Urban Vulnerability in Lowland Areas

The Example of Belem, the Amazon Region

Vulnerability, lowland, Amazon region

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Belém is the capital of the Brazilian Federal State Pará. It is located in the Amazonas river delta estuary at the mouth of Guamá River close to the Guajará Bay. Geomorphologically, it is an alluvial plain less than four meters above sea level, suffering the effects of tides and creating difficulties to the urban drainage. Traditionally the occupation process took place in low areas close to the river and therefore highly vulnerable to floods, so called "ribeirinha", the typical small village structure close to rivers in the Amazonas region. This work is aimed to analyze the urban structure of Belém in order to propose flood control and mitigation strategies.

1. Introduction

In Brazil, as well as in many other developing and transformation countries, floods have increased considerably due to an expressive population growth accompanied by growths in, population density and impermeable areas, surpassing the urban drainage network capacity. Although inadequate design, operation and maintenance of storm drainage pose on a considerable number of cities serious problems to the population, few has been accomplished in the sense of seeking to prevent and control this processes in Brazil, where the attitude of resignation due to the fatality of an event "natural" is common. The inclusion of administrative and technical flood control measures in the urban master plan is necessary to improve the situation [14]. Occupations of inappropriate urban areas can be avoided through land use planning of lowlands, which must be regulated in urban master plan of cities. These measures can help to reduce the impacts of floods, giving people more time to be moved from areas at risk to security, as well as to protect the property [9].

The municipality of Belém, with 1.5 million inhabitants, is the 10th largest Brazilian city. It is located on the estuary-Amazonas River delta, more precisely at the mouth of Guamá River close to the Guajará Bay, suffering tide influences reaching 3.80 meters. Since 40 % of its urban area lies below four meters above the sea level [5], much of the city is frequently flooded. When high tide coincides with intense rainfall, the flood severity increases in the city, resulting frequent concerns even for a population traditionally adapted to floods.

This study aims to analyze the main characteristics relating to risks of urban flooding in lowland areas in the Amazon region, focusing the discussion on the aspects associated with the occupation of Belém, identifying its causes and evaluating possible measures to flood control, emphasizing the social, environmental and economic aspects.

2. Characteristic of the study area

The Amazonian floodplain is characterised by seasonal floods, influenced by rain regimes characteristic of the tropics and subtropics, with localized events of short duration, causing floods of large impacts. Geomorphologically it is an alluvial plain located below four meters above the sea level, tide influenced and with low rainwater drainage potential. The alluvial plain near the sea, where Belém is located, is predominantly composed of fluvial sediments, also presenting marine deposits. The lithology is predominantly ARENE-clay, or with conglomeratic or with silty levels [3]. The climate is hot and humid with average annual rainfall of 2834 mm. The average temperature ranges from 25 °C in February to 26 °C in November. It is a tropical rainforest climate with no cold season and mean monthly lowest temperature above 18 °C.

The flooded lands encompass practically the whole urban area of Belém, which presents a typology originally fairly segregated, great population density, economy based on informal labour and stilt or pile dwellings on public land and/or inappropriate for settling. There are 28 main drainage channels in the city of Belém [8].

Due to the fixation of streams banks, new areas have emerged, receiving the designation of "marshland", i.e. lowland areas located in areas close to sea level. In the year 2002, 40 % of the municipal area of Belém with approximately 550 thousand inhabitants was located in marshlands, ca. 38 % of the population. This has direct and indirect social implications for local population, reflected e.g. by the conflict of interests between the

Frequency / Severity	A Very unlikely	B Remote	C Occasional	D Probable	E Frequent
4 Catastrophic	2	3	4	5	
3 Critical	1	2	3	4	5
2 Moderate	1	1	2	3	4
1 Minor	1	1	1	2	3

***Figure 1**. Risk matrix classification– Frequency vs severity [1].*

Table 1. Occurrence frequency categories [2].

Frequency category	Title	Frequency range (annual)	Description
A	VERY UNLIKELY	$f < 10^{-4}$	Extremely unlikely to occur
B	REMOTE	$10^{-4} < f \cdot 10^{-3}$	Not expected to occur
C	OCCASIONAL	$10^{-3} < f \cdot 10^{-2}$	Unlikely to occur
D	PROBABLE	$10^{-2} < f \cdot 10^{-1}$	Likely to occur
E	FREQUENT	$f > 10^{-1}$	Expected to occur multiple times

Table 2. Categories of severity of the identified hazards [1].

Hazard severity category	Damage potential	Intensity of action on the environmental receiver	Restore time (years)	Financial resources deployed for recovery
Minor (1)	No damage/deaths and material losses are smaller	Restricted effect	< 1	Small
Moderate (2)	Minor damage with material losses	Moderate effect	1 and 2	Moderate
Critical (3)	Damage of moderate severity, with great material losses	Significant effect	2 and 5	Significant
Catastrophic (4)	Causes deaths or damages severe in several people, with material losses involving in State of emergency	High effect	> 5	Bulky

parties, with a plurality of values and diffuse responsibilities [6].

