustrative photographic examples are given in online resource 4.

The overall increase in flood exposure is expected to contribute to change how residents perceive flood risk and consequently their investment in specific adaptation capacity (Adger et al. 2007). Our analysis, however, shows that specific adaptation capacities in Belém are relatively weak and constantly undermined by the lack of generic capacities. As discussed above, there is a lack of private and public initiatives addressing flood problems, including a lack of initiatives aimed at providing information and knowledge on how to reduce vulnerability and to mitigate flood risks to the most vulnerable sectors of the population. This is a common problem in many other urban communities (Kiunsi et al. 2013; Adger and Kelly, 1999; Adger 1999; Revi et al. 2014).

We found a positive relationship between generic infrastructure and average household income, suggesting that sectors with lower average incomes have a lower percent of provisioning of generic capacity related with infrastructure. However, in a study published in 2015, Belem ranked first among Brazilian cities with the highest deficit of infrastructure and services provided to poor and low-income families, and second in a deficit of infrastructure and services to high-income families (Marques, 2015). In other words, generic infrastructural deficiencies affect most people in Belem. On the other hand, poor and low-income families have further undermined in their specific adaptation capacities because of financial limitations as well as a sense of powerlessness created by a history of disregard from policy makers, and difficulties to mobilize collective action in their neighborhoods. In fact, both residents and policy makers tend to treat river channels as sewage channels, even though the tidal dynamic that is characteristic of the region spreads polluted water widely, thus affecting, directly or indirectly, water used for drinking and leisure, as well as areas used for fishing.

Households tend to take individual informal actions and complaints to pressure politicians, but usually, actions are diffused and weak. Furthermore, because of the scale of deficiencies households have little incentive to engage in practices such as cleaning river channels, removing trash, creating public green spaces, and restoring riverine vegetation and aquatic systems that use to be an important part of their livelihoods.

In addition, as the case of the Una River Macro-drainage project illustrates, corruption in the city of Belém varies from small-scale to high-level abuses including public and private sectors involved in infrastructural projects. Government sectors are seen to be the most corrupted by residents, corroborating with the political scenario of the entire country (Global Corruption Barometer 2013). Belém, as other larger cities in the Amazon, has high levels of youth prostitution and high levels of violence (Brondizio, 2016). Due to the strategic position for distribution, marketing, and drug consumption, these areas are often controlled by drug trafficking and constantly marked by violent conflicts. According to Waiselfisz (2012), from 2001 to 2004, the national rate of homicides by fire weapons per hundred inhabitants has increased 88.6%, placing Belém in the 26th position among the fifty most violent cities in the world (El Consejo Ciudadano para la Seguridad Pública y la Justicia Penal, 2016). Violence increases from the historical parts of the city to subnormal agglomerations near water streams (Anuário Estatístico de Belém, 2010). How corruption and violence affect local adaptation to environmental change remains a major gap in the literature.

The case of Belem presented above, and the problems of flooding as a whole, encapsulate the challenges faced by a growing number of cities in the global south. It reminds us that individuals, families, and communities are limited and can be undermined in their creativity and adaptive capacity to respond to fast change environments. The sustained improvement of urban infrastructure, particularly in the global South, remains one of the biggest challenges of aligning the Sustainable Development Goals and efforts to mitigate environmental and climate change.

Acknowledgments

We acknowledge the Belmont Forum program for the project BF-DELTAS "Catalyzing action towards sustainability of deltaic systems with an integrated modeling framework for risk assessment" funded in part by the National and State Science Foundations in the United States of America (Grant #1342898). Andressa V. Mansur acknowledges the Erasmus Mundus programme: EMJD Marine and Coastal Management for their support, the ''Sociocultural adaptations of Caboclos to extreme tidal events in the Amazon estuary'' sponsored by the International Development Research Centre (IDRC) of Canada, two field work assistants and Oriana Almeida, for supporting the fieldwork in Belém. We thank the opportunity to collaborate with colleagues in the stakeholder workshops in the Amazon Delta as part of the BF-DELTAS and the Center for the Analysis of Social-Ecological Landscapes (CASEL) at Indiana University, where this research was developed. A special thanks goes to the residents of Belem who participate in this research, members of the ''Frente dos Moradores Prejudicados da Bacia do Una'' for their friendly support during the fieldwork, in particularly José Alexandre de Jesus Costa and Antônio Carlos Pantoja Soares and to Raul Arzúa Solari, for his kind support and help with the interviews.

