Climate Change Adaptation Planning in Latin American and Caribbean Cities

COMPLETE REPORT: SANTOS, BRAZIL

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Climate Change Adaptation Planning in Latin American and Caribbean Cities

A report submitted by ICF GHK
in association with

King's College London and Grupo Laera

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Cover photo: East Santos as shown from Monte Serrat, October 2012.

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Abbreviations

ACI……………………...Adaptive Capacity Index

ADCIRC…………………………………………………………………...*Advanced Circulation Model*

BSMR..*Baixada Santista Metropolitan Region*

CEDEC.....………………………………………….......Coordenadoria Estadual de Defesa Civil de *São Paulo*
State Civil Defense Coordination

CODESP...Companhia Docas do Estado de São Paulo
Santos Port Authority

COHAB..Companihia de Habitacao da Baixada Santista
Regional Housing Department for "Baixada Santista"

CSR...*Corporate Social Responsibility*

DRM……………………………………………………………………….*Disaster Risk Management*

ENSO..*El Niño/Southern Oscillation*

GDP...*Gross Domestic Product*

HEC-RAS...*Hydraulic Simulations Mathematic Model*

IBGE..Instituto Brasileiro de Geografia e Estatística
Brazilian Instiute of Geography and Statistics

IPCC..*Intergovernmental Panel on Climate Change*

IPT.. Instituto de Pesquisas Tecnológicas
Institute for Technological Research

LAC……………………………………………………………………..*Latin America and the Caribbean*

MHDI...*Municipal Human Development Index*

NCDC..Núcleos Comunitários de Defesa Civil
Community Civil Defense Centers

NGO...*Non-Governmental Organization*

NOAA...*National Oceanic and Atmospheric Administration*

NRC..*National Research Council*

NUDECs....... ………………………………………………………Núcleos Comunitários de Defesa Civil
Community Nucleus of Civil Defense

PAC..Programa de Aceleração do Crescimento
Growth Acceleration Program

PEM..Programa Especial de Melhorias
Program of Improvements

PMRR………………………...Plano Municipal de Redução de Riscos
Municipal Plan for Risk Reduction

PNMC…………...…Plano Nacional Sobre Mudança do Clima
National Policy on Climate Change

PPDC...Plano Preventivo de Defesa Civil
Civil Defense Prevention Plan

SACZ..*South Atlantic Convergence Zone*

SALF..*South American Low Level Jet*

SEDES...Secretaria de Desenvolvimento e Assuntos Estratégicos
Municipal Secretariat of Development and Strategic Affairs

SEPLAN…………………...Secretaria Municipal de Planejamento de Santos
Municipal Secretariat of Planning

SESEG……...Secretaria Municipal de Segurança
Municipal Secretariat of Security

SESERP…..Secretaria Municipal de Serviços Públicos
Municipal Secretariat of Public Services

SIEDI..Secretaria Municipal de Infraestrutura e Edificações
Municipal Secretariat of Infrastructure and Construction

SINDEC………………………………………………………………..Sistema Nacional de Defesa Civil
National Civil Defense System

SLOSH...,,................*Sea, Lake, and Overland Surges from Hurricanes*

SLR..*Sea Level Rise*

UN-HABITAT..*United Nations Human Neighborhoods Programme*

UNIP...Universidade Paulista
Paulista University

UNISANTA…………………………..…..Universidade Santa Cecília
Santa Cecília University

ZEIS...,,,,............................Zonas Especiais de Interesse Social
Special Social Interest Zones

ZPP……………………………………………………………………Zona de Preservação Paisagística
Landscape Preservation Area

Glossary

The following glossary is from the United Nations' International Strategy for Disaster Reduction (UNISDR) terminology on disaster risk reduction (2009 version). The terms are defined by a single sentence. The comments paragraph associated with each term is not part of the definition, but is provided to give additional context, qualification and explanation.

Adaptation

The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Comment: This definition addresses the concerns of climate change and is sourced from the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). The broader concept of adaptation also applies to non-climatic factors such as soil erosion or surface subsidence. Adaptation can occur in autonomous fashion, for example through market changes, or as a result of intentional adaptation policies and plans. Many disaster risk reduction measures can directly contribute to better adaptation.

Capacity

The process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals, including through improvement of knowledge, skills, systems, and institutions.

Comment: Capacity development is a concept that extends the term of capacity building to encompass all aspects of creating and sustaining capacity growth over time. It involves learning and various types of training, but also continuous efforts to develop institutions, political awareness, financial resources, technology systems, and the wider social and cultural enabling environment.

Climate change

The Inter-governmental Panel on Climate Change (IPCC) defines climate change as: "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use".

Comment: This definition can be paraphrased for popular communications as "A change in the climate that persists for decades or longer, arising from either natural causes or human activity."

Coping capacity

The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.

Comment: The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during crises or adverse conditions. Coping capacities contribute to the reduction of disaster risks.

Disaster

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

Comment: Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation.

Disaster risk

The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

Comment: The definition of disaster risk reflects the concept of disasters as the outcome of continuously present conditions of risk. Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socio-economic development, disaster risks can be assessed and mapped, in broad terms at least.

Exposure

People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Comment: Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

Forecast

Definite statement or statistical estimate of the likely occurrence of a future event or conditions for a specific area.

Comment: In meteorology a forecast refers to a future condition, whereas a warning refers to a potentially dangerous future condition.

Hazard

A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: The hazards of concern to disaster risk reduction as stated in footnote 3 of the Hyogo Framework are "… hazards of natural origin and related environmental and technological hazards and risks." Such hazards arise from a variety of geological, meteorological, hydrological, oceanic, biological, and technological sources, sometimes acting in combination. In technical settings, hazards are described quantitatively by the likely frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis.

Mitigation

The lessening or limitation of the adverse impacts of hazards and related disasters.

Comment: The adverse impacts of hazards often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness. It should be noted that in climate change policy, "mitigation" is defined differently, being the term used for the reduction of greenhouse gas emissions that are the source of climate change.

Resilience

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Comment: Resilience means the ability to "resile from" or "spring back from" a shock. The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need.

Risk

The combination of the probability of an event and its negative consequences.

Comment: This definition closely follows the definition of the ISO/IEC Guide 73. The word "risk" has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings the emphasis is usually placed on the consequences, in terms of "potential losses" for some particular cause, place and period. It can be noted that people do not necessarily share the same perceptions of the significance and underlying causes of different risks.

Vulnerability

The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Comment: There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time.

Source: extracts from UNISDR terminology (2009 version), http://www.unisdr.org/we/inform/terminology

Executive summary

The *Climate Change Adaptation Planning in Latin American and Caribbean Cities* project is designed to inform policy making and climate change adaptation planning in small and medium-sized cities. The focus is on floods and landslides, which are two of the most common climate-related risks in cities across the Latin America and Caribbean region.

Five cities were selected for involvement: Castries, Saint Lucia; Cusco, Peru; El Progreso, Honduras; Esteli, Nicaragua and Santos, Brazil. For each city, five main activities were carried out:

1. A climate-related hazard assessment focused on floods and landslides
2. An urban, social and economic adaptive capacity assessment
3. An institutional adaptive capacity assessment
4. A climate-related vulnerability assessment; and
5. Based on the findings of the four assessments, a combined strategic climate adaptation institutional strengthening and investment plan, intended to complement and be integrated into existing urban, environmental and disaster risk reduction planning instruments for each city.

The figure below graphically shows the process and main activities carried out under the project.

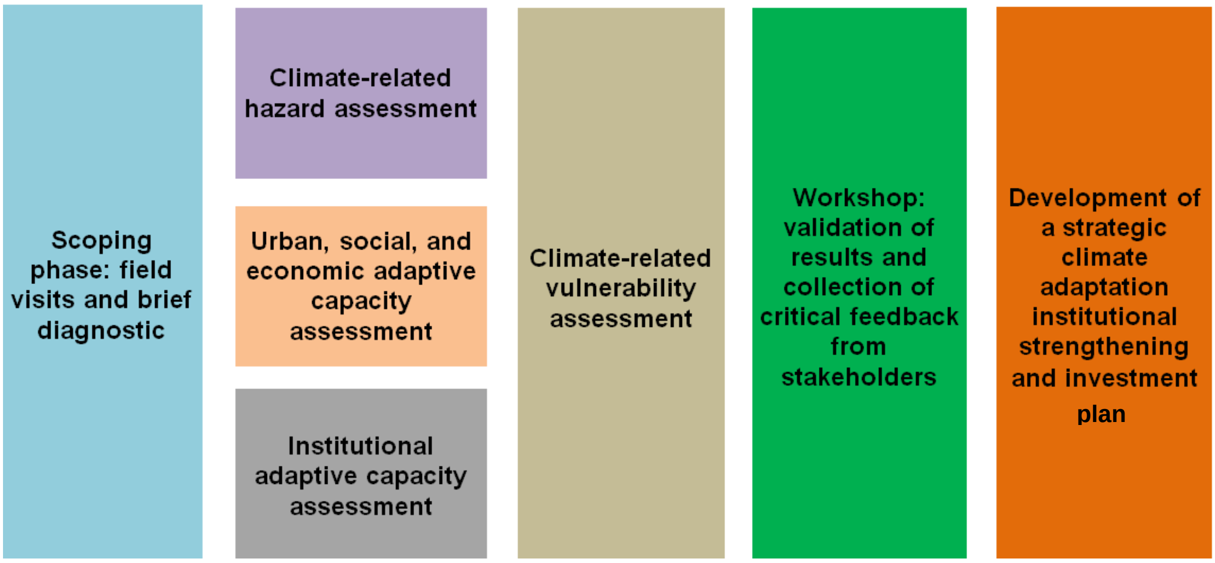


Figure 0.1: The process and main activities of the project

A summary of key findings of this report now follows.

Understanding the problem of flooding and landslides

Climate related flood and landslide hazard risks

Santos is susceptible to both flooding and landslides. Floods have not caused any casualties but have resulted in traffic disruption in the city, while landslides have claimed lives and destroyed houses and infrastructure.

In Northwest Santos, the flooding associated with a precipitation event worsens during high tide due to the rising sea waters infiltrating the existing drainage system. However, as these floods have not caused any causalities and the water retreats within hours, they are not systematically reported by the authorities. Impacts associated with these floods are mostly related to traffic disruption. Due to the channelization works from 1900s, Southeast Santos does not experience considerable coastal flooding.

Due to climate change, precipitation patterns are projected to change in the future, possibly resulting in a decrease in precipitation-induced floods, though coastal flooding from storm surge and high tide may increase. There may be a decrease in the overall frequency of landslides, but an increase in the occurrence of extreme landslide events.

In particular, for coastal locations in Northwest Santos, climate projections suggest that the threat of precipitation-induced floods may be reduced as seasonal and extreme rainfall is generally expected to decrease or experience no change in the area. On the other hand, the area may experience an increase in coastal flooding associated with storm surge and high tide as sea level rises. The Southeast regions may become areas of concern over the coming decades and experience an increase in the frequency of floods. The southern coastline will likely experience an increase in flooding which may impair the use and integrity of infrastructure along the coastline. Additional study is warranted that would investigate the potential future exposure of the city of Santos to storm surge under given sea level rise scenarios.

With regards to landslides in the hilly environs of the city, decrease in monthly and seasonal precipitation may lead to an overall decrease in soil saturation, but the projections also suggest an increase in landslide indices used to determine if conditions are favourable to landslide events. This analysis assumes land-use and other factors that affect landslides do not change over time. The health of the forests and other vegetation cover in the area will play a key role in preserving the soils properties. Responses of forests' or other natural vegetation types to climate change in the region are not investigated in this analysis, but if deforestation or landscape transformation continues in the area, reductions in precipitation and covered soils could exacerbate soil erosion, and lead to a higher overall incidence for landslides.

Urban development and exposure to disaster risk and climate change

The city of Santos is one of the most important municipalities in the State of Sao Paulo. Its main socio-economic drivers are industrial and port activities. This high concentration of people and economic assets increases exposure to climate change impacts and the risks of disasters that accompany it.

In economic terms, Santos is of national significance: the port is the largest in South America, and is responsible for handling around 25% of Brazil's foreign trade (by value). The city is located 65 km from São Paulo, which is Brazil's largest city and the capital of the country's economically most important state, the State of São Paulo. In fact, Santos serves a hinterland which generates approximately 55% of the Brazilian Gross Domestic Product (GDP). Moreover, approximately 30% of the jobs offered in the Baixada Santista Metropolitan Region (BSMR) are located in Santos. While in the past the transport and logistics sector was the main economic driver, Santos is currently experiencing rapid economic growth and development driven by a variety of economic factors, including energy, tourism, research and technology, and real estate. This diversification of the economy is an important factor that increases resilience to climate-related hazards.

The municipality of Santos is separated into two distinct areas: an area located on an island, where the city of Santos is situated and a continental area. According to the 2010 Population Census, the total population of the municipality is 419,400 inhabitants, of which, 99 percent is considered urban (the continental area of the municipality of Santos is considered rural). Over the past two decades, population growth has slowed down considerably and the city is currently not growing. While absolute population growth is flat, Santos is characterized by complex spatial dynamics. The slowing down of the population growth is not related to social immobility, but rather, it reflects intra- and inter-metropolitan migration flows influenced by social and economic policy decisions directly related to urban development. In short, Santos is attracting a higher income population while a lower income population is, of necessity, settling in other neighboring areas and cities, where land is cheaper and informal residential conditions predominate.

The city's Master Plan directs future industrial investment and port expansion largely to the continental area. However, given that "Santos is full!" (in the words of one informant), this does not establish scope for accommodating demographic growth in wider spatial terms – demographic growth is directed vertically. Such densification is possible in Santos given that in most parts of the city there appears to be adequate urban infrastructure to support this process. While the city has benefited overall from substantial investments in urban infrastructure, the Northwest area still concentrates a great number of informal, low income and low quality neighborhoods (including *palafitas,* stilt-housing *neighborhoods* in the water). Slums can also still be found in the area of the hills and in the central business district (which coincides with the historical center). The historical center however benefits from its high concentration of jobs and services, and good urban infrastructure. To address poverty, the municipality has undertaken numerous initiatives, notably in housing and urban services financed by the national Growth Acceleration Program (PAC) program and the World Bank.

The Northwest area and the hill area are exposed to flooding and landslides respectively. Since 1968, the zoning system of the city progressively attempted to capture risk areas but development was always ahead of planning (irregular occupation begun before 1968). The municipality has developed specific plans for landslide risk, the latest being the Municipal Plan for Risk Reduction 2012 Plano Municipal de Redução de Riscos, PMRR 2012). The PMRR has been largely successful in directing development, although in many cases people still settle in risk areas. The short term response to landslide risk has been emergency planning (notably an early warning system) and relocation, while the long term response is to develop a regulatory framework to stop development in high and very high risk areas.

The World Bank-financed program Novos Tempos and the social housing programs financed by the Regional Housing Department for “Baixada Santista” (COHAB-ST) incorporate components for guiding development in no-risk areas. In particular, these programs aim to relocate people from high and very high landslide risk areas, as well as from the *palafitas*. While risk *per se* is not taken into account in land use (zoning), landslide risk in particular, is considered when the municipality designated an area as a preservation zone or *Zona de Preservação Paisagística* (ZPP). This complicates relocation, as there exist non-legal residents in ZPP areas. For example, the land use plan preserves the vegetation of the slopes based on environmental criteria: this indirectly addresses landslide risk-related issues. Zoning is now a strong tool for reducing climate-related hazards risk and is very important that the municipality enforces that category.

Future development in inappropriate areas will also be dealt by a new cross-institutional decree that will allow the municipality to demolish encroachments in ZPP areas. Currently the city of Santos has not prioritized flood risk to the same degree as landslides. According to stakeholders, this is because in the past flooding has caused only material impacts (and limited, at that) and has never threatened people’s lives. Flooding problems in Santos are mainly caused by drainage problems and have been historically dealt with by channelization and macro-drainage works, and more recently with relocation of households from the *palafitas*.

Institutional vulnerability issues

Santos has a robust institutional structure for managing disaster risk and climate related hazards. The city’s systems for risk management are considered amongst the best in Brazil, with a strong focus on preparedness and risk reduction. This forward-looking approach offers a contrast to the largely reactive and response-led institutional frameworks for risk management found in the other four city sites for this study.

Catalyzed by the high number of mortalities experienced during landslide events in the 1970s and 1980s, the municipality of Santos developed comprehensive plans and procedures for risk reduction and management. More recently, investments have been made to improve government processes of risk management along with a traditional focus on technical and engineering-led mitigation actions. The municipality, led by the mayor, has developed an integrated process of disaster management that has a clear chain of command and engages all relevant government actors on a regular basis. The emergency management plan for the city is coordinated through the mayor’s office, along with the Police and Fire departments.

In contrast, the role of the Civil Defence Department in Santos is focused primarily on risk prevention, preparedness and adaptation activities. Along with risk monitoring and strategic planning for flood and landslide hazards, the Civil Defence Department undertakes public education campaigns and direct community engagement in high risk areas. The organization works in a pre-emptive manner by removing at risk populations both in advance of and during the impact of events. The focus on risk prevention and reduction activities before the onset of a disaster, rather than the response phase, characterizes the progressive and adaptive approach to risk planning in Santos.

There is good evidence of learning and adaptive capacity for risk management within the institutional framework in Santos. Policy strategies and risk management practices have been revised over time to better address changing risk contexts. When necessary, the municipality has demonstrated capacity to effectively change local laws and regulations to reflect changing regulatory needs. For example, the city has recently passed a law giving municipal authorities the jurisdiction to pull down illegal construction that does not comply with land use controls as a measure towards preventing risky neighborhoods. The institutional willingness to plan and coordinate is in part a reflection of the overall culture of planning and risk management in the city, which is built on swampy mangrove land and has a Century-long history of proactive engagement with drainage and land use planning.

Although the institutional framework is progressive in addressing the root causes of risk, the overall approach to risk has, thus far, focused on planning for existing hazards and vulnerability, with little consideration of future climate variability and its potential impacts. For example, landslide and flood risk assessments for the city are of a good standard and revised regularly, but the latest version of the risk map for Santos (to be released soon) is the first one to consider future projections of climate change. The municipal outlook is thus now changing as the global import of climate change becomes clearer, reflecting an overall change in national priorities from a focus on mitigation to adaptation.

Strategic climate adaptation investment and institutional strengthening plan

The findings of the four assessments provide the basis from which to identify and prioritize a set of strategic climate adaptation investments and institutional strengthening interventions that can be linked or incorporated into existing priorities, sectoral plans and planning instruments in Santos. A strategic, longer term view is proposed, coupled with action planning on a shorter time horizon.

The plan draws accordingly on the conclusions and the feedback obtained during a workshop held in Santos in March 2013. The feedback served to validate assessment findings, update or readjust them and establish a set of specific actions to be proposed based on the needs and major issues identified by stakeholders. This process helps ensure that the proposed climate change adaptation measures can be mainstreamed within the policy and institutional framework, and form part of an overall climate change adaptation strategy for Santos.

The overreaching goal of the strategic plan is to increase resilience to floods and landslides in Santos. On the basis of planning themes, specific measures to address particular urban development challenges as well as institutional shortcomings are identified. These measures also promote a more sustainable and resilient urban development process. Finally, a set of specific actions that can be undertaken to implement climate change adaptation measures are proposed.

The planning themes that create the foundation for a climate change adaptation strategy to help Santos build its resilience against floods and landslides, both now and in the future, are:

(i) horizontal and vertical (cross-scale) integration of risk management practices; (ii) mechanisms for data collection, storage and dissemination to be created and/or improved for better climate monitoring, risk planning, and information sharing; (iii) improved insurance mechanisms and climate financing for long-term recovery and building resilience against floods and landslides; and (iv) a shift from disaster management to long term risk reduction and climate change adaptation to ensure a proactive and forward-looking system of risk governance.

Our proposal considers the potential for utilizing the output of this project for inclusion in current and future urban planning and management activities in Santos; notably the potential links with The World Bank-financed program Novos Tempos and the social housing programs financed by the Regional Housing Department for “Baixada Santista” (COHAB-ST) incorporate components for guiding development in no-risk areas. Similarly to the Santos Novos Tempos program, our proposed measures follow a “no-regrets” approach.

An integrated strategic plan requires the use of both structural and non-structural measures. They include structural measures such as (i) ‘greening’ infrastructure measures for reducing the amount and speed of rainwater runoff in urban areas; (ii) rebuilding of natural ecosystems and protecting mangroves; (iii) incorporation of projected precipitation and SLR levels in the upgrading of the drainage system in the North-West; and iv) ensuring sustainability of existing drainage systems in East Santos. Non-structural measures include: (i) prioritizing and enhancing civil society’s awareness to risk; (ii) capacity building in national and city level government institutions engaged in climate planning and flood and landslide risk; (iii) integrated land use planning and risk-sensitive zoning; (iv) improved budgetary resources and climate financing; (v) formalized structures of cooperation with the private sector in planning and risk reduction; and (vi) improved insurance mechanisms and climate financing for long-term recovery and building resilience against climate change hazards.

In addition, the creation of a "City-Region Observatory" as a partnership between local universities, Baixada Santista Metropolitan Region, Santos Municipality and other municipalities, could help to build the knowledge base that government, private sector, the civil society and citizens all need to make their cities and the region spatially integrated, environmentally sustainable and socially inclusive. In particular, the Observatory will collect data and benchmarks of the city-region, provide policy analysis and support, and undertake applied research.

The timing and scale of local climate change impacts affects the types of measures to be adopted and prioritization of investments and action. The main challenge for policy- and discussion-makers is to implement a climate change adaptation process that considers the trade-offs between current development priorities and long-term risks and embraces uncertainty. The ability and willingness of key actors to address climate change impacts will be of utmost importance.

1 Introduction

1.1 About the project

An ICF GHK consortium was commissioned in May 2012 by the World Bank's regional Urban and Disaster Risk Management Unit for Latin America and the Caribbean (LAC) (LCSDU) to carry out second phase activities for the initiative *Climate Change Adaptation Planning in Latin American and Caribbean Cities*. This initiative started in April 2010 and will be completed in 2013.

The wider initiative seeks both to build and to strengthen capacities for adaptation to climate change in LAC cities. The primary focus is cities in the region less likely to have had access to climate change (CC) adaptation training, finance, or knowledge networks. In practice, this implies a focus on medium and small-sized cities, as larger cities have more human and financial resources to draw on.

Five medium-sized cities were therefore selected: Castries, Saint Lucia; Cusco, Peru; El Progreso, Honduras; Esteli, Nicaragua and Santos, Brazil.[1] The first phase was involved an initial institutional mapping and rapid diagnostic for the initiative. The second phase assignment's objective is to inform policy making and adaptation planning at the city level by incorporating local and international technical knowledge, tools and expertise into existing planning structures to better respond to the adverse effects of climate change.

The emphasis is on floods and landslides, which are two of the most common climate-related risks in cities across the LAC region. Poorly planned and managed urban development and spatial expansion also contributes to flood and landslide hazard risks. **The ultimate goal is to strengthen local adaptive capacity and to increase urban resilience through mainstreaming climate change adaptation into current planning systems.**

For each involved city, there were four main activities specified for the second phase:

1. A climate-related risks assessment focused on floods and landslides
2. A socio-economic adaptive capacity assessment
3. An institutional adaptive capacity assessment
4. Based on the findings of the three assessments, a combined strategic climate adaptation institutional strengthening and investment plan, which will complement and be integrated into existing urban, environmental and disaster risk reduction planning instruments for each city.

The outputs from the above-mentioned activities in this assessments report constitute a critical input for the main output of the overall initiative in its third phase: a regional Guidebook for city officials on urban adaptation to climate change.

1.2 Outline of the report

This report is divided into the following sections:

- ***Climate-related hazard assessment.*** This section first provides an assessment of current coastal and inland flood risk and landslide risk for Santos. It then considers how climate change may impact these existing flood and landslide hazards in the future.
- ***Urban, social and economic adaptive capacity assessment.*** The section assesses how vulnerability to climate-related hazards is linked to topographical, human neighborhood and urban development characteristics: the location and condition of

[1] The selection of the pilot cities was based on the following: a) survey results from Phase 1 of the project; b) diversity of geographic region and climate; c) recommendations provided by World Bank staff leading operational activities across LAC, ensuring the cities' political willingness, interest, and commitment to working with the initiative; d) prevalence of floods and/or landslides as major climate change-related risks; and e) availability of climate risk-related data.

neighborhoods and the materials used in their construction have a direct impact in the level of exposure they have for landslide and flood risk. Studying these variables allows assessment of how the urban development trajectory of Santos impacts upon climate change vulnerability in the city.

- ***Institutional adaptive capacity assessment.*** The institutional assessment focuses on the disaster risk management and urban planning structures and capacities of institutions and stakeholders in Santos and how they take into account and incorporate climate change adaptation.
- ***Climate-related vulnerability and risk assessment.*** Using the information from the three previous assessments, this section synthesizes information on landslide and flood vulnerabilities, focusing on physical risk, urban, social and economic conditions and institutional arrangements to create maps that identify the most vulnerable areas and populations within the city exposed to flood and landslide hazards. The analysis considers the exposure, sensitivity, and adaptive capacity of neighborhoods and critical infrastructures to flood and landslide hazards, and provides an informative screening of which neighborhoods and critical infrastructures are more likely to be affected by and be vulnerable to landslides and floods some 30 years into the future (i.e., the 2040s).
- ***Strategic climate adaptation investment and institutional strengthening plan.*** The *Climate-related vulnerability assessment* provides the basis from which to identify and prioritize a set of strategic climate adaptation investments and institutional strengthening interventions that can be linked or incorporated into existing priorities, sector plans and planning instruments in Santos. A strategic, longer term view is proposed, coupled with action planning on a shorter time horizon.

The above-mentioned assessment approach is broadly consistent with the Urban Risk Assessment (URA) tool developed by the World Bank, but at the same time incorporates aspects that can add a dynamic element to the analysis.[2]

Assessments in the URA tool are associated with three levels of complexity (primary, secondary, and tertiary). The primary level provides an ‘entry point’ to assess the challenges posed by climate-related hazards. The secondary level provides a more ‘refined’ analysis to identify and map the most vulnerable areas and populations exposed to climate-related hazards and to consider how hazards may change in the future. Finally, the tertiary level undertakes specific probabilistic risk assessments and makes use of advanced risk management tools.

Progression from the primary to the tertiary level in any city or town is dependent upon the availability of what can be significant amounts of data, the technical capabilities of relevant staff and actors, and the ability and willingness of politicians, officials and others to commit what can amount to not inconsiderable financial resources and time to conducting assessments – and to building policy, strategy and action plans on the basis of findings. Box 1 below elaborates on our experience for the case of Santos.

Box 1 Using the URA for Assessment in Santos

The Terms of Reference for the phase two activities described above derives from the World Bank’s Urban Risk Assessment tool. As will be seen in the sections of this report which follow, we were able to apply the URA approach to guide and create our assessments for each city, in a process which saw good collaboration with local governments and other stakeholders.

Some provisos are nonetheless required. The URA is avowedly a flexible tool, as it needs to be. In Santos, data availability and time and resource constraints meant the following adaptations to the ‘pure’ URA approach:

1. **Climate-related risks assessment for floods and landslides**: It was possible to assess present-day current flood and landslide hazard levels, both of which are well-understood and the

[2] World Bank (2011) *Urban Risk Assessment: An Approach for Understanding Disaster and Climate Risk in Cities*. Urban Development and Local Government Unit; Finance, Economics and Urban Department, The World Bank.

subject of much study for the city. Local-level precipitation data was made available which allowed consideration of the likely impacts of climate change and, consequently, a projection of changes in hazard levels for a period of some 30 years in the future. Full assessment of the risk levels for the flooding and landslide hazards, both currently and for the future, were not possible as the financial and the demographic data necessary was not readily accessible to us. In addition, the projection for future changes in hazard levels on account of climate change is broad-brush rather than detailed, as this level of detail requires such efforts as hydrologic/hydraulic modelling under future scenarios. This certainly does not preclude future elaboration of risk levels (i.e. detailed risk assessment) in the future on the part of government authorities and other stakeholders in Santos, where multiple sources of data have been collected and do exist (unlimited availability is not assured, however). The findings of our analysis based on simpler approaches can in fact provide guidance regarding the best use of funds for conducting such a vulnerability and risk analysis (e.g., which hazards are likely to worsen, are there potential hotspots where hazards may get even worse, amongst others.). The first assessment in this report is therefore titled – and more correctly seen as – a climate-related hazard assessment.

2. **Socio-economic adaptive capacity assessment**: in Santos, the availability of some data meant that it was possible, within the time frame, to conduct socio-economic assessment, and ascertain the exposure and sensitivity of urban residents to current and future flood and landslide hazards. We attempted to add to and 'thicken' the URA approach with more detailed consideration of the dynamics of both urban and economic growth, change and development for Santos, within its broader 'metropolitan' and regional spatial contexts. Adding this dimension makes assessment more dynamic (i.e., 'adaptive') – accordingly, we have re-titled this assessment to emphasize these urban and economic aspects.

3. **Institutional adaptive capacity assessment**: the real willingness of stakeholders to share their experience in planning, primarily for urban development and disaster risk, rather than climate change itself, permitted a full assessment within the time frame. Our assessment attempted to incorporate the dimension of how institutions in Santos had changed over time, notably in the past decade, again to stress the element of dynamism that has (or may have) inhered to the institutions under study.

