ENVIRONMENTAL VULNERABILITY INDICATORS OF THE COASTAL SLOPES OF SÃO PAULO, BRAZIL*

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Abstract

In the context of current discussions regarding the human dimensions of climatic change, it is essential to locate and to characterize populations in situations of risk. It is necessary to adopt methods that allow differentiating these populations on an intra-municipal scale considering that extreme climatic events can affect population in different ways. We used a hybrid approach to distribute the population of the São Paulo Coast on a grid. We performed an overlay operation of layers showing socio-demographic data and slope. Based on this procedure we were able to estimate and to characterize the population in areas of geological-hydrological risk in spatial units smaller than the census tracts. The methodology adopted shows to be adequate in studies of Population and Environment, creating a new analytical perspective and enabling a joint evaluation of the dimensions studied.

Keywords: climate change, Brazil, regular grid, risk

The climatic changes' impacts on populations depend on several aspects including physical, environmental, social, economic, and cultural, as well as the local infrastructure (JIANG and HARDEE 2011). In the context of current discussions regarding the human dimensions of climatic change, it is essential to locate and to characterize vulnerable populations in situations of risk. It is necessary to adopt methods that accurately allow to differentiate these populations on an intra-municipal scale considering that extreme climatic events can affect them in different ways and degrees.

The boundary mismatches between statistical units that follow a political administrative structure and the social, environmental, or artificial units is a major obstacle to the integration of socioeconomic and environmental data. Furthermore, the smallest spatial units commonly available for demographic data – the census tracts or enumeration areas – are inadequate for studies where more detail is required.

An approach to address these problems is to use a regular grid as the spatial unit for data from census surveys. This grid can be generated by geostatistical methods (GALLEGO 2010), by dasymetric methods (MENNIS 2003), or by the aggregation of microdata (GALLEGO 2010). Given the smaller dimensions of the grid cells (compared to census tracts, for example), the grid also contributes to better distribute environmental variables such as the slope.

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We used a hybrid approach to estimate the population in areas at risk of landslides and to characterize this population in spatial units smaller than the census tracts. We performed an overlay operation of layers showing socio-demographic data (2010 Population Census) and slope. Based on this procedure we were able to estimate the resident population in areas affected by geological-hydrological risks – based on geological data from environmental aspects (relief/unconsolidated material/rock) associated with human settlements (IPT 1994; 1999), and also a slope greater than 30° usually more susceptible to landslides (OGURA et al. 2004).

The statistical grid

The hybrid approach mixes bottom-up (aggregation) and top-down (disaggregation) techniques. This joint methodology is a new approach in Brazil, and is suitable for many countries.

In Nordic countries for example, the population grid has been offered by statistical agencies since the 1970s. They have developed a building-code system that is the basis for aggregating the data into a statistical grid (UN 2007). In countries where the aggregation approach has not been officially adopted, it is necessary to use some method to reallocate census data from irregular units into a grid-based unit. Among the methods to perform the disaggregation without ancillary data, we can mention areal weighting, pycnophylactic interpolation (TOBLER 1979), and the kernel estimation (BRACKEN and MARTIN 1989). Among the methods that use ancillary data – such as land use classification derived from remote sense images (REIBEL and AGRAWAL 2007), a network vector layer (REIBEL and BUFALINO 2005), or point addresses (ZANDBERGEN 2011), Dasymetric mapping is the most common (BUENO et al. 2013).

In Brazil, two technological advances have made it possible to aggregate census data into small geographical units since the 2010 Census. Digital census mapping which integrates urban and rural areas has allowed for the locations of the dwellings in urban areas using addresses. The *Address List for Statistical Purposes*, coupled with the use of handheld computers with GPS, has allowed for the capture of the coordinates of buildings in rural areas. However, we observed that the aggregation approach is not enough to put all collected aggregated census data on square grids because there is an amount of records without locational data. That limitation of the hybrid approach was used here to create a Brazilian statistical grid: the aggregation approach is used in regions where there is data that gives their geographic location and the disaggregation approach is used where these locational data do not exist (BUENO et al. 2013).[1]

The grid used here has square cells with sides around 1 km for rural areas and 250 m for urban areas, since geographic projection has been used.

Study Area

The São Paulo state coastal area (around 400 km long; almost 2 million inhabitants) encompasses 16 municipalities grouped into three sections: the Northern Coast, the Santos Metropolitan Region, and the Southern Coast (FIGURE 1). The coast is characterized by extensive occupation of the Serra do Mar mountain where most of the remaining Atlantic Forest in the state is located. These slopes have high steep inclines

[1] The grid is part of a PhD research in Demography, funded by the IBGE – Instituto Brasileiro de Geografia e Estatística and by CAPES (#17235-12-0). The 2010 Census microdata and mapping were provided by IBGE in an exceptional character for use in the mentioned PhD research.

and consequently, they are highly susceptible to landslides during periods of intense rainfall.