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Footnotes

[1]IPCC (2014) defines adaptation deficit as "*the gap between the current state of a system and a state that minimizes adverse impacts from existing climate conditions and variability*".

[2]The Brazilian Institute for Geography and Statistics (IBGE) defines census sectors as the minimum units of area created for the purpose of cadastral surveys, taking into consideration the geographical extent, political administrative divisions and territorial interest (IBGE 2010).

[3]Amazon Delta-DAT is the geospatial platform created as part of the Belmont Forum Deltas Project (see Brondizio et al. 2016)

[4]In 2010, the minimum wage was equivalent to approximately 301.24 US dollars per month.

[5]Many of the members the commission Managing Council of the New Basin of the Una Basin (CONGEB / Una) received temporary positions in organs of the Municipal Administration (CRBU, 2013).

[6]Nelson e Finan (2009, p. 118) define that "Vulnerability is determined by the underlying factors that define human agency and access to public sector in time of crisis". With Project for the Una watershed, the human agency on the environment has decreased, while the access to public policy has occurred unevenly, which consequently had increased vulnerability.

Online resources

Online Resource 1. Evolution of population growth in Belém (data estimative population: Penteado, 1968; IBGE 2000, 2010)

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Online resource 4. Illustrative photos of the city of Belém. Source: Andressa Vianna Mansur and “Frente dos Moradores Prejudicados da Bacia do Una” (an organization of harmed residents in the Una River watershed).

Figure

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Figure 1. A conceptual framework for urban adaptation to flooding risk: An example of the city of Belém

Figure 2. Changes in urban growth in the city of Belém, data for years 2000 – 2010.

Figure 3. Changes in the proportion of households in the city of Belém connected to water supply, domestic effluent collection and trash collection, data for years 2000 – 2010.

Figure 4. Proportion of households in the city of Belém with storm drain; distribution of sectors group: with high and low probability of flooding (Adapted from Mansur et al. 2016); distribution of average household income based on based on different categories of incomes; Box-plots representing percentage of houses with storm drain and percentage of households in each category of income, divided by probability of flooding (low and high) of each sector

Figure 5. Examples specific adaptations to flood risk at the household and community levels in the city of Belém.

Figure 6. Distribution of generic and specific capacities in the city of Belém. Adapted from the capacities matrix described in Eakin et al. (2014)

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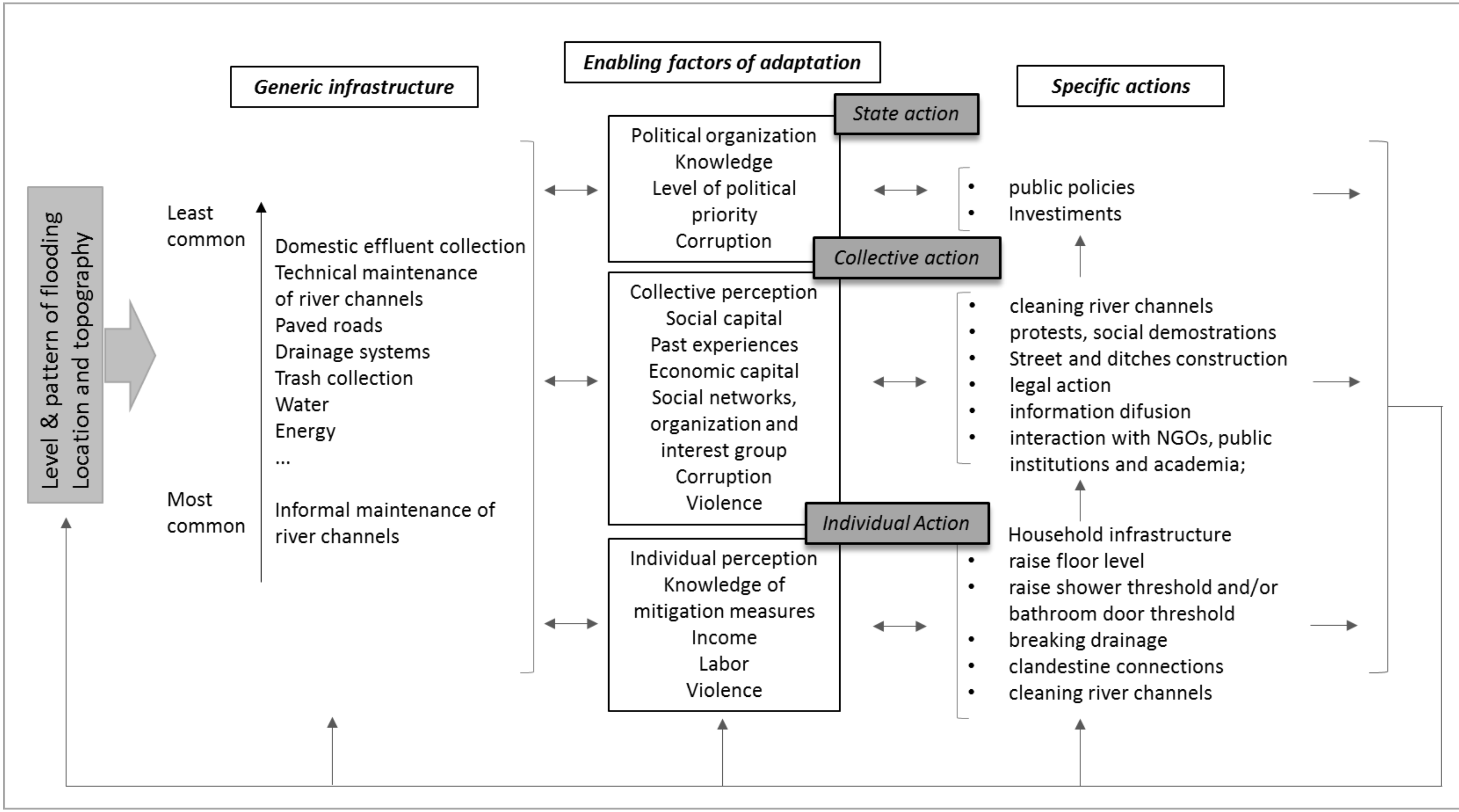