3. Risk analysis for Belém City

For environmental hazards analysis of lowland areas, the *PHA* methodology (*Preliminary Hazard Analysis*), a structured inductive methodology based on a system approach to identify potential hazards that may lead to an accident, was applied [10]. The analysis includes the following steps:

- list of hazards in each subsystem;
- description of the causes that can promote the occurrence of hazards and their consequences;
- review frequency of occurrence of the causes and severity of the consequences of unwanted events (hazards), both based on pre-established criteria;
- determination of the risk level and
- elaboration of statistics of hazards identified by risk categories.

The analysis is performed in a worksheet with the following structure:

- 1st column – hazard: unwanted event.
- 2nd column – causes: responsible for hazard occurrence.
- 3rd column – consequences: associated with a hazard occurrence.
- 4th column – frequency: set as described in **table 1**.
- 5th column – severity: set as described in **table 2**.
- 6th column – risk is estimated from the risk matrix, by the combination of frequency and consequence (**Figure 1**).

4. Results

Table 3 and **Figure 2** illustrate the numeric result obtained.

The figures in each cell of the array represent the amount of hazard framed in each risk category. Among the identified hazards 26 % have negligible environmental risk; 58 % are minors and 16 % are moderated.

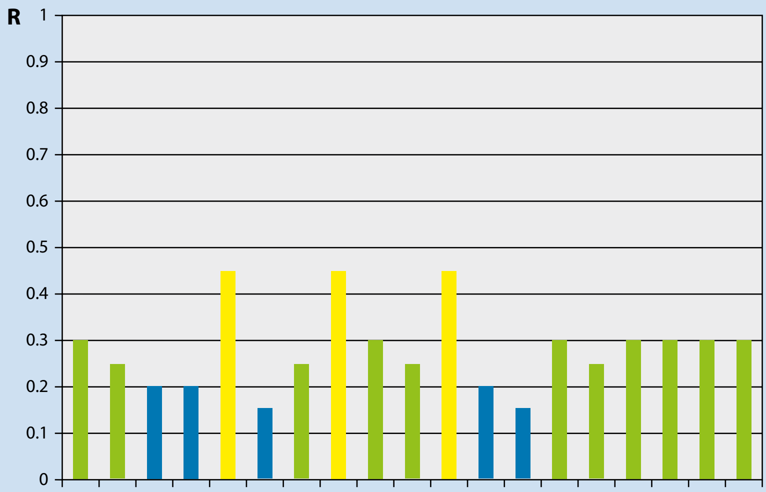
The analysis Frequency x Severity shows that low topographies help to minimize some types of flood effects and the occurrence of events involving fatal casualties are less likely to occur. However, there are a set of combinations resulting in losses of different magnitude and that can become more significant due to their annual recurrence.

The occurrence of urban floods in the municipality may be due to both natural aspects, depending on the hydrological characteristics and anthropogenic impacts as by modification of the natural system. The municipality of Belém has an inadequate planning, which does not consider the physical characteristics of the drainage basin and is not based on technical feasibility, economic and environmental studies. Besides technical problems like reduced slope for drainage, inappropriate sewer system design, construction, maintenance and land sealing, Belém faces other problems related to public sector organization (not avoiding invasions and occupation of high-risk areas), sanitation and street cleaning, awareness, apart from extreme weather events, which over the years are becoming increasingly intense.

According to [9] the hydrological regime is affected by the city expansion. Impervious surfaces such as rooftops, streets, roads, parking lots and driveways reduce the soil infiltration capacity and result in a large increase in the volume of runoff. The urbanization including informal settlements affects the alluvial (Pleistocene) plains as well as the drainage network. This leads to transformations of the urban environment and poses serious problems to Belém [4].

Table 3. Risk evaluation, whereas A=1, B=2, C=3, D=4, E=5.

	Environmental aspect for the central region and lowland areas	Frequency	Severity	Risk
1	Landslides caused by the action of mass floods	C	2	0.3
2	Accumulation of organic residues in flooded areas	E	1	0.25
3	Particulate generation around the flooded areas by slope blasting	B	2	0.2
4	Acid drainage generation	B	2	0.2
5	Topographic change with changing geometry of lowland	C	3	0.45
6	Accumulation of metals in flooded areas	C	1	0.15
7	Build-up of sediment in flooded areas	E	1	0.25
8	Contamination of groundwater by infiltration of long period in flooded areas	C	3	0.45
9	Generation of subsidence in flooded areas	B	3	0.3
10	Modification in food supply for aquatic fauna	E	1	0.25
11	Poisoning by direct contact with the quality waters changed	C	3	0.45
12	Local extinction of species	B	2	0.2
13	Introduction of exotic species	C	1	0.15
14	Migration of aquatic fauna	C	2	0.3
15	Damage the movement of vehicles in flooded areas	E	1	0.25
16	Gas leak due to flooding	C	2	0.3
17	Death by drowning	B	3	0.3
18	Accidents caused by the action of currents	B	3	0.3
19	Loss of cultural heritage in flooded areas	B	3	0.3



