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ORIGINAL PAPER

A globally deployable strategy for co-development of adaptation preferences to sea-level rise: the public participation case of Santos, Brazil

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Abstract Sea-level rise (SLR) poses a range of threats to natural and built environments in coastal zones around the world. Assessment of the risks due to exposure and sensitivity of coastal communities to coastal flooding is essential for informed decision-making. Strategies for public understanding and awareness of the tangible effects of climate change

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are fundamental in developing policy options. A multidisciplinary, multinational team of natural and social scientists from the USA, the UK, and Brazil developed the METROPOLE Project to evaluate how local governments may decide between adaptation options associated with SLR projections. METROPOLE developed a participatory approach in which public actors engage fully in defining the research problem and evaluating outcomes. Using a case study of the city of Santos, in Brazil, METROPOLE developed a method for evaluating risks jointly with the community, comparing 'no-action' to 'adaptation' scenarios. At the core of the analysis are estimates of economic costs of the impact of floods on urban real estate under SLR projections through 2050 and 2100. Results helped identify broad preferences and orientations in adaptation planning, which the community, including the Santos municipal government, co-developed in a joint effort with natural and social scientists.

Keywords Sea-level rise · Adaptation preferences · Climate change · Participatory approach · Santos · Brazil · METROPOLE Project/Belmont Forum

1 Introduction

There is a growing recognition of the need for methods that can help stakeholders holding diverse value positions and responsibilities come together in planning adaptation to current and future climate change-associated risk. Adaptation measures focus on proactive measures that minimize the potentially negative social and economic impacts expected as a result of a changing climate. Adaptation measures have a cost; yet, delay in implementing these options can be more expensive and may endanger lives and property (Richards and Nicholls 2009). Under conditions of economic constraint and where stakeholders hold a range of aspirations for the future, not all expectations can be met. As part of enabling inclusive and accountable governance for adaptation, a key contribution comes from science–policy collaboration methods that can help surface the range of possible adaptation options and arrive at preferences that are acceptable to multiple stakeholders (Loos and Rogers 2016). The current paper responds to this challenge and presents a transdisciplinary methodology for generating, evaluating, and arriving at publically sanctioned preferences for adaptation where multiple choices are possible. The method was designed and deployed as part of a transdisciplinary research project leading to new knowledge production and policy outcomes.

Sea-level rise is a tangible and tractable effect of climate change that poses significant challenges to society from the next 50–100 years, or earlier (Hauer et al. 2016). Global mean sea level rose by 0.19 (0.17–0.21) mm year^{-1} over the period 1901–2010 based on historical tide gauge records; these rates are observed globally on average, as measured using satellite data collected since 1993. Between 1993 and 2010, the average global sea-level rise rate was near 3.2 (2.8–3.6) mm year^{-1}. Similarly, high rates likely occurred between 1920 and 1950 (Rhein et al. 2013). In coastal states of Latin America and the Caribbean, for example, sea level rose between 2 and 7 mm year^{-1} between 1950 and 2008 depending on location (Losada et al. 2013; Guarderas et al. 2008).

A rising sea level combined with high tides and storm surges is expected to impact the human-built environment along coastal zones of the world as well as coastal ecosystems such as wetlands, coral reefs, beaches, and estuaries. Higher sea level typically leads to increase coastal erosion, high risk of flooding, and contamination of freshwater sources through saltwater intrusion (Mcleod et al. 2010). Many of these coastal ecosystems are already impacted by human uses that have weakened their resilience (Hinkel et al. 2010).

Nearly 7% of all human communities have developed in areas where the elevation is less than 5 metres from historical sea level (McGranahan et al. 2007). Most of the world's 60 million poor people living in low-elevation areas reside in just 15 countries, including Brazil (Seto et al. 2011; Wong et al. 2014; Reguero et al. 2015). The historical sea level corresponds to the mean sea level as computed using the longest available sea-level time series.

Building resilience in this context requires coastal communities to increase both their knowledge of the local consequences of climate change and to openly explore preferences for adaptation options. Global mitigation of climate change will not help diminish the short-term risk of flooding to these communities (Kulp and Strauss 2016). The continuous assessment of hazards induced by sea-level rise is essential for informing local decision-making. Stakeholder perceptions of risk and vulnerability are important in the process of building inclusive and responsive decision-making processes for adaptation (Slovic 1987). As important, but less studied is the need to develop methods that can help stakeholders surface and make judgements between different *preferences* for adaptive action. Stakeholders with diverse value positions and understanding of risk can be brought together through these methods to arrive at a transparent consensus for adaptive action.