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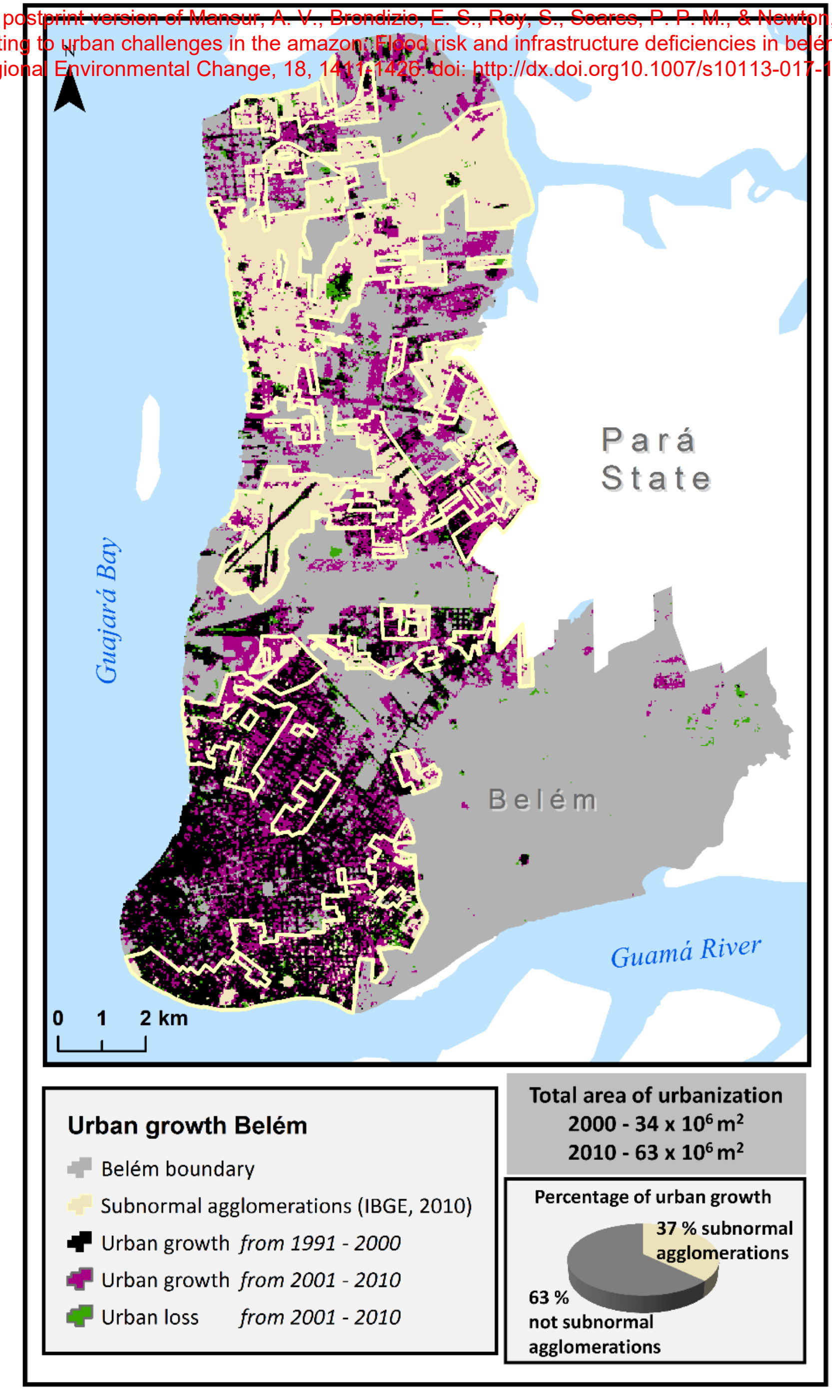
N
Pará
State
Guajará Bay
Belém
Guamá River
0 1 2 km
Urban growth Belém
Belém boundary
Subnormal agglomerations (IBGE, 2010)
Urban growth from 1991 - 2000
Urban growth from 2001 - 2010
Urban loss from 2001 - 2010
Total area of urbanization
2000 - 34 x 10⁶ m²
2010 - 63 x 10⁶ m²
Percentage of urban growth
37 % subnormal agglomerations
63 % not subnormal agglomerations