	R	(%)
DESPICABLE	≤ 0.2	26.32
LESS	0.25-0.4	57.89
MODERATE	0.4 - 50.6	15.79

***Figure 2.** Risk allocation.*

The terms of **Table 3** as elements:

	$R = F \cdot S$	Risk scale	
Minimal risk	1	0.05	DESPICABLE
	2	0.1	DESPICABLE
	3	0.15	DESPICABLE
	4	0.2	DESPICABLE
	5	0.25	LESS
	6	0.3	LESS
	7	0.35	LESS
	8	0.4	LESS
	9	0.45	MODERATE
	10	0.5	MODERATE
	11	0.55	MODERATE
	12	0.6	MODERATE
	13	0.65	SERIOUSLY
	14	0.7	SERIOUSLY
	15	0.75	SERIOUSLY
	16	0.8	SERIOUSLY
	17	0.85	CRITICAL
	18	0.9	CRITICAL
	19	0.95	CRITICAL
Maximum risk	20	1	CRITICAL

The urban watersheds draining the municipality of Belem accumulate the water of the whole basin. Any response to flood events has to take into account changes in the upper part of the river basin.

5. Institutional framework for disaster management

The urban planning in Brazil foresees a Municipal Master Plan considering growth and development and guaranteeing appropriate areas to live and work with dignity and security. Law No. 8,655, July 30, 2008, addresses the master plan of the city of Belem. Art 31 item III, IV, VII and VIII of chapter III on infrastructure and environmental policy addresses the following topics:

1. Reconcile, integrate and coordinate the preparation and implementation of sectorial plans of water supply, sanitation, drainage, solid waste, environmental risk control and environmental management;
2. Adopt the basins of the municipality as Municipal Policy Planning Units environmental sanitation;
3. Control the use and occupation of the banks of watercourses, areas subject to flooding, watershed areas, areas of refills and areas of high slope and drainage headboards;
4. Ensure the maintenance of permeable areas in the territory of the municipality.

Despite the master plan and its guidelines for environmental risk control, very few results concerning flood can be identified. Currently the Municipal Secretary of Urban Drainage and Sanitation (SESAN) and Municipal Secretary of Urbanization (SEURB) can not contribute adequately to the civil defence and fire brigade, for example with flood area or vulnerability maps.

According to PATEL *et al*, (2001), the political-institutional level reveals a lack of inter- and trans-institutional cohesion and coordination, needing a readjustment of competences and performance monitoring. Another observed problem is the lack of assessment of staff qualification and technical training.

6. Improvement of measures for urban floods in lowland areas

It is common in developing countries the execution of too ambitious projects or designs that do not achieve the expected objectives and exhaust the financial resources before the project conclusion. For [15] it is important to note that there is a tendency to give greater emphasis to the structural solutions, ignoring the fact that many failures are related to organizational factors. Flood control is based on a sum of measures, which are non-structural and structural measures. One of the mitigation measures is the creation of appropriate early warning systems including a hydro-climatologic network and alert dissemination. The use of hydrologic-hydraulic models would contribute not only to redesign the drainage network but also to cope with flood disaster, supporting the civil defence during emergency operations. Figure 3 describes the stages of a early warning system.

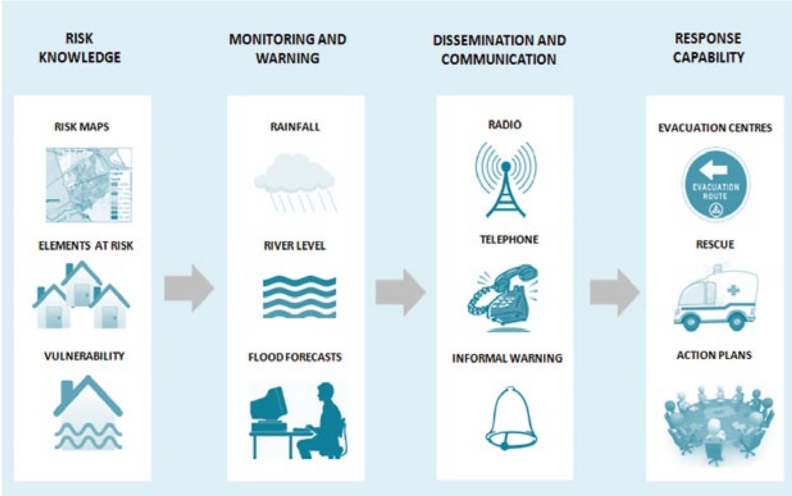


Figure 3*. Components of an effective flood early warning system.*
Source: Adapted from GTZ (2009)

7. Conclusion

Informal and inadequate settlement in flood exposed areas as well as low resilience level requires solutions in balance with environmental, cultural and socioeconomic reality of Belém. The urban space of Belém, conditioned by social relations and natural conditions, is characterized by high degradation and rapid changes in lowland areas. Due to the rapid urbanization and to climate change impacts, more attention has to be given to cope with and to adapt to flood disasters. Physical processes are of course vital for the drainage system. However, organizational, legal and institutional issues pose problems which are currently even more difficult to overcome.

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