The METROPOLE study goals were to determine to what extent stakeholder beliefs, values, and preferences regarding adaptation options and funding choices may facilitate or hinder adaptation. The METROPOLE project encompassed a three-part, integrated environmental, economic, and social analysis embedded in a municipal planning effort involving stakeholders and decision-makers in Brazil, the UK, and the USA. The first part included the use of the COastal Adaptation to Sea-level rise Tool (COAST) model (Catalysis Adaptation Partners 2015, GEI Consultants 2015, 2016) to show visualizations of SLR, infrastructure impacts, costs–benefits for adaptations, and small group discussions to define stakeholder estimates for action. The second piece involved administering pre- and post-workshop surveys to participants, to identify links between risk experiences, beliefs, values, and attitudes about local government priorities for possible adaptation actions and public financing, and to assess change after seeing the COAST visualizations and discussing scenarios. The third element was the Adaptive Capacity Index (ACI), an assessment of institutional and individual interactions that shape local and regional adaptive capacity. The project was conducted in the city of Santos (state of São Paulo, Brazil), city of Selsey (West Sussex, UK), and cities in Broward County (Florida, USA). This paper focuses on the Brazilian COAST Workshops participatory engagement process.

METROPOLE used the approach of Daniels and Walker (2001) and Bursch et al. (2010) to explore the complex issue of how communities of different cultural backgrounds respond to risk and adaptation related to climate change. The IPCC defined this as the process of adjustment to actual or expected climate and its effects, including either moderate harm, or the opportunity to exploit beneficial opportunities. For this study, the IPCC Glossary (IPCC 2012) was adopted to establish the theoretical framework for adaptation and evaluation of risks, hazards, and vulnerability. The exception is that in the context of METROPOLE, 'mitigation' means risk management or reduction in risk due to a hazard, and not reduced emissions of greenhouse gases.

METROPOLE researchers and the Santos staff co-organized the stakeholder workshops to engage decision-makers, citizens, and representatives of the public and private sectors to develop and evaluate adaptation options to two areas of Santos (South-east and North-west Zones).

To create the data for the workshops, our team and municipal managers reviewed the estimated SLR/flood risks and discussed potential adaptation actions. After consulting with other staff and elected officials, the municipal managers selected several realistic and potentially useful combinations of actions to be discussed by stakeholders at Workshop 1. The workshops presented and discussed maps of future flooding projections due to sea-level rise for 2050 and 2100. Workshop participants were shown the respective estimates of economic damages to real estate for the SE Zone (SEZ) and NW zone (NWZ) of Santos. The small group discussions at these workshops focused on adaptation options for the city of Santos.

The observed sea level is the composition of tide and surge, the former being due to astronomical effects and the latter due to meteorological influence. The tides have a periodic and deterministic character, so they can be accurately predicted anywhere in the ocean. Predictions of surges are more difficult and usually depend on precise meteorological predictions and on the timescale of interest. Large-scale climatological variations induce large-scale variations in the ocean, which are referred to as sea level variations, the most important being the sea-level rise, due to its inherent risks to coastal populations. As consequence of surges and long-term sea-level elevation, coastal areas are subject to flooding, which may be temporary (associated with intense surges) or quasi-permanent (in the case of a consistent sea-level rise).

2 Participatory process for evaluating adaptation preferences for the city of Santos

2.1 Study area: south-east and north-west Santos

Santos occupies an area of 281 km^2. Of this, 39.4 km^2 lies in an insular domain (São Vicente Island) and 231.6 km^2 is located on the mainland part of the municipality (Fig. 1). The insular domain has a high population density, housing, with over 99% of the Santos population living on it (Gasparro et al. 2008). The Port of Santos services the transport of products from the largest industrial park in Brazil, handling around 25% of Brazil's foreign

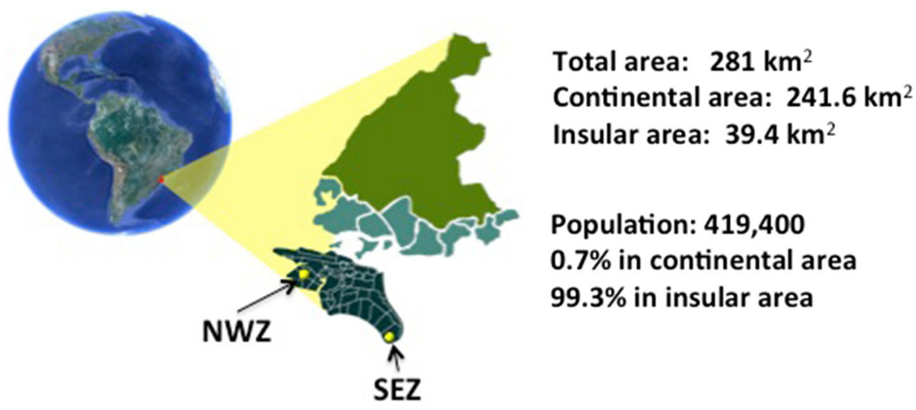

Fig. 1 Location of the study area

trade (ICF-GHK 2012). The proximity to the Metropolitan Region of São Paulo (60 km) has transformed Santos and the neighbouring municipalities into a strategic economic centre. Santos is also amongst the most important tourist destinations in the state of São Paulo and in Brazil. Thus, any threat to this city has profound implications for the economy of the country.