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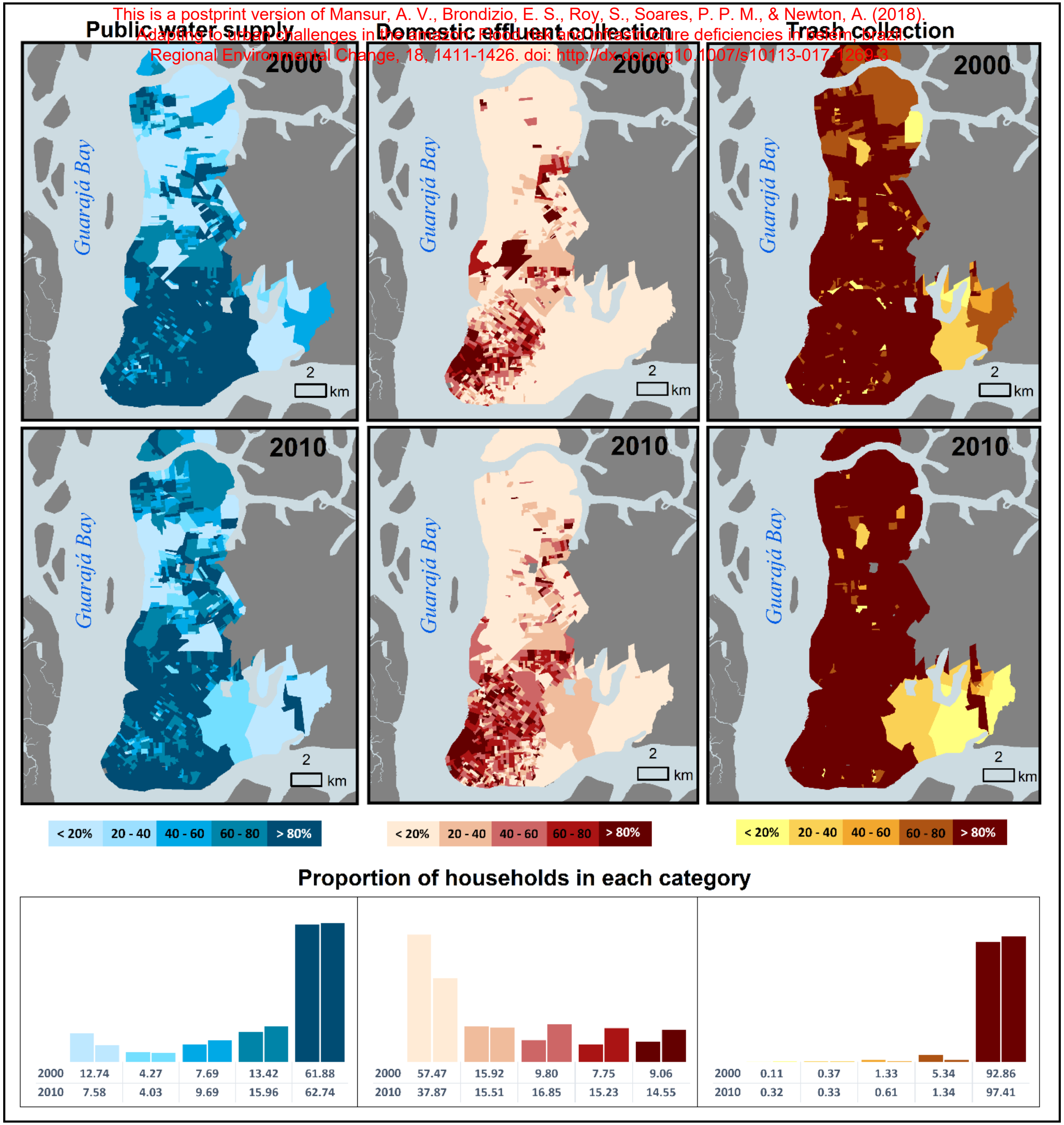
Public water supply
Domestic effluent collection
Trash collection
2000
2010
Guarajá Bay
2 km
< 20%
20 - 40
40 - 60
60 - 80
> 80%
Proportion of households in each category
2000 12.74 4.27 7.69 13.42 61.88
2010 7.58 4.03 9.69 15.96 62.74
2000 57.47 15.92 9.80 7.75 9.06
2010 37.87 15.51 16.85 15.23 14.55
2000 0.11 0.37 1.33 5.34 92.86
2010 0.32 0.33 0.61 1.34 97.41