4. **Climate-related vulnerability and risk assessment**: to compensate for the limitations on risk assessment, we developed a wider vulnerability assessment than originally intended. This is based on the findings of the three preceding assessments, and identifies and maps, to the degree possible, the most vulnerable neighborhoods, populations and infrastructures within the city that are exposed to floods and landslide hazards both currently and in the future. This should be seen as an overview of vulnerability, rather than a full assessment: this vulnerability 'screening' could usefully be complemented by fuller and more detailed vulnerability analyses on the part of local stakeholders in the future. The assessment concludes with a section on risk information, which suggests studies and data collection activities to continue the development of pertinent risk information for Santos.

5. **Combined strategic climate adaptation investment and institutional strengthening plan**: In a workshop in March 2013 in Santos, there was enthusiastic participation by stakeholders in discussing initial assessment findings and suggesting future strategy and concrete measures for adapting to current and future flood and landslide hazard risks. This interaction forms the basis for the plan as outlined in this report. It should be emphasized that, by design, this plan has no particular institutional affiliation or 'official' status – it, and the assessment and analysis upon which it is founded, now stands as a contribution offered to a debate that is already occurring on climate change adaptation in Santos. Again, stakeholders in Santos will be able to adopt and elaborate the measures proposed as they see necessary.

1.3 Context and study area

Santos is located on the Southern Brazilian Coast, in the estuarine system of Santos. The city of Santos is considered one of the most important municipalities in the State of Sao Paulo. The city's main socio-economic drivers are industrial and port activities. The total current population of the municipality is 419,400 inhabitants, of which 99 percent is considered urban. Over the past two decades population growth in Santos has slowed down considerably and the city is currently not growing.

Santos is mostly exposed to two natural hazards: flooding and landslides. In the northwest part of the city, many neighborhoods surrounding the port area often suffer damages due to flooding caused by rains and high tides. On the hills of the city of Santos, low income households are at risk from landslides, especially in the summer period when the highest rainfall in the region is recorded.

As seen in other cities in the LAC region, there is an emphasis on disaster response. In Santos's case, though, preparation for disaster is also well-advanced. The other cities can certainly learn from the experience of Santos in this regard. Climate change adaptation, however, is not yet high on the agenda. In Santos in particular, and in Brazil in general, people have only recently started thinking about climate change adaptation – the focus so far has been on mitigation.

The municipality's keenness to collaborate is a strong prospective asset for the embedding of results into the planning system, and for their wider dissemination. Both the technical and political levels of the Municipality have already expressed genuine interest in supporting this initiative.

The administrative boundaries of urban Santos (the insular area of the city as shown in Figure 1.1) are the basis for the area of study. The continental area is largely protected area, and in the main uninhabitable, except along major roadways: the Municipality is not concerned with landslide and flood risk in the area. Given the important linkages of the city of Santos with the Baixada Santista Metropolitan Region (BSMR), there is discussion of the area's social, economic and spatial dynamics within the regional context in the socio-economic assessment.

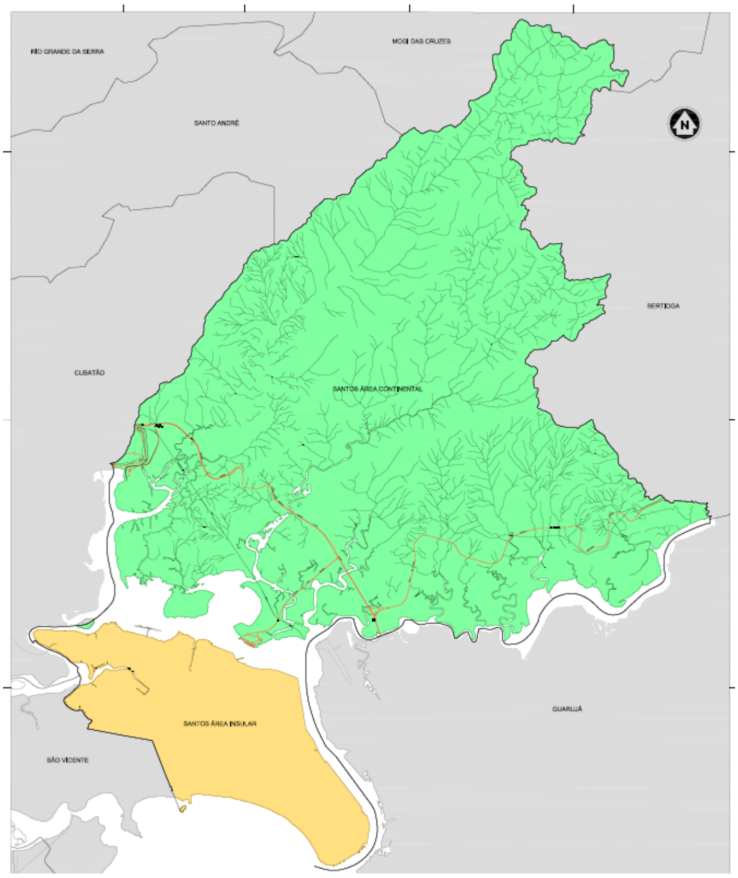


Figure 1.1 **Insular (orange) and continetal (green) Santos, Source: Prefeitura Municipal de Santos, 2011.**

2 Climate-related hazard assessment: floods and landslides

2.1 Introduction

This chapter evaluates present and future floods and landslides in Santos. According to our interviews with the Santos municipal government, the city is considered susceptible to landslides and floods, which is confirmed by this assessment. Each hazard is discussed and draws from available information and data. This chapter divides the analysis into the following sections:

- **Methodology:** considering how current and future climate, aka climate change, may impact floods and landslides
- **Physical description**: an overview of physical characteristics in Santos that are relevant to floods and landslides, and the meteorological drivers of events associated with flood and landslide hazards
- **Flooding**: a general description of inland floods relevant to Santos, a summary of prior events, and a description of the flood tools used to inform disaster management and municipal planning
- **Landslides**: a general description of landslides relevant to Santos, a summary of prior events, and landslide hazard maps, and a description of the landslide tools used to inform disaster management and municipal planning
- **Future hazards**: an overview of future changes of climate and the potential impacts on future landslide and flood events relevant to Santos, including a section describing gaps and limitations.

2.2 Methodology

This analysis utilizes existing tools used by the Santos government to consider how flood and landslide hazards may change in the study area by mid-Century (2040s). To effectively inform future urban planning, it is important that our approach be appropriately aligned with the available local data and resources. The steps taken to consider how climate changes by the 2040s may impact the timing and frequency of future landslide and flood events included:

1. Review available information describing the physical system such as hydrology and geomorphology to understand the drivers that affect landslides and floods.
2. Collect and investigate data on past landslide and flood events in Santos to assess the degree of impact per event and the conditions that precipitate events.
3. Assess available resources used by the municipality to describe zones vulnerable to landslides and floods, and inform emergency planning.
4. Assess available future precipitation and temperature data for the 2040s.
5. Assess the application of three distinct approaches that consider how climate change may impact the tools investigated in Step 3.

Each step, available data, and tools are discussed in greater detail in Annex 1.

Local stakeholders use flood and landslide susceptibility maps as described in Sections 2.3, 2.4, and 2.5 to identify areas prone to floods and landslides. These maps were linked to meteorological and oceanographic thresholds. The current and future values for these thresholds were considered in this analysis to understand the implications for floods and landslides. The precipitation projections from recent reports were also used to help supplement discussion of how climate may affect future floods and landslides in Santos.

2.3 Physical environment

This section provides an overview of the physical attributes that affect floods and landslides in the Santos study area: geomorphology, hydrology, and climate and weather. Further descriptions as related to landslides and floods are provided in Sections 2.3.3 and 2.4.3.

2.3.1 Land Characteristics

The city of Santos, largely an urban island environment, is flanked by the Sierra del Mar Mountains surrounded by water at an elevation slightly above sea level. Figure 2.1 illustrates the city of Santos with a red boundary line. The hilly region within the city of Santos is prone to landslide activity and the northwest section of Santos is particularly prone to flooding.

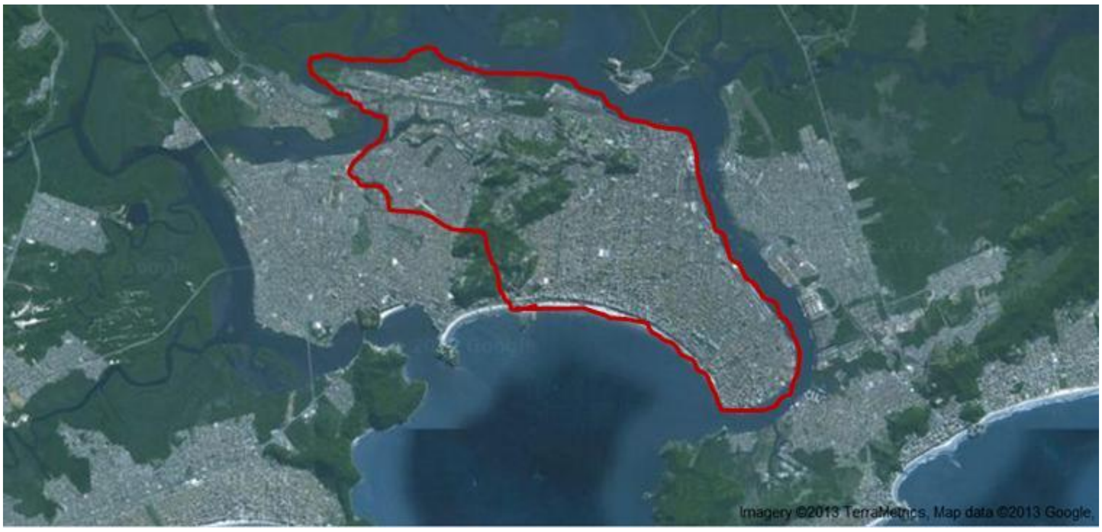


Figure 2.1 Satellite image of the Santos area, Google maps, accessed February 5, 2013.

The area surrounding Santos is characterized by its rich biodiversity. Natural ecosystems in and around Santos have been considerably altered over hundreds of years by urban, industrial, and port development. Its extensive areas of mangrove, with associated fauna and flora have been destroyed over time and are now partially degraded (Neves et al., 2008) and there are very few remnants within the city. Reforestation programs within the hills of Santos have successfully restored some of the city’s forests.

Slope is considered an important factor when considering areas prone to landslides. High-slope areas subject to rock or landslides pose special hazards in the hilly environs of Santos. In developing a plan to reduce municipal risk to landslides, the city of Santos’s technical staff assessed the slopes of hills across Santos. Slopes associated with the hills were determined to range from low to over 40 percent (IPT, 2012).

Geologically, Santos features a combination of clay, sands, and granite (see Figure 2.2). This is particularly important because these soils can become unstable during the summer season when the soils can become saturated. See Section 2.5.3 for a description of additional geological and geotechnical characteristics that were used to define landslide hazards. The Northwest Santos is prone to flooding. Interviews with local authorities and researchers confirm that in some areas the depth of sediments (mud) can be as thick as 40m. These areas are not suitable for construction and require houses to have very deep foundational pillars.

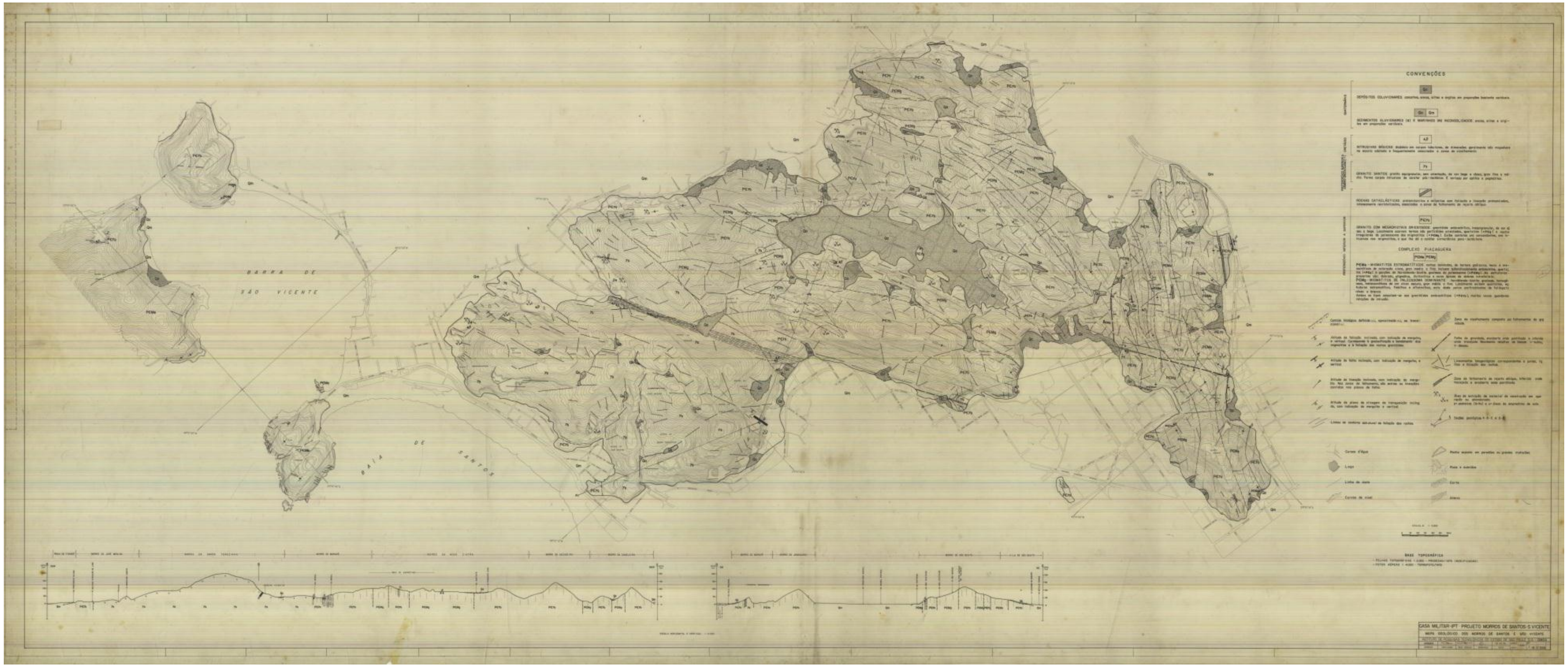


Figure 2.2 Geological characteristics of the landslide-prone hilly areas within Santos. The legend provides the following information: (1) Quaternary includes Qc represents colluvial deposits of gravels, sands, silts and clays in proportions quite variable; Qa, Qm - alluvial sediments (a) and marine (m) unconsolidated sands, silts and clays in varying proportions; Cretaceous includes β which represents basic intrusives, diabase bodies, often associated with shear zones; Late Proterozoic to Cambro-Ordovician includes granite saints: equigranular granite without orientnacao-beige to rosea, gran thin media. Intrusive bodies form of post-tectonic character; Lower Proterozoic includes Bar - cataclastic rocks: protomilonitos and mylonites with foliation and lineation pronounced intensely recrystallized, associated with zones of faulting tailing oblique; Peyo - Granite with megacrysts oriented. peme / pemg - migmatites estromatiticos: Embrechitos include subordinately, quartzites and portions of hornblende - biotite gneisses of paleosome. Migmatites of paleosome dominant: hornblende-biotite gneisses, homogeneous, melanocratic of dark gray, medium to large fine. Locally exhibit quartzites, estromatitica structures, and flebitica oftalmitica, this given by porphyroblasts of feldspar roseo white, Source: Prefeitura Municipal de Santos.

2.3.2 Hydrology

The city of Santos is located on the Southern Brazilian Coast, in the estuarine system of Santos. The estuarine system is comprised of three major estuarine channels: Sao Vicente, Santos, and Bertioga. Santos and Sao Vicente channels cover approximately 44,000 m^2; the average depth is 15m for Santos channel and 8m for Sao Vicente (Mateus et al., 2008). Six main rivers discharge in the Santos estuary: Piacaguera, Boturoca, Cubatao, Mogi, Quilombo and Jurubatuba (see Figure 2.3). The Santos estuary and its landscape have been classified as a sub-tropical mangrove system. Urban and port expansions over the mangrove forests have largely reduced the natural distribution of this intertidal ecosystem that naturally traps sediments before they reach channels. Mangrove destruction and degradation are considered to be responsible for the greater discharge of sediments into the estuary channels.

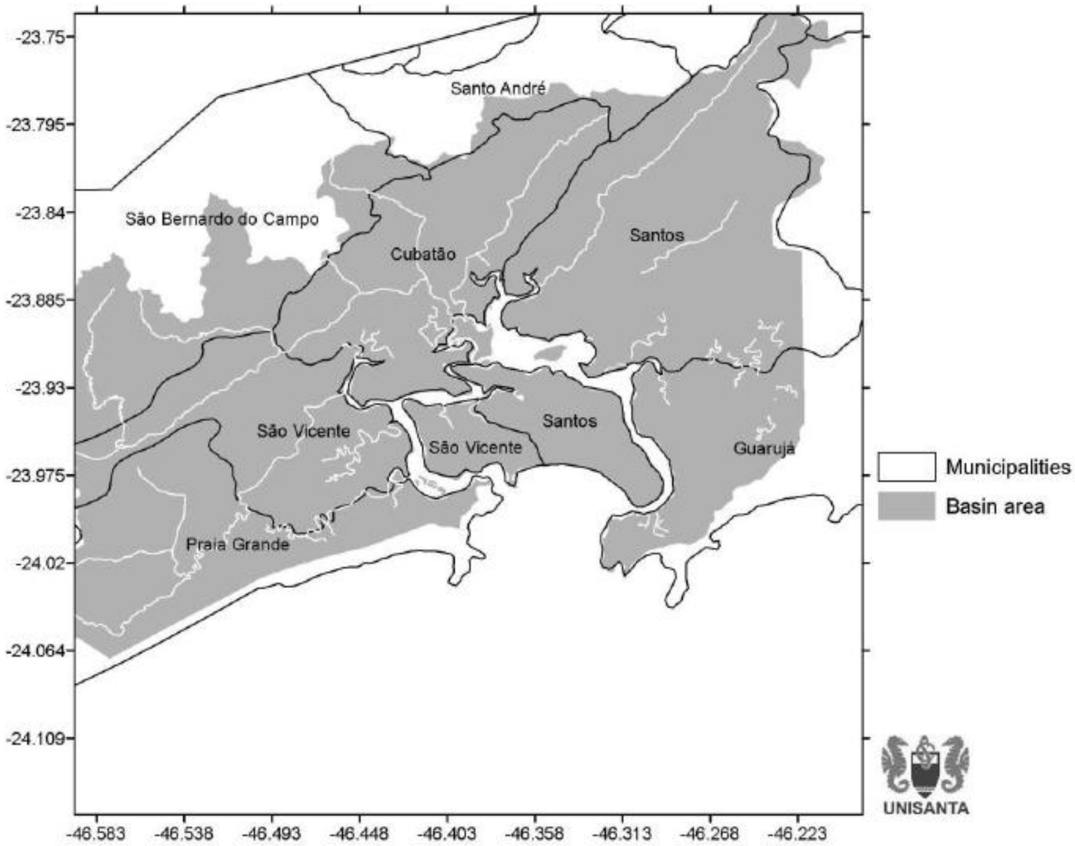


Figure 2.3 The Baixada Santista Metropolitan Region and Santos basin area. Source: Neves et al., 2008.

2.3.3 Climate and weather

Santos's climate is warm and wet throughout the year (see Table 2.1, Figures 2.4 and 2.5). The annual temperature is about 21.9^{o}C with a 5^{o}C difference between the summer and winter seasons. Santos receives about 2,500 mm of total annual rainfall with 75 percent of the total rainfall occurring during the months from October through April. For purposes of this analysis, October through April is defined as the "wetter/warmer" season and May through September is defined as the "wet/warm" season. During our interviews, stakeholders suggested that landslides are more likely to occur during the "wetter/warmer" period.

There is large variability in year-to-year monthly precipitation for the period of record from 1940 to 2012 as shown in Figure 2.5 through the 'bars' which represent the range of 1 standard deviation from the average total monthly precipitation (e.g., inspecting all January monthly totals from 1940 to 2012 suggest an average monthly total of 317 mm with a standard deviation of +/- 125 mm). Interestingly, in some instances, one extreme daily observation tended to account for (on average) 68 percent of the monthly total.

Table 2.1 Monthly average temperature and total precipitation from 1950 to 2000 and total precipitation from 1940 to 2012 for the Santos area. Sources: temperature adapted from Hijmans 2005, precipitation estimated from station 02316279.

Month	Temperature (°C)	Precipitation (mm)
January	25.1	317
February	25.3	297
March	24.3	313
April	22.2	221
May	20.4	155
June	18.8	114
July	18.7	116
August	19.3	102
September	20.3	160
October	21.7	200
November	22.7	197
December	23.4	262
Annual	**21.9 (average)**	**2,455 (total accumulation)**

Where blue shading approximates the wetter, warmer season and red shading approximates the wet, warm season.

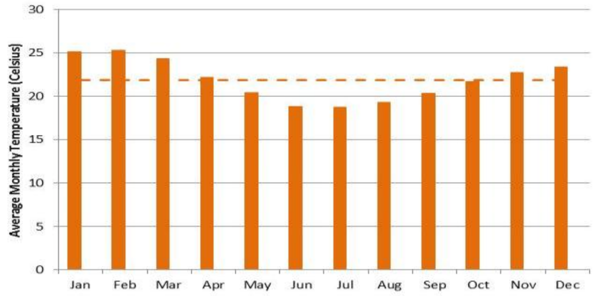


Figure 2.4 Average monthly temperature (°C) for the Santos from 1950 to 2000 with the dashed line representing the average monthly temperature over the year. Source: based on data from Hijmans, 2005.

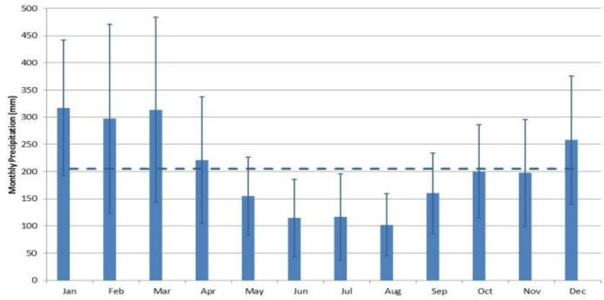
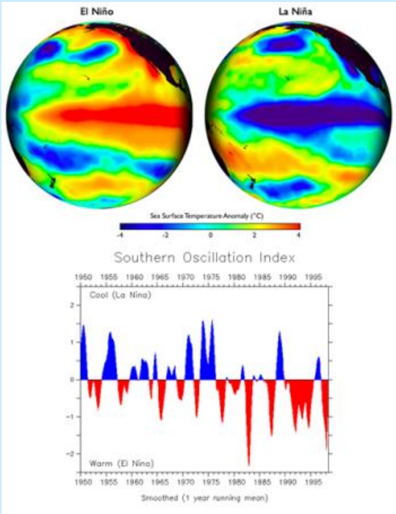


Figure 2.5 Average monthly precipitation (mm) for the Santos area for 1940 to 2012 with the dashed line representing the average monthly precipitation over the year. Source: based on data provided by the Civil Defense for Santos municipal meteorological station (02316279).

A number of phenomena affect Santos's weather and extreme events including the El Niño/Southern Oscillation (ENSO), the South Atlantic Convergence Zone (SACZ), and the South American Low Level Jet (SALLJ) (Marengo, n.d.). ENSO can affect the inter-annual variability while SACZ and SALLJ can affect intra-seasonal variability (see Box 2).

Brazil experiences significant changes in rainfall during El Niño events. For example, the country experienced a 70 percent increase in rainfall above normal conditions during El Nino events of 1987 and 1992 (NOAA site[3]). However, how rainfall changes during an El Nino event varies depending on the region within Brazil. In Santos, El Niño events tend to bring higher amounts of rainfall. During an El Niño event in 2010, there was so much heavy rainfall in Santos that it forced ships to wait weeks to load sugar into their holds – rain falling into ships' holds can damage the consistency of the sugar - causing sugar prices to rise (Murphy, 2012). The heavy rain around Santos during an El Niño event is contrasted by significant drying conditions to the north (Sentelhas, 2006). Conversely, during La Nina events, Santos tends to receive lower amount of rainfall than normal conditions (Ibid.).

Box 2 Overview of ENSO which affects Santos climate



The El Niño/Southern Oscillation (ENSO) cycle is the cyclical change in sea surface temperatures, rainfall patterns, surface air pressure, and atmospheric circulation that occurs around the Equatorial Pacific Ocean. The extremes of the ENSO cycle are termed El Nino and La Niña. El Niño is when the sea surface temperature in the Pacific becomes warmer than normal and the strength of winds reduce. Conversely, La Niña is when the sea surface temperatures become colder than normal and the strength of the wind increases. These events usually occur every 3 to 5 years and can last over 12 months.

Figure 2.6 Top: Sea surface temperatures for El Niño and La Niña events; Bottom: El Niño (blue) and La Niña (red) events from 1950 to 2000.

Source: NOAA, 2012a

2.3.4 Sea level

Globally, mean sea level has risen approximately 1.7 mm per year over the past Century (IPCC, 2007). This trend has accelerated in recent years. Since 1993 (when satellite observations became available increasing the accuracy of sea level measurements), mean sea level has risen at a rate of about 3 mm per year (IPCC, 2007).

There are a few recent studies exploring sea level variability for the Southeast Brazilian coastline. One study used two long-term sea level records that were available for Cananeia and Rio de Janeiro and estimated that sea level had risen by 3.2 and 3.6 mm per year since 1950, respectively (Franca et al., n.d.). This is greater than the rate of global mean sea level rise. In Santos, the Santos Harbour tidal gauge suggest mean sea level has risen at a rate of 1.2 mm per year over the past 30 years, with an increasing trend in the past decade (Alfredini et al., 2007). This rise is slightly less than the global mean sea level rise, suggesting a 30 percent reduction in local rise compared to global rise. This suggests additional factors such as ocean circulation patterns or land subsidence may be contributing to changes in local sea levels.

2.4 Current flooding

Flooding in Santos generally occurs when the soils have reached their full carrying capacity and/or from increases in ocean water levels (i.e., high tides, and storm surges), causing some disruption to normal activity in the Northwest region. Flooding is not associated with mortality.

This section provides: (1) a description of the flooding in Santos, discussing both the general conditions that cause or exacerbate flooding and the locations where flooding occurs; (2) a

[3] http://www.pmel.noaa.gov/tao/elnino/impacts-brazil.html

general summary of when prior flood events have occurred over time; and (3) a description of the flood maps used by the city planners and emergency management in Santos.

2.4.1 Description of flooding

In Brazil, floods are generally categorized into two types: anegamiento and inundacion. Anegamiento refers to a less severe flooding, e.g., enough precipitation occurs that soils reach their carrying capacity and water starts to runoff the land or collect in low-slope areas. Inundacion refers to severe flooding, e.g., when the precipitation amount causes flood waters to collect or travel at a certain depth above the ground. In Santos, the most common type of flooding is the less severe 'anegamientos.'

In Northwest Santos, the flooding associated with a precipitation event will worsen during high tide due to the rising sea waters infiltrating the existing drainage system. However, as these floods have not caused any causalities and the water retreats within hours, they are not systematically reported by the authorities. Impacts associated with these floods are mostly related to traffic disruption.

Due to the channelization works from 1900s, East Santos does not experience considerable coastal flooding. The southern tip of the south-eastern coastline (Pta. de Praia) has experienced significant beach erosion while the beach further north has expanded/accreted. Though it is not proven, our interviews with local stakeholders suggest the public believes the loss of the south-eastern beach that protects against coastal flooding is due to human causes (the annual dredging of the river since the 1970s).

2.4.2 Historical and observed flooding

Two areas of Santos are discussed in this section: East Santos and Northwest Santos. East Santos has a complex drainage system built in the early 1900s that allows tidal and rain water movement through the channels, protecting against floods. Northwest Santos experiences flooding during spring tides, this is particularly problematic during the summer season when the floods are compounded with rainfall. These floods may last a day and can alter the normal operations of the city. Some activities have been undertaken to reduce flooding such as tidal flood pumps, dredging, and the environmental recuperation of San Jorge River.

News reports of past storm surge events describe damages to infrastructure and business. Most damages reported were related to traffic interruption and damages and destruction of beach infrastructure. A few recent events in Santos that illustrate the damage associated with high tide, storm surge, and/or battering waves include the following:

- May, 1999: High tide peaked at 1.6 m caused serious damage to the region of Santos, making many areas impassable due to flooding (Segunda-Feira, 1999).
- April, 2005: Storm surge damaged a seawall causing inland flooding with maximum waves of 3 meters in Santos Bay and a tidal rise of 80 cm (Alfredini et al. 2008).
- April, 2011: Advancing waters where tides reached 1.6 m in Santos hit a building, caused a power outage, and broke low walls along the beachfront (Pupo, 2011).
- December, 2012: Strong rain affected many coastal cities of Sao Paulo State. In Santos, reports are related to traffic interruption and material damages. Trees feel into the channels causing channels to overflow, magnifying the flooding (Alexandre, 2012).

This section provides a description of flooding for East Santos and Northwest Santos.

East Santos

Between 1890 and 1900, nearly half of the Santos population died of yellow fever, malaria, dysentery, typhoid, bubonic plague, smallpox, tuberculosis, and other diseases brought on by poor sanitation conditions, imperfect water supply, and lack of good drainage system (Marchi, 2011). This prompted a sewage commission which built an intricate drainage system that includes a series of canals at the eastern section of Santos, with the inauguration of the first channel in 1907 (Marchi, 2011). This system transformed rivers into canals, channelling the water to the estuary and bay.