The sea-level threat analyses were performed for two contrasting areas of Santos. One is the North-west Zone (NWZ), which encompasses 13 neighbourhoods in an area of 10 km^2 with 20,000 parcels and 83,000 inhabitants. The other is the insular South-east Zone (SEZ), which includes four neighbourhoods spread over 2 km^2, with 1400 parcels and a population of 34,000 inhabitants (Fig. 1).

Most of frontal systems in the south-eastern Brazilian coast are associated with higher precipitation rates and strong southern winds, which produce significant surface waves and induce currents that transport water towards the coast, thus increasing the sea level. In most cases, flooding in coastal areas is due to the combined effects of precipitation, waves, and sea-level rise. Nevertheless, depending on the frontal systems evolution, one or two of these three effects are less intense, so the coastal flooding may be due to sea-level rise or high precipitation only. Flooding in the NWZ is a consequence of riverine and hydrometeorological dynamics and can occur often without precipitation.

The NWZ concentrates large pockets of poverty and land used for irregular occupation by low-income families. In 1958, city authorities drained and claimed the land previously occupied by mangroves for agriculture (banana plantations) by building a drainage canal system. By the 1960s, the area had started to be urbanized. This part of the city is built on a 40-m-thick layer of fine and loosely compacted sediments, at an elevation of less than 1.5 m above sea level. Unplanned neighbourhoods stretch along the canals and at the edge of the estuary. The poverty level is high. Fragile wooden and cardboard houses built on stilts are regularly flooded during high tides and even minimal rainfall. Some measures to prevent floods have been attempted, for example higher doorways near the mouth of the canal to protect against flooding from the sea. Other efforts involve dredging the canal, implementing a waste management program to reduce the amount of garbage that often clogs the drainage system, and building high walls along the edge of the estuarine channel to prevent residents from throwing trash into the canal.

The SEZ is closer to the mouth of the Santos estuarine channel, along the seafront. Coastal erosion and coastal inundation are common hazards in the area and are caused by storms, high tides, and tide surges; as a consequence, strong waves overtopping the existent sea wall frequently invade the streets.

SEZ concentrates population that has a much higher average income. Real estate value increased in the first decades of the 2000s, but infrastructure is vulnerable to sea-level rise. This area is densely built up on highly impermeable soils, and since it is low-lying relative to present sea level, it is exposed to coastal flooding. The SEZ has a complex drainage system built in the early 1900s: channels cross the coastal plain and allow for tidal and surface run-off to protect the island from floods. In addition, along the mouth of the estuarine channel, a sea wall made of reinforced concrete and barriers, reinforced by large stones, has been built to protect the area, but recent events of storm surges registered in April, August, and October of 2016 partly damaged these structures. Further, extratropical cyclones have been important contributors to flooding in both areas (ICF-GHK 2012).

2.2 Stakeholder engagement workshops

A consensus on adaptation preferences was arrived at through a series of public workshops. Workshop 1 (30 September 2015) had 42 attendees from various sectors, government departments, and NGOs. In the first part of the meeting, projections of sea-level rise and storm surges were presented. Impacts on low-lying areas were characterized visually, by use of maps of the area and by showing cumulative costs of extreme events over time given today's cost of the built environment of Santos. The projections were derived using the COAST platform. COAST is an integrated impact simulation model developed through the University of Southern Maine (Merrill et al. 2008, 2012; Kirshen et al. 2012, Catalysis Adaptation Partners 2015). It is intended for application by municipalities, state agencies, and groups interested in cost–benefit analysis for adaptation strategies aimed at minimizing possible future real estate damages from sea-level rise and storm surge.

Figure 2 shows the conceptual model developed for application of COAST in the SEZ and NWZ. The COAST model incorporates a database containing the following parameters describing local conditions: (1) sea-level rate of rise based on historical tide gauge records and satellite altimetry; (2) digital elevation model (DEM) from LiDAR; (3) elevation of mean high tide, where the model adds sea-level rise and storm surge to a mean high water height; (4) surge height, with probabilities and surge heights (water levels above high tide) for the 500-, 100-, 50-, and 10-year-storm events; (5) flood maps, representing the spatial extent of the area of flooding that has a 1% chance of occurring; (6) digital tax parcel map, considering value of buildings/tax assessment values of buildings; and a (7) depth damage function (DDF). The value and tax assessment values of buildings comes from a table with

