Urbanistic Subsidies for a Metropolitan Drainage Plan, Belem, Brazil

Juliano Pamplona Ximenes Ponte, Ana Júlia Domingues das Neves Brandão

Abstract – **This paper is an exploratory study to bring upon discussion technical (both urbanistic and environmental engineering) subsidies in order to build a Metropolitan (urban, mostly) Drainage Plan for the Metropolitan Region of Belém (RMB), Brazil. Located in the Amazon Region, North Brazil, RMB is the metropolitan area with the highest levels of domiciles in slums and shantytowns, according to 2010 official data. Its territory is a plain site, with low declivities and intense pluviometry rates, and its floodplains are usually precariously occupied. Serious sanitation problems may be found in those areas, which are extensive in territory. GIS is applied alongside with theoretical issues to discuss the case of RMB flooding phenomenon, considered its main environmental risk problem. Finally, directives are listed, recommending combining and systemic use of both *structural* (highly artificial, concrete-based drainage structures) and *non-structural* (less artificial, more based on water and basins management, soil infiltration and natural processes, such as retention and flow), differentiated by the characteristics of urban occupation and demographic densities.**

Index terms - **environmental engineering, GIS, urban drainage, urbanism.**

I. Introduction

THE so-called Metropolitan Region of Belém (RMB, which means *Região Metropolitana de Belém*, in Portuguese), located in North Brazil, is a 2.2-million people urban settlement [1], nationally known for its extremely precarious urban infrastructure, statistically significant poverty and extensive occupied floodplains. It has been legally established in 1973, during the 1964-1985 dictatorship period in Brazil, when territorial and economic planning was considered a central activity for power maintenance and for a certain model of economic growth and development – which has been revealed as environmentally and socially disastrous.

The RMB urban sprawl is now an association of seven Municipalities, called Belém (the capital city of Pará State), Ananindeua, Marituba, Benevides, Santa Bárbara do Pará (where the last three Municipalities became part of the RMB in the 1990s)[2], Santa Isabel do Pará (which entered in RMB in 2010) and Castanhal[3] (which took part of the RMB in 2012, for explicit, thus non-technical, political reasons).

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In Brazil, as in other underdeveloped countries, there is a formation of a specific kind of urban periphery. In Brazil there are numerous *slums* and *shantytowns*, locally called *favelas* (even though there are several other denominations for the phenomenon), which are particularly critical in Belém. This city and its entire Metropolitan Region has been recently reckoned as the most precarious Metropolitan Region of the country, with 52,5% of its domiciles located in *slums, shantytowns* or *favelas*. Locally, the usual name of those slums is *baixada* (lowland, in Portuguese), denoting the legally irregular occupation of floodplains and, thus, regular exposition to environmental risks such as floods and diseases, as well as material losses. Those factors state that the main urban environmental risk in those Equatorial urban settlements, in lowlands, is flooding. Those settlements vary, in density, from 120 inhabitants per hectare to about 580 inhabitants per hectare, without proper sanitation or circulation infrastructures. Epidemiological data supports this assessment.

This paper is an exploratory study and collects (using reference from previous research experience) urbanistic elements, and GIS, in order to create directives and tendencies for a Metropolitan Drainage Plan. Those elements are produced for the territory of the five Municipalities that represent RMB´s densest urbanized parcels. For this task, this work uses mostly official *shapefile* cartography, from Federal and State institutions (IBGE, IDESP) in Brazil. These references are the polygonal shapes of municipalities; the delimitation of forty river basins in this territory; the hydrological network of the area; the polygonal definitions of slums and the street network, alongside with the road system. In the preliminary results, this study points out expressive incidence of those slums in flood-exposed terrains, riverine, dense, urban and poor, as well as in proximity with a few road and structural streets in the Metropolitan Region[4].

An analysis of the average declivities of the site indicates low general declivities (under 2.5%) and potential to drainage retention. This is an aggravation factor, as soon as pluviometry is locally intense. Those data were calculated using the hypsometry for the forty urban river basins of the RMB, and the spatial definition of a flooding spot. This flooding spot is based on local Engineering fieldwork, drainage projects and in-site experience; that is, the terrain located under the 4.5 meters contour lines, extended to, eventually, 6.0 meters contour and above (there are registered sites with flooding in 12-meter contours, for instance). This is related to a five-decade register in flood monitoring in the Region[5].