The water height in the channels varies with the tides. Ultimately, 8 channels were built covering more than 21 km in length (Marchi, 2011). As shown in Figure 2.7, the channels can discharge both to the bay and the estuary; during high tide, one side of the channel is blocked and the remaining water is stored in the channels. During low tide, channels are opened and water can flow towards the estuary and the bay.

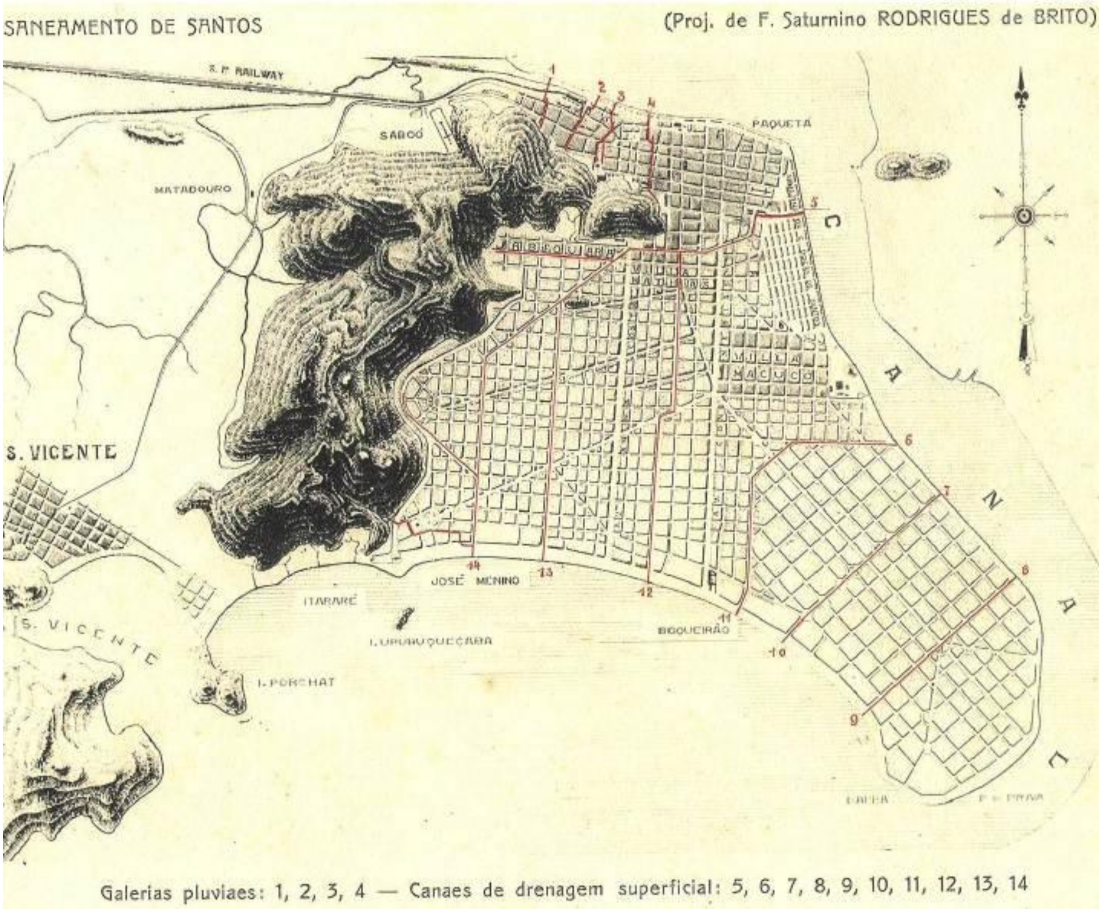


Figure 2.7 The canal system built in the early 20th Century, Source: provided by the Prefeitura Municipal.

Figure 2.8 Waves crashing onto the pedestrian walkway along the south beach of East Santos during an unusual event, Source: http://www.santosnaweb.com/praias/fotos-ineditas-da-ressaca-do-mar-hoje-em-santos/

Blocking the canals during high tide does not create flooding conditions even during precipitation events since the canals are deep enough for substantial water storage. During our interviews with representatives from the municipality, there were some concerns regarding the state of the canal infrastructure, including: the iron gates within the canal being susceptible to corrosion over time and needing to be replaced, and some revisions to the channels may be needed to accommodate the beach erosion along the southern beach and sedimentation in the northern side.

Though Santos is considered somewhat protected from storm surge, there are recent instances of coastal flooding. Coastal flooding occurred during storms in 1999, 2005, 2006, and 2012. During these storms, there were reports of traffic interruption due to storms surges along roadways (see Figure 2.8). During a storm in April 26, 2005, the maximum waves reached 4 m in Santos Bay, damaging the seawall and causing inland flooding (Alfredini et al., 2007). The Baixada Santista, the metropolitan area that includes Santos and a number of other districts, has experienced areas of coastal erosion up to 60 percent (Souza, 2009). Storms have been partly attributed for causing this erosion. Upon review of the literature, it does not appear that the impacts of sea level rise on the functioning of the channels have been investigated.

Northwest Zone of Santos

Northwest Zone of Santos has been relatively recently populated. In 1958, the city authorities drained and claimed the land for agriculture by adopting a similar drainage canal system as in East Santos. Though these channels were built for the purpose of supporting agricultural land, urban developers quickly urbanized the area. The neighborhoods in this area are built upon 40 meters of mud, requiring strict building codes that are often not complied with. In addition, the land is approximately at 1.4 m above sea level, though some neighborhoods have an elevation that is lower than the high tide experienced about twice a month.

During instances of higher high tides (approximately 10 times a year), these neighborhoods experience flooding as water percolates up from the drainage system. A rain event coinciding with a high tide may significantly increase the level of flooding, affecting roads and houses. Some adaptation in response to flood conditions has already occurred with some houses using higher doorways to protect against flooding water. Currently, there are no working pumps in the Northwest.

There are informal neighborhoods along the channels and estuary where wooden houses are built on stilts (see Figure 2.9). These houses can regularly flood during high tide. In addition, the port was filled to a higher elevation to protect against tidal flow; however, this action resulted in trapping the water in the Northwest, preventing water from naturally flowing into the estuary.

Figure 2.9 Informal neighborhoods along the water's edge in the northwest zone of Santos, Source: provided by the Prefeitura Municipal.

A number of actions have been implemented to maintain the canals. The Civil Defense has implemented a waste management program to reduce the amount of garbage that can clog the drainage system. This was evident during our site visit where large centrally-located garbage bins were available for local residences and disposed of daily (in some locations, twice daily). Walls were also erected in some locations to prevent local residences from throwing the trash directly into the water. However, there was still some limited evidence of trash in the local rivers.

Santos Novos Tempos Program: A new drainage system under development.

A new drainage system is being developed through the Santos Novos Tempos Program supported by the World Bank. Part of this program is to restructure the urban macro drainage system, installing new channels and pumps, along other drainage infrastructure. Figure 2.10 illustrates the new drainage system that is currently underway as well as identifying the areas currently impacted by heavy rain ("chuva forte") and high tide ("mare alta").

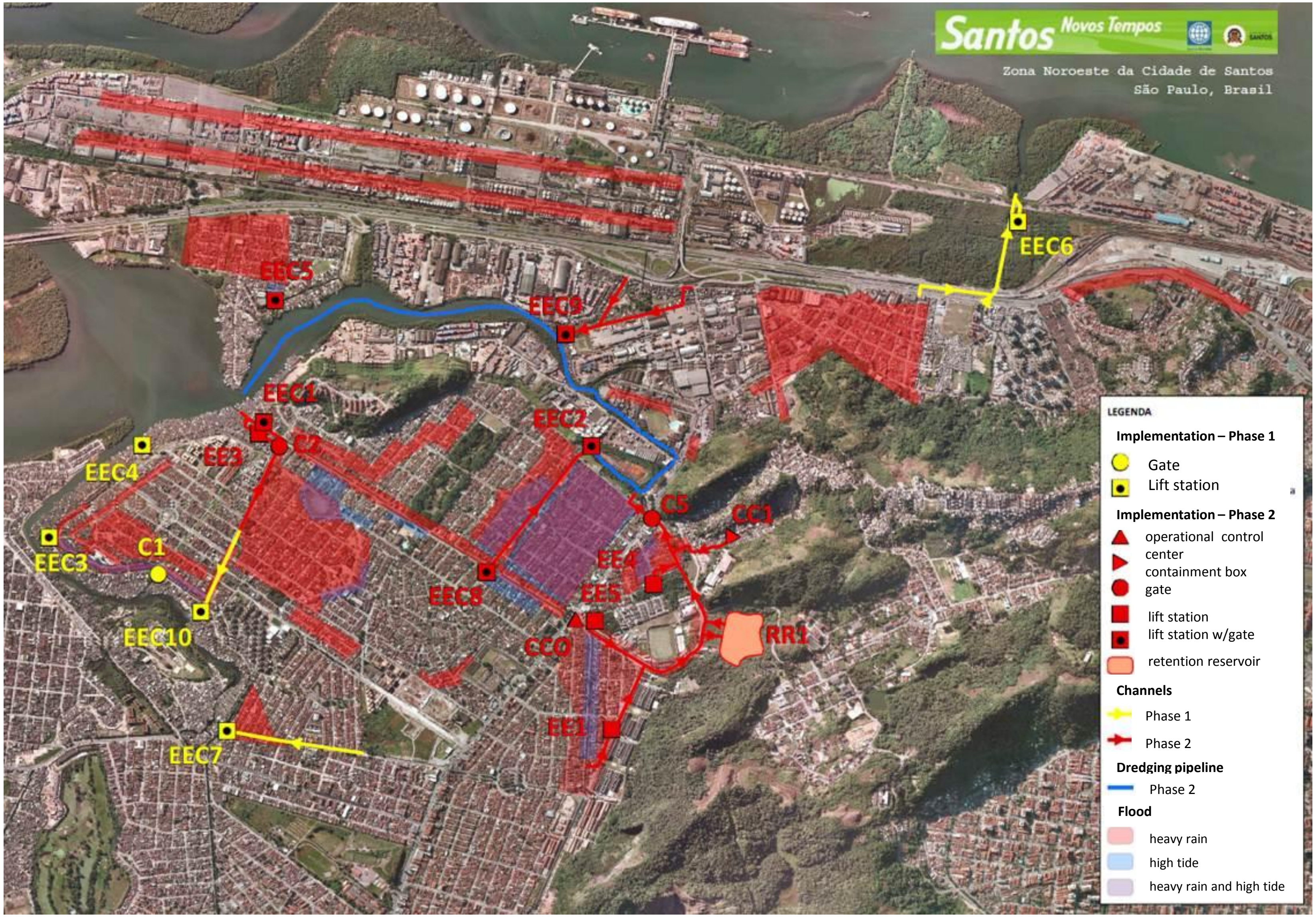


Figure 2.10 The new drainage system in the Northwest Zone of Santos, Source: provided by MC Consulting.

The following general description of the proposed macro-drainage system for the Northwest Zone of Santos is summarized from the detailed information provided by MC Consulting (2012).

In the 1990s, the municipality of Santos conducted a hydraulic study to determine the risk of failure of the drainage structures and devices for the Northwest Zone of Santos. Table 2.2 states the risk of failure of drainage structures and devices designed for a flow of different return periods, before completing a period of time of N years. For structures designed with a useful life of 50 years, the risk of failure (last column in the table) is very high.

Table 2.2 Risk of Failure of a Work Designed for a Flow of TR Years of Return Period, Before Completing a Period of N years. Source: MC Consulting, 2012.

Adopted Period of Return (TR) (years)	Probability (P) of Failure in Any Year (%)	Risks of Failure (R) Before Completing a Period of Time of N years (%)			
		N = 5 years	N =10 years	N = 25 years	N = 50 years
5	20	67	89	99,6	100.0[(a)]
10	10	41	65	93	99,5
25	4	19	34	64	87
50	2	10	18	40	64
100	1	5	10	22	39

[(a)] It is not an exact value, but very close to 100%.

Under the Santos Novos Tempos Program, to meet the standard recommendations by the Department of Water and Electric Power, the return periods of 50 years and 100 years, respectively, were adopted in the hydrologic studies for the hydraulic dimensioning and verification of the draining devices. The Santos Novos Tempos Program used the CAbc hydrologic model to simulate the hydrologic process of rainfall-retention-infiltration in a hydrographic basin.

The hydrologic model considered 6 basins: Sao Manuel District, Faria Lima Avenue, Haroldo de Camargo, Jovino de Melo, Nossa Senhora de Fatima Avenue, and Saboo/Lenheiros River. Figure 2.11 shows the initial configuration for the CAbc Model to simulate the drainage basins.

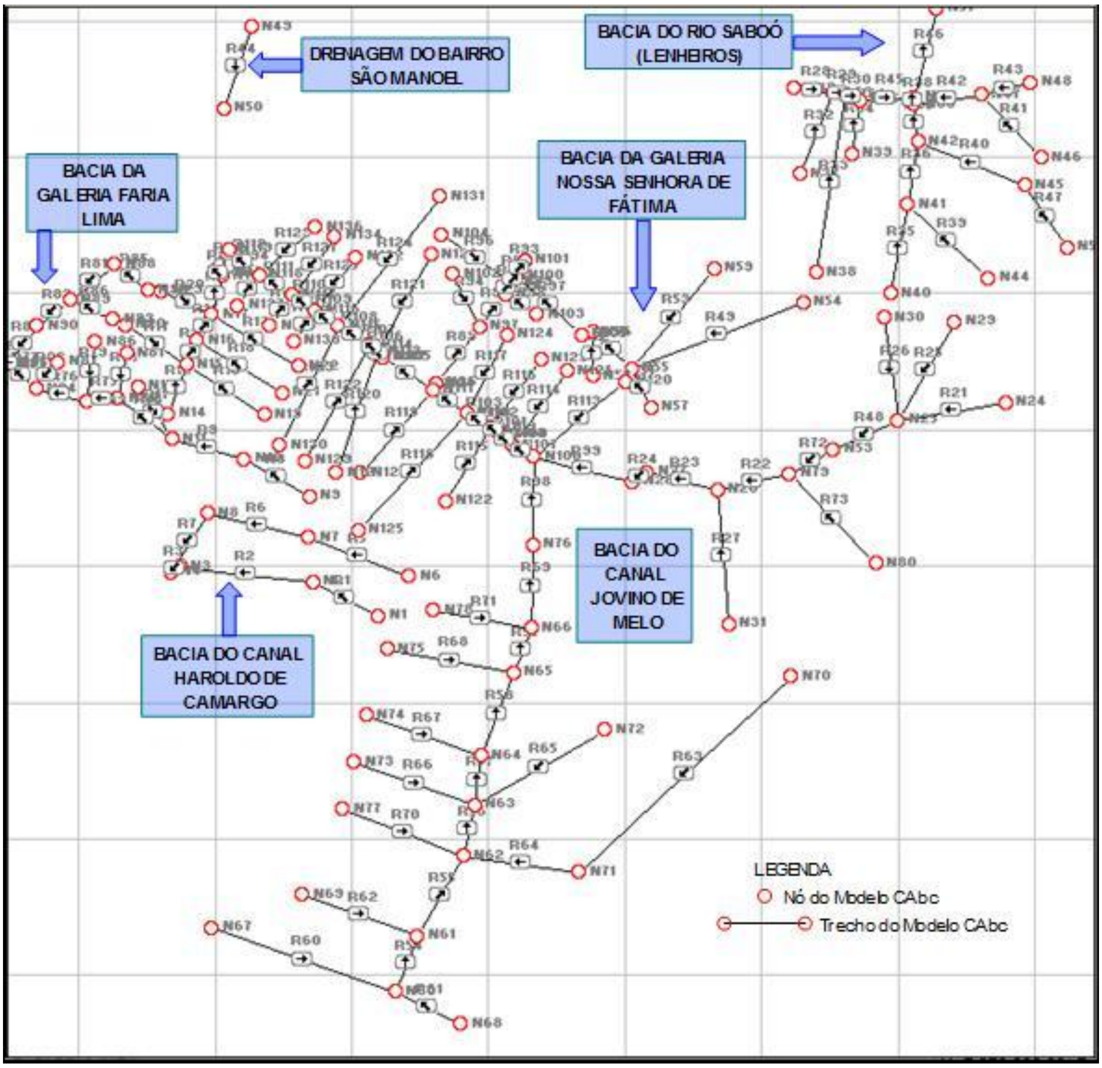


Figure 2.11 The configuration of the drainage basin in the CAbc model for the Northwest Zone of Santos under the Santos Novos Tempos Program (MC Consulting, 2012).

This model requires the following input: maximum rainfall, soil infiltration parameters, indices of impermeable areas, and indices of areas directly connected to the surface drainage. The new drainage system is designed to protect against the 100-year precipitation return period. This is quantified as extreme precipitation (mm) received per minute at 10 minute to 240 minute intervals. The return periods are estimated and applied consistently across the study area.

Hydraulic evaluations were done using the Hydraulic Simulations Mathematic Model (HEC-RAS) to consider the insertion of new control structures and mitigation of floods; HEC-RAS is a one-dimensional model that simulates the hydraulics of water flow through natural rivers and other channels The proposed drainage system will have 13 pumping stations: 5 within Jovino de Melo Basin[4], 2 within the Faria Lima Avenue Gallery[5], 2 within Hugo Maia Avenue

[4] Border Pumping Station– Situated in the area restricted by Gersino Hugo Caparelli Avenue (EE1), Fritz Gut Street and Domingos José Martins Street; Jovino / CaneleiraPumping Station – Situatedin the Francisco Ferreira Canto Avenue, nearby the end of Eleonor Roosevelt Avenue (EE5); Jovino / Molina Pumping Station – Situatednext to the confluence between the Jovino de Meloand Roberto Molina channels (EEC8); Jovino – FozPumping Station – Situated next to the right margin of Jovino de Melochannel, just downstream from the Hugo Maia Avenue bridge (EEC1); Caneleira Pumping Station – Situated in a low point of the Caneleira area, next to the block formed by Ângelo Martins Meleiro, Gilberto F. da Silva and Miguel Rocha Corrêa streets (EE4).

[5] Situated outside of the dike next to the crossing of Caminho de São Sebastião with Antônio Ablas Filho Street (EEC3); Situated outside of the dike close to the crossing of the Contra-Almirante Esculápio C. de Paiva Street (EEC4).

Channel Basin[6], 1 within Roberto Molina Street Channel Basin[7], 1 located within the Sao Manuel District[8], 1 within Haroldo de Camargo Street Channel Drainage[9], 1 within Sabooor Lenheiros River Basin[10], and 1 within Alemoa District drainage[11]. Figure 2.12 illustrates the location of these stations. The new pumps will be made out of stainless steel instead of cast iron (which is soluble in water). Seven of the pumping stations will require reservoirs for the pumps' water catchment.[12] These reservoirs are connected to the channels by a side spillway. Nine tide control gates and four drainage isolation gates are also proposed. The tide control gates will be near pumping stations.[13] A control centre will shut these gates during high tide to reduce flooding from the sewage drains.

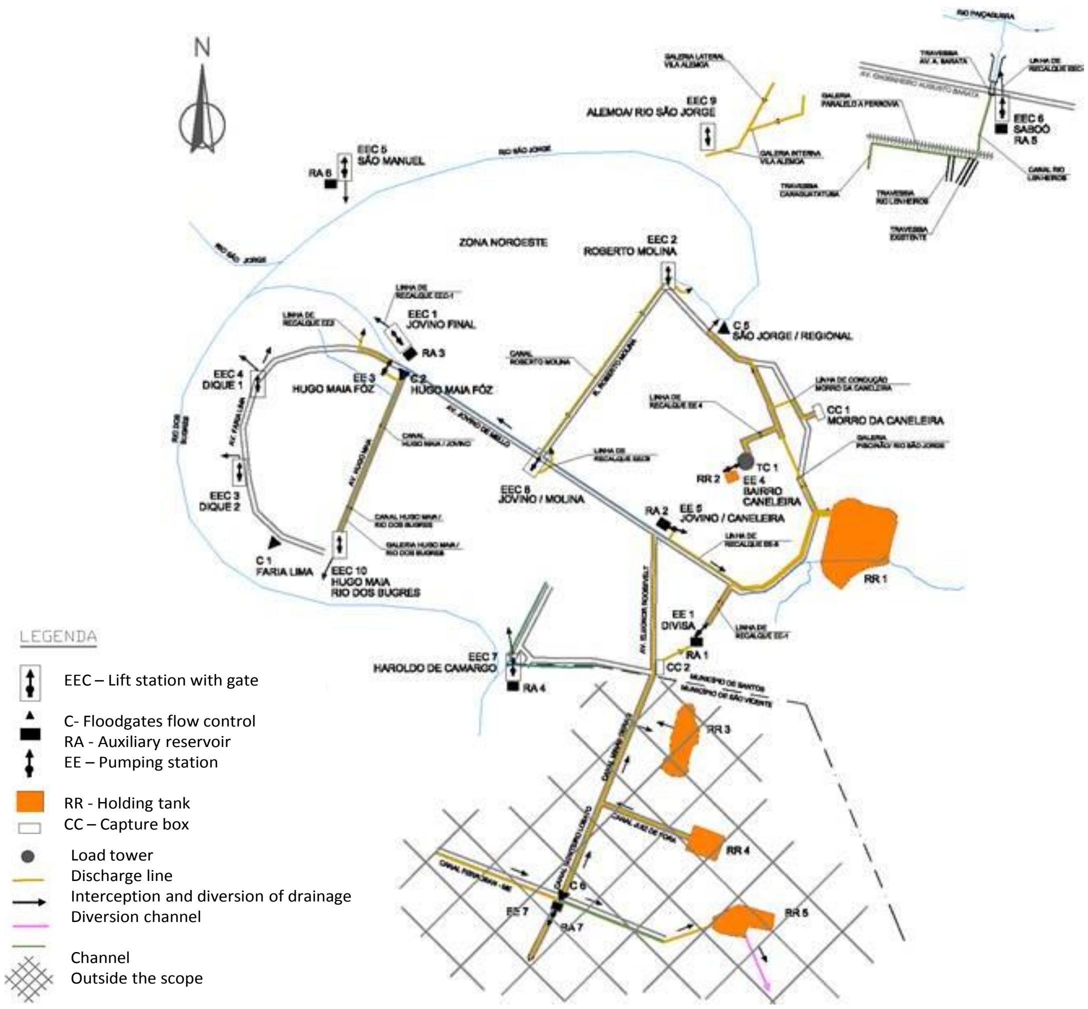


Figure 2.12 Macro-drainage system for the Northwest Zone of Santos proposed under the Santos Novos Tempos Program. Source: MC Consulting, 2012.

6 Situated next to Hugo Maia Avenue, on the right margin of *dos Bugres* River (EEC10); Situated next to the confluence with the Jovino de Melo Channel, close to the crossing of Stefan Bryk Street (EE3).

7 Situated next to the mouth of the São Jorge River. Crossing of the Dr. Pedro de Castro Rocha Street with Alberto de Carvalho Street (EEC2).

8 Situated at the crossing of Abel Simões de Carvalho Street and unnamed Street (EEC5).

9 Situated just downstream from the confluence of the Haroldo de Camargo and Horácio Flor Cirilo channels (EEC7).

10 Situated a little upstream from the crossing manhole of the Lenheiros River, under Augusto Barata Avenue (Portuária Avenue) (EEC6).

11 Situated in the right margin of São Jorge River, in theinternal alley of Vila Alemoa (EEC9).

12 These pumping stations include EEC1, EEC5, EEC6, EEC7, EE1, EE$, and EE5.

13 These stations are EEC1, EEC2, EEC3, EEC4, EEC5, EEC6, EEC7, EEC9, and EEC10.

Considering future weather events, the new drainage system may be vulnerable under extreme precipitation events and/or sea level rises. Given the information collected during our interviews, the northwest zone may be vulnerable to flooding after the new system is built if the tide is above 1.5 m and the rainfall is above the 100-year precipitation return period. Currently, these thresholds have not been surpassed by past events. The approximate sea level that the new drainage system infrastructure is designed to sustain is provided in Box 3. Sea level rise as a consequence of climate change was not considered on the project design.

Box 3 Drainage design

- Dykes can sustain up to 1.7m above SL
- Pump can sustain up to 2.3m above SL
- Gates can sustain up to 2m above SL

2.4.3 Flood maps

In addition to the map presented in Figure 2.10 which illustrates areas susceptible to flooding in the northwest zone of Santos, Figure 2.13 illustrates the locations around Santos that are subject to flooding during high tides based upon elevation:

- The neighborhood area along the southern coastline is protected by sea walls, the crest of which is 2 to 3 m above mean sea level.
- The Northwest coastline is protected by sea walls. The crest of these is 1.5 to 2 m above mean sea level; however, there are pockets throughout the Northwest that are not adequately protected where a rise in sea level of less than 1.5 m can cause flooding.
- The port, the key economic asset for Santos, has some terminals that may be affected by higher sea levels, though most sections are built to withstand water level increases of as much as 3 m above mean sea level.

This additional water level can be a combination of both the tidal height and the storm surge (wave heights and run-up are not considered). Though the discussions during our interviews suggested storm surge was not a concern since the bay is naturally protected against major storm surge, there have been some notable recent events of coastal flooding.

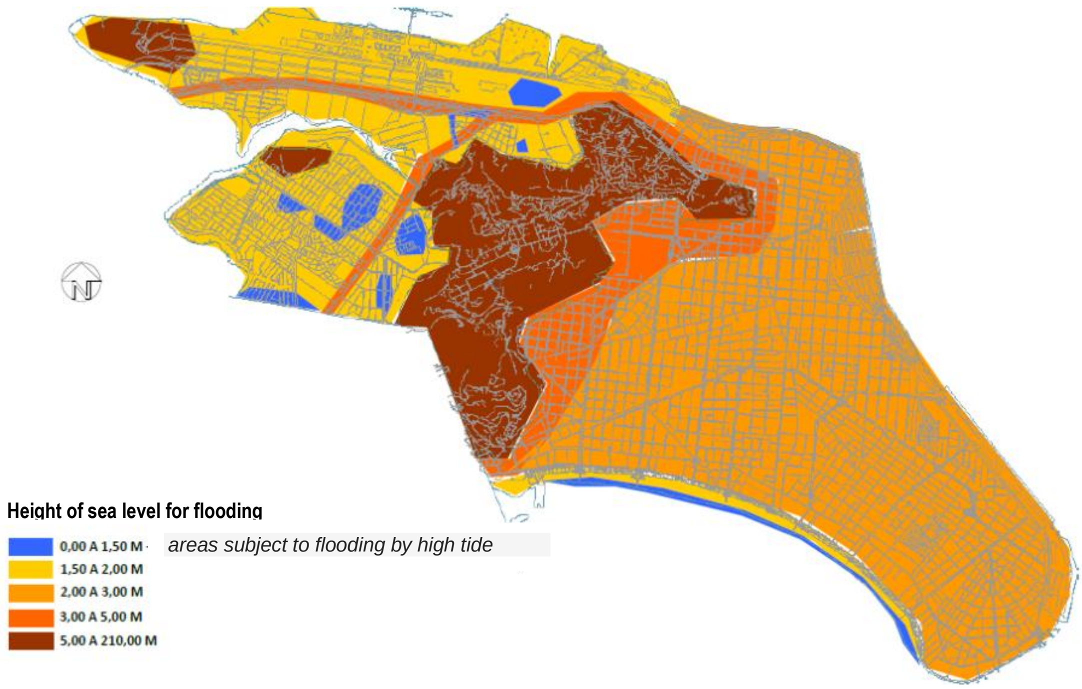


Figure 2.13 Locations in Santos subject to flooding at varying sea levels, Source: Provided by the Prefeitura Municipal.

2.4.4 Warning System

The local government does not have a formal warning system for floods. This is because to date, floods have not led to victims or casualties.

2.5 Current landslides

Landslides are generally caused by precipitation events and isolated to the hilly terrain separating East Santos from Northwest Santos.

This section provides: (1) a description of the landslides in Santos; (2) a summary of past landslide events; and (3) a description of the landslide risk management planning tools and resources used by the city planners and emergency management.

2.5.1 Description of landslides

The Brazilian government considers four processes that may impact gravitational mass movements (Macedo et al., 2011):

- **Creep:** Several internal displacement planes with very low to low velocities which decrease with depth. The movement may be constant, seasonal, or intermittent.
- **Slides**: A few external displacement planes with medium to high velocities. This may be associated with small to large volumes of material.
- **Falls:** This is free fall or inclined plane-type movement with very high velocities. The material may be rocky and consist of small to medium volume of material.
- **Flows**: May include many displacement surfaces both internal and external with movement at medium to high velocities (may be similar to that of a viscous liquid). Flow may consist of soil, rock, debris, and water with large volumes of material. The range may be extensive, even in flat areas.

