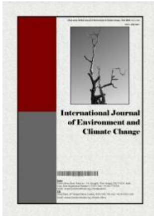

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Estimating Economic Impacts of Sea Level Rise in Florianópolis (Brazil) for the Year 2100

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Florianópolis is a city bathed by the ocean for most of its limits, which makes it a vulnerable environment to the effects of sea level rise (SLR). Thus, estimating the economic impacts of SLR in Florianópolis for the year 2100 may serve as a basis for designing public policies. The SLR scenario in Florianópolis for the year 2100 was generated by using geoprocessing techniques. In order to design the urban growth, the CityCell model was used and the economic impacts were estimated with the Adaptive Regional Input-Output (ARIO) model. The area affected in Florianópolis by SLR comprised 13.4% of its territory. The modeling for the year 2100 showed that the city will have a small urban growth. The direct cost of SLR in 2100 is predicted to reach 13 billion *reals* and the total cost is estimated to be 63 billion *reals* in the same year.

Keywords: Climate change; geoprocessing; urban growth.

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1. INTRODUCTION

Due to the interface among ocean, atmosphere and lithosphere, coastal areas are recognized as a hazardous geographical region, since they are liable to extreme events coming from these three elements. Adding to this scenario, climate change can bring new environmental standards, whose evolution is significantly uncertain.

Threatened coastal areas today consist of nearly 2% of the planet's land area and are home for about 10% of the world's population [1]. Florianópolis, the state capital of Santa Catarina (Brazil), is part of this reality, for its entire population is located on the coastal zone. The city's territory is composed by an island and a peninsula on the mainland portion. Therefore, it is a city bathed by the ocean for almost all its geographical boundaries. This peculiarity makes the environment vulnerable to the effects of climate change, particularly sea-level rise (SLR), among others.

Adding to this environmental vulnerability is the fact that one of the city's greatest sources of income is tourism, mainly owing to its natural beauty (beaches, dunes, lakes, etc.). With the possible SLR, these attractions may disappear and, consequently, undermine the city's economy.

According to the Intergovernmental Panel on Climate Change [2], SLR in 2100 will be around 1 meter. This increase will occur mainly due to the warming of the oceans, since more than 60% of the energy growth in the climate system is stored within this ecosystem, allowing it to expand and thus increasing sea level. Despite the warnings of the scientific community and the mobilization of the population to study and implement countermeasures, government action in this regard is virtually non-existent, and there are no effective measures in the case of Florianópolis.

Estimating the economic impact of climate change is a difficult task due to the complexity of the interface among climate change, society and the global economy. In spite of the difficulty, these impacts must be estimated in order to provide grounds to the formulation of public policies at the municipal level for the implementation of mitigation and adaptation measures.

It is increasingly clear that climate policies achieve better results when applied at the local level, particularly in cities. Most of the population in Brazil lives in urban areas, and many impacts of climate change will affect cities; consequently, specific adaptation measures are required [3].

With the possible SLR, economic and human losses can increase significantly in cities without protection or urban planning [3]. Therefore, the SLR mapping and its economic losses to Florianópolis will serve as a basis to develop adaptation public policies, either through new structures or through non-structural measures.

2. METHODOLOGY

The methodology used in this work was adapted from Hallegatte [3] and Fig. 1 illustrates the methodological flow that was taken in order to fulfil the objectives of the study.

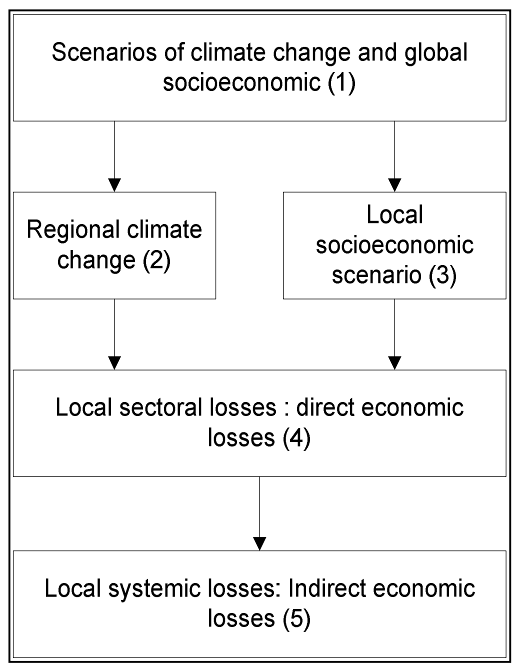

Fig. 1. Methodology components to estimate the economic impacts of climate change Fonte: Adapted from Hallegatte [3]

The methodology steps were: (1) Searching in the literature what the physical and socio-economic scenarios to climate change at a global scale were; (2) Translating these global scenarios of physical climate change into a regional scale; (3) and socioeconomic scenarios. From the understanding of these scenarios, (4) Direct and (5) Indirect economic losses were assessed. In this study, the impact of climate change in question was the SLR. The first step was carried out through the literature itself, especially using the International Panel on Climate Change [2] and the United Nations [4] guidelines.