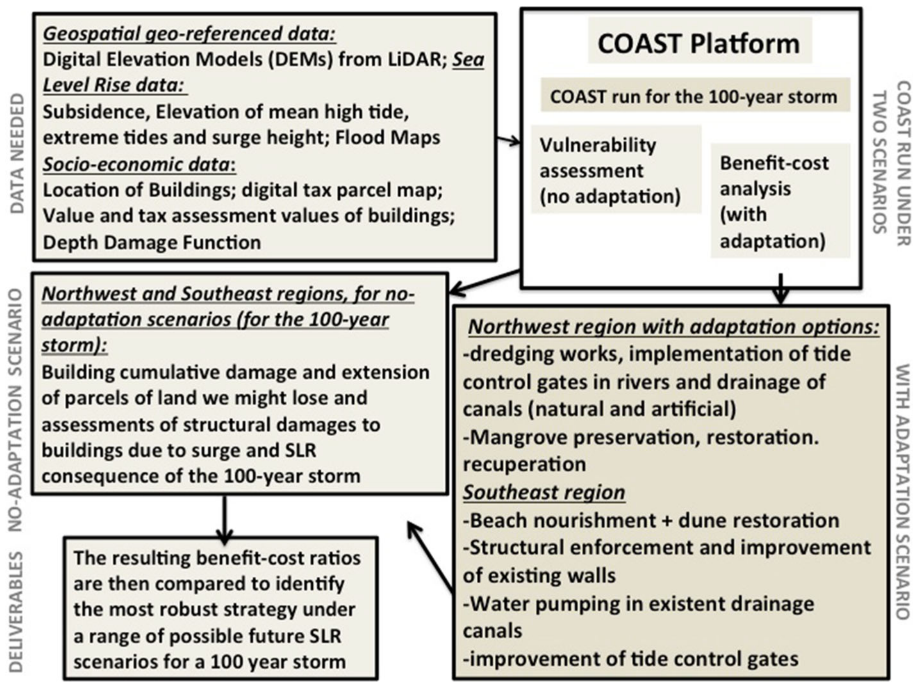

Fig. 2 Conceptual model developed for the application of the COAST tool in Santos

the value of the building or buildings on each property of the parcel map, and were extracted from Santos City Hall Database. The parcel map and values need to be reviewed locally before the model is run, to avoid any problems with multi-unit condominium properties or other improper assignments of building values. The value of the building needs to be as close as possible to the real market value. The DDF comes from tables, which indicates the predicted per cent loss to the value of a building in relation to the Venal Value of Fiscal Parcel. It is based upon the flood depth at its base, with damage functions for different structure types (such as residential or commercial and properties with or without basement).

Parameters (1), (3), and (4) were generated by our team. Parameters (2), (5), and (6) were obtained in the databases from different municipality departments, such as Finance, Urban Development, Environment and Civil Defence.

An optional input to the COAST model is the tectonic subsidence rate of the local land mass. No information was available on subsidence rates in Santos, so therefore this variable was not used. Subsidence may be an issue in silty deltas, such as the Mississippi River delta (Yang et al. 2014) but has minor effects in Santos. Figure 2 is one example for one physical event—the 100-year storm. No other processes such as erosion or short-term flooding were modelled.

Using these input variables, the COAST tool produced conservative estimates of direct damage for buildings. For instance, it does not consider (1) beach processes such as erosion or accretion over time (i.e. results representing cumulative effects such as shoreline, dune, and other geomorphological conditions remained static in the model); (2) natural or human-driven changes in sedimentary processes, including expansion or contraction in tidal flats and mangroves; (3) changes in local tides, ocean circulation, salinity, temperature, and other factors that may affect future local sea level; (4) damage from winds, erosive forces, and rainwater drainage system that affect surge and surge impacts; (5) impacts to public services, urban infrastructure, or business interruptions or clean-up costs after extreme weather events; (6) the value of commercial properties; (7) damage to building contents, automobiles and other transportation assets, or other site-specific vulnerable assets; (8) changes related to population changes; and (9) changes related to the resilience of the ecosystems and related ecosystem services.

The COAST simulations provided results on real estate impacts of SLR and storm surge, given scenarios for 2050 and 2100 (Fig. 2). The results if no-adaptation actions are taken (i.e. the 'no-action' scenario) were calculated for particular flood events for one of these given years plus expected SLR due to a surge (e.g. damage from a 1 in 100-year-storm event with high sea-level rise). Flooding was calculated as the total water level by means of a linear addition of present storm surge levels, which have been experienced by the population plus the projected SLR. This process neglected tides, waves, erosion, short-term flooding, and possible land subsidence if any. Basically, the 'no-action' scenario under conditions of present sea level represents a current vulnerability assessment. It identifies, qualifies, and quantifies relevant local vulnerabilities. The model then evaluated how many land parcels could be lost to SLR over time, and computed the damage to real estate.