Landslides can occur depending on the complex interaction of a number of destabilizing processes as described in Table 2.3. In addition, the table provides a description of evidence of mass movement also used to assess risk to landslides

Table 2.3 Data identified and collected in Santos to describe risk to landslides

Local Characterization ■ Natural slope / cut slope ■ Slope height ■ Distance from home ■ Unfavorable structures in soil/rock ■ Presence of rock, boulders, and walls ■ Presence of trash and debris ■ Amphitheatre landfill ■ Occupation of headwaters	**Movement Evidence** ■ House cracks/landfill ■ Trees, poles, walls inclination ■ Etch-plains ■ Landslide scars ■ Swollen walls ■ Erosion features ■ Stream margins undermining **Streams** ■ Channel type (natural, winding, rectified) ■ Distance from shore ■ Height of marginal embankment ■ Height of flood
Presence of Water ■ Surface concentration of stormwater ■ Release of wastewater into surface ■ Presence of septic tanks/sewage/water mains ■ Upwelling water ■ Leaks	**Presence of Vegetation** ■ Trees ■ Undergrowth ■ Deforested areas ■ Farming areas

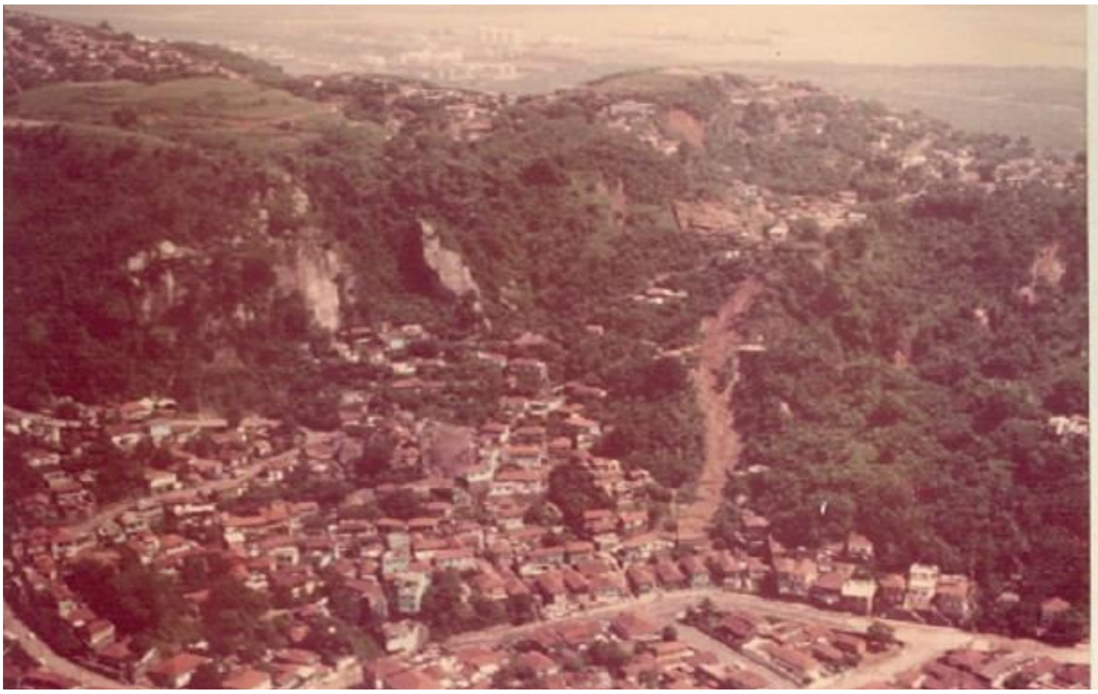
Source: IPT 2012; Macedo et al. 2011.

2.5.2 Historical and observed landslide events

Historically, Santos experienced deadly landslides in 1928, 1956, 1979, and 2000 (see Figure 2.14). These landslides were isolated to the hills in northern Santos. The deadliest landslide was in 1928 on Monte Serrat, responsible for 80 fatalities and destroying a hospital.

1928

1956



1978/1979

Figure 2.14 Photos capturing the aftermath of severe landslides in Santos, Source: photos provided by the Department of Civil Defense, Santos.

According to a Report of the Regional Morros' Technical Staff (Freire, 1995), the following is a chronological sequence of the most relevant land mass movement events reported by the local press:

- October, 1928: Landslide on the slopes of Monte Serrat. About 50,000 m^3 of soil and rock detached, killing 80 people, burying eight houses and destroying part of Santa Casa de Santos.
- April, 1941: The detachment of a large rock block in the Morro Marape destroyed two wooden chalets and killed three residents. Monthly rainfall totalled 242 mm with 57 mm of rain falling on April 17 followed by 186 mm of rain falling on April 18.
- 1950: A landslide in Monte Serrat killed three people and left several injured.
- January, 1956: A landslide caused by the detachment of soil and rocks from the Morro de Santa Terezinha destroyed 50 homes, killed 21 people and injured more than 40. The monthly rainfall totalled 104 mm, with a 3-day total exceeding 102 mm at the beginning of the month (the 3-day total began on December 31, 1955).
- April, 1956: More than 60 landslides occurred with the most significant in Monte Serrat, Caneleira / Embaré, St. Therese and Marap responsible for destroying 100 houses, 43 deaths, and injuring hundreds. The monthly rainfall totalled 340 mm with two particularly heavy rains on April 9 (60 mm/day) and April 27 (80 mm/day).
- December, 1959: A landslide from Morro Bufo killed two people. The monthly rainfall total was 361 mm with a 3-day total on April 20 of 190 mm.
- January, 1978: Landslides in Villa Progreso and the Morro Nova Cintra caused four casualties. The monthly rainfall totalled 429 mm, with a remarkable amount of rain on January 15 of 241 mm followed by 63 mm of rain on January 16.
- October, 1978: A landslide occurred from Morro de Jabaquara, attributed to rainfall, high slopes, and removal of base material and vegetation. Monthly rainfall was 60 mm with no individual day recording rainfall above 11 mm.
- January, 1980 – A landslide on the access to Morro da Cintra caused 10 deaths. The monthly rainfall was 292 mm with 112 mm of rain falling on January 13.

The following daily precipitation thresholds of 100 mm, 150 mm, 200 mm, and 250 mm were considered for the period of record from 1940 to 2012 to determine how unusual the events described above were. As shown in Figure 2.15, the greatest number of daily rainfall events at or above 100 mm occurs in January. Interestingly, two extreme daily rainfall events that well exceeded 250 mm occurred on February 18, 1942 and March 24, 1956; neither of which are associated with reported landslide activity.

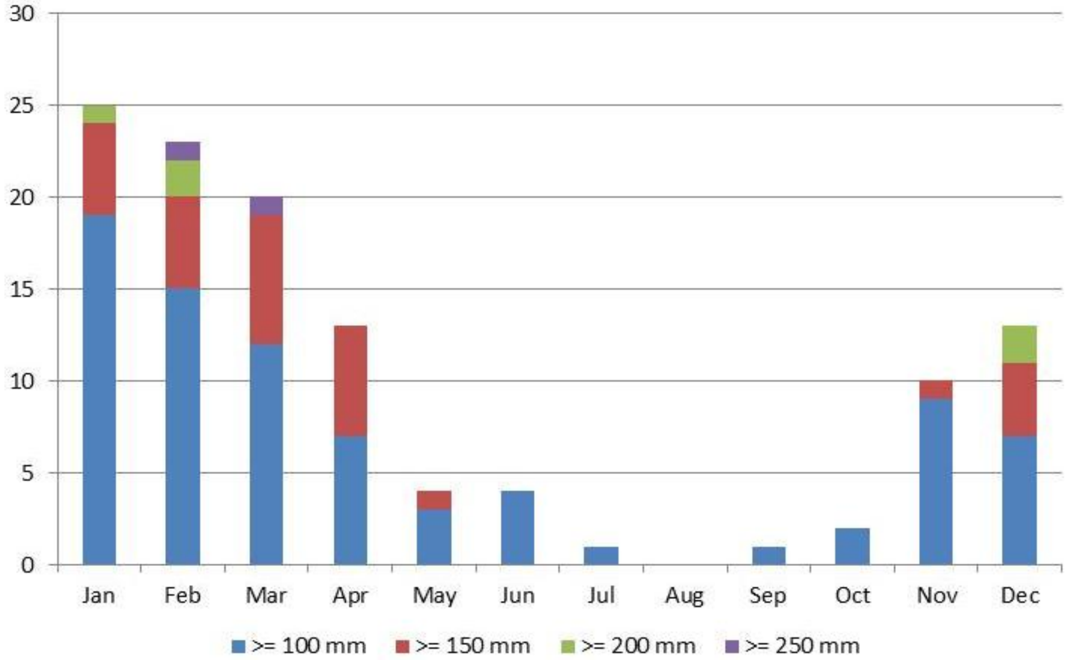


Figure 2.15 Number of daily rainfall events that exceeded 100 mm, 150 mm, 200 mm, and 250 mm thresholds from 1940 to 2012. Source: estimated from Santos meteorological station.

The last landslide fatality in Santos was in 2000. Though landslides have occurred since 2000 and are monitored throughout the year, the reduction in associated fatalities is attributed to the early warning system initiated by the Civil Defense since 1988 during the rainy season. For example, according to the local authorities the amount of rain received during the 2010 wet season was equal to that received in Rio de Janeiro, no casualties or landslides were reported in Santos whereas it was a national tragedy in Rio de Janeiro.

2.5.3 Landslide management resources and warning systems

Landslide management resources

Landslides in Santos are caused by a combination of factors including geomorphology, intense rainfall, and deforestation. Seismic activity does not play a role. In response to numerous landslides occurring in 1967 and 1978, the Brazilian government initiated the development of the nation's first geotechnical map based upon geological information (soil, slope, and vegetation cover) and human intervention. The first geotechnical chart of Brazil was produced in 1978 in Santos and clearly showed which areas were suitable for habitation or no occupation due to landslide risk. This chart informed the first landslides contingency plan.

The 1980 geotechnical map was constructed based on an analysis of climatic-hydrologic, geological, geomorphological, vegetation and urban dynamics components that identified unstable locations for urban infrastructure. Table 2.4 describes the criteria used to divide the area into two groups: "areas for urban occupation with restrictions" and "unfit to occupy urban areas." The two groups were subdivided into 6 different types with the following distinctions: locations more favorable to urban neighborhood were represented in greens, urbanized areas with median restrictions are represented by yellows, and areas unfit for occupation or severe restrictions on occupancy are represented by red.

Table 2.4 Description of areas in the hilly region of Santos deemed acceptable for urban occupation and areas considered unsuitable due to landslides. Source: provided by the Civil Defense.

Áreas			Features of the Physical Environment		Problems existing or expected	General characteristics for occupancy	* Compulsory Specifications	
Groups	Types		Geomorphology	Geotechnics			Area	Lot
Areas for urban occupation provided they obey the recommendations and specifications.	I		Floodplain docked on the hilltops.	Floodplain deposit with a thickness of 5m. Water level near the surface. Predominant clay deposits with coarser lenses.	Adduction and destination stormwater and served / flooding and silting. / Low carrying capacity.	Area essentially flat with the possibility of predominantly internal circulation road.	° Implement separate system of stormwater runoff and served. ° Establish efficient garbage collection.	° tying the construction of buildings to current standards for flat areas of Santos and São Vicente (current building codes).
	II	a	Hilltops and hillside segments straight or convex, slightly sloping (<20 °).	Area soils thicker (up to 10m) with profiles change variables according to lithology	Erosion since removed the topsoil organic clay. / Landslides associated localized removal of material.	Areas gentle topography with possible access and internal circulation for streets and / or stairs, depending on the size and location of the area. Some locations may be availed as loan area, since the exploration project has been previously approved, within specifications proposed in studies of the area.	° Implement separate system of stormwater runoff and served, integrated with downstream. ° Establish efficient garbage collection. ° Educate lots with their larger parallel the contour of the slope. ° Keep the occupational density not exceeding the types 1 and 2. (see Annex III)	° tying the construction of buildings in any flat areas, existing standards for flat areas of Santos and S. Vicente (current building codes). No limit on the width of the platform 8m, restrict the maximum height of 1.5 m on the slope of the cuts, without retaining or coating.
		b	Segments slope straight or concave, slightly sloping (<20 °), usually associated with accumulation zones.	Detrital deposit with variable thickness and grain size and can superimpose up to previous soil profiles.	Erosion in the segments of straight slope since withdrawn the surface layer of loamy topsoil. / Mass Movements unlikely associated with detrital deposit. / Siltation areas of accumulation.		° Implement separate system of stormwater runoff and served, with integrated downstream. ° Establish efficient garbage collection. ° Educate Their larger lots parallel with the contour of the slope. Keep the density occupational ° Exceeding not the types 1 and 2. (see Annex III)	
	III	a	Segments predominantly rectilinear slope with inclination between 20 ° and 30 °.	Areas with soil generally small thicknesses (<2.00 m)	Slip usually caused by mutilation, the accumulation of waste and stormwater concentrations or served.	Areas with steep topography requiring characteristics appropriate to their occupation. Access and circulation may be by stairs or road, depending on the surrounding areas, the size and its location on the hillside.	° Implement separate system of stormwater runoff and served, integrated with downstream. ° Establish efficient garbage collection. ° Implement system for internal circulation stairs along the line of greatest slope and byways horizontal platform with maximum of 2.00 m in width. ° Educate lots with their larger parallel the contour of the slope. ° Keep the occupational density not exceeding the types 3 and 4. (see Annex III)	No limit on the maximum width of 6m platform. Restricting ° to 1.5 m in maximum height of cut. ° Provide protection of breadwinners or superficial cuts and embankments as the case may require.
		b			Slip usually caused by mutilation, the accumulation of waste and stormwater concentrations or served. / Impact and deposition of materials arising from potential landslides upstream.		° Implement system stormwater runoff and served, to be integrated with upstream and downstream. ° Establish efficient garbage collection. ° Implement system for internal circulation stairs along the line of greatest slope and byways horizontal platform with maximum of 2.00 m in width. ° Educate lots with their larger parallel the contour of the slope. ° Keep the occupational density not exceeding the types 3 and 4. (see Annex III)	

Urban areas unsuitable occupation.	IV	a		Segments predominantly rectilinear slope with inclination between 30 ° and 40 °	Areas with little soil thickness (1.5 m) can achieve greater thicknesses sectorally or present exhibitions rock.	Passing and / or initiation of natural landslides, with relative frequency. High sensitivity to any kind of mutilation.	Areas with highly inclined occupation incipient industries located. Due to the large figure of the works necessary to urbanization, buildings and minimizing risks geological and	° Keep the occupation at the current stage of consolidation. ° Implement separate system of stormwater runoff and served, integrated with upstream and downstream. ° Establish efficient garbage collection. ° Run small works stabilization to minimize risks to which it is subjected to current occupation.	° Prove retaining and drainage cuts and existing landfills.
		b		Rectilinear segments with slope steeper than 40 °.	Areas characterized by predominant rock exposures, or thin soil (1.00 m) and strong evidence of instability.	Landslides with high natural frequency, coupled to the dynamic evolution of these hillsides and accelerated by anthropogenic factors. / Area of recurrence slip.	Areas with excessive slope, suffocated by scars slip, being in most cases occupied by crops (banana) and / or shrubs.	° reforest deforested areas with species selected, the appropriate region and adapted to the real needs stabilization. ° relocate immediately the houses located in these areas, areas for geotechnical stable.	
	V	a		Deposition zone (talus) may occur seemingly stable surface in large blocks.	Deposits and hillside base, thick and granulometry (average matrix blocks surrounded by the thick).	Impact of blocks from the block areas decreases upstream. / Movements and blocks by maiming or erosions of the soil surrounding the blocks outcropping.	Areas with slopes varied, localized destabilization may occur involving blocks of rock.	° Keep the occupation at the current stage of consolidation. ° Implement separate system of stormwater runoff and served, integrated with upstream and downstream. ° Promote the pavement and waterproofing around the existing blocks. ° Establish efficient garbage collection.	° Promote the pavement and waterproofing the area around the block, situated on the outskirts of the lots.
		b		Bodies of talus with strong evidence of movement.		Transactions resulting from any type of mutilation and may involve large masses. / Impact and deposition of materials arising from potential landslides upstream.	Areas gentle topography with thick soil, but with high sensitivity to any kind of harm and / or water infiltration.	° Prevent any type of occupancy (buildings, crops). ° Prevent any kind of mutilation (deployment of access roads, exploration of materials). ° promote drainage system in the body and head of the talus.	
	VI	a		Explored areas for exploration or removal of material (borrow areas and quarries)		Localized landslides and siltation in surrounding areas.	Areas with highly irregular topography and locally suffocated by erosion and are not currently employed.	Regulate ° topography of the areas that suffered exploitation of earth materials to prevent erosion and siltation of the surrounding areas. ° Promote the reframing of the areas with topography regularized by the competent court according to the parameters contained in this table.	
		b		Tracks located immediately below unstable areas and areas released immediately prior to occupancy and can be located on the hillside or at the foot of the hills. (Tracks up)		Impact and systematic deposition of materials from natural landslides associated with changing slopes.	Areas topography designed to receive soft material eventually escorregados areas upstream.	° Provide barriers vegetables consistent with the expected type of problem. Construct ° boxes waiting at specific locations to ensure retention of the material slipped. ° Prevent any occupation (construction, farming).	
		c		Area hilltop, hillside slopes variables and small deposits.		Possible landslides on slopes steeper minimized by the vegetation.	Green areas with natural secondary vegetation, no human occupation.	° Preserving these areas regardless of their character geotechnical purposes of tembawang or similar recreational areas.	

Figure 2.16 illustrates the 1980 geotechnical map, where the classification of areas shown corresponds with the area types included in Table 2.4. This map served as a planning instrument of neighborhoods within the Santos hills. After more than 30 years since the development of this map, there have been some modifications to the land features that affect the map’s usability. For example, Category VI-A suggests a holding area exploited for the removal of material, which is not relevant today as the exploration activities ceased by the 1980s.

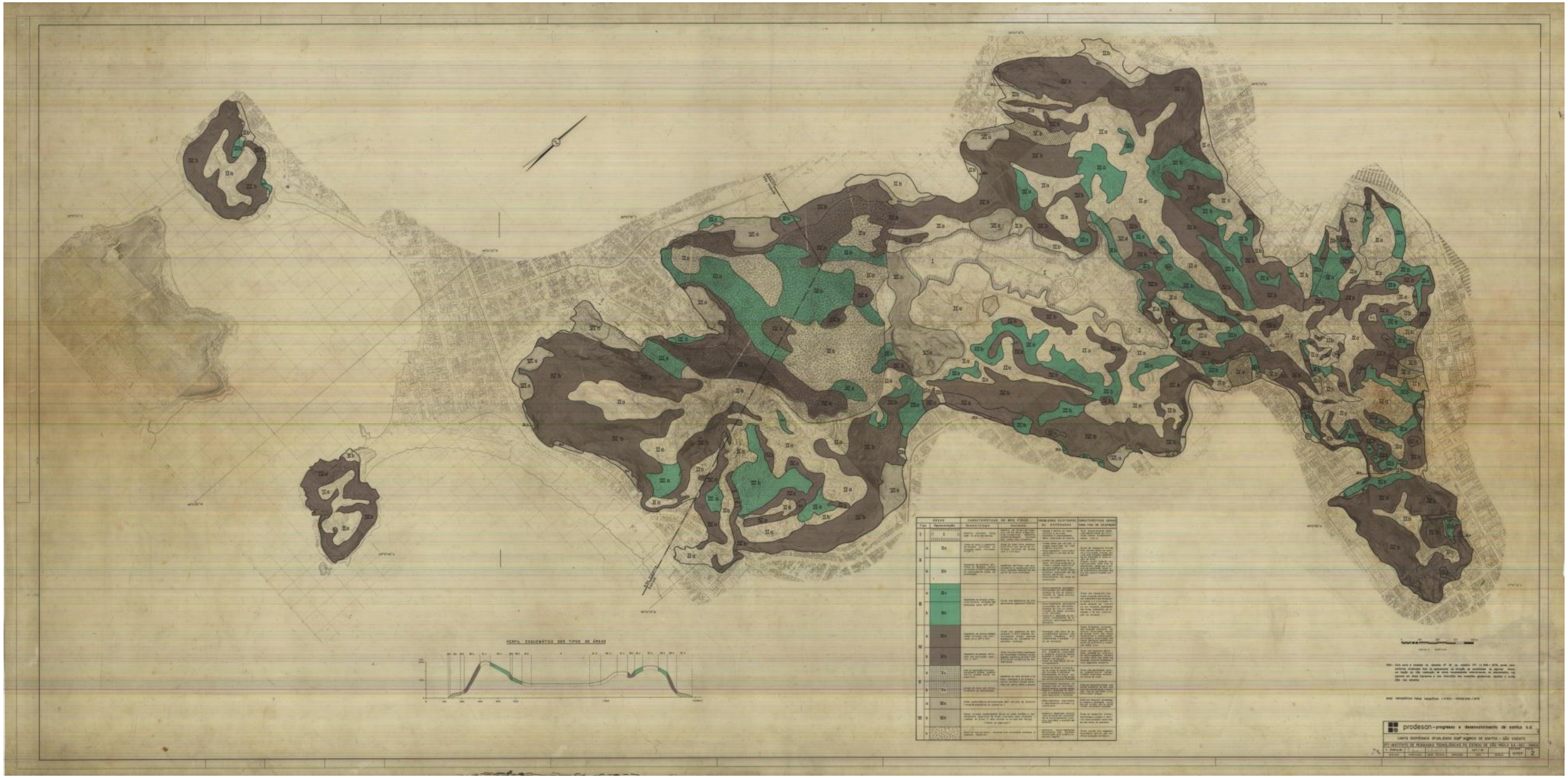


Figure 2.16 The 1980 geotechnical map of the hills of Santos, Source: Prefeitura Municipal de Santos.

The 1980 geotechnical map was the basis of the 2005 landslide risk map by PMRR and its updated version in 2012. Until the 2012 maps have been validated (public consultations are currently ongoing), the basis for identifying areas potentially unstable to landslides remains the 2005 landslide risk maps. The new 2012 legislation requiring landslide maps was issued by the Brazilian government and is required to be updated periodically to capture changes in drainage, land use, and vegetation cover (IPT, 2012). The federal requirement of periodic updates is to ensure timely identification of risky areas, stemming from the political pressures of protecting population against landslide mortality.

As with the earlier maps, the risk classification was first established based on technical information and then adjusted using subjective expertise. The relevant land characteristics were grouped into classes and then classified by risk. The level of risk from one to four was assigned to each class. The levels of risk provides an indication of the likelihood of destabilization occurring in a given area, as follows (IPT, 2012; Macedo et al., 2011):

- **R1:** Low risk to develop landslide processes. No evidence of instability of slopes and drainages margins.
- **R2:** Medium risk to develop landslide processes with some indicators of instability processes observed. Low possibility of destructive events during episodes of intense and prolonged periods of rainfall.
- **R3:** High risk to landslide processes where relevant indicators of instability processes have been observed (e.g., cracks in the ground). Possible occurrence of destructive events during intense and prolonged periods of rainfall.
- **R4:** Very high risk to landslide processes where almost all indicators of instability processes have been observed (e.g., cracks in the ground, erosional features, proximity of houses in relation to the margin of streams, etc.). Very probable those destructive events may occur during episodes of intense and prolonged rainfall.

Annex 3 provides a full assignment of classes describing geotechnical and geological conditions that are relevant to risk categorization by neighbourhood (IPT, 2012).

Zones of risk described in the landslide risk map allow for the incorporation of hazard into municipal law by clearly showing which areas are suitable for habitation. The 2012 landslide risk map illustrated in Figure 2.17 expands the areas previously identified. The Civil Defense focuses on monitoring the location of about 2,500 households living in R3 and R4 zones (IPT, 2012).

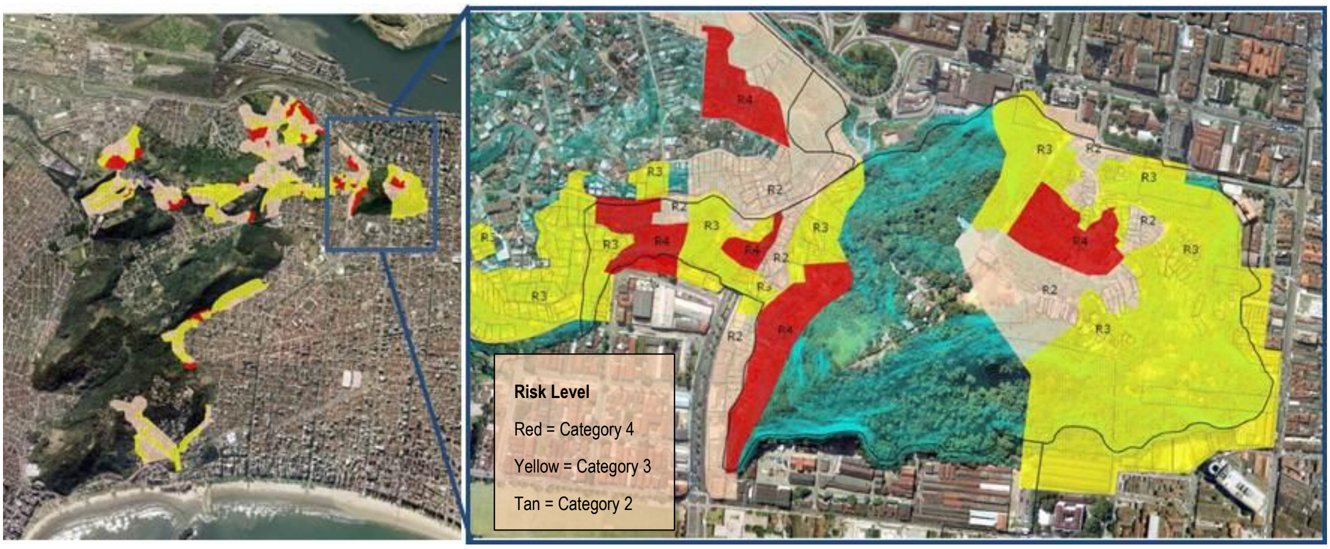


Figure 2.17 The 2012 landslide risk map of Santos. Source: IPT, 2012.

From discussions with the Civil Defense, it was suggested that for the 2012 landslide risk map, IPT developed a new methodology that used two algorithms to identify conditions that may trigger landslides:

- Monthly average precipitation is greater than 120% of the historical average for that month, and
- Average 6 month precipitation divided by the historical average of precipitation is greater than 120%.

In Santos, the application of this analysis relies on daily precipitation observed at one local meteorological station. Santos would benefit from additional observation locations. These thresholds are one set of factors that are part of a collection of information used to determine the threat of a landslide. In other words, the precipitation thresholds only suggest the possibility of a landslide but are not the only factors that are considered when determining the actual threat of a landslide.

Warning system

Though landslides continue to occur, the reduction in associated fatalities is attributed to the early warning system initiated by the Civil Defense since 1988. Field visits to monitor risk areas to landslides are initiated if the precipitation surpasses a threshold of 100 mm over 3 days and/or the average of daily precipitation is greater than the monthly total.

There have only been two events that initiated field visits and then continued to high alert requiring a general evacuation: March 22, 1990 and February, 1996. Using this early warning system, the municipality has successfully identified potential landslides before they have occurred and evacuated people from the risk. Another example in 2010, landslides occurred throughout the region but there were no casualties reported in Santos.

In addition to the early warning system, the municipality has taken measures for slope stabilization and, from 2009 to 2012, has relocated families from high risk landslide areas. The relocation effort to remove all families from the high and very high landslide risk areas is ongoing.

2.6 Future hazards

This analysis uses available information and data to identify areas within the study area region that are vulnerable to floods and landslides. This analysis reviewed available climate change projections and considered their impact on these existing hazards. This analysis does not account for future changes in the landscape (e.g., deforestation or urbanization) that may shift and/or expand current areas threatened by landslides and floods.

As flood and landslide events for Santos have been connected to storm events and relevant precipitation indices, projections of how precipitation may change under a changing climate can help assess future vulnerability to flood and landslide events. In addition, sea level rise will exacerbate and may trigger flooding. The findings presented should be carefully applied to the municipality planning within the context of the associated uncertainty.

2.6.1 A changing climate

By the 2040s, Santos is projected to experience warming temperatures and a small reduction in precipitation. This section discusses future changes in monthly temperature and precipitation, precipitation indices relevant to landslides, and extreme rainfall events.

Box 4 Scenarios for this Analysis

Scenario 1. The climate model ensemble average under the low (B1) emission scenario

Scenario 2. The climate model ensemble average under the moderately-high (A2) emission scenario

Monthly temperature By the 2040s, monthly temperatures[14] are projected to warm, as can be seen in Figure 2.18, which shows the projected change of monthly temperature in the 2040s compared to the 1961 to 1990 baseline conditions:

- During the wetter/warmer season (October through April), monthly temperatures are projected to rise between 1.0°C and 1.2°C for Scenario 1 and between 1.2°C and 1.6°C for Scenario 2 relative to a 1961 to 1990 baseline.
- During the wet/warm season (May through September), monthly temperatures are projected to rise approximately 1.1°C for Scenario 1, and between 1.2°C and 1.6°C for Scenario 2 relative to a 1961 to 1990 baseline.

As shown in Figure 2.18, there is a tendency of greater variability amongst the climate models for Scenario 1 (i.e., the bar on the figure that indicates the range between the climate model projecting the greatest increase in temperature and the climate model projecting the smallest increase in temperature), particularly September through November.