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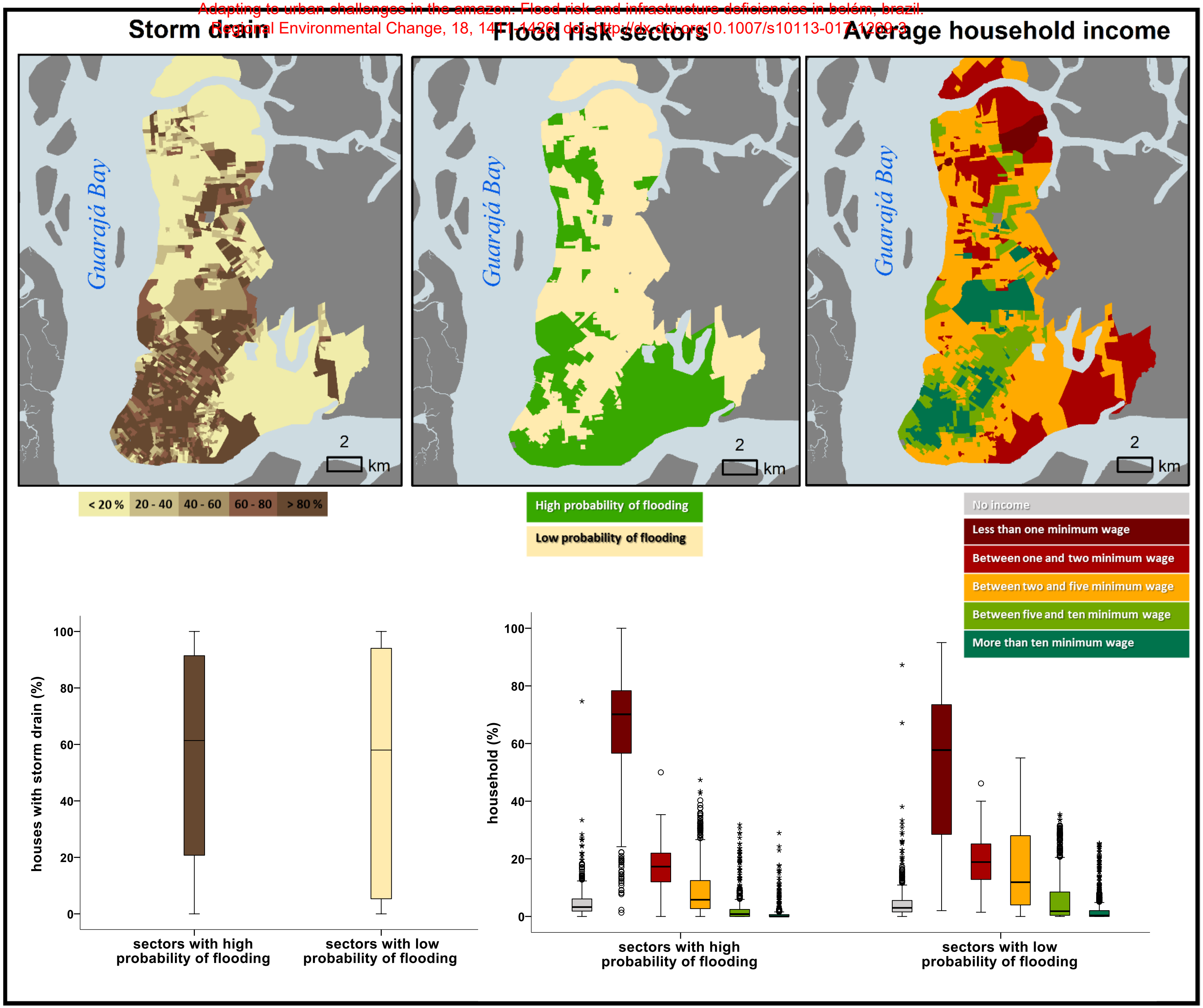
Storm drain
Flood risk sectors
Average household income
Guarajá Bay
Guarajá Bay
Guarajá Bay
2 km
2 km
2 km
< 20 %
20 - 40
40 - 60
60 - 80
> 80 %
High probability of flooding
Low probability of flooding
No income
Less than one minimum wage
Between one and two minimum wage
Between two and five minimum wage
Between five and ten minimum wage
More than ten minimum wage
houses with storm drain (%)
100
80
60
40
20
0
sectors with high probability of flooding
sectors with low probability of flooding
household (%)
100
80
60
40
20
0
sectors with high probability of flooding
sectors with low probability of flooding