The sea level considered for any simulation of adaptation or no-adaptation action is always a sum of the particular effect of a storm surge and the sea-level rise. For a storm surge effect, one might consider either the present storm surge levels or the expected maximum for return periods of 50 and 100 years (or any other predicted storm surge level). For the sea-level rise, conservative, actual or extreme trends might be considered.

Two sets of data were used in the computations: (1) hourly sea-level observations from the tide gauge data of Torre Grande (Santos), 23°56.95′S 46°18.50′W, in the period from 1945 to 1990, and (2) multi-satellite altimetric dynamic topography at the position 23.875°S 46.375°W, from 1993 to 2014. Two processes were modelled: the sea-level trend or sea-level rise (using both sets of data) and the expected maximum for return periods of 50 and 100 years (using the tide gauge data only). Hourly tide gauge data from Torre Grande were used to estimate the expected maximum for return periods of 50 and 100 years, by using the Gumbel distribution on the yearly mean values, giving the heights of 1.60 m in 2050 and 1.66 m in 2010, for an observed maximum of 1.45 m in the sampling period.

Figure 3 illustrates for SEZ the flood scenario expected for 2050, for a low sea-level rise scenario (0.18 m + 1.60 m) and lost asset value for year 2050. The 0.18 m is due to SLR and 1.60 m is due to storm surge. The sea level associated with both effects was simply computed as their addition, which was considered for simulations of coastal flooding, which in turn also depends on the coastal topography. Table 1 shows the projections of sea-level increase given several possible trends for Santos; for this study, it was considered the projections for 2050 and 2100. Table 2 shows the magnitude of the damage.

Figure 3a illustrates for SEZ the flood scenario expected for 2050, given low sea-level rise (0.18 m + 1.60 m). Figure 3b shows lost asset value for the year 2050 under these simulated conditions. Figure 4a presents the expected situation under a higher sea-level rise rate for 2050 (0.23 m + 1.60 m). Figure 4b shows the lost asset values under this scenario. What could happen to the area in 2100 is presented in Fig. 5a, b (i.e. under low sea-level rise rate, 0.36 m + 1.66 m) and Fig. 6a, b (under high sea-level rise of 0.45 m + 1.66 m). Table 2 presents the magnitude of damages under each scenario. Similar figures for the NWZ were computed and used in the workshops but are not shown here since they show similar trends.

Facilitators explained to participants that the estimated real estate damages included the real value of buildings but not the value of the content of affected buildings, houses, and infrastructure (pavement, bridges, etc.). The future scenarios of impacts and losses in 2050 and 2100 under the 'no action' considered heavy rainfall from storm along with changes in

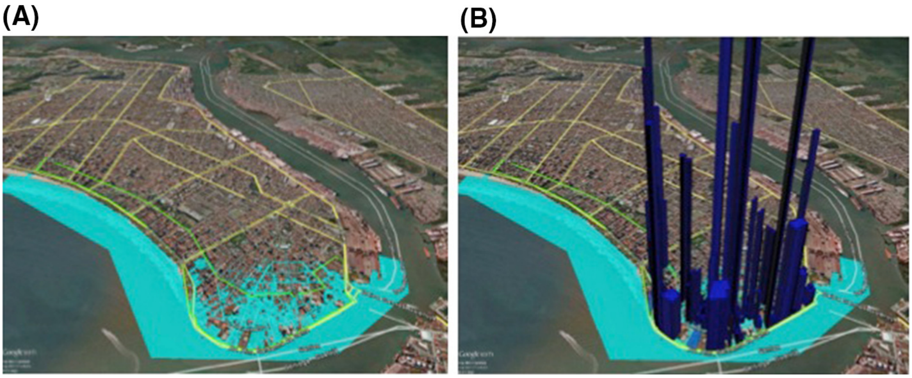

Fig. 3 **a** (*Left*) Flood scenario in the SEZ expected for 2050 for the low SLR (0.18 m + 1.60 m); **b** (*right*) lost asset value for year 2050, low SLR. *Blue bars* (on a logarithmic scale) indicate in a qualitative way the amount of damage produced by the flood—the bigger the bar, the bigger the damage. *Light blue* shading shows the regions affected by flooding due to the 1 in 100 storm under the considered high- and low-SLR scenarios. Magnitude of damages is shown in Table 3

Table 1 Projections of SLR increase under several trend scenarios in Santos (Harari and Camargo 1995; Harari et al. 2007)

Years	Sea-level increase (cm): trends		
	0.27 ± 0.06 cm year^{-1}	0.36 ± 0.18 cm year^{-1}	0.45 cm year^{-1}
2000	0	0	0
2015	4.05	5.40	6.75
2025	6.75	9.00	11.25
2050	13.50	18.00	22.50
2075	20.25	27.00	33.75
2100	27.00	36.00	45.00