Step 2, regional climate changes, translated the SLR setting into a regional scale. In other words, the increase of SLR in Florianópolis for the year 2100 was mapped. In Step 3, local socioeconomic scenarios, urban growth (urban sprawl and population growth) in Florianópolis for the year 2100 was designed, also based on the overall socio-economic scenario.

Steps 4 and 5 estimated the economic impact of SLR in Florianópolis for the year 2100 based on the scenarios of Steps 2 and 3. Step 4 focused on the direct economic impact, while Step 5 estimated the indirect economic impact. Each of these steps is detailed as follows.

2.1 Sea Level Rise Mapping

This step relates to the translation of SLR from a global scenario into the local scale, the city of Florianópolis. Although there is extensive research on SLR, the information provided by the IPCC [2] for scenarios creation was used: 0.98 meters (with an SLR rate of 8-16 mm/year), rounding the value up to 1 meter.

In order to draw the SLR scenarios, a digital terrain model (DTM) was used in a geographic information system (GIS). This DTM was generated from an aerophotogrammetric survey [5] conducted by the Government of the State of Santa Catarina (Brazil), through the Secretariat of Sustainable Economic Development (SDS/SC).

The survey mapped the state at 1:10,000 scale during the years 2010 and 2012 and one of its products was the altitude. The DTM for the city of Florianópolis was in 1:5,000 scale, with a 1-meter spatial resolution, using the Universal Transverse Mercator (UTM) cartographic projection system, with horizontal datum SIRGAS2000 in central meridian 51 and geoid model EGM2008. Both the DTM and all spatial analyses were handled through a GIS.

After processing the DTM in a raster format, the result was converted into a vector file, in order to facilitate intersection calculations and other cartographic bases. The vectors of the census tracts were provided by the Brazilian Institute of Geography and Statistics (IBGE), and the aerial image of the aerial survey came from the SDS/SC [5]. The highways were obtained from the IBGE and corrected based on the SDS/SC [5] aerial image, at 1:25,000.

A map of land use based on the SDS aerial image was prepared. The satellite image was interpreted visually and then validated during fieldwork. Following the field survey, the final version of image interpretation and subsequent calculation of areas of each land-use class were carried out.

2.2 Urban Growth and Population Projection

Urban growth was performed by using the CityCell model [6] developed by the Laboratory for Studies on Urbanism, at the Federal University of Pelotas (the Rio Grande do Sul State – Brazil). The modelling process followed three steps: (1) setting the input data and processes; (2) model calibration and (3) modelling for the year 2100.

Due to the limited computational capacity, the cell size (spatial resolution) was set at 400 meters. In this study, cells could represent three basic types: (1) non-urbanized environment, given by the natural territory and occupied by rural activities; (2) urbanized environment, which could be urban areas of low or high density and (3) institutional areas, either because of zoning or specific laws.

Two base images of Florianópolis were used. The first image was of the year 1985, from the Landsat 5 satellite, with the composition of blue, green and red bands. The second image, of 2014, was obtained through the Google Earth software [7]. Both images were georeferenced (horizontal datum WGS84, UTM projection system) in a GIS, imported and classified in City Cell.

For the calibration, three different growth potential scenarios were prepared, and for each of these three scenarios, additional five scenarios for the growth shape were created. Altogether, fifteen different scenarios were processed, as simplified in Table 1.

These settings were chosen because the variable expressed by the growth potential, which ranges from 1,3 to 2,0, would allow adjusting the value of quantitatively different speed and intensity of growth – that is, the lower the value, the greater the speed and intensity of growth. In this manner, scenario 01 grows more slowly than scenario 03.

The tension distribution was assigned according to known patterns of urban expansion, as follows: A) axial distribution; B) polar distribution and C) diffuse distribution. Axial distribution captures the preferred system cells' linking routes and is associated with an urban road system. It is divided into two groups: A1) related to the preferred route of the cell itself; A2) for cells located in the vicinity of the preferred path. The polar distribution shows spatial differences at the local level, in the immediate surroundings of the stress generator attribute. Finally, diffuse distribution is intended to capture aspects with the most locational unpredictability in the urban fabric, yet specifiable according to two standards: C1) for the formal real estate development and C2) related to real estate self-promotion processes and informal real estate development [8].