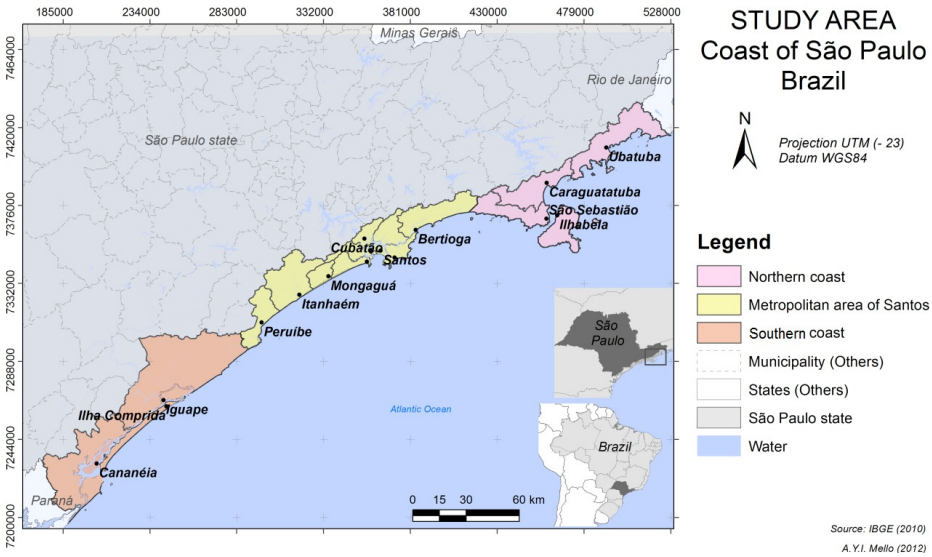

FIGURE 1. **Coast of the state of São Paulo, Brazil.**
Source: Malha Municipal 2010, IBGE.

Findings

FIGURE 2 shows the area susceptible to landslides and the population potentially vulnerable to geological hazards.[2]

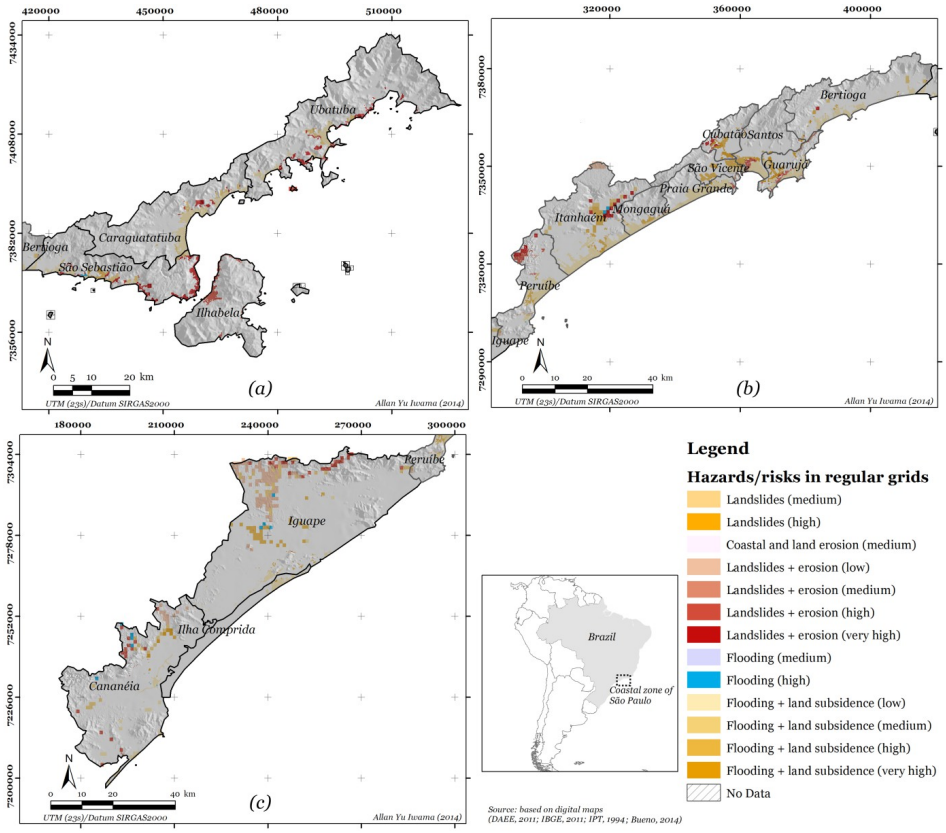

FIGURE 2. **Spatial distribution of geodynamics risks and socio-demographic data by region**. (a) Northern, (b) Santos Metropolitan Region, (c) Southern.

The grid accurately allows us to estimate and characterize the population affected by different hazards as TABLE 1 exemplifies.

TABLE 1 - Estimated Population by hazards of landslides+flooding+land subsidence.

Region	Pop. Affected	Indigenous	Illiterate
Northern	246,716	581	14,097
Santos Metropolitan Region	1,622,689	2,687	84,075
Southern	33,462	74	2,238

[2] This result is part of a PhD research in Environment and Society (FAPESP #2010/18501-8), into the scope of the project 'Urban Growth, Vulnerability and Adaptation: social and ecological dimensions of climate change on the Coast of São Paulo' (FAPESP #2008/58159-7).

The methodology adopted is adequate to Population and Environment studies, creating a new analytical perspective and enabling a joint evaluation of the dimensions studied. The statistical grid seems to offer a more accurate representation: the cells are generally smaller than census tracts, which are better to distribute population and environmental variables; the hybrid approach is more consistent than the exclusive use of disaggregation methods. As mentioned before, it is a technique only recently possible in Brazil, so it should be the subject of further studies.

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