Figure 4. Proportion of households in the city of Belém with storm drain; distribution of sectors group: with high and low probability of flooding (Adapted from Mansur et al. 2016); distribution of average household income based on based on different categories of incomes; Box-plots representing percentage of houses with storm drain and percentage of households in each category of income, divided by probability of flooding (low and high) of each sector

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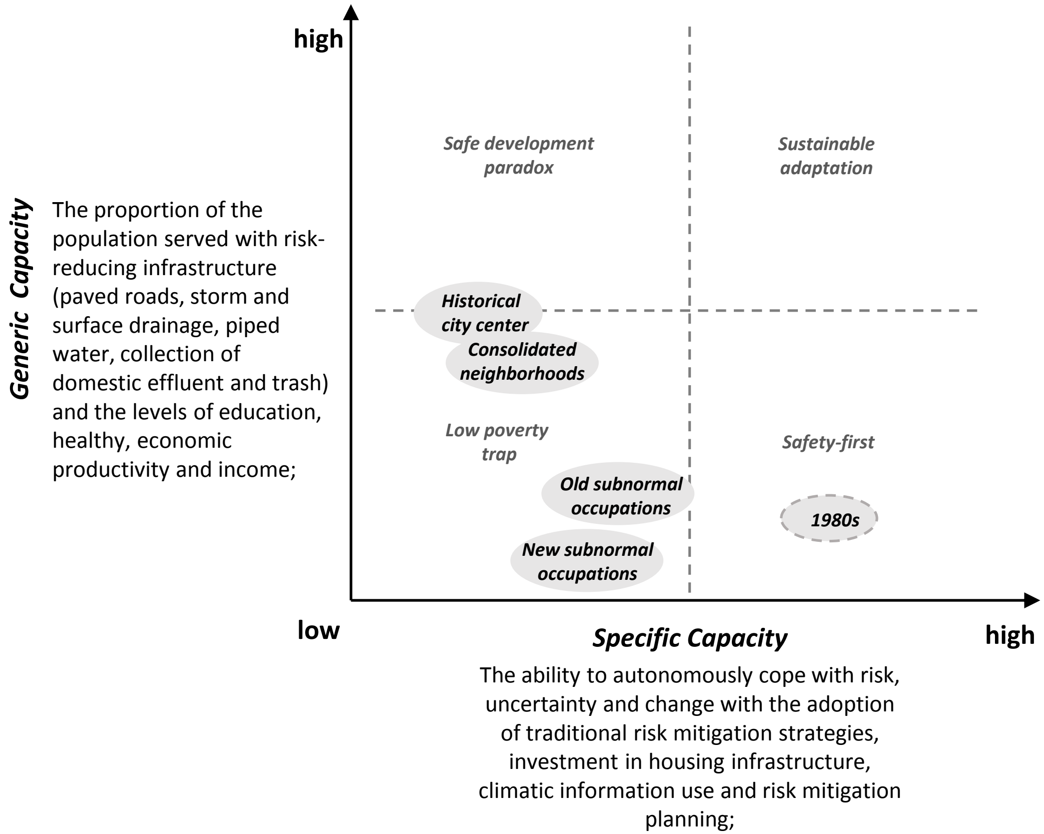