The variation in the tension distribution is adapted from Polidori [8] as follows: a) no predominance of any kind of distribution (20% for each); b) predominant distribution of axial stress (80% for axial and 10% for others); c) predominant polar voltage distribution (80% for polar and 10% for others); d) predominant diffuse tensions (80% for diffuse and 10% for others); e) predominant polar and axial stress (40% for each and 20% for diffuse).

As a means to model for 2100, the starting point for modelling was the year 2014. Thus, modelling Florianópolis for the year 2100 followed the best distribution scenario of tensions at growth potential. Three scenarios with three different growth rates were elected.

In addition to the urban growth data, population growth was projected. The official IBGE methodology developed by Madeira and Simões [9] was used. This method requires the existence of a population projection, which considers the changing demographic components (fertility, mortality and migration), to an area larger than the municipality, such as the Federation Unit, Greater Region or Country.

In this case, the population of Florianópolis was estimated based on the application of the model described. Brazil, whose projection was prepared by the United Nations [4], was considered as a larger area, whereas the Santa Catarina State was taken as a smaller area. Data from the 2000 and 2010 censuses of the IBGE [10] were used for the initial population of Florianópolis, Santa Catarina.

2.3 Estimating the Economic Impact

SLR will result in physical and economic consequences of human activities. These consequences can be classified into two broad categories: Market impacts, which directly affect the economy and off-market impacts, which affect human life and the environment (health and biodiversity, for instance). This study only evaluated market impacts. Within these, the SLR can be classified into direct and indirect dimensions.

Climate change can affect sea level around Florianópolis in two ways. Firstly, through gradual elevation of the sea level and secondly through changes in the sea level caused by storms. For the purpose of estimating the economic impact, the second way was considered, with the SLR as a single event.

At this step, an exposure map was designed. It showed the spatial distribution of properties in the study area and the crossing with the SLR coverage, in order to estimate the affected exposure. The spatial distribution of urban growth in Florianópolis from the City Cell model served as input data for this step.

For the estimated direct cost, the urban growth map modelled for the year 2100 and the generic plant values (GPV) of Florianópolis [11] were crossed. It shows the value per square meter (R$/m^2) in different regions of the city. The value expressed in GPV reflects the market value of the land and construction on it. The GPV was vectored based on the value per square meter of the main roads and expanded to the neighbourhoods.

Therefore, three pieces of information for the direct costs were crossed: a) SLR coverage; b) chosen modelled scenario of urban growth in Florianópolis for the year 2100 and c) generic plant values.

The last step aimed at estimating the cost of systemic losses in the economy due to SLR. In order to quantify the indirect costs of SLR in

Florianópolis, the ARIO model was used in a numerical computing environment. This model is based on the input-output (IO) model.

In Brazil, the official organ for the construction of input-output matrices is the IBGE. However, the latest information published by the IBGE on the topic was from 2005 [12]. Thus, the WIOD input-output information of 2011 was preferred [13].

This matrix provided information about 35 industrial sectors in US dollars. In order to put them into ARIO, these sectors were grouped into only 15, namely: 1) agriculture, forestry, fishing and hunting; 2) mining; 3) utilities; 4) construction; 5) manufacturing; 6) wholesale trade; 7) retail trade; 8) transporting and warehousing; (9) information; 10) finance, insurance, real estate, rental and leasing; 11) professional and business services; 12) educational services, health care and social assistance; 13) arts, entertainment, recreation, accommodation and food services; 14) other services except for government and 15) government.

Due to lack of data on GDP per industry for the township, an intermediate matrix was designed for the Santa Catarina State in order to build the local IO matrix to Florianópolis. For the IO matrix of Santa Catarina, GDP per industrial sector (for the year 2011) and the national IO matrix were used, assuming in each industrial sector a proportion between GDP and the intermediate consumption.

The IP array of Florianópolis was built upon the proportionality of the city's total GDP instead of GDP per industrial sector since this information was not available for cities in Brazil. Even for Santa Catarina, the IBGE had information from eleven industrial sectors, and some of them were divided to form fifteen sectors required for the ARIO.

For disaster data, previously calculated results from the assessment on the direct cost were used. The distribution of this damage over the industrial sectors was carried out according to empirical observations of Hurricane Catarina.

2.4 Study Area - Florianópolis

Florianópolis is located on the coast of Santa Catarina (Brazil), consisting of an island portion and a mainland portion. The island of Santa Catarina is up to 5 km away from the coastline and is located between latitudes 27°22' and 27°50' parallel to the coast, with the longitudinal axis of approximately 55 km in the NS direction. It is separated from the mainland by the northern and southern bays, which provide straight where the Pedro Ivo Campos and Colombo Salles bridges link the island to the mainland and where the depth reaches 28 meters [14].