Table 2 Cumulative damages for two scenarios of SLR (low and high) in the SE and NW zones over different time slices (no-action scenario)

Period	SLR	SE zone	NW zone
2010–2050	Low (0–0.18 m)	83,942,520	12,106,613
2010–2050	High (0–0.23 m)	95,234,891	15,492,935
2051–2100	Low (0.18–0.36 m)	187,615,944	40,060,210
2051–2100	High (0.23–0.45 m)	230,858,312	58,383,975
2010–2100	Low (0–0.36 m)	271,909,114	52,166,823
2010–2100	High (0–0.45 m)	326,093,203	73,876,910

Units are in $US

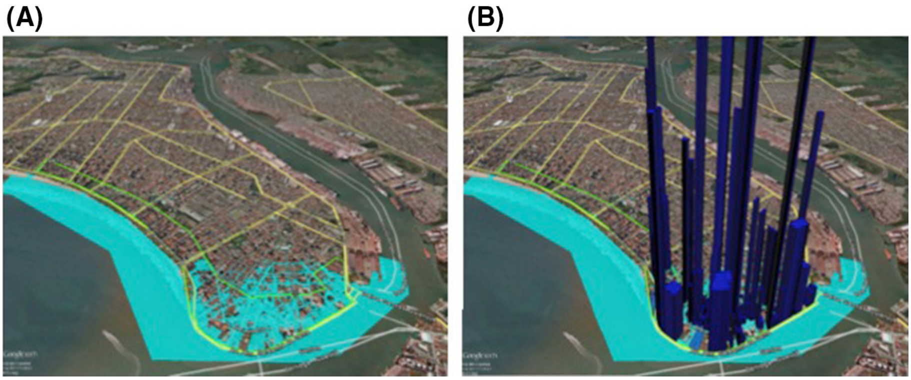

Fig. 4 **a** (*Left*) Same as in Fig. 3a, b, but for high SLR (0.23 m + 1.60 m)

sea level. Examples of adaptation options evaluated and adopted in other areas of the world were presented to the participants. The advantages and disadvantages of each were highlighted and discussed.

Within the suite of adaptation measures that the workshop participants evaluated were as follows: fortification (e.g. the construction of levees and sea walls), accommodation (e.g. raising awareness, adapting behaviour, and flood-proofing.), and relocation (i.e. migration). Fortification includes modifying the flow of water, while accommodation

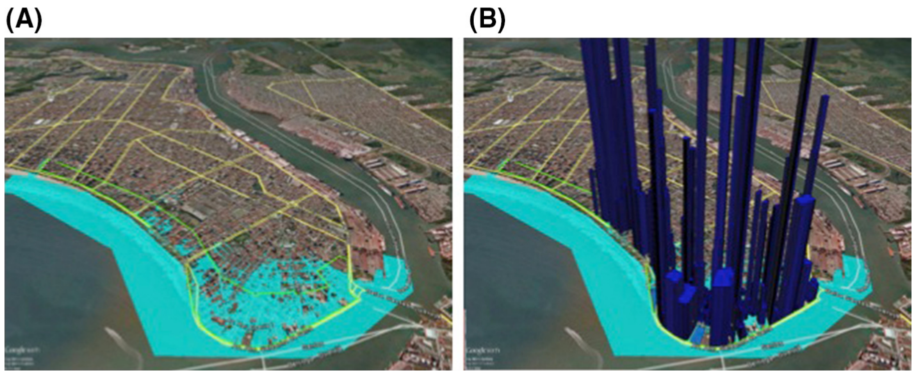

Fig. 5 **a** (*Left*) Same as in Fig. 3a, b, but for 2100, low SLR (0.36 m + 1.66 m)

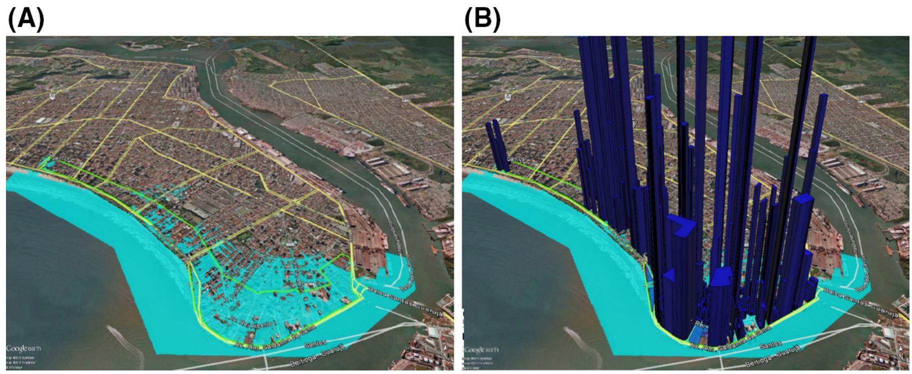

Fig. 6 **a** (*Left*) Same as in Fig. 3a, b, but for 2100, high SLR (0.45 m + 1.66 m)

means modifying the impact of water; relocation refers to migration away from potentially affected areas.