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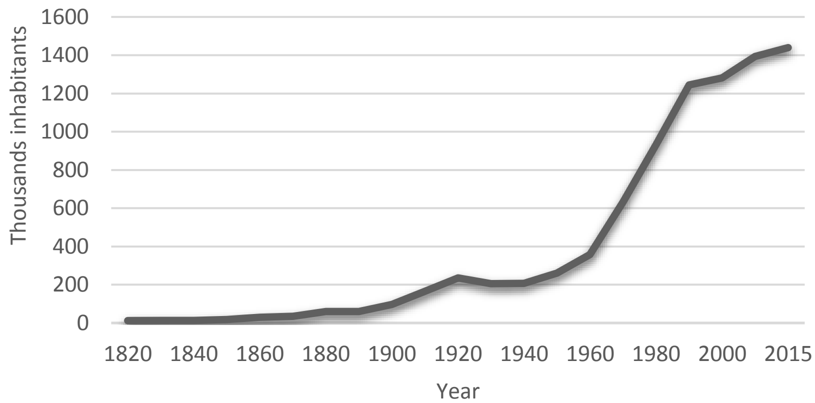

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Online Resource 2. Spearman´s correlation matrix between variables average household income and percentage of generic infrastructure, including storm drain, trash collection, sewage collection and water supply, divided by sectors probability of flooding.

Correlations

	flood risk			average household income	% household with storm drain	% households with trash collection	% household with sewage collection	% household with water supply
Spearman's rho	no	average household income	Correlation Coefficient	1.000	.626**	.487**	.696**	.267**
			Sig. (2-tailed)	.	.000	.000	.000	.000
			N	683	683	683	683	683
		% household with storm drain	Correlation Coefficient	.626**	1.000	.464**	.613**	.290**
			Sig. (2-tailed)	.000	.	.000	.000	.000
			N	683	683	683	683	683
		% households with trash collection	Correlation Coefficient	.487**	.464**	1.000	.470**	.343**
			Sig. (2-tailed)	.000	.000	.	.000	.000
			N	683	683	683	683	683
		% household with sewage collection	Correlation Coefficient	.696**	.613**	.470**	1.000	.338**
			Sig. (2-tailed)	.000	.000	.000	.	.000
			N	683	683	683	683	683
		% household with water supply	Correlation Coefficient	.267**	.290**	.343**	.338**	1.000
			Sig. (2-tailed)	.000	.000	.000	.000	.
			N	683	683	683	683	683
	yes	average household income	Correlation Coefficient	1.000	.469**	.325**	.412**	-.035
			Sig. (2-tailed)	.	.000	.000	.000	.382
			N	613	613	613	613	613
		% household with storm drain	Correlation Coefficient	.469**	1.000	.359**	.499**	.227**
			Sig. (2-tailed)	.000	.	.000	.000	.000
			N	613	613	613	613	613
		% households with trash collection	Correlation Coefficient	.325**	.359**	1.000	.340**	.342**
			Sig. (2-tailed)	.000	.000	.	.000	.000
			N	613	613	613	613	613
		% household with sewage collection	Correlation Coefficient	.412**	.499**	.340**	1.000	.298**
			Sig. (2-tailed)	.000	.000	.000	.	.000
			N	613	613	613	613	613
		% household with water supply	Correlation Coefficient	-.035	.227**	.342**	.298**	1.000
			Sig. (2-tailed)	.382	.000	.000	.000	.
			N	613	613	613	613	613

**. Correlation is significant at the 0.01 level (2-tailed).

Significant correlations: red= strong, orange = moderate, gray = weak

Yes = High probability of flooding, No= Low probability of flooding (Based on Mansur et al. 2016)

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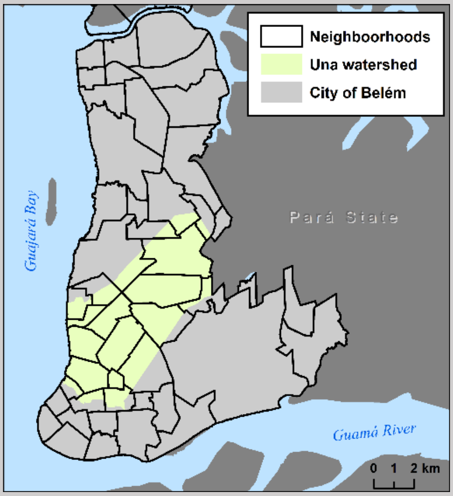
The macro-drainage project of the Una watershed