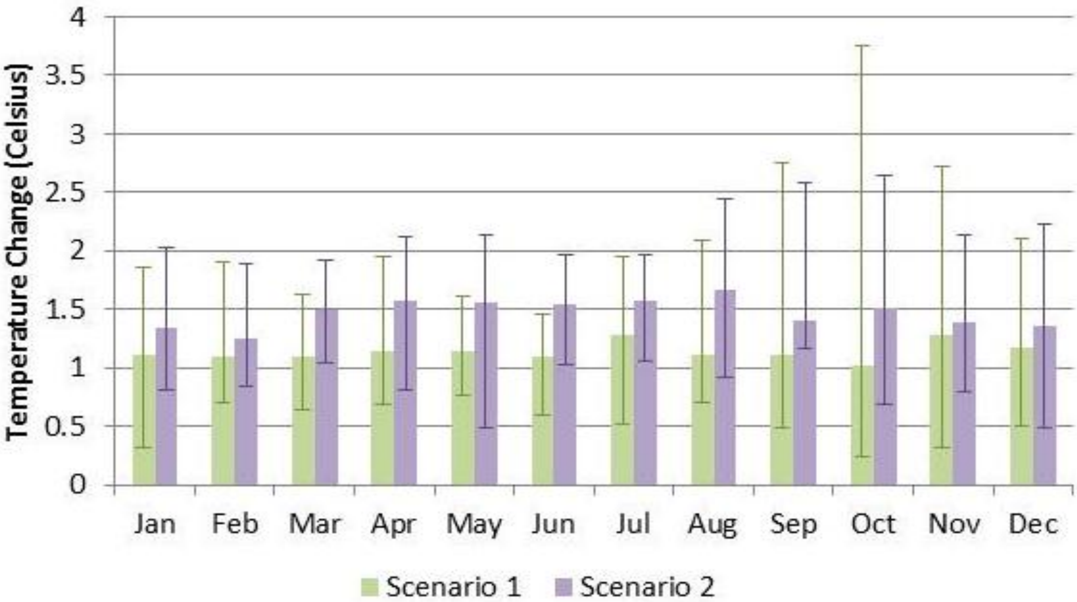


Figure 2.18 Projected change of monthly temperature in the 2040s compared to 1961 to 1990 baseline conditions for the wet season in the Santos area. The error bars provide the range in projections across climate models. Source: based on data collected from Givetz et al., 2009.

Monthly Precipitation. Overall, monthly precipitation is projected to decrease, particularly during the summer months[15], as can be seen in the top graph of Figure 2.19 which shows the projected percent change of monthly precipitation in the 2040s compared to 1961 to 1990 baseline conditions. This would lead to an increase in evaporation rates and a decrease in soil moisture. However, the projected change in precipitation varies considerably from month to month. Relative to a 1961 to 1990 baseline, changes in projected monthly precipitation range from an increase of 4 percent to a reduction of 10 percent under Scenario 1 and range from an increase of 6 percent to a reduction of 9 percent under Scenario 2 (see Figure 2.19).

[14] Monthly projections of temperature were gathered from Climate Wizard for the 2040s relative to a 1961 to 1990 baseline (Girvertz et al., 2009). This data provides statistically downscaled projections of 15 climate models under two emission scenarios.

[15] Monthly projections of precipitation were gathered from Climate Wizard for the 2040s relative to a 1961 to 1990 baseline (Girvetrz et al., 2009). This data provides statistically downscaled projections of 15 climate models under two emission scenarios.

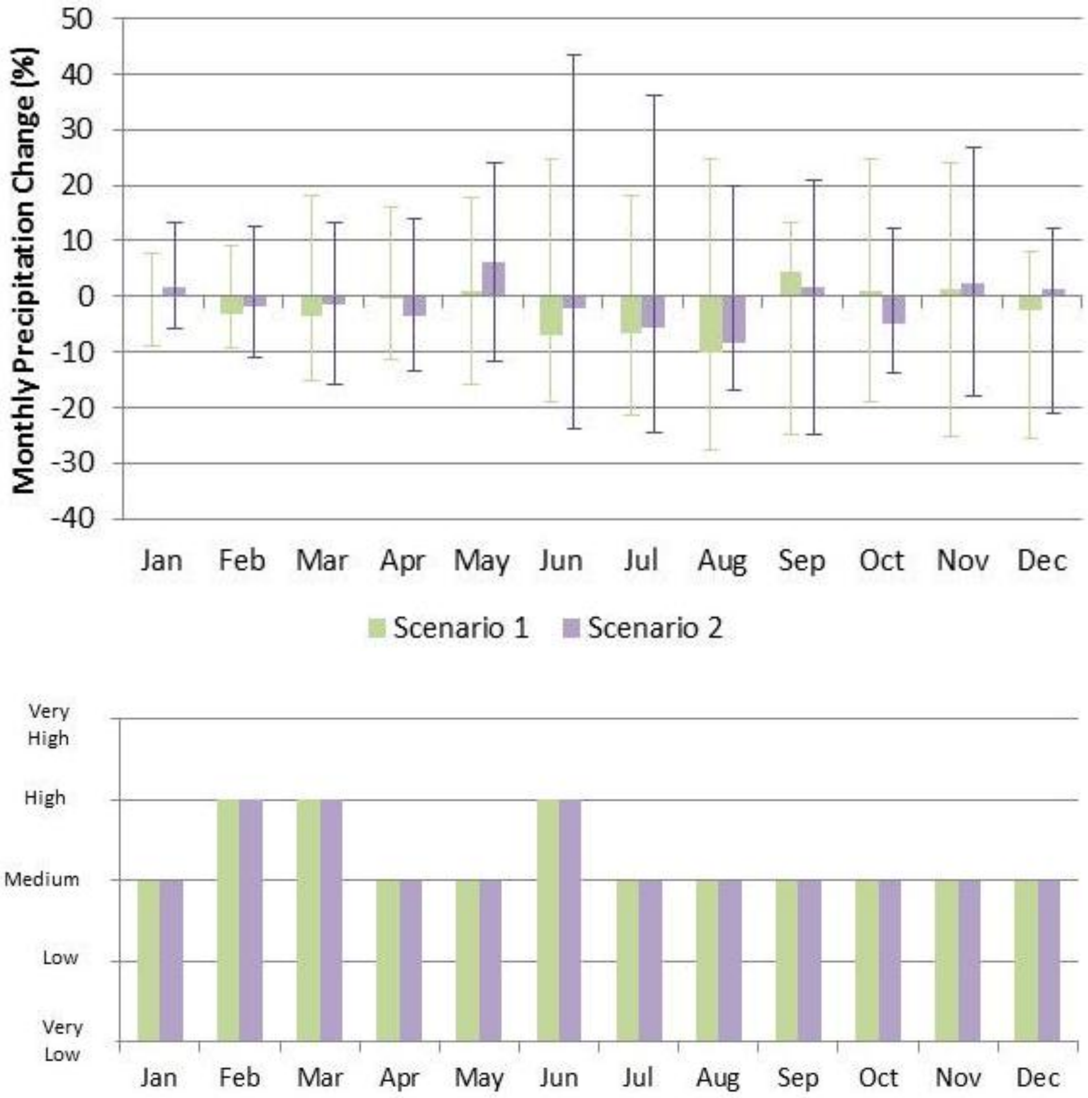


Figure 2.19 Top graph: Projected percent change of monthly precipitation in the 2040s compared to 1961 to 1990 baseline conditions for the wet season in the Santos area. The error bars provide the range in projections across 15 climate models. Bottom graph: Confidence in the projected change of monthly precipitation as suggested by the climate model ensemble average. A "very high" suggests 13 to 15 climate models agree, "high" suggests 11 to 12, "medium" suggests 6 to 10, "low" suggests 3 to 5, and "very low" suggests less than 3. Source: based on data collected from Givetz et al., 2009.

A description of the "confidence" that precipitation may decrease in the 2040s (i.e., the number of climate models that agree that the future climate may experience a reduction in precipitation) is also illustrated in Figure 2.19. For both Scenarios 1 and 2, there is "medium" and "high" confidence that precipitation will follow the climate model ensemble average. This suggests the climate model ensemble average is representative of the potential future.

Table 2.5 provides the average across all climate models under a given scenario (labelled "mean") as well as the minimum and maximum projection simulated by a given climate model. This provides another indication of the uncertainty associated with the average precipitation of the climate model ensemble mean. For Scenarios 1 and 2, though, there is substantial range across the precipitation projections (noted by comparing the minimum and maximum projected values for each Scenario) rainfall is not projected to change substantially though favouring a slight decrease.

Table 2.5 Projected temperature and precipitation in the Santos area for the 2040s relative to a 1961 to 1990 baseline. Projected data is shown for the minimum and maximum results from climate models ("min", "max"), and the climate model ensemble mean. Source: based on data collected from Givetz et al., 2009.

		Obs	Scenario 1			Scenario 2		
			Min	Mean	Max	Min	Mean	Max
October through April	Avg Seasonal Temperature (°C)	23.5	24.0 (0.5)	**24.6 (1.1)**	25.8 (2.3)	24.3 (0.8)	**24.9 (1.4)**	25.6 (2.1)
	Total Seasonal Precipitation (mm)	1,911	1,605 (-16%)	**1,892 (-1%)**	2,198 (+15%)	1,643 (-14%)	**1,892 (-1%)**	2,198 (+15%)
May through September	Avg Seasonal Temperature (°C)	19.5	20.1 (0.6)	20.6 (1.1)	**21.8 (2.3)**	20.4 (0.9)	**21 (1.5)**	21.7 (2.2)
	Total Seasonal Precipitation (mm)	639	498 (-22%)	**613 (-4%)**	767 (+20%)	511 (-20%)	**626 (-2%)**	824 (+29%)

Projections for landslide analysis. Climate projections were developed to consider/asses how the two precipitation algorithms connected with landslides (as presented in Section 5.2.5) may change in the 2040s.

- **Short-term index**. First, the percent-change in the number of months where the monthly average precipitation was greater than 120 percent of the monthly historical average was considered. This provides some indication of events triggered by more short-term rainfall conditions. Scenario 1 suggests January, May, July, September, October, November, and December may experience an increase from 1 to 18 percent, while Scenario 2 suggests January, March, May, September, November, and December may experience an increase from 4 to 27 percent (see Figure 2.20).

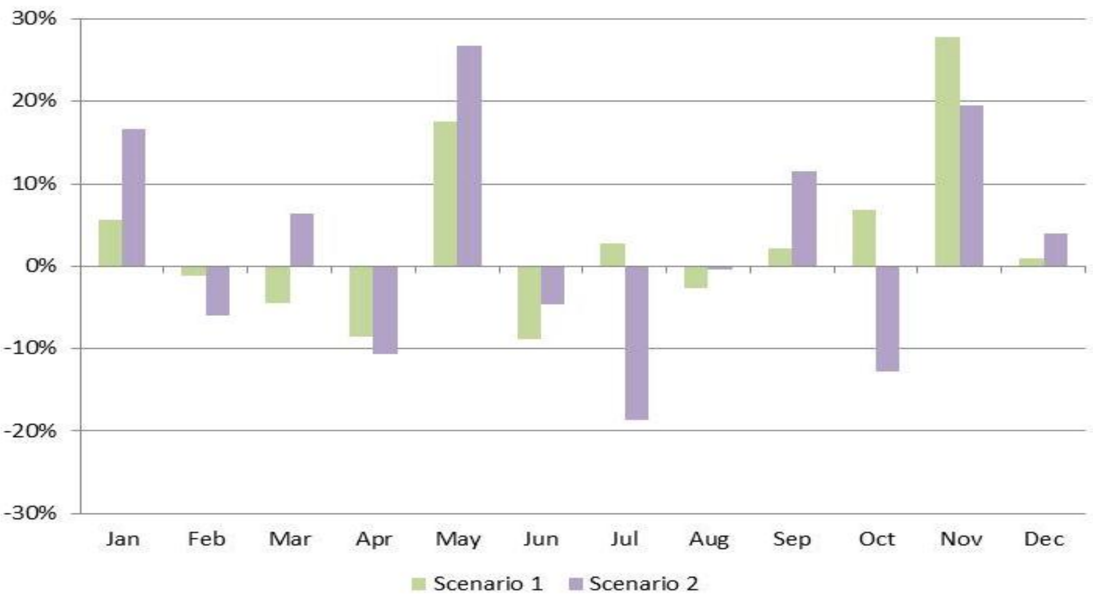


Figure 2.20 The percent change in the months where the monthly average precipitation is greater than 120% of the historical average comparing 2040s to 1970s. Source: based on data collected from Givetz et al., 2009.

- **Long-term index**. Second, the change in the number of episodes when the average 6 month precipitation divided by the historical average of precipitation was greater than

120 percent was considered. This targets events that may be triggered by long-term rainfall conditions. Figure 2.21 illustrates the change in the occurrence of this variable over a 30 year period. Both scenarios suggest an increase for February through May and a decrease from June through December.[16]

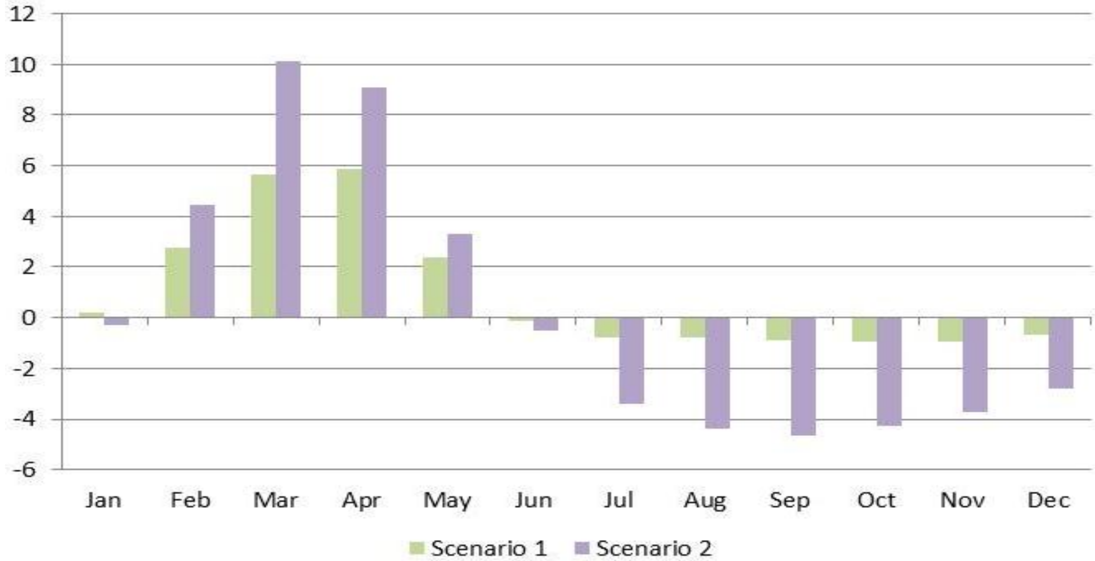


Figure 2.21 The change in the number of episodes where the average 6 month precipitation divided by the historical average of precipitation is greater than 120 percent comparing 2040s to 1970s. Source: based on data collected from Givetz et al., 2009.

These two variables suggest that the months where landslides have a tendency to occur - December through April – may experience an increase in the precipitation metrics, which could result in a potential increase of landslide events.

Projections for extreme flood event analysis. A number of precipitation indices can be considered that are relevant to flooding (see Table 2.6). This data was originally developed to consider climate change and extreme events in Brazil but is limited in its usefulness as it is based upon a single dynamically downscaled climate model under a moderate (A1B) emission scenario (Marengo, n.d.). Given this is not consistent with the more robust climate ensemble analysis presented above for monthly and seasonal change, these regional precipitation indice results should be viewed as describing just one of the potential plausible futures. The indices describing changes in rainfall events suggest a reduction in extreme precipitation events and very little change in maximum 5-day precipitation (an index that is generally associated with flooding).

Table 2.6 Projections of precipitation indices in the 2030s relative to the 1961 to 1990 baseline for the Southeastern region of Brazil based on the Eta CPTEC model for a moderate (A1B) emission scenario. Source: Marengo, n.d.

Precipitation Indices	1961-1990 value	2030s	
		Value	Change
Maximum number of consecutive dry days (days)	48.6	74.4	25.8
Maximum number of consecutive wet days (days)	14.5	16.9	2.4
Number of days with precipitation greater than 20 mm (days)	21.4	19.8	-1.6

[16] The month is associated with the month and the 5 months previous. For example, the month of July represents the average from February through July.

Precipitation Indices	1961-1990 value	2030s	
		Value	Change
Fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for wet day amounts (mm/year)	314.7	306.1	-8.6
Maximum 5-day precipitation, the annual maximum consecutive 5-day precipitation total that could lead to flooding (mm/year)	143.7	143.8	0.1

Projections for coastal flooding. A number of studies suggest global mean sea level may rise within the range of 0.5 to 2.0 meters by 2100 (IPCC, 2007; Rahmstorf, 2007; Grinsted et al., 2009; Rohling et al., 2008; Pfeffer et al., 2008; NRC, 2011). This range demonstrates the large uncertainty associated with estimating sea level rise. The contribution of thermal expansion (i.e., ocean water volume expanding as ocean water warms), ice caps, and small glaciers to sea level rise is relatively well-researched, while the impacts of climate change on ice sheets are less understood. The lower end of the range of 0.5 meters is based on the IPCC (2007) analysis which did not account for the ice sheet contribution.

This rise is not expected to occur linearly over this Century. Figure 2.22 shows estimates of sea level rise based on Rahmstorf (2007). Though this is just one of the studies that endeavors to project global sea level rise, it demonstrates a consistent theme that the rise will accelerate towards the second half of the Century. By the 2040s, the global mean sea level rise could be approximately 0.4 meters relative to 1990.

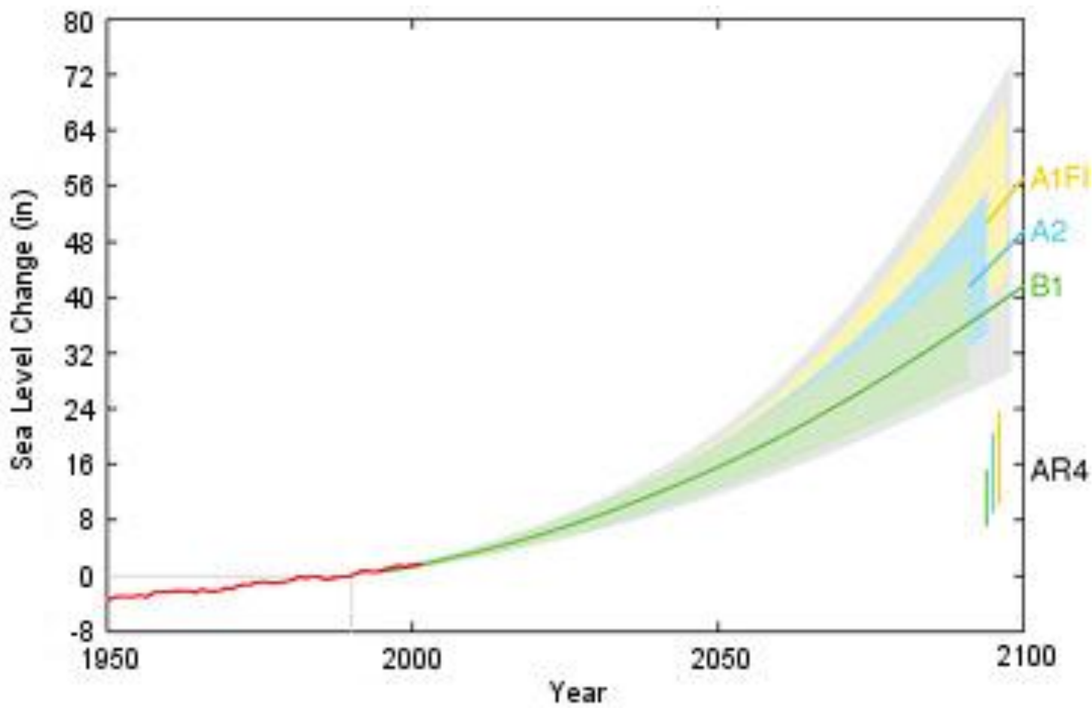


Figure 2.22 Projection of global mean sea level rise from 1990 to 2100 (where 60 inches is approximately 1.5 m; and 40 inches is approximately 1 m), and observations of global sea level rise are provided by the red line, relative to 1990. Source: NRC, 2010.

As noted in section 2.3.4, sea level rise may differ locally due to locally-specific factors such as changes in salinity, ocean circulation, sediment and erosion, and geomorphology (uplift/subsidence). Assuming mean sea level rise for Santos Bay will be approximately 30 percent less than the global mean sea level rise (see section 2.3.4), local mean sea level rise could be approximately 0.3 meters. By the end-of-Century, local mean sea level could rise between 0.7 and 1.4 meters (assuming a global mean sea level rise between 1 and 2 meters).

These estimates do not take into account any changes that might occur at the local level and affect relative sea level (e.g., subsidence/uplift, changes in local ocean circulation patterns and/or salinity, etc.).

A recent study suggests additional findings useful for this analysis. Assuming an increase of 1.5 m by end of Century (i.e., an approximate rate of 1.5 cm per year), this study projects the following (Alfredini et al., 2007):

- Velocities may increase in Santos mouth suggesting favourable conditions for dredging maintenance of Santos Harbour.
- Increase of salinity intrusion along the estuarine areas increasing water intakes and affecting the biological environment.
- Wetland flooding may lead to a general loss of mangrove vegetation impacting aquatic biotic and reduce sedimentation services affecting the environment and navigation activities and requiring additional dredging. This study, though, does not consider the capacity of mangroves to respond to sea level rise.

This study suggests additional ecosystem services and coastline will be affected by sea level rise which may impact the severity of coastal flooding.

No studies of projected changes in storm surge for Santos were available.

Summary. The projected precipitation and temperature changes associated with each of the two scenarios developed for this analysis are summarized in Table 2.7. While there is considerable uncertainty associated with the available climate projections, this first order approach indicates that, by the 2040s, precipitation may be slightly reduced.

Both seasons are projected to experience an increase in temperature and a relatively modest decrease in precipitation. The combination of these two factors suggests a potential reduction in soil moisture.

Table 2.7 Summary of the projected change in seasonal temperature and precipitation for the 2040s. Source: based on data collected from Givetz et al., 2009.

Seasonal Change in Temperature and Precipitation (2040s)				
	October through April		May through September	
	Temperature Projected	Precipitation Projected	Temperature Projected	Precipitation Projected
Scenario 1	+1.1°C	-1%	+1.1°C	-4%
Scenario 2	+1.4°C	-1%	+1.5°C	-2%
Change in landslide indices (2040s)				
	Scenario 1		Scenario 2	
Short-term index	Range of + 1 to 18% per month (January, May, July, September, October, November, December)		Range of +4 to 27% per month (January, March, May, September, November, December)	
Long-term index	Range of +2.5 to 5.9% per month (February, March, April, May)		Range of +3.2 to 10.1% per month (February, March, April, May)	
Change in flood indices (2030s)*				
5-day maximum precipitation	No change			
Sea level rise	~0.3 m			

**Note: Unlike the other projections presented in the table, the 5-day maximum precipitation is based upon the results of one dynamically downscaled climate model for a moderate emission scenario.*

Figure 2.23 qualitatively illustrates today's wetter/warmer and wet/warm seasons and the associated changes projected for each of the scenarios. Both seasons are projected to become drier and warmer under both scenarios. The difference projected between the two scenarios is small; though, Scenario 2 is projected to be somewhat warmer during both seasons and Scenario 1 is slightly drier than Scenario 2 during the winter months.

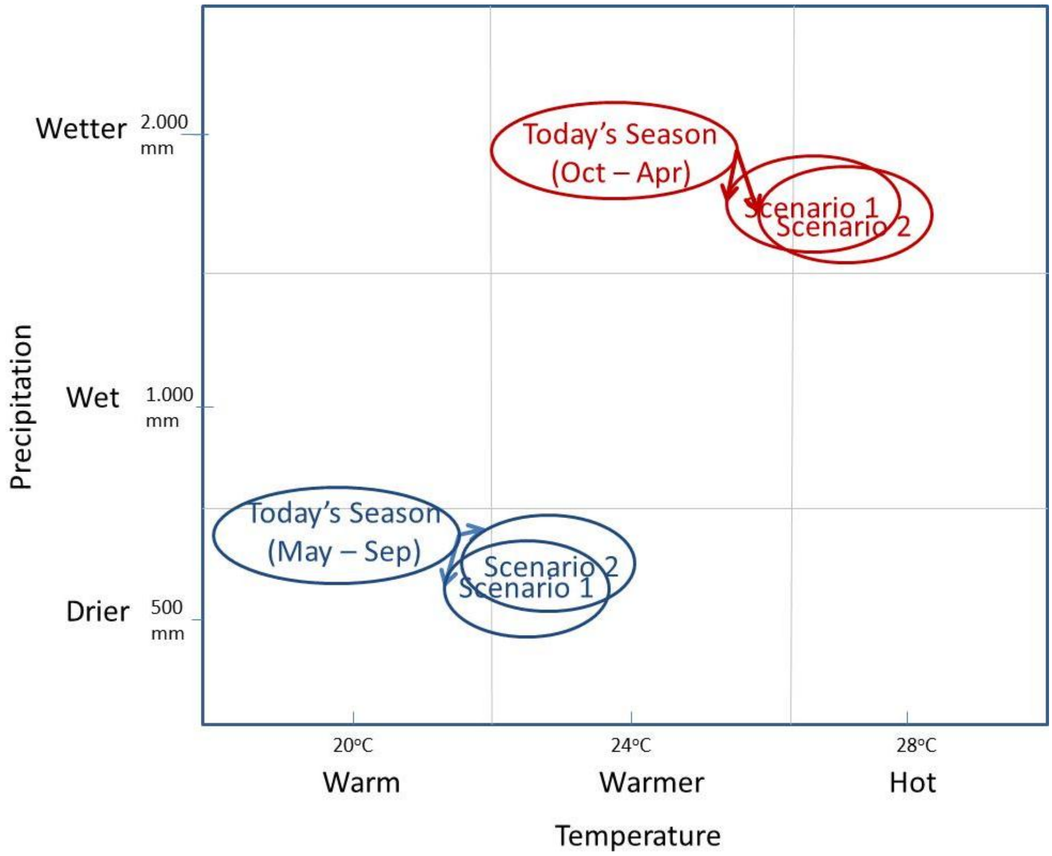


Figure 2.23 Illustrative diagram of the projected mid-Century change of today's wetter, warmer (summer) and wet, warm (winter) seasons (not to scale).

2.6.2 Changes in future floods and landslide events

Our assessment uses available information and data to identify areas within the study area that may be vulnerable to future floods and landslides. These first-order results suggest that the current locations prone to landslides and floods described in the maps provided in sections 2.4.3 and 2.5.3 may change by the 2040s. Table 2.8 provides a summary of the locations threatened by each hazard and qualitatively considers how future climate change in the 2040s may affect these threats.

Table 2.8 Qualitative summary of change in areas currently prone to flood and landslide hazards in Santos by the 2040s.

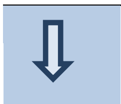
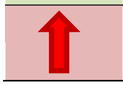
Hazard	Location	Projection	Projected change in hazard
Floods	Northwest Santos; Coastal Locations	■ The climate projections suggest that the threat of precipitation-induced floods may be reduced as seasonal and extreme rainfall is generally expected to decrease or experience no change in the area.	

Hazard	Location	Projection	Projected change in hazard
		■ Increase in coastal flooding associated with storm surge and high tide as sea level rises.	
Landslides	Hilly environs of the city.	■ Decrease in monthly and seasonal precipitation may lead to an overall decrease in soil saturation, but the projections also suggest an increase in landslide indices used to determine if conditions are favourable to landslide events.	

Additional factors are not incorporated into Table 2.8. For example, precipitation reduction may stress forests and reduce forest cover; in response, soils may become more prone to erosion increasing the threat of landslides.

The remainder of this section discusses how the intensity and/or frequency of floods and landslides may change. The rankings described in Table 2.9 distinguish areas on the hazard maps where the projections suggest a reduction, increase, or no change in flood and landslide events. This approach could be broadened and enhanced by engaging local stakeholders to consider how the climate projections presented in this analysis may impact the findings of these maps.

Table 2.9 A ranking system to distinguish areas on the map projected to experience change or no change in landslide and flood hazards.

Ranking	Description of Projected Change in Hazard
	Projections suggest that an overall reduction in the intensity and/or frequency of the hazard.
	Projections suggest that areas prone to the hazard will not change in the future.
	Projections suggest that an overall increase in intensity and/or frequency of the hazard.

Future threat of landslides. Figure 2.24 denotes the areas that are currently prone to landslide events and suggests how the hazard may change in the future based on climate projections summarized in section 2.6.1. The hazard is projected to increase as indicated by the red lines surrounding the landslide hazard areas. This determination is consistent for both Scenarios 1 and 2, which project an increase in the precipitation indices that are associated with landslides, suggesting a potential increase in landslide events.

Figure 2.24 Projected change in areas prone to landslides in the 2040s for both Scenario 1 and Scenario 2 where the red line denotes areas that are currently prone to landslide events which are projected to increase, Source: adapted from IPT, 2012.

This analysis assumes land-use and other factors that affect landslides do not change over time. The health of the forests and other vegetation cover in the area will play a key role in preserving the soils properties. Responses of forests' or other natural vegetation types to climate change in the region are not investigated in this analysis, but if deforestation or landscape transformation continues in the area, reductions in precipitation and covered soils could exacerbate soil erosion, and lead to a higher overall incidence for landslides.