II. THE METROPOLITAN REGION OF BELÉM (RMB): CITY AND WATER

The cities that compound the RMB are, inevitably, related to water bodies and the Region hydrologic network. Their histories are linked to17th Century European colonization in the Americas, creating coastal fortresses and, later, expressive commercial points, in the spicy traffic of the 18th Century. Later on, imported technologies and European and North American industrial expansion brought steel and iron artifacts, such as railroads, urban furniture or infrastructure. As this all happened, also ports technologies were exported to South America at that time, bringing the efficiency of the commercial fluxes and the poverty of the ancient operators of that economic activity. By the 19th Century there were some historical records telling about the necessity to put into legal, stable and clear terms the posse of the land nearby water bodies, namely the river that crosses South and East RMB, called Guamá, as well as its bay, called Guajará (both indigenous names). In the 20th Century, as sanitation developed, water in the city became more *technical*, approached as *substance*, rather than *vehicle* (as it is in ports), *landscape* (in contemporary waterfronts) or *resource* (in industrial production or in water management economical logic)[6]. This *technical* approach of cities´ water was historically accompanied by social segregation in underdeveloped countries such as Brazil. The costs, and the long-time debt with the poor in providing adequate infrastructure created such a passive amount that, in present times, sanitation policies seem to manage crisis and not to solve the enormous deficiency of the question. Modern sanitation infrastructure is based upon rational Engineering-Epidemiological measurement[7] and conservative economical assessment; thus, it is likely that the poor, in chronic scarcity of public financial resources, such as underdeveloped countries experience, suffer from this very same restrictions.

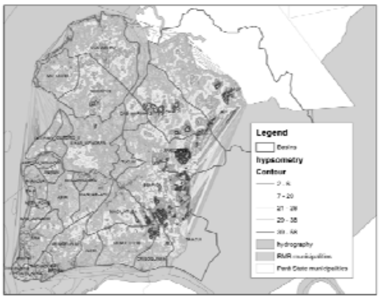
Present times are quite specific. Brazil is now trying to put in practice an ambitious national sanitation plan, ever since one Federal Law (11.445/2007, which establishes the National Sanitation Policy[8]) came to public. This landmark calls State, Republic members, and Municipalities, local governments, to the solution of the problem. Each one of these political and territorial agents must construct a plan (regional, for the State members of the Brazilian Federation; local for the Municipalities) in order to access public low-taxes or taxes-free resources to built sanitation structures in all of its variations (water, sewage, drainage, garbage), as soon as the plan shows the physical and financial dimensions of this challenge. It is important to mention the dictatorial period in Brazil (1964-1985), when a great amount of sanitation infrastructure interventions took place, tough, in a conservative pattern of location and technical choices. Drainage interventions, for example, were often excessively artificial, structural, and then they accelerated flood picks in lower areas, creating higher impacts in poor residential neighborhoods[9].

As Belém, and it´s Metropolitan Region, are a terrain with evident flood-risk questions, and as national sanitation policies demand solutions, this work intends to develop a technical contribution to the construction of a Metropolitan Drainage Plan, which, obviously, needs further data and collaboration, whether from technical agents of the State or civil society as well. This paper may collaborate in academic, technical and political debate on this theme.

III. METHODS, DISCUSSION

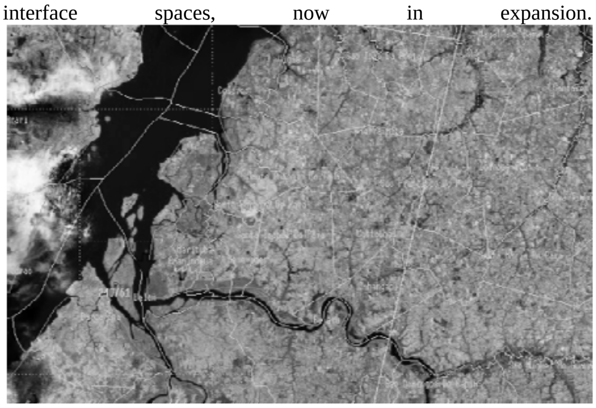
The Metropolitan Region of Belém, located nearby the Equator, is a hot and humid climate metropolis in the Brazilian Amazon Region. The sanitation deficiencies are secular, and the problem of the slums is the center of the question for a drainage plan in the RMB territory, as soon as urban drainage is, mainly, the environmental risk problem of this Metropolitan Area.

Fig. 1 The densest urbanized territory of the Metropolitan Region of Belém: river basins and contours.