The western side of the island, in contact with the tranquil waters of the northern and southern bays, has smooth highs, and its coast is designed by small coves. Various coastal plains are drained by river basins that turn into small estuaries, particularly the bays of Ratones (61 km^2) and Rio Tavares (31 km^2), both containing mangroves on their lower and middle courses. The east face, exposed to the open sea, the ocean waves and winds, has its plains lined by quite long beaches. It also bears large moving dunes or dunes covered by vegetation [14].

The BR 101 and BR 282 highways serve as the main access to the island. BR 282 accesses Pedro Ivo Campos and Colombo Machado Salles bridges, as mentioned above, with an approximate length of 1,250 m, connecting the mainland to the island of Santa Catarina. The state highways that serve the city are SC 401, SC 402, SC 403, SC 404, SC 405 and SC 406 [15].

According to IBGE [16], the estimated population of Florianópolis in 2014 consisted of 461,524 inhabitants. Since the Florianópolis land area is that of 675.41 km^2, there is then a population density of 623.68 inhabitants/km^2. Florianópolis has 229,002 economically occupied people. The economic sector with most jobs in the tertiary sector, with 200,246 people (88%). This sector is represented mainly by the provision of services, public administrative activities and tourism. The primary sector absorbs only 1% of Florianópolis workforce (3,171 employees), and the secondary sector, 25,587 people (11%) [10].

According to the IBGE Central Register of Enterprises [17], Florianópolis had 24,463 companies in 2012, and they were mainly concentrated in the tertiary sector. The commerce and public administration sectors have the largest number of companies, which, together represent 45% of all enterprises in the city.

Table 1. Growth scenarios used for modelling urban growth in Florianópolis from 1985 to 2014

	Calibration							
ID	Tension distribution					Growth Potential		
	A1	A2	B	C1	C2	Scenario 01	Scenario 02	Scenario 03
a	20%	20%	20%	20%	20%	2	1,5	1,3
b	40%	40%	10%	5%	5%	2	1,5	1,3
c	5%	5%	80%	5%	5%	2	1,5	1,3
d	5%	5%	10%	40%	40%	2	1,5	1,3
e	20%	20%	40%	10%	10%	2	1,5	1,3

In Florianópolis, there is no measurement of the long-term average sea level. However, in Imbituba (90 km away from Florianópolis), there is an IBGE tide station. According to the IBGE [18], sea level increased at the Macaé/RJ and Imbituba/SC stations, with an average elevation of 37.0 mm/year and 2.5 mm/year, respectively. However, it is not possible to attribute this increase in average only to climate change, since the measurement time took only 5 years (2002 to 2006). According to IOC [19], this happens to be representative if the measurement takes at least 30 years.

3. RESULTS AND DISCUSSION

3.1 Sea Level Rise Mapping

The map in Fig. 2 resulted from crossing the DTM and the SLR scenario estimated by the IPCC for the year 2100. The area affected by the SLR would cover 13,4% of its territory, that is, 54.63 km^2.

The class nomenclature of land use followed the Technical Manual of Land Use by the IBGE [20]. Seven land use classes were used: urbanized area, dunes, mangrove, water, beach, undergrowth and forest.

As it is located in low levels, one of the most affected ecosystems is the mangrove. Thus, all mangroves in Florianópolis would be somehow affected by SLR.

Another class highly affected would be the beaches (nearly half of them - 46,8%). The use of Florianópolis beaches for leisure reflects a long process of expansion that began early in the last century [14]. However, it was not before the 1970s that the growth of tourism accelerated exponentially. According to a survey conducted with tourists by the Santa Catarina Tourism Agency [21], a state government agency, the main attraction of Florianópolis is the immense variety of beaches (urban, rustic, with still or rough waters, extensive or anchored on small bays), not to mention other attractions provided by the use of its diverse natural environments.

The urban area to be affected by SLR would comprise 10.12 km^2. This is the class where homes and businesses are concentrated, and it will be the focus of this study when estimating economic impacts.

In order to estimate the population affected by SLR, the study used the population information from the 2010 census tracts for the impact in the year 2100. For the year 2010, the number of affected people reached 179,964, or 43% (the total of inhabitants according to the IBGE census units in Florianópolis was 418,623), and the total of affected households was 62,578, or 42% (the total of existing homes in the city was 147,434, as of 2010).