Future threat of floods. Though precipitation events associated with flooding are not projected to increase, sea level rise may increase the risk of flooding during high tides in the Northwest zone of Santos and along the southern beach. Figure 2.25 outlines in red the areas that are most vulnerable to increased flooding in the 2040s. Storm surge is not considered an issue by the local government but there are instances where it has occurred and stakeholder interviews suggest some of the avenues in the southeast currently flood during storm surges. After the 2040s, additional areas will likely be at risk to sea level.

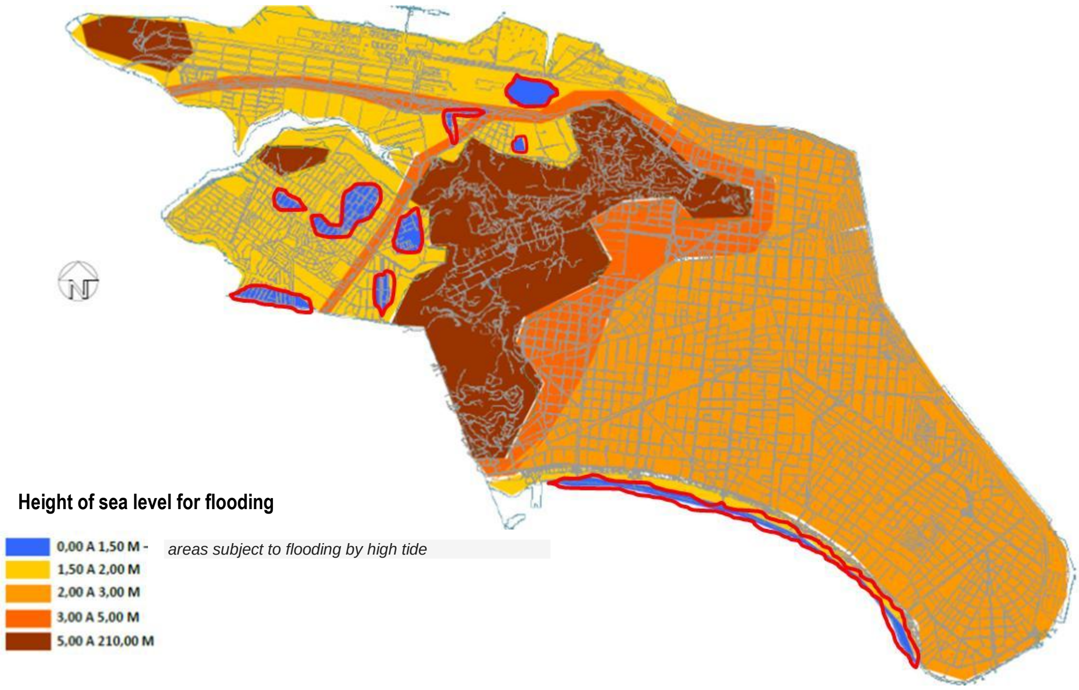


Figure 2.25 Projected change in flood areas due to high tides in the 2040s based on sea level rise of approximately 0.3m, , Source: Underlying map provided by the Prefeitura Municipal..

2.6.3 Gaps and limitations

This section provides an overview of the gaps and limitations for each of the two hazard analyses.

The flood hazard assessment is subject to the following data gaps and limitations:

- Climate projections of extreme rainfall events used in this study are limited to one downscaled climate model.
- There are not specific relationships available connecting historical precipitation events and environmental conditions (e.g., long-term precipitation conditions) to past flood events; hence, relevant flood precipitation thresholds are not available.
- Data from tide gage stations of Santos Bay was not available for this analysis.
- This analysis does not consider potential changes in local circulation, salinity, etc. that may affect local sea level rise.
- Future precipitation projections are associated with a high level of uncertainty; models often differ widely in both the magnitude and direction of changes in precipitation. This affects the application of the findings of future change in landslide and flood hazards presented in this report.

This landslide hazard assessment is subject to the following data gaps and limitations:

- Extreme precipitation events will also affect landslide risk, but there is a high level of uncertainty in how this relationship may be influenced by the likely decrease in storm intensity. Further examination of specific historical events and landslide hazards may help increase understanding in how individual extreme events contribute to landslide hazard.
- Other factors, such as forest cover loss, urban land use development, and soil erosion will also affect landslide hazard risk. These factors have not been explicitly considered in the hazard analysis.

3 Urban, social and economic adaptive capacity assessment

3.1 Urban, social and economic context

Santos is located on the Southern Brazilian Coast, in the estuarine system of Santos. The first neighborhoods in Santos date back to the early 15th Century. Because of its unique coastal location, a small harbour for the movement of ships emerged (Gasparro et al, 2008). This set up the first stages of the Santos harbour. Later on, Santos became an important point for the transportation of goods as early as the 19th Century. The city grew and prospered due to coffee exports. Industrial development followed in the second half of the 20th Century. The arrival of industries linked to the port generated high growth and allowed the emergence of Santos as a petrochemical complex. Industrial development has sustained and nowadays Santos is strategic due to its proximity to Sao Paulo and its status as the largest port of Latin America.

The city has a population of around 420,000 inhabitants and is characterized by increased levels of wealth and social prosperity. Santos is an integral part of a wider consolidated metropolitan area, the Baixada Santista Metropolitan Region (BSMR). Holding a population of around 1.4 million, the BSMR is composed by nine municipalities: Bertioga, Cubatão, Guarujá, Itanhaém, Mongaguá, Peruíbe, Praia Grande, Santos and São Vicente (Figure 3.1).

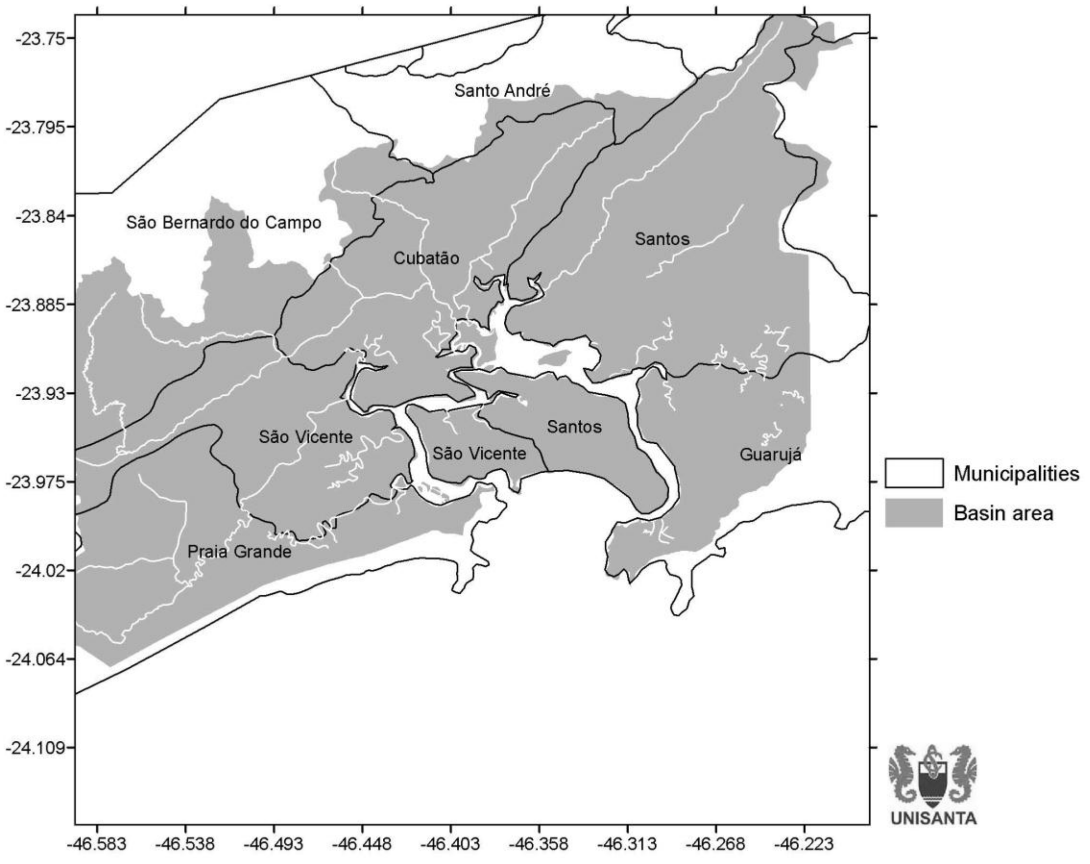


Figure 3.1 The Baixada Santista Metropolitan Region, Source: Sampaio et al, 2008.

The municipality of Santos is separated into two distinct areas: an area located on an island, where the city of Santos is settled, and a continental area, which is mostly uninhabited. The continental area and the island are separated by an estuary. Santos's urban layout was established as early as the 19th Century, through the work of Saturnino de Brito, a sanitary engineer. De Brito developed an urban development plan meant to address sanitary concerns at the time. The plan guided urban expansion through the 20th Century, and established Santos's structure following a grid pattern. Currently, the inhabited area of the municipality occupies most of the available land: space for expansion is scarce, which created real estate pressures and allowed the emergence of a verticalization pattern of urban development.

Santos's urban structure is divided into three areas:

- The southeast of the city, in proximity to the beach, concentrates much of the economic dynamism.
- The north of the city, corresponding to the old historic core, went through recent period of disinvestment. It is now undergoing a phase of revitalization.
- The northwest, concentrating pockets of poverty and informal neighborhoods.

The physical aspect and environmental conditions of the region have changed drastically due to urbanization and industrialization (Alfredini et al, 2008). Environmental preservation is of significance, not only because of its importance for quality of life, but also because the Santos area is home to the most important remnants of the Atlantic Forest, holding rich biodiversity and ecosystems (Costa Ferreira et al, 2011). In addition, the coast of Sao Paulo is strategic given its importance for the economic dynamism of the country.

3.2 Methodology

For the assessment, qualitative information supported by the quantifiable data which was collected during consultations and from publicly available reports and other material are both used to discuss a number of issues. These include economic and residential land uses, their interplay, and the connectivity provided by infrastructures as well as the distribution and quality of critical infrastructure networks, including those that extend beyond the urban administrative boundaries. This is set within the trajectory of urban expansion and growth as it is currently taking place in Santos.

3.3 Population growth, spatial expansion and urban economic development

An early urban expansion driven by coffee exports

Santos is marked by a unique economic and spatial expansion history. The appearance of Santos as a port and harbour dates back to the 16th Century, when a neighborhood for the movement of ships was founded in the southern part of the Sao Vicente Island. Nevertheless, it was until the 19th Century that the city's development truly took off. In the 1830s, the harbour started to export coffee, which was the first major economic breakthrough for the region, fostering growth (Gasparro et al. 2008).

Later on, the establishment of a direct link between the port of Santos and coffee farms in the central part of the state of Sao Paulo through the arrival of the Railway Company in 1867 boosted economic dynamism in the region. Industrial chemical development followed the port's development, as in the decade of 1910 chemistry industries started to settle in the Santos estuary (Gasparro et al. 2008). Further communication networks fostered growth in the city, notably the opening of a road linking Santos to Sao Paulo.

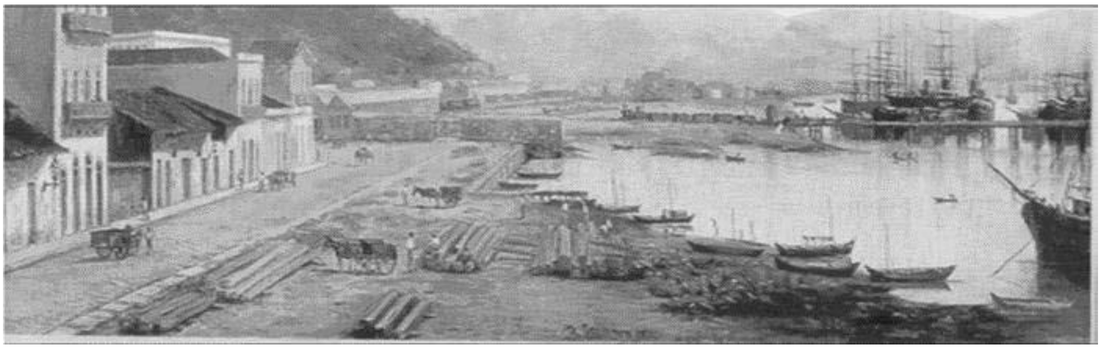


Figure 3.2 The port of Santos in the 18th Century from artist Benedito Calixto.Source: Biblioteca Nacional in Sampaio et al, 2008.

Similarly, in the early 20th Century, the trade of coffee went through a phase of strong growth, which allowed Santos to become the largest Brazilian port exporting this product (Sampaio et al, 2008). This made the city an important centre for commercial and financial activities. During this period, Santos was also a significant immigration hub, as newcomers arriving to Brazil would enter through the city and often settle there. Strong economic dynamism strongly stimulated urbanization in Santos in the early 20th Century.

In an attempt of guiding Santos's expansion, the state of Sao Paulo commissioned Saturnino de Brito, one of Brazil's most prominent sanitary engineers at the time, to develop an urban development plan. The plan was meant to address yellow fever epidemics, which severely affected the city at the end of the 19th Century. de Brito structured Santos's water, sewage and drainage infrastructure around the flow theory, which combines both the removal of polluted waters and the complete separation of water, wastewater and rainwater.

All these measures were anchored on a strong sanitation rationale: they seeked to prevent the proliferation of microbes in urban rivers. In addition to improving sanitary conditions in Santos, the plan defined guidelines for urban expansion: it incorporated a drainage system and the establishment of extensive channels meant to orient growth in the large wetlands located south of the urban core at the time (Piochi Bernardini, 2012). de Brito's plan defined Santos's existing urban layout and guided the city's expansion through the 20th Century.

Industrialization and urbanization

In the second half of the 20th Century, Santos went through a phase of major transformation with the arrival of the car industry and the emergence of the region as a leisure and tourism hub for the state of Sao Paulo. This strong phase of economic activity strongly fostered urban development in Santos: as it can be seen on table 3.1, population growth in Santos in the second half of the 20th Century occurred very rapidly, until it reached stagnation in the 1990s and 2000s.

Table 3.1 Population growth in Santos (1940-2020)

1940	1950	1960	1970	1980	1991	2000	2010	2020
158,998	203,562	262,997	342,055	412,448	417,450	417,983	433,502	440,370
N.A.	22%	23%	23%	17%	1%	0.1%	4%	1%

Source: SEADE & FIGBE.

A significant and visible impact that the rise of the tourism industry had in Santos was a complete shift in the spatial and urban configuration of the city. The demand for vacation housing, services and the attached commerce strongly rose. Given Santos's insular and relatively small land availability, this gave rise to a pattern of high-rise constructions. This allowed for the appearance of a great urban agglomeration. As this process occurred extremely rapidly, it resulted in an urban saturation effect from the late 1960s. By that time, the degree of urbanization in the city had already reached 95 percent (Sampaio et al, 2008).

Demographic pressures in the insular part of Santos drove real estate prices upwards. This process, associated with land shortages in the city, had two direct consequences visible in the physical expansion of the city.

The first consequence was the migration of low-income population to the peripheral zones of the city and to other municipalities. This leaded to the appearance of informal and unplanned neighborhoods throughout the metropolitan region (Sampaio et al, 2008). Given the high prices of land in the established urban core of Santos, informal neighborhoods are located in environmentally fragile areas, notably along mangroves and river banks. These locations are marked by their difficult access and completely lack of infrastructure.

The second consequence, visible since 1980, was the appearance of three migration flows by middle-income families, as land in central Santos became scare and increasingly expensive (Sampaio et al, 2008):

- The first migratory flow concerns continental Sao Vicente and its closest neighbour, Praia Grande

- The second flow is directed towards Cubatao
- The third flow is towards the district Vicente de Carvalho de Guaruja.

These flows consolidated Santos as an urban agglomeration and transformed the city's structure. The city's expansion is marked by the presence of migratory flows that gave rise to the emergence of slums within the urban structure.

The consolidation of a large-scale urban petrochemical complex

Simultaneously, the region also went through a strong phase of industrial development in the second half of the 20th Century, giving rise to an integrated petrochemical complex. As the only city of the region without a beachfront, and because of its proximity to the estuary, Cubatao started to attract industry. With the establishment of the Presidente Bernardes refinery, the supply of raw materials needed for its activity induced the neighborhood of attached industries. This was accompanied by the construction of large iron and steel factories (notably the *Companhia Sider'urgica Paulista* – Cosipa), as well as a series of other industries in the chemical sector, including fertilizers. As such, this strong industrial development contributed extensively to economic growth and increased job supply, which in turn attracted newcomers from other regions of the country, searching for new job prospects (Sampaio et al, 2008). Regional industrial development thus also contributed to fostering urban growth in Santos.

Urban expansion driven by industrial development would not happen without severe environmental consequences for Santos's harbour. Heavy industries caused serious air and water pollution. This was strongly associated to the lack of environmental regulations at the time of strong industrial development (Sampaio et al, 2008). Nowadays, Santos suffers from several clearly identified sources of pollution, namely: the Santos port and the associated ship traffic, the industrial pole of Cubatao, as well as the domestic waste coming from Sao Vicente and Santos (Neves et al. 2008). Domestic discharge is not to be undermined, as it accounts for the high levels of pollutants discharged through sewage water. Slums play an essential part in this: sewage disposal from slum quarters located along the channel and harbour margins strongly contribute to the degradation of the system. This, coupled with hazardous compounds discharged due to industrial activity make of water quality a public health issue in Santos's coastal zone.

All of these factors have been the cause of a serious process of environmental degradation in Santos. The urban agglomeration came to be regarded as one of the most polluted cities in the world in the 1980s (Sampaio et al, 2008). Starting in the 1980s, this then affected the tourism industry, as environmental conditions, associated to the urban saturation that started to be seen, pushed visitors away and look for other regions as their holiday destinations.

Urban economic development

In economic terms, Santos is of national significance. The port is the largest in South America, and is responsible for handling around 25 percent of Brazil's foreign trade (by value). The city is located 65 km from São Paulo, which is Brazil's largest city, and the capital of the country's economically most important state. In fact, Santos serves a hinterland which generates approximately 55 percent of the Brazilian GDP.[17] Further, approximately 30 percent of the jobs offered in the Baixada Santista Metropolitan Region are located in Santos (World Bank, 2009).

This proximity between the mega-region of Sao Paolo and Santos has created a dynamic environment, suitable for boosting economic and social growth (UN-HABITAT, 2012). While in the past the logistics sector was the main economic driver, Santos is currently experiencing rapid economic growth and development driven by a variety of economic factors, including energy, tourism, research and technology, and real estate (World Bank,

[17] http://repositories.lib.utexas.edu/bitstream/handle/2152/13799/PUBRevistaBrasilMEPortosI.pdf;jsessionid=144636702DE39324E7005C360B08258C?sequence=29

2009). This diversification of the economy is an important factor that increases resilience to climate-related hazards.

Strategic investments are directly related to the port of Santos (Figure 3.3). The port's annual freight volume has seen a significant increase over the last decades and a US$3 billion port expansion project is under way which will duplicate the port's annual cargo capacity by 2022. In addition, Brazil's semi-public oil company Petrobras, is investing US$18 billion in gas and oil extraction in the Bay of Santos, another growing key activity for the city.

Figure 3.3 Aerial photo of insular Santos, and parts of the port in insular and continental Santos, Source: Tecon.

Current patterns of expansion and revitalization strategy

Industrial dynamism paved the way for the consolidation of Santos as a major urban agglomeration. The Baixada Santista Metropolitan Region (BSMR) concentrates a population of around 1.4 million. The region benefits from the presence of high public and private investments in strategic sectors such as logistics, petrochemicals, steels and energy.

Nowadays, Santos is divided into three core areas: (i) the southeast area, located in proximity to the beach, concentrates most of the investments and economic dynamism; (ii) the north area, which coincides with the old historic core; and (iii) the northwest area. While absolute population growth is flat, Santos is characterized by complex spatial dynamics. The slowing down of the population growth is not related to social immobility, but rather, it reflects intra- and inter-metropolitan migration flows influenced by social and economic policy decisions directly related to urban development (Prefeitura Municipal de Santos, 2009; Neves et al., 2008). In short, Santos is attracting a higher income population while a lower income population is, of necessity, settling in other neighboring areas and cities, where land is cheaper and informal residential conditions predominate.

The city's Master Plan directs industrial investment and port expansion largely in the continental area. However, given that "Santos is full!" (as one informant put it), it does not establish scope for accommodating demographic growth in wider spatial terms – demographic growth is directed vertically (Figure 3.4). Such densification is possible in Santos given that in most parts of the city there is adequate urban infrastructure to support this process.

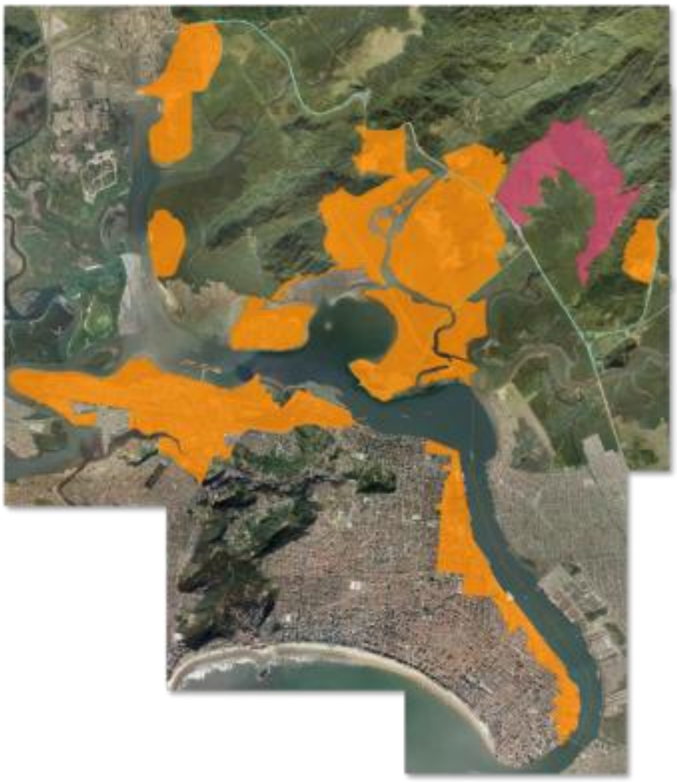


Figure 3.4 Port and port expansion (in the continental area) in orange and proposed technological park in purple, Source: provided by Codesp.

Nevertheless, due to the fact that land in central areas is becoming expensive and scarce, increasingly only the better-off can afford to stay in Santos. This, and the fact that the widening development gap between Santos and other areas of the BSMR, has generated a continuous flow of in-migration of better off populations, and out-migration of lower income groups, virtually resulting in zero demographic growth for the city. The locational dynamics of the urban population is a key issue in this context. A big challenge for Santos is to balance this socio-economic process and allow low income population to stay in the city.

Fully aware of its environmental and urban imbalance problems, the city of Santos has launched strategy of revitalization to improve its urban environment. The economic hardship that Brazil went through in the 1980s resulted in a rise of unemployment and disinvestment in both regional industries and some sectors of the city, notably the northwest, where the old historic core is located.

In order to cope with this urban degradation, the city has launched the Santos Valongo regeneration scheme in an attempt to link the old historic core to the waterfront. The project was set up as a public-private concession and its main purpose is to transform the historic centre into a hub for culture and tourism by restoring warehouses and facilitating pedestrian movement between the old centre and the waterfront.

Further, areas which were formerly used for warehouse port functions will be transformed and house a new cruise ship terminal, a marina, as well as retail and office spaces, and a variety of hospitality and entertainment facilities (see Figure 3.5). The main aim of the initiative is to improve Santos's urban environment and attempt to restore its urban image.

Figure 3.5 The historic centre and parts of the port on the left (the specific location of the scheme is marked in orange) and the proposed development on the right, Source: provided by the Municipality of Santos.

3.4 Urban poverty

Strong economic dynamism has manifested itself in relatively high social indicators. Santos has the third-best Municipal Human Development Index (MHDI) in the state, the fourth best in the southeast region, and the fifth best in the country. About 75% of the city benefits from high urban and environmental standards and high-quality public and private services (World Bank, 2009). Safety, a significant matter in present-day Brazil, is also considered high in Santos.

Overall household indicators show a relative low persistence of bad housing conditions in Santos. As Table 3.2 shows, inadequate land occupation, overcrowding, as well as lack of access to sanitary conditions and infrastructure affect a small portion of Santos's population. Santos's urban environment is thus marked by a relatively high level of socio-economic development conditions.

Table 3.2 Inadequate urban household indicators

Inadequate land		Overcrowding		Households without bathroom		Lack of infrastructure	
Absolute	% of urban households	Absolute	% of urban households	Absolute	% of urban households	Absolute	% of urban households
7,197	5,52	4,900	3,76	1,274	0.98	6,712	5.15

Source: Source: Fundação João Pinheiro, 2004. IBGE, Censo Demográfico, 2000 in Prefeitura Municipal de Santos, 2009.

Similarly, relevant data on population living in slums is lower than in other cities of Brazil and Latin America. As seen in Table 3.3, it is estimated that around 7.5 percent of the city's households live in subnormal agglomerates[18] (a terminology developed by IBGE to designate informal and poor neighborhoods), which accounts for 9 percent of the city's population.

This contrasts with data for the BSMR, as their estimations show that around 20 percent of the urban population lives in subnormal agglomerates, pointing to the fact that Santos's is characterized by higher levels of wealth and development, as compared to the other cities that form the metropolitan region.

Table 3.3 Number of households in subnormal agglomerates

Total Number of Private Occupied Households	Households in subnormal agglomerates	Percentage (%)	Population in Private Occupied Households	Population in subnormal agglomerates	Percentage (%)
144,715	10,767	7.5	417,864	38,159	9

Source: IBGE Population Census 2010.

Despite the relative small presence of low-grade human neighborhoods within Santos's urban fabric, it is important to highlight that around 60 percent of them are estimated to have over 1,000 inhabitants (Sampaio et al, 2008). This, points to a pattern of high population density within slums. Further, due to the fact that they are informal, these neighborhoods are often not recognized officially by local authorities, and as such, their informal status impedes access to basic public services such as water and sewage. Finally, informal neighborhoods in Santos appear to be located in the north-west part of the city, most often in flood and landslide hazard-prone areas.

Table 3.4 shows various disaggregated socio-economic data for neighbourhoods located in flood and/or landslide hazard-prone areas, as per the climate-related hazard assessment.

[18] According to IBGE subnormal agglomerates include irregular neighborhoods such as favelas, invaded properties, caves, slums in glens, poor communities, shanty towns, slums in backwaters, mocambos (type of shack), and stilt houses among others.

Table 3.4 Disaggregated socio-economic data for neighbourhoods exposed to landslide and flood hazards

Neighbourhood	Households	Percentage of HH with subnormal houses	Percentage of HH without toilet	Percentage of HH without electricity	Literacy rate of 10 yrs. and older	House ownership
Alemoa	281	100%	0.4%	0.0%	92.30%	95.7%
Aparecida	13,536	4.4%	0.0%	0.0%	99.00%	75.9%
Areia Branca	1,925		0.1%	0.1%	96.20%	75.8%
Bom Retiro	2,696		0.1%	0.0%	96.10%	79.3%
Boqueirão	12,181	2.6%	0.0%	0.0%	99.40%	73.4%
Castelo	3,395		0.1%	0.0%	96.20%	82.0%
Chico De Paula	912		0.3%	0.2%	90.40%	82.9%
Embaré	14,012		0.0%	0.0%	99.20%	70.9%
Gonzaga	10,064	1.7%	0.0%	0.0%	99.40%	70.8%
Jabaquara	817		0.0%	0.1%	98.30%	51.2%
José Menino	3,813	1%	0.0%	0.0%	99.10%	62.7%
Morro Caneleira	320		0.3%	0.0%	90.70%	89.1%
Morro Fontana	236		0.0%	0.4%	94.90%	43.6%
Morro Marapé	290		0.3%	0.0%	96.00%	63.8%
(Morro) Monte Serrat	375	19%	0.0%	0.0%	95.70%	77.9%
Morro Nova Cintra	1,532		0.1%	0.1%	95.20%	68.1%
Morro Santa Maria	805	29%	0.0%	0.0%	95.80%	90.4%
Morro Santa Terezinha	77		0.0%	0.0%	100.00%	88.3%
Morro São Bento	2,131		0.1%	0.0%	93.90%	53.4%
Pompéia	4,575	5.5%	0.0%	0.0%	99.70%	72.4%
Ponta Da Praia	11,854	10.9%	0.0%	0.0%	99.20%	71.3%
Saboó	3,235	23%	0.0%	0.0%	97.60%	70.0%
Santa Maria	2,011		0.0%	0.0%	98.20%	66.6%
Vila Haddad	60	100%	0.0%	0.0%	96.70%	55.0%
Vila Progresso	1,120		0.0%	0.2%	93.90%	70.0%

Source: 2010 Census, http://www.censo2010.ibge.gov.br/agsn/

The Master Plan identifies special social interest zones (*Zonas Especiais de Interesse Social – ZEIS*) in which a significant percentage of the population (if not the majority) lives in social housing or informal neighborhoods with limited (or even non-existent) provision of basic services. Poverty and location of the population interrelate and this social geography of the city influences climate vulnerability.

Figure 3.6 shows the location of ZEIS in Santos which allows the determining of socio-economic disparities amongst the zones/neighbourhoods of the city.