As a technical and urbanistic subsidy (not financial, though) for this plan we are suggesting an analysis with GIS technologies. Using a hypsometry *shapefile* created by the Pará State Research Institute (IDESP)[10], we were able to detect the frequency of slum areas in flood-exposed sites. There are urban basins in RMB that have about 40% of their territories exposed to periodical flood risks, mostly those in South Belém and in the axis of Northwest Belém. From another point of view, most of these precarious (in urbanistic terms) areas in RMB are located in flood-exposed sites. The declivities in those sites are often smooth, low; under 2,5% in most of the cases (according to preliminary measurements in the map), but the crescent waterproofing of the urban surfaces, associated with precarious drainage implanted infrastructure and street garbage surface deposition, create an critical environmental framework in a Metropolitan Region[11].

Fig. 2 The LANDSAT 3 satellite image shows the urbanized and impermeable areas in RMB territory, as well as its rural/urban interface spaces, now in expansion.



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The study is, actually and presently, calculating the average declivities of the site of the RMB in proximity with its several urban rivers and canals (some of them occupied by the poor). Then, calculating the flood-exposed areas in each river basin of the RMB territory. Then, calculating their percentages over the total basin area; aerial photograph guarantee some estimated permeating areas inside those basins, in order to put together declivities, potential percolation sites and areas, low-valley areas, slums locations, roads and streets and permeating/waterproof sites. Those data may create a database, in a GIS system, which is now in course, to identify different intervention patterns, in either urbanistic and Environmental Engineering terms. Those intervention recommendations may consider the prevalence of non-structural urban drainage models, often appropriate to the reality of Belém, where low-declivities and associated with the expansion of construction, soil occupation, the decreasing of green and permeating areas, and where rainfalls are very expressive, as Equatorial climate shows. These calculi are simple, but efficient enough to orient urbanistic and urban drainage planning in a Metropolitan scale[12].

Table 1 Densely urbanized river basins in RMB, with mean site declivities, in percentage, and population living in slums and shantytowns, according to official 2010 data.

Basin	**Mean declivity** (flood spot to periphery)	**Permeable surface**	**Slum pop.**
Estrada Nova	2,4%	4%	118.219
Una	1,8%	5%	187.987
Tucunduba	2,5%	7%	93.657
Mata fome	2,9%	27%	38.708
Paracuri	2,3%	23%	62.221
Pau grande	2,9%	93%	9.434
Macajatuba	4,5%	65%	105.456
Maguarizinho	3,0%	19%	32.610
Maguari-Açu	1,4%	21%	101.133
Tamandaré	4,5%	7%	221
Magalhães Barata	1,8%	15%	-
MEAN	**2,7%**	**26%**	**74.965**

The assessment of these data may construct and orient the making of local and Metropolitan drainage plans, demanded by Brazilian authorities and needed by local population.

Calculating the contour lines under 6.0 meters above sea-level, and their due surface areas, the results pointed a 24% flood spot area, in comparison with the whole surface of the five municipalities that make RMB´s densest territory. It is a proportion of 182 thousand hectares of the five densest urbanized municipalities over 43 thousand hectares inside the 6.0-meter high flood spot. Although local Engineering (and, somehow, empirical) knowledge has been registering a successive 4.5 m contour line as Belém´s flood level, recent events show that higher plains have been affected by insufficient drainage, rainfall and high tides. Rainfall, in RMB, reaches an average rate of 241 mm in one month of the year[13].

Calculating declivities, using the contour lines (in 2 meters intervals) for the densest parcels of the urban RMB territory, was a procedure to seek parameters to future urban drainage interventions. The mean declivities, calculated from the flood spots inside eleven river basins, reached 2.716%. Although this is slightly higher than 2.50%, a turning-point[14] for the decision among structural and non-structural drainage interventions, it is fairly possible to consider the Metropolitan Region of Belém as a plain site territory. For this reason, runoff is, obviously, slow and frequently exposed to retention.

The decision of analyzing the specific declivities of eleven of the forty river basins of RMB´s territory is due to the intensity of urban occupation, and is related to some of the highest densities among them, as shown in Table 2. In a GIS software environment the declivities were calculated, with starting points from the initial (that is, the 6.0 m contour lines) flood spots in each of these dense and urban river basins. Most of RMB´s river basins territories are low-density areas, but there is an obvious concentration of slums inside some of those basins. Frequently, then, flood spots are located exactly where the poor live, in high-density and

Table 2 River basins, estimated population (2014) and densities, in people per hectare.