According to the mapping process, the most affected district in absolute numbers would be the centre, a place that houses most of the population (59%) of Florianópolis. The total population affected by SLR in the centre would be 75,479 (or 30% out of the total). The most affected districts would be Barra da Lagoa, Pântano does Sul and Ratones, with 100% of its inhabitants. The least affected neighbourhood would be Ingleses do Rio Vermelho, with only 3,712 inhabitants, or 12% of the inhabitants of the district.

The urban area of Florianópolis has been developed primarily on marine sediment storage areas, which are lower. Therefore, the road network followed this route. SLR could damage many major highways of the city; altogether there are seven major hits. The whole northern part of the island would be isolated, thus damaging districts that would otherwise be very little affected directly, as many roads would be jeopardized.

3.2 Urban Growth and Population Projection

The second step of the study mapped urban growth and projected population growth in Florianópolis from a global social scenario. At this step, the population growth for 2100 did not consider SLR as an obstacle. That is to say, the urban area can grow without it as a limiting factor.

Projecting urban expansion is a difficult task, and it is often easier to assess the future impact on current society and economy. The advantage of this method is the control upon uncertainties and the reduction of the number of unknown parameters. However, this approach is not always acceptable, especially in developing countries where urban growth is accelerated, causing the exposure and vulnerability to varying greatly within a short period [22].

During the calibration of CityCell to Florianópolis in three different urbanization potential scenarios (urbanization speed), the kind of urban growth that most resembled the year 2014 was that of polar predominance. This similarity was given by the percentage of correct answers out of the total number of simulated cells, reaching 73.53%, 76.15% and 77.50% accuracy in urbanization potential scenarios 1c, 2c and 3c, respectively.

The percentage of success for the total number of simulated cells intersects the percentage of cells in the final state (urban 2014) with the last model interaction in relation to all cells resulting from the union of these two groups. That is, the greater the number of overlapping cells in regard to the total of cells being compared, the greater the percentage of success.

Another parameter for similarity analysis is the total number of cells at the end of the simulation compared to the total in 2014. Scenario 3c, besides presenting the highest percentage of accuracy in relation to the year 2014 with the total number of simulated cells, also presented the highest similarity to the total number of cells at the end of the simulation, with an 8.5% error rate.

The predominant polar distribution illustrates the urban growth in Florianópolis. As pointed by Reis [14], the urban structure that has been consolidated in the city is the result of local growth, that is, the pre-existing nuclei (neighbourhoods). Despite the small growth along the highways (axial) and the diffuse growth, it is the neighbourhoods that end up attracting more people and increasing urban growth.

This type of urbanization happens due to historical and geographical factors. Growth in Florianópolis is dictated by strong limitations to the urban occupation, with major discontinuities of the urbanized space. The areas defined by steep slopes, mangroves and dunes, currently protected by environmental legislation, are spaces less transformed by human occupation.

Thus, the scenarios that best represented urban growth in Florianópolis were the three ones with polar predominance. The polar distribution shows spatial differences at the local level, in the immediate surroundings of the stress generator attribute.

For the 2100 modelling, three scenarios with polar predominance were used. The scenario 1c simulation began with 1,088 urban cells, and at the end of 86 iterations (equivalent to 86 years), it reaches 1,160 cells, an increase of 72 cells (equivalent to 11.52 km^2 or 6.62%). The scenario 2c simulation also started with 1,088 urban cells, and at the end of 86 iterations, it reaches 1,171 cells, an increase of 83 cells (equivalent to 13.28 km^2 or 7.63%). The scenario 3c simulation began with 1,088 urban cells, and at the end of 86 iterations, it reaches 1,175 cells, an increase of 87 cells (equivalent to 13.92 km^2 or 8.00%).

The small growth of Florianópolis, even when modelling with the growth potential of 1.3, complies with what was discussed, since urban growth is confined to small portions of the territory, causing a small expansion.

What may happen in the city is a densification of the existing urban area. Unlike other areas being converted into urban, this will become increasingly dense in order to hold the city's growth. This pattern of population density is already happening in Florianópolis. As shown in Table 2, while the urbanized area grew 27.88%, the number of inhabitants increased by 111.19%.

Finally, this accelerated growth was selected in order to estimate the direct costs of economic impacts. This choice was related to the dynamics of accelerated growth in the capital of Santa Catarina, as will be discussed later.