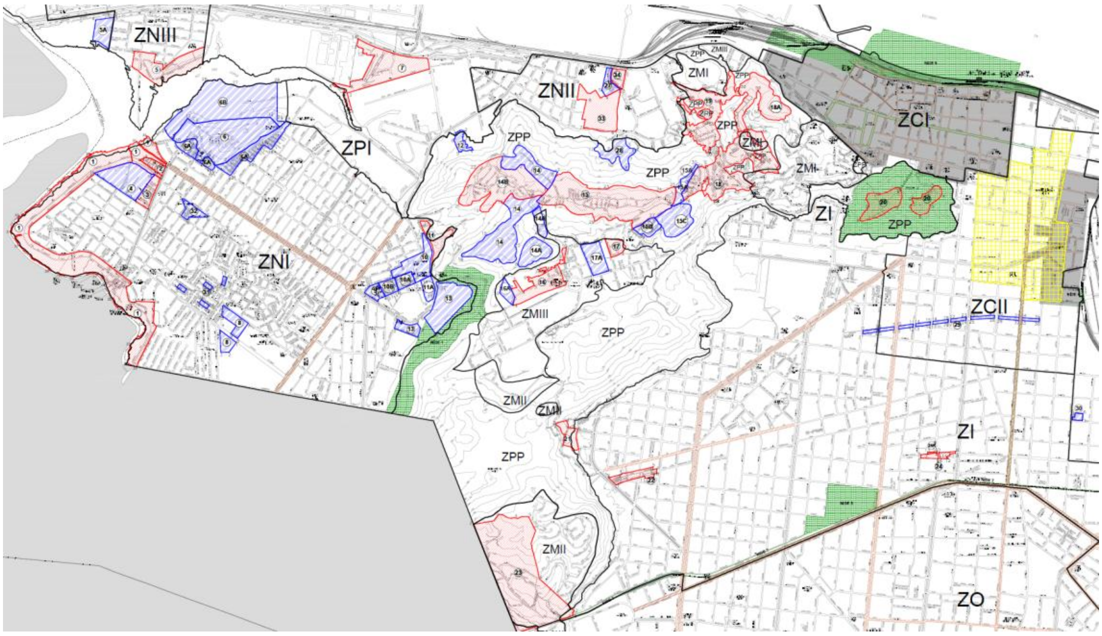


Figure 3.6 Special social interest zones (ZEIS) are shaded in blue, red, and yellow. Source: adapted from Prefeitura Municipal de Santos, 2011.

Urban poverty and its relationship to floods and landslides risk

Although the presence of low-income neighborhoods in Santos is relatively small, it is important to highlight that this type of urban form tends to be geographically concentrated. Indeed, there is a marked presence of people living in *palafitas*, and many have established themselves along mangrove areas (Sampaio et al, 2008).

This process has often been the result of lack of planning guidance and control coming from public authorities and has important environmental consequences. As these neighborhoods are not formal, their emergence was not accompanied by the adequate provision of public services, notably sewage. As such, the disposal of domestic effluents into the estuary is a considerable source of pollution and environmental management, as it has been seen previously. Poor housing conditions and the lack of access to public services, combined with low level of resources, are major impediments for resilience when flooding occurs. As such, poverty and location intertwine in the exposure to flooding risk.

In addition, slums in Santos also tend to be geographically located on hills in the north-west area of the city. The 1980s saw a rapid proliferation of slums on slopes in Santos (IPT, 2012). This was due to:

- Growing rural neighborhood into Santos (in-migration)
- City development (urban growth and expansion)
- Socio-economic crisis in the 1980s in Brazil which lead to the occupation of inexpensive, risky areas.

Hills in north-west Santos, however, are highly susceptible to landslides. And as is with the case of flooding, poverty combined with risk creates high levels of vulnerability.

Socio-spatial integration of low income neighborhoods within the urban fabric

Although overall poverty levels in Santos are low and there is a small presence of slums within the urban fabric, poverty tends to be concentrated in risk areas in the city. In order to cope with this, and complementary to the initiatives to revitalize the city's urban image, Santos launched an ambitious Municipal Housing Plan. The Plan is a city-wide strategy aiming at improving housing conditions in Santos while mitigating the presence of slums (Plano Municipal de Habitação de Santos, 2009). It includes relocation measures and establishes the creation or improvement of residential units for families to be relocated. Amongst other projects, the Plan comprises a project that is specifically directed at slums in the north-west of the city (Table 3.4).

Table 3.5 Housing improvements in north-west Santos slums

Project	Residential units to be created for relocated families	Residential units to be improved	Total investment (in USD)
Favelas da Zona Noroeste – PAC II (Stages 1, 2, 3 and 4).	1,144	476	3,400,000

Source: Prefeitura Municipal de Santos, 2009.

Further, the plan also includes programs in land regularization and land conflict mediation. These programs have as a main objective public intervention in low quality, low income neighborhoods. Intervention is to be made following an integrated approach, combining infrastructure and legal measures to achieve both the urban and legal regularization of slums. Thus, the socio-spatial integration of low income neighborhoods within the urban fabric is given priority.

Linked to these initiatives, the World Bank has established programs that include a slum upgrading and neighborhood component, notably targeting slums in north-west Santos. The aim is to provide urban infrastructure and improve the quality of urban services in this area, and other low-income neighborhoods in the city. A total of 2,400 families are meant to benefit from the program. It included the neighborhood of about 1,100 families living in stilt housing.

3.5 Floods and landslides exposure

Municipal Risk Reduction Plan

Historically, Santos experienced deadly landslides in 1928, 1956, 1979, 1988, and 2000. Nowadays, the landslide-exposed neighborhoods in Santos are located in the northwest of the city. Low-income populations have settled in hilly slopes in the northwest of Santos.

Given the recurrence of landslide events in Santos, the Institute of Technological Research (Instituto de Pesquisas Tecnólogicas – IPT), a research facility tied to the State's Ministry of Economic Development, developed a Geotechnical Map of Santos and São Vicente Hills as early as 1980 (IPT, 2012). This map was an instrument that offered guidance for planning urban expansion through the division of land into different units: restrictions and measures for each unit were clearly defined. This served as a basis for land use planning and for setting up guidelines for the city's urban expansion.

The State of Sao Paulo and the Santos Municipality, through the IPT, were further proactive in developing risk reduction strategies. A detailed Municipal Risk Reduction Report for Santos was produced in 2005 and updated in 2012. It consists in mapping and creating a diagnosis of risk areas in Santos. The emphasis is on landslides, with specific focus on populated areas on hills that are not destined for neighborhood (IPT, 2012).

The Report aims at incorporating a socio-economic dimension in the evaluation of risk. It places strong consideration to informal neighborhoods and low-quality constructions. The Report clearly recognizes that it is low-income groups the one that suffer the most from exposure to landslide events: it states that low-income groups often live in informal neighborhoods, linked to unplanned urbanization, which often results in exposure to landslide risk.

Figure 3.7 shows the identified landslide risk areas in Santos. Figure 2.17 in the climate-related hazard assessment chapter describes the zones of risk and clearly shows which areas are suitable for habitation.

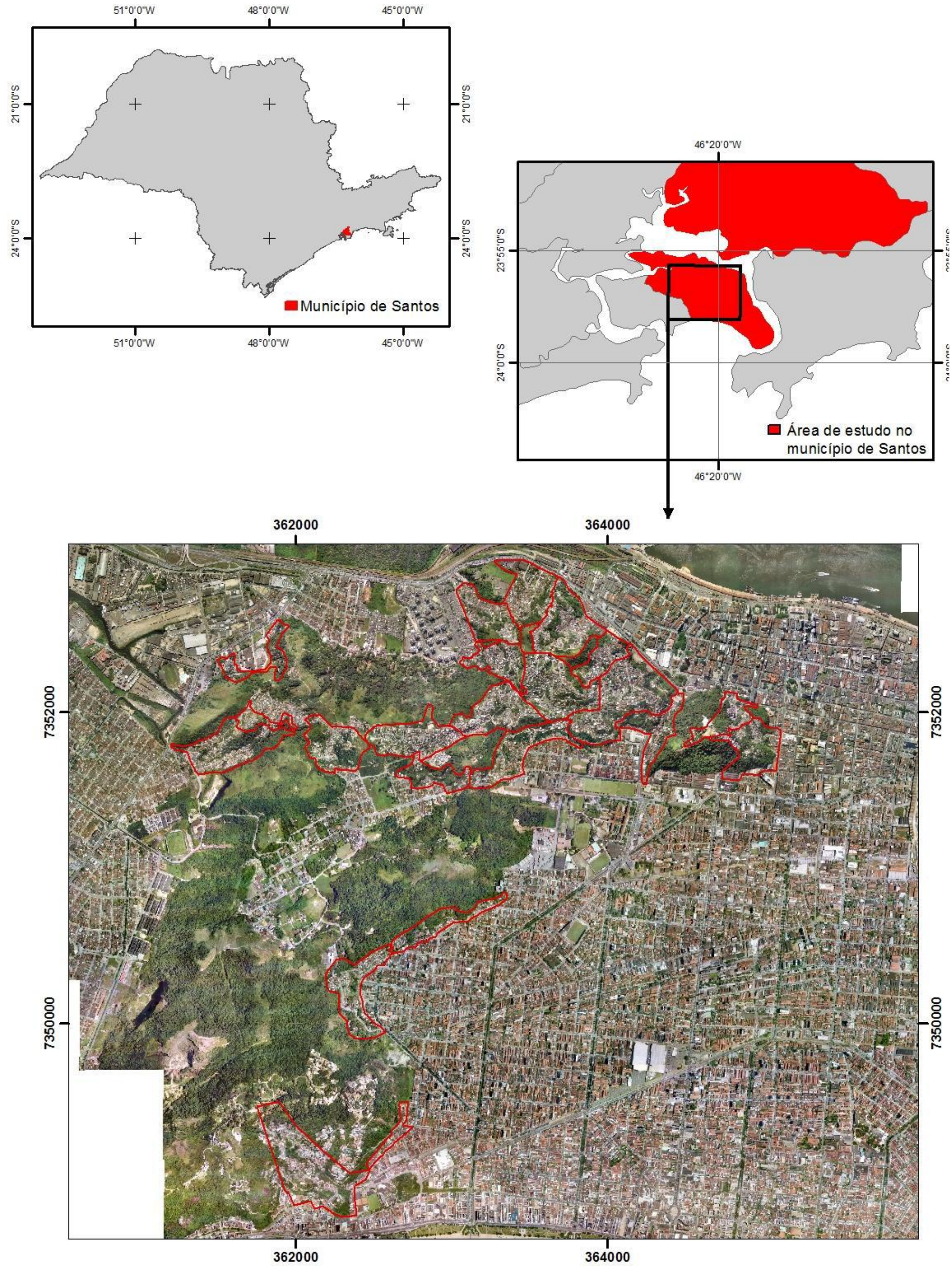


Figure 3.7 Location of high landslide risk areas in north-west Santos, Source. IPT, 2012

Taking into account all these elements, the 2005 Report identified 19 at risk neighbourhoods. The 2012 updated Report increased the number to 22 (Table 3.5). In total, more than 11,000 households are located within the areas identified as landslides risk areas in Santos. The 785 of those households located in high and very high landslide risk areas will be relocated.

Table 3.6 Identified landslide risk areas in Santos

Area	Number of households	Number of households to be relocated
José Menino	709	40
Santa Teresinha	207	0
Marapé II	659	30
Marapé I	228	10
Monte Serrat I	465	30
Monte Serrat II	300	20
Fontana	236	40
São Bento – Santas	800	50
Vila São Bento	460	15
Pacheco	1,057	40
Penha	561	30
Penha Lomba	568	30
Saboo	608	40
São Bento – Santos	687	40
São Bento – Lindóia – São Roque	599	20
Jabaquara	563	20
Nova Cintra II	189	30
Vila Progresso	679	30
Nova Cintra I	574	100
Caneleira	648	100
Santa Maria I	410	50
Santa Maria II Cúria	200	20
Total	**11,407**	**785**

Source: IPT, 2012.

The 2012 Municipal Risk Reduction Report also makes reference to critical infrastructure networks in Santos, and it does mention that the location of basic infrastructure, notably roads, is taken took into consideration when assessing risk. However, a detailed study on critical infrastructure in Santos is not available.

Flood and landslide impacts to infrastructure in Santos could result in disruption of transport networks. In fact, heavy rains in February 2013 impacted the Santos region and caused a landslide on the Imigrantes Highway, which links São Paulo to Santos. As a result of the landslide, the road was blocked for more than 30 hours.[19] Disruption of transportation between the two urban centres can have significant impact to the local economy. Hence, more emphasis can be given to the connectivity provided by infrastructures as well as the distribution and quality of critical infrastructure networks, including those that extend beyond the urban administrative boundaries and with special focus on transportation, water, and energy.

Risk mitigation measures

The report thus clearly assesses the related risks to natural hazards by estimating the possible affected areas and the level of risk. The report also identifies measures to mitigate

[19] http://infosurhoy.com/cocoon/saii/xhtml/en_GB/newsbriefs/saii/newsbriefs/2013/02/25/newsbrief-07

against and diminish or eliminate landslide risk: these include cleaning and recovery services, infrastructure work, and relocation.

The World Bank-financed program Novos Tempos and the social housing programs financed by the Regional Housing Department for “Baixada Santista” (COHAB-ST) also incorporate components for guiding development in no-risk areas. In particular, these programs aim to relocate people from high and very high landslide risk areas, as well as from the *palafitas* which are exposed to flooding. It is important to note that the programs attempt to relocate all families within the city and the municipality supports that by reserving land for social low-income housing purposes rather than for port expansion or the market (Figures 3.8 and 3.9).

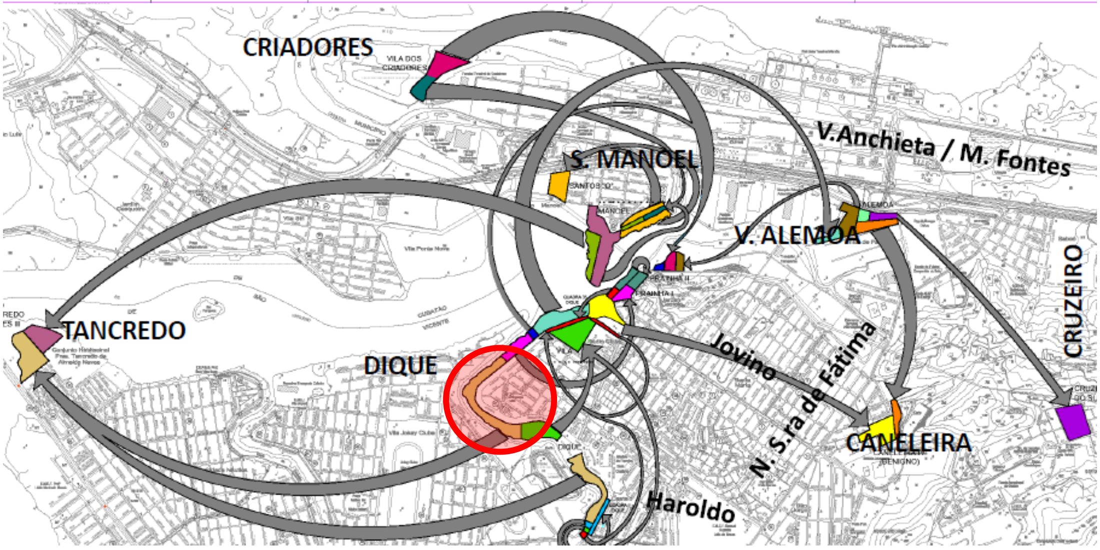


Figure 3.8 Housing construction and relocations under the Novos Tempos program. Figure 1.5 below shows a detail from the red circle. Source: provided by the Municipality of Santos.

Figure 3.9 Housing units that will be relocated under the Novos Tempos program are shaded in blue. New road is shaded in grey. Source: provided by the Municipality of Santos.

While risk *per se* is not taken into account in land use (zoning), for landslide risk in particular, the municipality considered risk when categorized an area as preservation zone or *Zona de Preservação Paisagística* (ZPP) (Figure 3.10). For example, the land use plan preserves the vegetation of the slopes based on environmental criteria: this indirectly addresses landslide risk-related issues. Zoning is now a strong tool for reducing climate-related hazards risk and is very important that the municipality enforces that category. Future development in inappropriate areas will also be dealt by a new cross-institutional decree that will allow the municipality to demolish encroachments in ZPP areas.

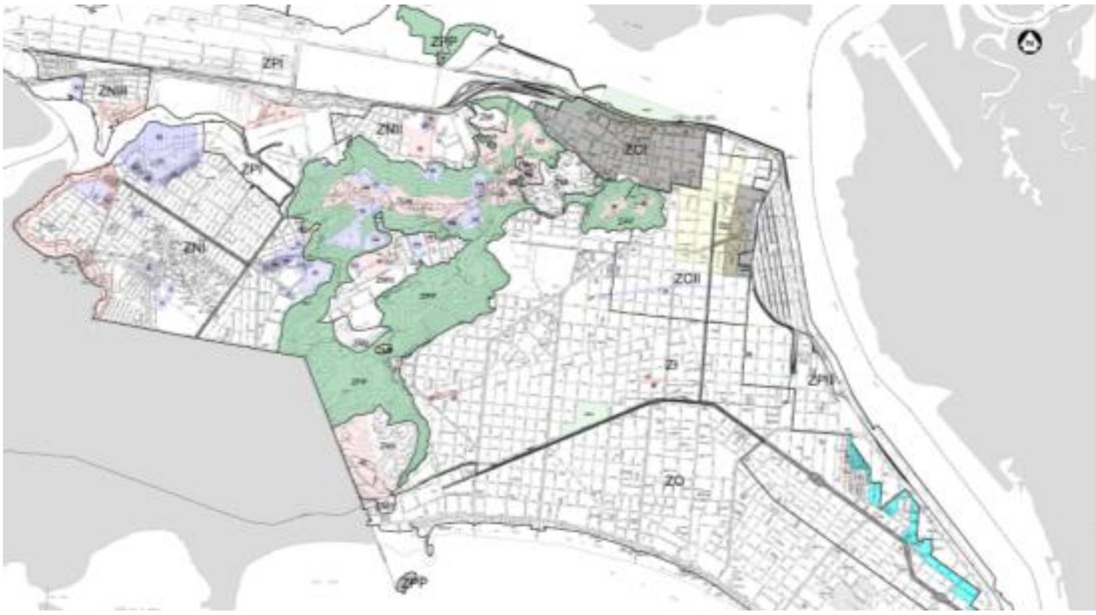


Figure 3.10 Preservation zones (ZPP) are shaded in green, Source: adapted from Prefeitura Municipal de Santos, 2011.

Currently the city of Santos has not prioritized flood risk to the same degree as landslides. According to our interviews, this is because in the past flooding has caused only material impacts and has never threatened people's lives.

Flooding problems in Santos are mainly caused by drainage problems and have been historically dealt with by channelization and macro-drainage works, and more recently with relocation of households from the *palafitas*. The drainage system however in the Northwest zone of the city is inadequate, and although Novos Tempos is improving the system, its design does not account for the projected precipitation and SLR levels.

3.6 Urban, social and economic impact upon disaster risk

Overall, the urban social and economic adaptive capacity assessment of Santos can be summarized in the following table. It describes key characteristics that impact upon climate related disaster risks, such as floods and landslides. A qualitative codification is applied to each characteristic: minimal (it is unlikely that this characteristic will impact upon disaster risk), moderate (it is likely that this characteristic will impact upon disaster risk), and significant (it is highly likely that this characteristic will impact upon disaster risk). Classification follows a subjective, multi-criteria approach. The level of influence assessment is thus based on a combination of stakeholder meetings, secondary literature and the institutional mapping and rapid diagnostic developed in the first phase of the initiative.

Table 3.7 Socio-economic characteristics that impact upon climate related disaster risks

Characteristic	Description	Likely level of influence
Location of economic assets and human neighborhoods	The southeast and north of the city, in proximity to the beach, concentrates much of the economic dynamism, including port activities. The northwest, concentrates pockets of poverty and informal neighborhoods.	Significant
Demographic	Population growth in Santos in the second half of the 20th	Minimal

Characteristic	Description	Likely level of influence
change	Century occurred very rapidly, until it reached stagnation in the 1990s and 2000s.	
Economic characteristics	The port is the largest in South America, and is responsible for handling around 25 percent of Brazil's foreign trade (by value). Further, Santos serves a hinterland which generates approximately 55 percent of the Brazilian GDP, while approximately 30 percent of the jobs offered in the Baixada Santista Metropolitan Region are located in Santos.	Significant
Spatial expansion	The city's Master Plan directs industrial investment and port expansion largely in the continental area. However, as "Santos is full!" (as one informant put it), it does not establish scope for accommodating demographic growth in wider spatial terms – demographic growth is directed vertically.	Minimal
Urban infrastructure	Lack of access to sanitary conditions and infrastructure affect a small portion of the urban population in the north-west of the city.	Moderate
Urban poverty	Although overall poverty levels in Santos are low and there is a small presence of slums within the urban fabric; poverty tends to be concentrated in risk areas in the city, mainly in the north and north-west. Further, household indicators show a relative low persistence of bad housing conditions in Santos.	Moderate

4 Institutional adaptive capacity assessment

4.1 Institutional context

The location of the largest port in the Southern hemisphere in Santos gives the city critical economic importance in the context of Brazil. It also provides the city with a major source of employment and revenue. Santos is divided into two distinct administrative zones, an urbanized on the island of Santos, and an undeveloped zone on the mainland that is mostly protected forest. Santos is one of nine small cities that together form the larger urban conurbation of Baixada Santista. Although disaster management functions and the administration of risk for each city are completely separate, they have shared risk zones that span across city boundaries.

Development and expansion in Santos is closely linked with economic and social activity of the port, and related industry. The city is completely urbanized, with most available land already constructed over. As such, the city no longer has space to expand horizontally, resulting in a push toward vertical expansion. The maintenance of transport and communications links between the port and the city, and onwards to Sao Paulo, is critical for business continuity and on-going economic and social activity in the city, especially during emergency situations. Although the city has efficient and forward looking systems for risk governance and disaster management, its particular setting and development trajectory pose challenges for future risk preparedness. Generally, Santos offers interesting insights into how a small city can develop and operationalize proactive systems of adaptive planning in order to meet the challenges encountered in managing risk to climate change in small and medium sized cities.

4.2 Methodology

Data collection for the institutional assessment was based on three phases. The first phase utilised background data provided in the local consultant's report from the initial rapid diagnostic, along with other relevant secondary data and reports. The second phase was undertaken during the preparatory scoping visit, where interviews with key informants were used to characterize the background institutional architecture and culture of decision-making for risk management in Santos, verify the appropriateness of the overall framework, and identify any remaining written data sources. Additionally, the visit was used to contact a wider range of stakeholders from government agencies, civil society and the private sector that were willing to complete a questionnaire survey on risk management practice in Santos. In the third phase, the questionnaire survey was circulated to these respondents, and the results collated with all other collected data.

4.2.1 Background data

For Brazil and Santos, a good proportion of the required data was available through documentary evidence – timeframe and extent of legislation, urban planning guidelines. Since the report prepared by local consultant was not sufficient in providing a detailed diagnostic of the relevant institutions and policy frameworks for climate change adaptation and risk management in Santos, desk based research and interviews with key stakeholders were undertaken to build a picture of the institutional framework operating in the city. Interviews using the Adaptive Capacity Index were conducted during the preparatory scoping visit in order to assess the efficacy and robustness of these risk management structures, and their potential to adapt in the context of increasing climate change risk.

4.2.2 Adaptive Capacity Tool

The institutional assessment focussed on the risk management and planning structures and capacities of city governments in each urban location, since adaptation is a planning challenge that must be incorporated into most areas of government activity in order to shape local changes; as well as positively influence the relationships between municipal authorities and local level organizations working to adapt to climate change.

For the analysis of the institutional context and capacity for adaptation building, the consultants deployed the Adaptive Capacity Index (ACI) developed for the EC FP7 project MOVE, which assesses institutional adaptive capacity for climate change and multi-hazard disaster risk at the local and national levels. The ACI seeks to measure disaster risk management in terms of the perceived performance of public policy and adaptive capacity for four fields: risk identification, risk reduction, disaster management, and adaptive governance. Each policy field is evaluated using the benchmarking of a set of sub-indicators that reflect performance targets associated with the effectiveness of disaster management activities. The participation of external experts as well as disaster managers in validating the quality of specific activities and capacities is incorporated to minimise bias. Each of the four elements of the framework identified above is populated by four sub-indicators. A detailed list of the variables can be found at http://www.move-fp7.eu/. The table below illustrates the framework structure of the ACI.

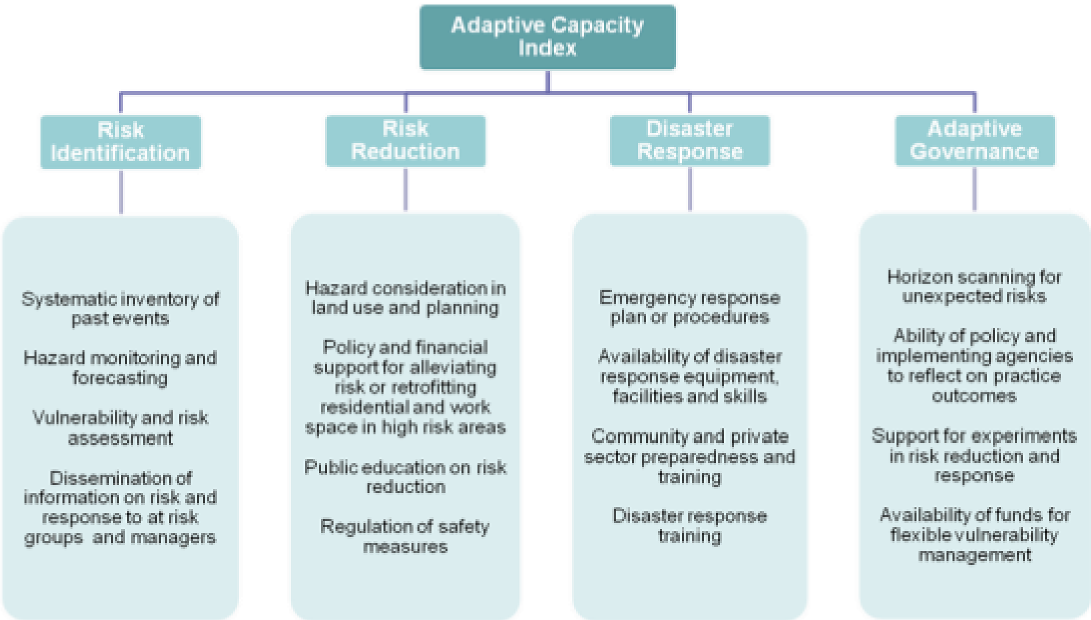


Figure 4.1 Framework structure of the ACI

The ACI was presented in questionnaire form to match the data collection needs of this project. The questionnaire survey is a single tool with different methods of data collection. In Santos, it was used by the consultant as a framework for discussion on the institutional risk management system with key respondents during the scoping visit. Some sections were be filled out by the consultant and others by the respondent as part of a detailed conversation about risk management and adaptation practices and policies. In addition to one-on-one interviews, a shortened version of the survey was emailed to a larger group of respondents identified during the initial visit. The combination of the two types of survey responses allowed for a wider sample of stakeholder groups, as well as providing a detailed discussion of risk management mechanisms in Santos.

A quantitative (though relativistic) assessment of each of the four topic areas in the ACI questionnaire was developed using the following performance levels:

- Limited (No formalized capacity; Activity is ad hoc, very infrequent and not planned or captured by strategy)
- Basic (A low level of formal capacity. Activity is planned. Action is infrequent and superficial, below the levels or intensity required to make a concrete difference to outcomes)
- Appreciable (A modest level of formal capacity. Activity is planned and strategic. Action is regular and outcomes can be identified but are limited in the depth of impact)

- Outstanding (Strong formal capacity. Activity is planned, strategic and integrated into all major sectors. Action is frequent, outcomes have made a clear difference to risk and its management), and
- Optimal (Very strong formal capacity. Activity is planned, strategic, integrated and a part of everyday practice. Action is constant, and outcomes have reshaped risk and its management and continue to do so in continuous cycles of activity).

Assessment of each topic area was also differentiated across prescribed time periods to generate a trajectory of capacity over time and assess how these trajectories are changing for different sample groups (e.g., public or private sector). The years 2000, 2005 and 2012 were selected as benchmark years, with a total time span of 12 years regarded by stakeholders as sufficient for capturing recent hazard events and for demonstrating trends in disaster risk management (while recognizing the limitations of institutional memory in each organization). The benchmark dates successfully reflected transformations in policy and capacity that occurred after significant disaster events.

There were an insufficient number of completed questionnaire surveys to attribute a numerical value to each performance level in order to derive a quantitative representation of management performance. However, the qualitative data generated using performance indicators was adequate in allowing for a direct comparison of performance across organizations and time. In addition, interviewed respondents were also asked for statements describing examples of capacity or of capacity changing tools or events. This discussion-review process served as a verification tool for the qualitative performance assessments, and was an important way of revealing cross-cutting and influential practices that could be transferred to other participating cities in a process of horizontal learning.

A final stage of the methodology will be local verification of findings. A draft assessment report will be circulated to respondents to provide scope for additional input and as a verification exercise.

4.3 Policy instruments

4.3.1 National

Brazil’s National Policy on Climate Change (PNMC) focuses largely on energy mitigation measures and does not consider adaptation to climate change in an integrative manner. Major adaptation challenges are omitted, and the focus of climate change planning is on emissions and the energy sector.