Basin	**Pop. (estimated for 2014)**	**Density (pop. per hectare)**
01-Tamandare	30.202	130,9
02-Estrada_Nova	277.611	296,38
03-Tucunduba	314.586	269,33
04-Murutucum	96.704	27,56
05-Aura	28.416	13,41
06-Magalhaes_barata	13.546	154,49
07-Reduto	13.313	78,25
08-Una	505.447	140,1
09-Val-de-cans	74.358	68,78
10-Mata_fome	35.375	62,11
11-Caje	33.134	148,58
12-Paracuri	134.763	73,88
13-Arari	259.255	69,55
14-Ananin	25.689	28,04
15-Outeiro	36.985	43,37
16-Itaiteua	18.811	13,56
17-Agua_boa	4.576	5,75
18-Outeiro Oeste	428	1,12
19-Outeiro Norte	388	0,46
20-Murubira	12.222	2,14
21-Marimari	1.335	0,17
22-Cajueiro	2.488	4,89
23-Santana	21	0,01
24-Mosqueiro	23	0,01
25-Carananduba	32.806	42,67
26-Jacarequara	5.237	3,34
27-Ipixuna	1.553	3,62
28-Irapara	1.873	3,15
29-Pau-grande	5.252	0,9
30-Macajatuba	201.633	35,58
31-Maguari_acu	203.836	64,22
32-Maguarizinho	45.181	61,07
33-Oriboquinha	779	0,28
34-Taicui	16.825	1,89
35-Benfica	25.243	3,5
36-Tucum	6.361	3,59
37-Paricatuba	10.950	1,08
38-Das_marinhas	3.237	1,71
39-Baiacu	4.027	0,42
40-Taua	25.467	0,61
MEAN	**62.748**	**46,51**

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precarious sanitation conditions[15]. Brazilian Government data classified those slums as *aglomerados subnormais* (*settlements under fair conditions*), and RMB is the Brazilian metropolitan region with the highest levels of slums, in 2010 census data[16].

Technical parameters for urban drainage systems, projected for RCP (*reinforced concrete pipes*) networks, deal with declivities in similar values as found in Table 1. In low declivities, similar to project values, acceleration of flow is usually recommended; but for the present context, our proposal is to combine structural and non-structural, comprehensive, drainage strategies[17] [18] [19]. Urban basins with localization nearby the city core (Estrada Nova, Una, Tucunduba) are simultaneously dense and impermeable; basins with peripheral localization (Paracuri, Mata Fome; Pau Grande) are not so densely occupied and have higher levels of permeable surface. It must be noticed that peripheral basins such as Pau Grande are urban-rural localizations, and have been experiencing expressive demographic growth in recent years, mostly with slum population. Although average declivities are low in RMB territory, periphery tends to be less plain than city core localizations.

IV. PRELIMINARY CONCLUSIONS AND DIRECTIVES

Those differences among basins show that special approaches must be done to their urban drainage solutions. We recommend, as technical directives, the following points, due to the commented and explained previous data:

- Non-structural urban drainage technologies seem compatible with dense, lowland areas, such as low-declivities city core basins. Those basins demand micro and macro drainage systems in connection to permeable landscape design areas, with the use of polders, reconstructed floodplains (although in small-scale, due to space restrictions) and permeable river banks and slope solutions (with timber, for example).
- On the other side, extensive basins, with lower density occupation, may require a combination of structural solutions, in canals with larger flumes, and non-structural, small-scale projects, in organic parceling areas, with high contiguity among buildings. This combination requires systematic maintenance, which is difficult to manage in underdeveloped countries such as Brazil, but we reckon that this is a question that must be faced, though.
- Urban-rural basins are delicate, due to their proximity with headwaters and because those are preferred areas in contemporary slum occupation in the whole RMB, unfortunately – those areas are isolated and segregated in even higher levels, in comparison to old metropolitan peripheries. The intense slum occupation, without social housing consequent projects, is creating a critical urban landscape, combining violence, environmental degradation and irrational urban sprawl logic – *functional* to real-estate developers, actually.
- Synthetically, a Metropolitan Plan for the question of urban drainage in the territory of RMB requires both structural (highly artificial and based on strictly planned flows) and non-structural (flexible structures, river basins water management, permeable surfaces, comprehensive low-impact interventions, environmental management and education) solutions;
- The lack, and deficiencies, of a consistent water management State policy, and the inexistence of a Metropolitan Basins Council or Committee, as in North-American and European water management policies[20], is expressed in the persistent flood events, which expand to upstream lands, higher than original contour flood spots (that is, from below 4,0 meters to about 6,0 meters higher than sea-level). This aggravates flooding phenomenon as the main urban and environmental risk factor in the entire Amazon Region and, thus, in the Metropolitan Region of Belém, despite the extensive recommendations and the technical instruments provided by Federal environmental policies since the 2000s in Brazil.

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