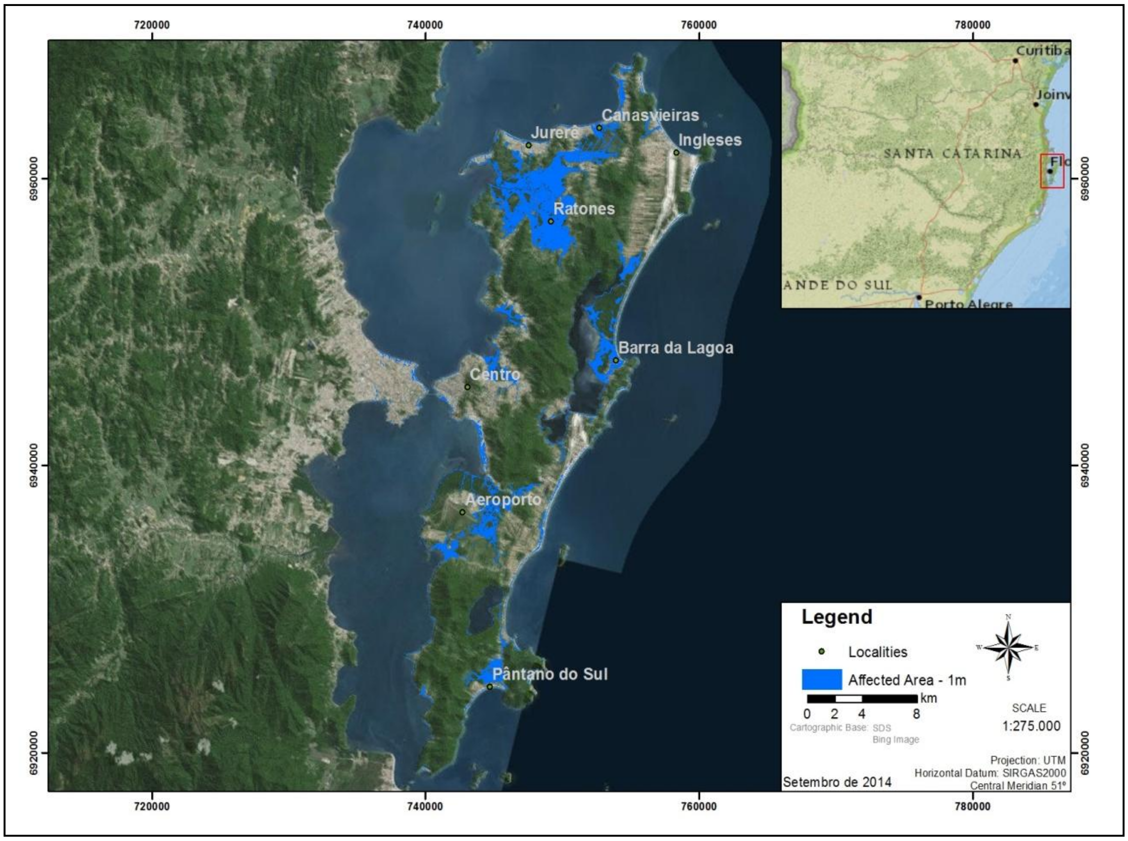

Fig. 2. SRL coverage area in Florianópolis for the year 2100

The United Nations [4] estimates the population for Brazil until 2010 and according to these numbers, by 2050 the country will reach the maximum population of 222,843,000 inhabitants. From this year on, the population declines until it reaches 177.349.000 inhabitants in 2100. On the other hand, the world population continues to grow until the year 2100, when it will reach just over 10 billion people.

Through this methodology and based on the estimated world population growth for 2100, it was estimated that Florianópolis will reach 696,499 inhabitants. This is, therefore, the population considered in the next steps of the study. Considering this population for the year 2100 and applying the same proportion of the population affected (43%) by SLR, the number of people affected would go up to 299,421.

3.3 Estimating Economic Impacts

The direct cost was estimated from the combination of the SLR coverage for 2100, the chosen modelled scenario of urban growth to Florianópolis for the year 2100 and the generic plant of values. As already mentioned, since SLR translates into a loss of dry area on the island, all affected buildings will be destroyed.

Upon crossing the modelled scenario of urban growth to Florianópolis with SLR information, the exhibition map was obtained. On this map, the values in *reals* per square meter were multiplied by their area in order to obtain the amount in *reals* for each polygon.

Although the most expensive areas are within the central region, Jurerê, the sea border of the continent and Ingleses, none of these has the highest direct damage. The most affected region was Canasvieiras, which has a relatively expensive square meter value (between R$ 755.00 and R$ 1,133.00 per square meter) and is geographically very affected, with a well-established urban area. Thus, crossing this information resulted in the value of 13 billion *reals* (according to today's currency) of direct costs for the projected 2100 scenario in Florianópolis.

Direct market impacts are only a fraction of all economic damages caused by the physical impacts of the SLR. Direct damages result from direct contact of flood water that comes from coastal erosion with goods. It is hence related to physical deterioration of assets. These damages also include the cost of relocating the damaged construction.