Examples from the legacy of the Project

Major flood events in Una watershed after conclusion of the project in 2004

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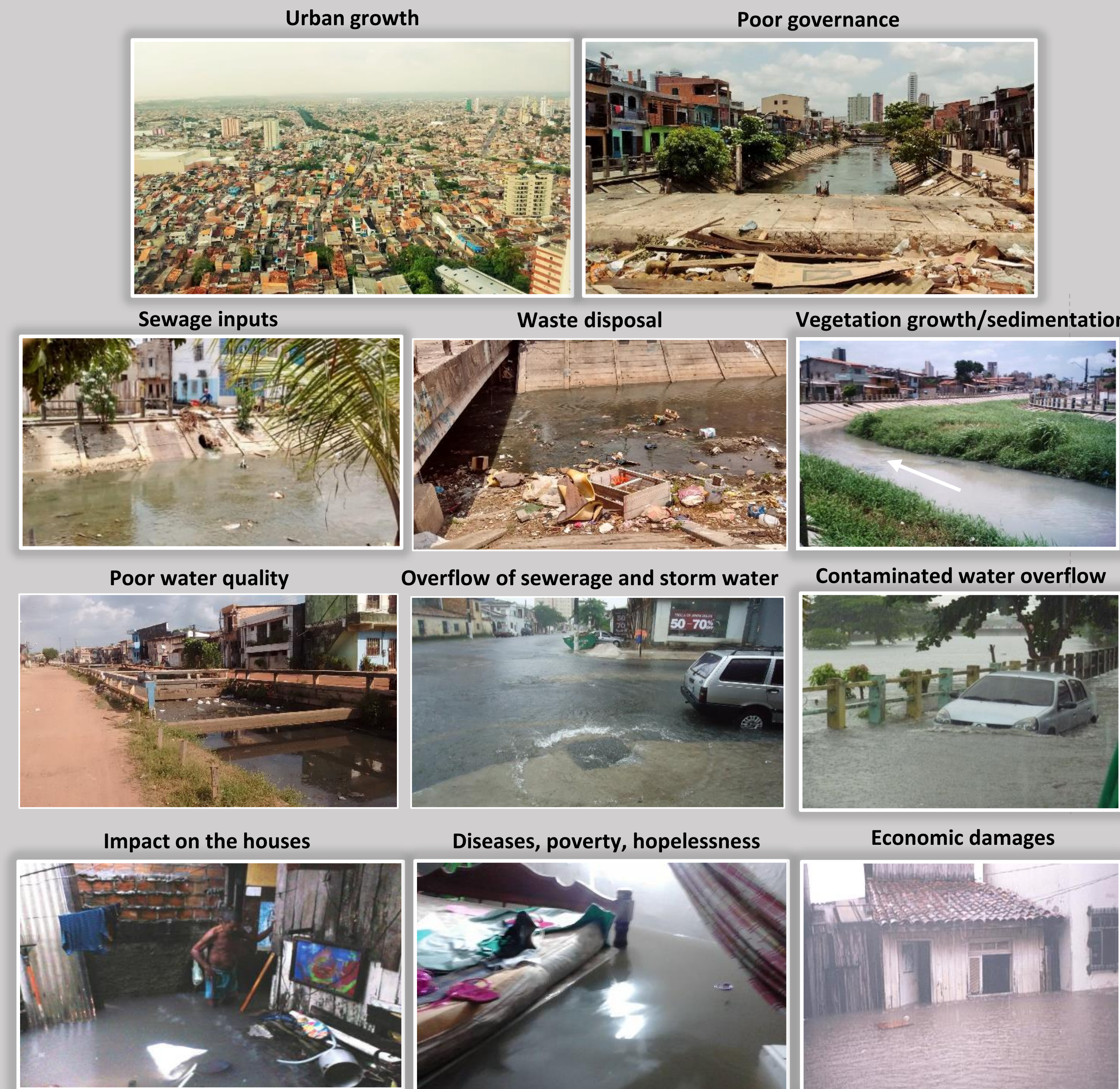
Socio-environmental changes reducing carrying capacity of the river channels in the city of Belém, Brazil



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