For the second part of the first Workshop, attendees were split into groups to discuss preferences for adaptation measures for both NW and SE Zones. Attendees were free to consider traditional measures and to create new ones that could be effective for each area. All measures suggested by each group were thoroughly discussed. A total of 20 different types of adaptation measure for the NWZ and 18 adaptation measures for the SEZ were proposed by workshop attendees, and a summary of adaptation options selected by the participants is shown in Fig. 7. Specifically, for the SEZ, workshop participants decided on preferences by vote. The most preferred adaptation options were fortification (66%) and accommodation (30%). For the NWZ, the fortification (50%) and accommodation (43%) actions were also preferred, while relocation was the least preferred option, with 4% in the SEZ zone and 7% in the NWZ (Fig. 7).

Between the first and the second stakeholder workshop, the COAST model was run again, to compare the ‘no-action’ scenario to the ‘adaptation’ scenarios, i.e. including the two adaptation measures prioritized by participants of the first meeting. The two adaptation measures chosen by vote were modelled in a subsequent run of COAST. The results were presented in the second METROPOLE workshop. The preferred options were as follows:

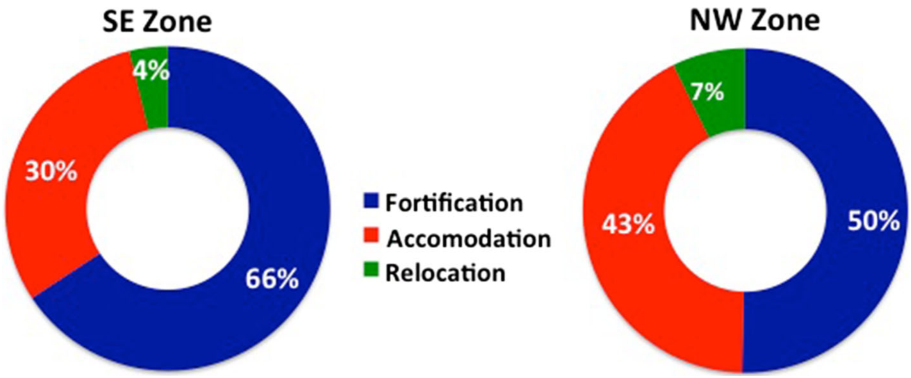

Fig. 7 Summary of adaptation options for Santos (SEZ and NWZ) selected by the participants

Table 3 Avoidable damages for both sites and benefit–cost ratios in the SEZ and NWZ, considering lower and higher flooding scenarios between 2010 and 2100

	SE zone		NW zone	
	Lower (0.36 m)	Higher (0.45 m)	Lower (0.36 m)	Higher (0.45 m)
Damages without adaptation actions	271,904,114	326,093,203	52,166,823	73,876,910
Damages with adaptation actions	0	0	38,639,998	53,571,712
Avoidable damages	271,904,114	326,093,203	13,526,825	20,305,198
Costs	11,410,691	11,410,691	63,124,856	63,124,856
Benefit–cost ratio	23.83	28.58	0.21	0.32

Units are $US

1. For SEZ: fortification (beach nourishment + dune restoration, structural enforcement/improvement of existing sea walls, water pumping, and implementation and improvement of tide control gates in existing drainage canals);
2. For the NWZ: fortification (improvement of existing measures such as dredging, construction of tide control gates in rivers and natural and artificial drainage canals, and implementation of tide control gates in rivers and drainage canals) and accommodation (mangrove preservation, restoration, and recuperation).

For the second Workshop, on December 2015, 25 participants from Meeting 1 returned and were joined by 6 new attendees, totalling 31 people. Participants reviewed the models generated following the first meeting jointly with the METROPOLE team. The COAST model results including adaptation measures were contrasted with the no-action scenario presented during Workshop 1. The costs of implementing the measures or not, in either case, helped illustrate savings and potential losses. Table 3 shows that the adaptation measures selected by participants (i.e. fortification and accommodation) would be cost-effective in both the lower scenario of sea-level rise (0.36 m; for the period 2010–2100) and for the higher scenario (0.45 m by 2100) for SEZ only: the economic damages in this site would be, respectively, nearly 24–29 times smaller with adaptation than damages projected if no action were taken.