Direct damage may be caused by changes in average conditions (for example, gradual SLR) or extreme changes (storms and undertow). Hallegatte [22] states that the assessment of impacts due to changes in average conditions and extreme changes should be distinct. This happens partly because their prediction requires different methodologies, but also because they will require different adaptation strategies.

In this study, however, there was no such distinction in the method. In other words, in order to estimate the economic impact, the study considered that there will be a single undertow event that will devastate the entire mapped area located just below 1 meter.

Ranger et al. [23] explain that after the event, the total economic costs can be amplified through 1) sectorial and spatial distribution of direct costs to a broader economic system; 2) social response to the disaster; 3) financial constraints that compromise reconstruction and 4) technical constraints decreasing the speed of reconstruction.

In order to model this effect over the economy, which is called indirect cost, the ARIO model was used. Following the event, the municipal added value decreases to almost 6%, then increases to levels higher than the pre-disaster values thanks to the construction industry.

The reconstruction is complete after about 24 months (2 years), but the total production is equal to or greater than the initial condition for less than two years due to the need for reconstruction. The disaster was responsible for the direct cost of 13 billion *reals*, which represents 20% of the total estimated cost of 63 billion *reals*. Fig. 3 shows the amounts required for reconstruction over the months.

3.4 Adaptation and Mitigation Measures

Climate variability poses a major challenge to society, and future changes in climate seem inevitable. According to the Brazilian Panel on Climate Change, all of this requires the development of adaptation strategies [24]. Long-term consequences of climate change are an important argument speaking in favour of mitigation policies and should not be disregarded.

Taking climate change for granted can currently increase vulnerability and limit the feasibility of future adaptations. According to the IPCC [2] projections for South America, adding to the SLR, Florianópolis might witness an increase in the number of tropical cyclones, heatwaves and rainfall. Managing these risks in combination can lead to a review on the urban planning practices adopted in the city, in order to reduce the risk of disasters and create adaptation measures to deal with climate change in everyday city life.

Table 2. Urbanized area and population growth in Florianópolis between the years 1985 and 2014

Year	Urbanized area* (km^2)	Inhabitants**
1985	140,00	218.533
2014	179,04	461.524
% growth	27,88%	111,19%

*Source: * Calculated on Citycell. ** IBGE, 2014*

An obstacle to adaptation in urban areas is the structural changes in infrastructure that can be very costly and occur too slowly. In order to measure the benefits of adaptation measures, it is essential to consider its positive and negative side effects. An example of an adaptation measure that could be considered in Florianópolis is a coastal infrastructure designed to protect the city against SLR and undertow, such as a concrete wall along the coast. This structure would lead to a drastic decrease in tourism because it would spoil the beauty of the beaches, the ecosystem's health, plus leisure loss on beaches, among other losses. Thus, a concrete wall on the beach in Florianópolis is not an option to stop SLR.

Nevertheless, adverse side effects can be offset to some extent thanks to positive side effects. Creating land-use zoning policies in order to limit urbanization and development in certain areas that impair the beaches' morphodynamics (*eg.:* excessive urbanization on beach sandbanks undergoing erosion in Florianópolis) would reduce losses today (due to undertow, even with the current sea level) and SLR threats would do nothing but make zoning even more attractive.

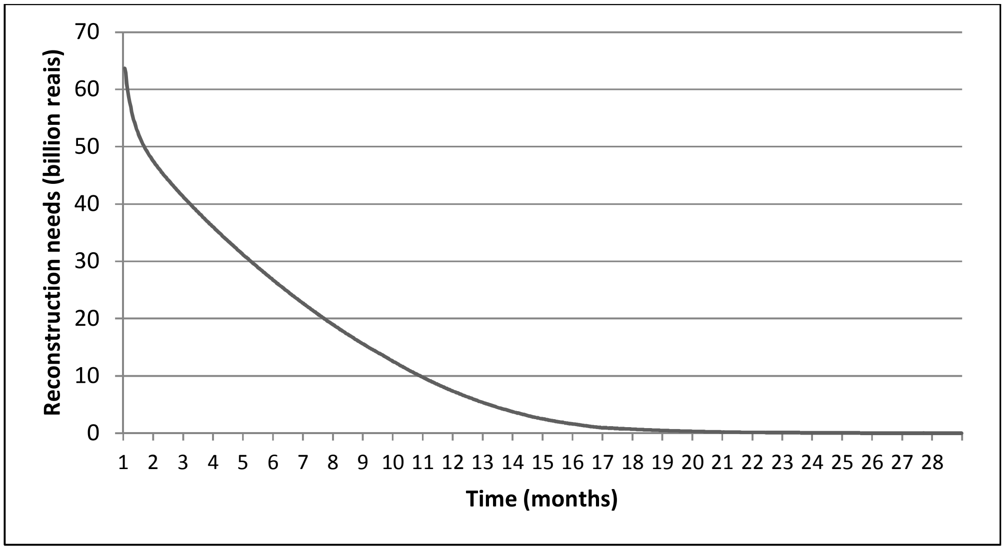

Fig. 3. Reconstruction needs in Florianópolis in billions (reals) due to SLR in 2100

Another way of adapting is to prepare society for possible disasters. Hallegatte et al. [25] mention, for instance, the increase of the local economic resilience, so as to make producers less dependent on a small group of suppliers who are located in risk areas. Florianópolis, a city whose economy is built mainly on tourism, has few and difficult solutions to reduce the direct impact. In this manner, it can suffer a significant loss due to indirect costs and unemployment. One solution is to get help from the national government in order to create new activities to compensate for such losses. Since SLR may damage the business model of Florianópolis, specific adaptation policies can be useful to help throughout the transition process with agility.

This study demonstrated some impacts caused by SLR, which are risks associated with climate change. An important limitation of this study is that the uncertainty of the analyses was not quantified. Uncertainties were incorporated in all analysis steps; as mentioned throughout the study, there were many simplifications.

More research is needed in order to consider the implications of uncertainties in climate projections for the adaptation planning in Florianópolis. For example, this study should include a broader range of SLR scenarios and gradually consider them in the economic impact. A single scenario of the future, as it was used, is not entirely appropriate to provide solid information for detailed adaptation measures. This study may serve as a basis and comparison to others with different scenarios, studying other possible aspects.

Due to the uncertainty of climate change and SLR, anticipation in risk adaptation requires the creation of defences that allow flexibility, so as to take into account the uncertainties in projections and open possibilities for improving defences, should the SLR be greater than expected.

As Hallegatte et al. [25] point out, the uncertainties about climate change are a strong obstacle when implementing measures in advance. While the cost of adaptations is immediate, the benefits of adaptation measures are uncertain and will only be seen in the future. For example, zoning that restricts occupation in an area that might become vulnerable to the effects of undertow has an immediate economic and political cost, but the benefits of this measure as to limit further losses are uncertain.

4. CONCLUSION

This study demonstrated the application of a number of tools in order to estimate the economic impact of SLR and inform the benefits of adaptation strategies against SLR in Florianópolis for 2100. The objective was not to carry out a thorough assessment, but to estimate the economic impact of SLR, so as to demonstrate the vulnerability of the capital of Santa Catarina, should the IPCC forecasts on climate change become a reality. This work also exposed the real need of seeking effective adaptation and mitigation measures.

As the study demonstrated, SLR will occur gradually in the city. Nonetheless, Florianópolis proved to be vulnerable to it, besides having no protection against its effects. Simple structural measures, such as building dykes, do not fit the municipality due to its touristic and landscape features. Due to the uncertainty of future projections about climate change, adaptation alternatives must be sought. They should provide benefits to a wide range of scenarios, such as zoning, in order to manage new constructions in areas that are already at high risk due to coastal erosion.

The modelling process of the urban expansion in Florianópolis showed that there are few areas fit for urban occupation, mainly due to ecosystems where occupation is complicated, such as steep slopes, lakes, dunes and mangroves. A trend that is already in progress on the island is the densification of the urban area, a fact that will be intensified throughout the coming years. The urban area grows at a slower pace than the population, and it should continue to do so.

As estimated in this study, according to the worst IPCC scenario for the SLR in the year 2100 and the modelled urban and population growth scenario for the same year based on the UN, the total cost of a 1-meter SLR in a sudden disaster was 63 billion *reals*. The direct cost impact by itself was estimated at 13 billion dollars, and job losses were 31,000.

Besides the economic impact, other impacts were not considered in this study, such as environmental impacts, casualties, illness, loss of state competitiveness, loss of cultural heritage, loss of tourist attractions and many others. Considering the economic impacts only, the reconstruction process would take around two years.

Estimating the impacts of climate change can provide local people with a better understanding of the benefits of some aggressive adaptation measures. As discussed previously, political adaptation strategies require a long time before they become fully mature and effective (such as zoning). At the local level, these predictions draw people's attention to climate change and open the debate on possible options for adaptation and mitigation.

It is noteworthy that more research should be conducted in order to detail possible climate change scenarios. Monitoring variables that measure the effects of climate change must also be more effective so that there is richer knowledge at the local level.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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