For the NWZ, the benefit–cost ratio for the lower and the higher sea-level rise scenarios of 0.21 and 0.32 suggests that adaptation measures chosen by the participants would cost more than the avoided damages for both SLR scenarios. In fact, the costs of the adaptation measures would be even greater because the damage values for the NWZ are underestimated due to the lack of time to calculate all costs involved in the implementation of the two adaptation measures chosen for this area, fact that was communicated to the attendees of the second meeting.

3 Conclusions

The participatory approach provided a structured and transparent method for surfacing, discussing, and arriving at consensus on adaptation preferences. The approach had at its core an opportunity for key stakeholders with responsibility for adaptation planning to participate in analysing locally scaled SLR data integrated with local economic data to define local impacts costs and potential solutions. The process was most effective when benefit–cost models were used to bracket the range of possible adaptation options.

Through this process, the initially high number of identified adaptation options was focussed to reveal preferences. Projections from the COAST model given a ‘no-action’ scenario provided an initial estimate of the possible costs of floods under a SLR scenario through 2100 for key regions of the City of Santos for the real estate sector. Model runs with adaptation options (accommodation and fortification) showed that the economic damages in the SEZ would be smaller than if ‘no action’ were to be taken. Thus, there is a potential efficiency to examining adaptation options in addressing the challenges of flood due to SLR and storm surge in the SEZ. For the NWZ, the benefit–cost ratio results suggested that costs of adaptation measures would be higher than the avoided damages for both SLR scenarios, suggesting than the adaptation chosen by the community would not be effective compared to doing nothing. The city would, in any case, suffer losses. Indeed, the hazards of sea-level rise were compounded by the threat of extreme rainfall events and storm surges.

With the results from METROPOLE, the City of Santos has increased its knowledge of impacts in specific areas. The stakeholders understood the limitations of the models, but were also able to appreciate the type of information required to conduct realistic assessments. The analysis was limited to simple projected sea-level rise estimates and to the real estate sector, and the adaptation measures chosen by the participants were anchored in the belief that in the future the land-use conditions would be similar to the present. The building damage estimates may also be difficult to compare because of the lack of data on real estate value, and especially about the value of the utilities infrastructure for Santos.

The method revealed adaptation options with economic costs varying by two orders of magnitude, even considering the limited scope of what the COAST model takes into account. These are powerful data for informing preference formation, but also lack key components. Primary amongst these is the absence of human loss (implications of mortality, morbidity or psychological harm) and of indirect impacts (on economic systems and consequences of impacts on public sector investment).

METROPOLE offered insights to the policy-makers to confront powerful interests of developers that might intend to put high-value new buildings, malls, hotels, and all facilities in areas under threat, which would bring in turn on the one hand more taxes for the municipality, but on the other, more problems to be solved. This confrontation might be facilitated with the continuous engagement of the population, and for this local government must provide a stable democratic structure over time that incorporates this participatory approach.

Future impact models need to consider some way of monetizing not only property damage, but also the suffering of people who will lose their homes and neighbourhoods and will be forced repeatedly to move with each new assault from the sea—and also as a result of adaptation projects. Indirect costs can be greater than direct economic costs, but vary enormously by context (Pelling et al. 2002). Certainly, the incorporation of these costs could affect benefit–cost ratios and final expressed preferences in this and other cases.

In the case of Santos, one legacy of the METROPOLE effort is that the municipality is actively assessing risks and alternatives, and is more prepared to seek robust adaptation strategies to build resilience. After the first workshop, the mayor of Santos created the Municipal Commission for Adaptation to Climate Change (Comissão Municipal de Adaptação à Mudança do Clima, Decree 7293 of 30 November 2015). This commission will seek to define areas that require flood protection and public education. Other cities in Brazil, such as Rio de Janeiro, are starting to examine the METROPOLE process.

The participatory engagement allowed safe exploration of possible alternatives but did not imply an endorsement of any action by local government. Such exercises bringing together scientists and decision-making members of the city council should be conducted regularly, and results continually evaluated. Thus, the local government must offer a stable democratic structure over time that incorporates this participatory approach.

The high degree of involvement of the city of Santos in the METROPOLE project was an important experience for the scientists and the community. Although the population has been experiencing an increase in the frequency of storm surges (in 2016, three severe events hit the city in April, August, and October), the current Brazilian economic and politic crisis creates new challenges for actions towards a safer future. This turbulent scenario of great social, economic, political and environmental uncertainties should be used by the local government in a proactive way, creating new jobs for implementing the measures chosen and a new agenda for the municipality, in which adaptation to climate change is a central issue. Because good practices can be followed, Santos can be transformed in a leader for adaptation measures in coastal cities, showing a creative new governance style in which the future is seen as the resultant of the (good) actions taken in the present, based upon anticipatory and planned activities and not on reactive and temporary actions.

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