However, the climate change policy processes have the potential to better integrate policy. The processes are underpinned by a number of presidential decrees, establishing influential institutions: a multi-stakeholder Brazilian Forum on Climate Change and an Inter-Ministerial Committee on Climate Change coordinated by the Office of the President. Day-to-day implementation of the national plan is delegated to an interdepartmental Executive Group on Climate Change coordinated by the Ministry of the Environment.

In 2009, the National Fund on Climate Change Law was created to finance climate change mitigation and adaptation activities of the national plan. The fund was officially established in 2010 and supports adaptation, combating desertification, education, training, REDD+, technology development, public policy development, sustainable production chains and payment for environmental services activities. Of the $226 million reais budget, the state-owned Brazilian Development Bank manages $200 million reais, for covering repayable loans and financing production areas. The Ministry of the Environment manages the remaining $26 million reais, which supports research projects, climate change impact studies and other activities. The revenue mainly derives from a special levy on the profits from oil production.

Within this context, the PNMC does set up principles, guidelines, and instruments for climate change adaptation, and specifically refers to adaptation measures that can be undertaken by local governments in urban areas.

These include:

- Housing alternatives to low-income population that are currently living in areas of risk
- Greater rigor in compliance with laws of land use and occupation
- Development and implementation of urban design plans with a focus on urban and environmental considerations, which are not determined by decisions made in the real-estate sector
- Implementation of measures to mitigate rising temperatures such as planting trees in cities and adaptation of buildings to tropical conditions
- Redesign of the road system and sewage collection, especially in coastal cities
- Restoration of micro-climates, re-vegetation, and revitalization of watercourses of urban areas
- Development of knowledge and technical alternatives to mitigate and adapt the population and cities to climate change
- Regulation of constructions through the Works Code and Director Plan, adapting to the effects of climate change.

Further, several federal programs can have positive contribution in disaster risk reduction through the mobilization of resources. They are operated by the Urban Programs Secretariat at the Ministry of Cities and mainly address housing improvement, land regularization, as well as the provision of basic sewage infrastructure.

The most relevant programs include:

- The Urbanization, Regularization and Integration of Informal Neighborhoods Program (*Urbanização, Regularização e Integração de Assentamentos Precários*) has as a main objective the prevention of risk through the regularization of informal neighborhoods and the provision of basic services.
- The Improvement of Living Conditions Program (*Melhorias das Condições de Habitibilidade)* supports interventions for land regularization, safety and the improvement of sanitary conditions. It also aims at strengthening the capacity of populations located in risk or inappropriate for development areas
- The program Prevention and Eradication of Risks in Precarious Neighborhoods (*Prevenção e Erradicação de Riscos em Assentamentos Preácarios*) consists of three key components: (i) training of municipal staff for the elaboration of a hazard risk maps in informal neighborhoods, (ii) preparation of a Municipal Risk Reduction Plan, by establishing safety measures and mobilizing financial resources for landslide risk reduction in informal neighborhoods, and (iii) integration of measures focused on sanitation, social housing and regularization of informal neighborhoods, in order to articulate risk reduction strategies.

Various programs at the state level, operated through the state´s Housing Ministry, can also mobilize resources for disaster risk reduction.

These include:

- The Special Improvement Program (*Programa Especial de Melhorias – PEM*) aims at physical and service improvements in marginalized neighbourhoods through infrastructure investments. Improvements include the paving of streets, the construction of rain treatment systems or contention walls. The main objective of the program is the integration of such neighbourhoods into the existing urban fabric.
- The Urbanization of Slums Program (*Urbanização de Favelas*) has as a main purpose the physical and legal integration of slums. This entails measures that allow populations to improve their living and sanitation conditions, as well as reducing risk conditions.

4.3.2 City Level

In Santos, the municipality has not initiated the development of any specific climate change adaptation plans.

Nonetheless, as at the Federal and State levels, municipal action is complemented by existing programs that can channel resources addressing disaster risk reduction and climate change adaptation at the local level. The most relevant program is the World Bank-funded

Santos Novos Tempos Project (*Programa Santos Novos Tempos*) that among its objectives is the revitalization of the now degraded north-west zone of Santos and the prevention of landslide risks in hillside adjacent to the northwest zone.

4.4 Institutional mapping

4.4.1 National

The Disaster Risk Management (DRM) system in Brazil is linked to the country's nature as a federal state. There are DRM structures at each administrative level: national, state, and local (municipal).

At the federal level, the 1988 Constitution established the need to promote permanent emergency planning actions to cope with natural disasters. Although the Constitution clearly referred to disaster planning, it wasn't until 1993 with the adoption of the Federal Decree 895/93 that the different organizational structures of the federation were established as operational arms of the national system of civil defense, the National Civil Defense System (SINDEC). The SINDEC established institutional structures responsible for disaster risk planning at the state (State Civil Defense) and municipal level (Municipal Civil Defense).

Three specific objectives are outlined for SINDEC:

- Planning and implementation of measures to deal with natural or human-induced disasters
- Timely response in disaster situations
- Post-disaster response and recovery.

The Civil Defense Prevention Plan (PPDC), which has been in operation since 1988, has had positive results in the reduction of deaths when disasters had occurred, notably in urban areas. In Brazil's Second National Communication[3] it is pointed out that the use of the PPDC has provided cities with a good organizational framework for civil defense systems and triggered the adoption of definitive measures to attack the risk problem, such as works, surveillance of areas and occupation planning.

In the state of Sao Paulo, the DRM system is structured around the State Civil Defense Coordination (CEDEC). The CEDEC is responsible for the management of actions and planning initiatives aimed to deal with disasters. Further, the state of Sao Paulo has developed a Civil Defense Prevention Plan, which is the key planning mechanism for risk management and climate change adaptation at the state level. The Plan clearly refers to geological risks associated to landslides.

4.4.2 City Level

At the municipal level, the municipality of Santos, through the Municipal Secretariat of Security (SESEG) takes the lead in the DRM system. Seseg operates the Municipal Civil Defense (COMDEC), which is the responsible institution for risk management and the execution of the Civil Defense Prevention Plan (PPDC). Technical experts from the Secretariat have undertaken important actions and field visits in order to minimize landslide risks. Trained staff have followed mandates related to prevention, mitigation, preparedness and response. The Urban Planning Department, on its side, has an important role in the DRM system as it is responsible for developing the regulatory framework to direct development away from risk areas.

The SINDEC also establishes the Community Civil Defense Centers (NCDC). This is an important program of the Civil Defense, which involves training of the population (some volunteers) to act in case of disasters. Specific attention is given to:

- The evaluation of disaster risk and the preparation of thematic maps related to hazards and vulnerabilities
- The promotion of structural and non-structural measures with the objective of reducing disaster risk.
- The elaboration of contingency and operation plans, and simulation exercises.

4.5 Gaps in existing capacity and opportunities for adaptation

Santos has a robust institutional structure for managing disaster risk and climate related hazards. The city's systems for risk management are considered to be one of the best in Brazil, with a strong focus on preparedness and risk reduction. This forward looking approach offers a contrast to the largely reactive and response-led institutional frameworks for risk management found in the other four city sites for this study. The field visit provided evidence of the manner in which changes at the federal level are influencing risk regulation at the city level; for example a federal law approved this year has provided new guidelines on methodologies for risk assessment and the creation of risk maps. It has altered the parameters of risk classification by making them more stringent, making it necessary to redraw the risk map for Santos.

Following on from the high number of mortalities experienced during landslide events in the 1970s and 80s, the municipality of Santos has developed comprehensive plans and procedures for risk reduction and management. Recently, investments have been made to improve government processes of risk management along with a traditional focus on technical and engineering-led mitigation actions. The municipality, led by the mayor, has developed an integrated process of disaster management that has a clear chain of command and engages all relevant government actors on a regular basis. The emergency management plan for the city is coordinated through the mayor's office under the Metropolitan Council of Santos, along with the Police and Fire departments. Although the Civil Defence collaborates with municipal committees for disaster response, its primary role in Santos is focused on risk prevention, preparedness and adaptation activities. Along with risk monitoring and strategic planning for flood and landslide hazards (operationalized in part through the annual contingency plan for excess rainfall), the Civil Defence undertakes public education campaigns and direct community engagement in high risk areas. The organization works in a pre-emptive manner by removing at risk populations both in advance of and during disaster events. The focus on risk prevention and reduction activities before the onset of a disaster, rather than the response phase, characterizes the progressive and adaptive approach to risk planning in Santos.

The availability of qualified staff and resources is clearly observable across city level institutions involved in risk management activities. There appears to be a good amount of capacity within municipal organizations to undertake risk management operations. For example, unlike other neighbouring municipalities, the Civil Defence in Santos has a full-time meteorologist on staff to provide focused weather information for the city. Additionally, each government department or secretariat engaged in risk monitoring and response across the city has a pre-designated member of staff who is responsible for planning and liaison on risk management issues with other government departments, and is on call 24 hours a day from December to April when the rainfall contingency plan is in effect. Such availability of dedicated professionals and services for risk management and coordination enables the municipality to effectively plan and respond to existing risk, and indicates strong capacity within the institutional system for adapting to future risk scenarios.

There is evidence of learning and adaptive capacity for risk management within the institutional framework in Santos. Policy strategies and risk management practices have been revised over time to better address changing risk contexts. When necessary, the municipality has demonstrated capacity to effectively change local laws and regulations to reflect changing regulatory needs. For example, the city has recently passed a law giving municipal authorities the jurisdiction to pull down illegal construction that does not comply with land controls as a measure towards preventing risky neighborhoods. The institutional willingness to plan and coordinate is in part a reflection of the overall culture of planning and risk management in the city, which is built on swampy mangrove land and has a history of proactive engagement with drainage and land use planning.

Overall, an evaluation of risk management practices in Santos through the Adaptive Capacity Index yielded positive results. Upward trends are observable in the risk identification and risk reduction (Figure 4.1), disaster management (Figure 4.2), and adaptive capacity indicators (Figure 4.4).

While risk identification, risk reduction and adaptive capacity were shown to be at basic/appreciable levels before the year 2000, disaster management practices were judged to be at appreciable levels even before 2000. This reflects the cities long history of dealing with landslide disasters.

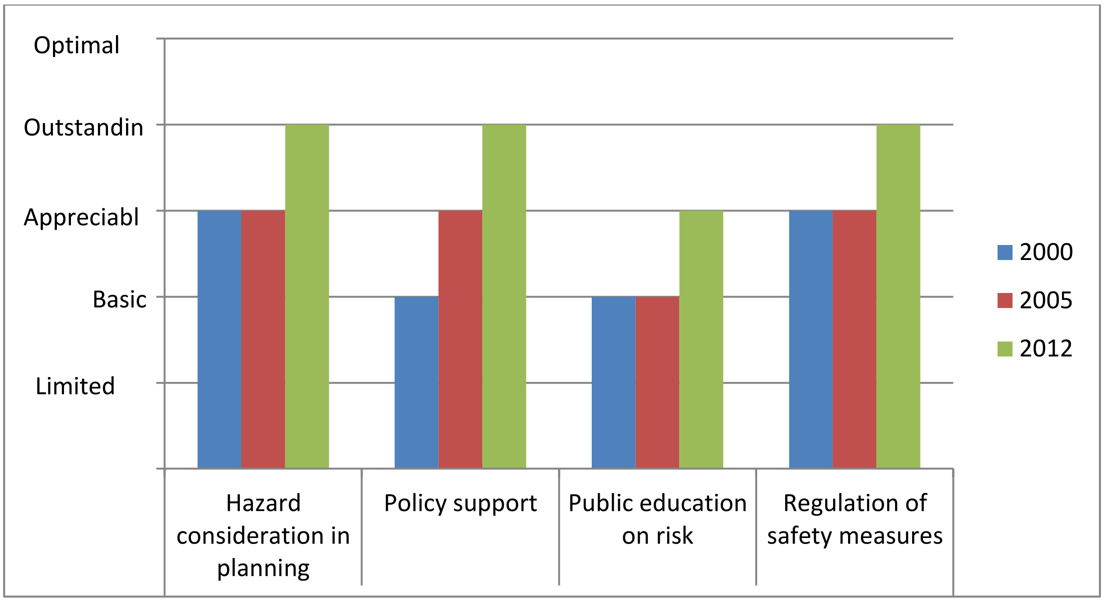


Figure 4.2 Risk reduction performance in Santos, Source: The Authors.

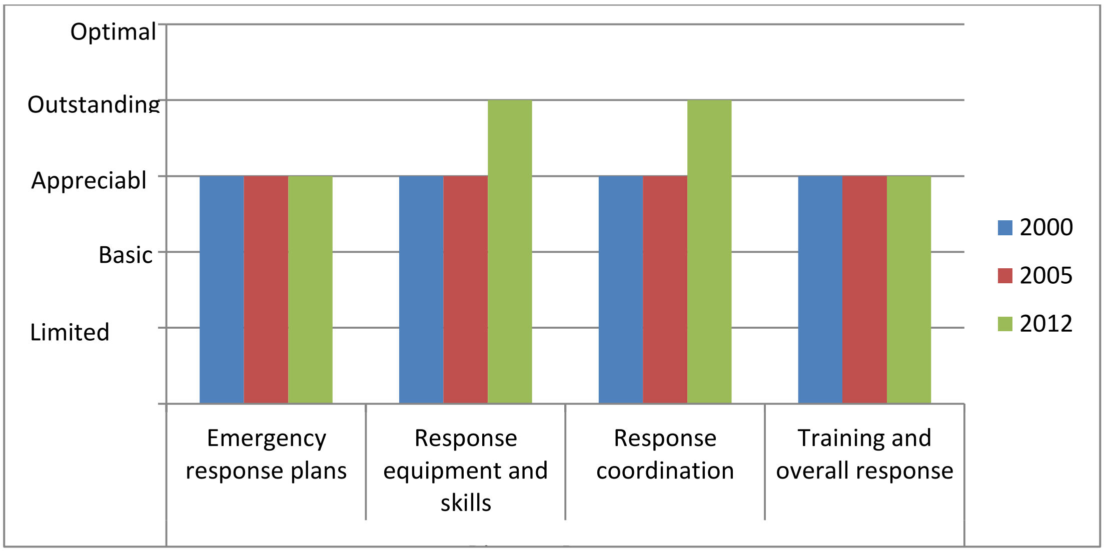


Figure 4.3 Disaster response performance in Santos, Source: The Authors.

Respondents posited that this pre-existing advanced level of disaster management capacity in Santos, combined with long-term engagement with hazard risk in the city, has allowed policy-makers to now focus on more preventative approaches that tackle the source of risk before it manifests into disasters. In addition, the increasing importance accorded to climate change hazards in national policy circles is resulting in a revision of risk management practices. This review process is not restricted to institutional goals for risk management, but is also filtering into institutional practices such that critical self-reflection, institutional learning, and capacity for adaptive governance are all gaining ground (see Figure 4.4). Risk practitioners expressed growing confidence in being able to influence policy decisions at higher levels.

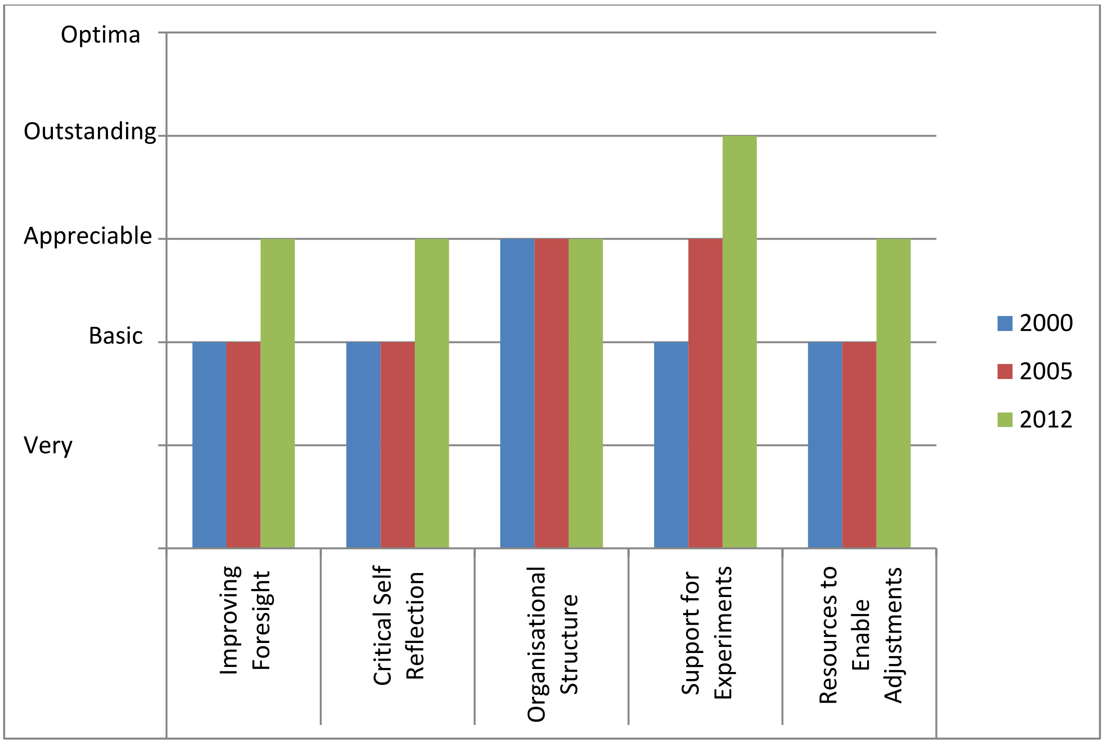


Figure 4.4 Adaptive governance performance in Santos, Source: The Authors.

To a great degree, this improved capacity and institutional flexibility is made possible through the availability of sufficient budgetary resources for risk management activities. Santos enjoys a surplus of municipal funds and is able to raise nearly 53% of the city's finances directly from taxation. Municipal tax receipts are high because of the presence of the Port within city limits, especially after a federal law in 1990s allowed for greater tax extraction from port authorities. The revenue generated from the port and related commercial activities has allowed the city to invest in risk reduction initiatives as well as long term strategic improvements in the drainage and transport infrastructure.

The activities of the Port also have a significant geophysical impact on the city, as evidenced by the rapid beach erosion in south west Santos. As yet, there appears to be no coordination between the city and the Port on issues of risk management and planning. The risk map for the city does not cover the areas within the port and although the Port has risk management and planning procedures, there is currently very little exchange of information or expertise between the two entities. Emergency response to a disaster in the port area would not be supported by the Civil Defence and vice versa. The geographical proximity and economic interdependence of the city and the port makes greater collaboration a potential means of strengthening planning for climate change adaptation.

The municipal boundaries of Santos within the larger urban conglomeration of Baixada Santista also present specific institutional issues. Most of the land within city limits is already constructed, limiting the scope for new construction. As such, zoning and land use laws are not very relevant for regulating risk, although the master plan for the city is revised every five years. New construction is controlled through the implementation of risk maps and regulations, making risk management an important aspect that shapes urban development. Additionally, the neighbouring cities of Saint Vincente, Guaraja and Cubitao are part of the same urban conglomeration as Santos, often with nothing but a street separating one city from the other. Despite this proximity, the municipal governments and civil defence organizations for each city do not formally collaborate or exchange resources for risk management. Each municipality can only initiate risk management procedures within its own boundaries. In reality, the surrounding cities act as suburbs that contain the population overflow from Santos. No mechanism for coordination exists to deal with climate change and disaster risk across all cities within BSMR, and the weaker standards of municipal planning and civil defence resources in the neighbouring cities pose a potential source of risk to Santos itself.

Although the institutional framework is progressive in addressing the root causes of risk, the overall approach to risk has, thus far, focused on planning for existing hazards and vulnerability, with little consideration of future climate variability and its potential impacts. For example, landslide and flood risk assessments for the city are of a good standard and revised regularly, but the latest version of risk map for Santos (to be released soon) is the first one to consider future projections of climate change in Santos. The municipal outlook is now changing as the global import of climate change becomes clearer, reflecting an overall change in national priorities from a focus on mitigation to adaptation. Landslides are higher priority for city management since they result in higher mortality and morbidity losses than flooding. Floods are considered to be a low risk hazard in Santos even though they occur regularly in several parts of the city. Flooding is perceived by the municipality as mostly a problem of drainage and further investments are being made to improve and update the existing system of canals and pumps in the city. Increased precipitation and sea level rise is acknowledged as a potential problem in the future but risk managers in the city are not currently concerned since they believe that it will take a long time before this manifests itself as a significant threat.

Civil society organizations such as Red Cross have a very small presence in the city and do not play an active role in influencing risk reduction and management practices in Santos. No other NGOs in the city are involved in disaster risk reduction activities. The Civil Defence has established NUDECs (Community Nucleus of Civil Defense) and engaged with local leaders as a means of engaging with local communities in high risk areas (Gandini, 2012). Partnerships are also being forged with universities and private sector actors to engage them in the planning and risk management processes of the city. Despite on-going community engagement and public consultations, most of the decision-making on adaptation planning takes place within the institutional hierarchy of the municipality. There is a heavy focus on relocation as the principal strategy for risk reduction in Santos. Financial resources and legislative support from the municipality allow for the development and implementation of relocation projects. Such relocation initiatives are based on a cost-benefit analysis by the municipality, taking into account the cost of intervention versus relocation. However, moving at risk populations is a lengthy and politically complicated process. Local stakeholder engagement is vital for the success of such risk reduction initiatives. Further input and participation by citizens and at risk communities is needed to develop more resilient systems for climate change adaptation and planning.

5 Climate-related vulnerability and risk assessment

The purpose of the climate-related vulnerability assessment is to identify flood and landslide hazards that may be caused or exacerbated by climate change in Santos, and to assess the likelihood and relative consequence of these hazards in order to prioritize responses and mitigate risks. Santos is mostly exposed to two natural hazards: flooding and landslides.

5.1 City profile

Santos is located in the estuarine system of Santos. The city of Santos is considered one of the most important municipalities in the State of Sao Paulo. The city's main socio-economic drivers are industrial and port activities. The city is located 65 km from São Paulo, which is Brazil's largest city and the capital of the country's economically most important state, the State of São Paulo. In fact, Santos serves a hinterland which generates approximately 55% of the Brazilian GDP. Further, approximately 30% of the jobs offered in the BSMR are located in Santos.

The municipality of Santos is separated into two distinct areas: an area located on an island, where the city of Santos is settled, and a continental area, which is mostly uninhabited. The administrative boundaries of urban Santos (the insular area of the city) are the basis for the area of study. The total population of the municipality is 419,400 inhabitants, of which, 99 percent is considered urban. Over the past two decades population growth has slowed down considerably and the city is currently not growing.

Nowadays, Santos is divided into three core areas: (i) the southeast area, located in proximity to the beach, concentrates most of the investments and economic dynamism; (ii) the north area, which coincides with the old historic core; and (iii) the northwest area, which concentrates a great number of informal, low income and low quality settlements. While absolute population growth is flat, Santos is characterized by complex spatial dynamics. The slowing down of the population growth is not related to social immobility, but rather, it reflects intra- and inter-metropolitan migration flows influenced by social and economic policy decisions directly related to urban development (Prefeitura Municipal de Santos, 2009; Neves et al., 2008). In short, Santos is attracting a higher income population while a lower income population is, of necessity, settling in other neighboring areas and cities, where land is cheaper and informal residential conditions predominate.

Although overall poverty levels in Santos are low and there is a small presence of slums within the urban fabric, poverty tends to be concentrated in risk areas in the city. Indeed, there is a marked presence of people living in *palafitas*, and many have established themselves along mangrove areas. This process has often been the result of lack of planning guidance and control coming from public authorities and has important environmental consequences. As these neighborhoods are not formal, their emergence was not accompanied by the adequate provision of public services, notably sewage. Poor housing conditions and the lack of access to public services, combined with low level of resources, are major impediments for resilience when flooding occurs. In addition, slums in Santos also tend to be geographically located on hills in the north-west area of the city. The 1980s saw a rapid proliferation of slums on slopes in Santos. Hills in north-west Santos, however, are highly susceptible to landslides.

In order to cope with this informal settling and complementary to the initiatives to revitalize the city's urban image, Santos launched an ambitious Municipal Housing Plan. The Plan is a city-wide strategy aiming at improving housing conditions in Santos while mitigating the presence of slums.

The World Bank-financed program Novos Tempos and the social housing programs financed by the Regional Housing Department for "Baixada Santista" (COHAB-ST) also incorporate components for guiding development in no-risk areas. In particular, these programs aim to relocate people from high and very high landslide risk areas, as well as from the *palafitas* which are exposed to flooding.

While risk *per se* is not taken into account in land use (zoning), for landslide risk in particular, the municipality considered risk when categorized an area as preservation zone or *Zona de Preservação Paisagística* (ZPP). For example, the land use plan preserves the vegetation of the slopes based on environmental criteria: this indirectly addresses landslide risk-related issues. Zoning is now a strong tool for reducing climate-related hazards risk and is very important that the municipality enforces that category. Future development in inappropriate areas will also be dealt by a new cross-institutional decree that will allow the municipality to demolish encroachments in ZPP areas.

Predominant features of the built environment and urban population that impact upon flood and landslide hazard risks are summarized in Figure 5.1.

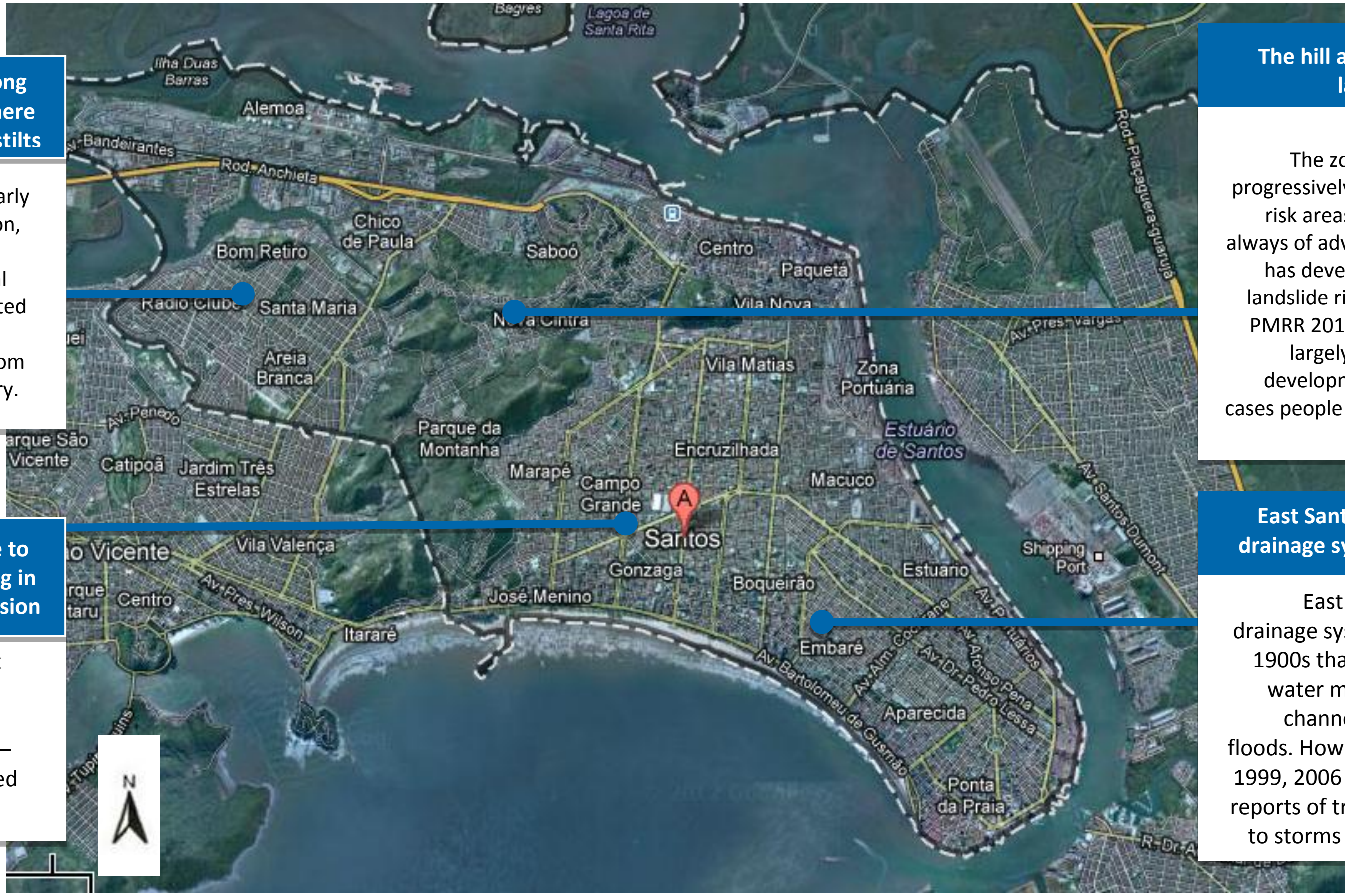
In the sections that follow, available information is compiled into a profile of vulnerability and risk for Santos. This is based on the evidence discussed in the *Climate-related hazard assessment*, the *Urban, social and economic adaptive capacity assessment*, and the I*nstitutional adaptive capacity assessment*.

Informal neighborhoods along the channels and estuary where wooden houses are built on stilts

These neighborhoods can regularly flood during high tide. In addition, the port was filled to a higher elevation to protect against tidal flow; however, this action resulted in trapping the water in the Northwest, preventing water from naturally flowing into the estuary.

The city no longer has space to expand horizontally, resulting in a push toward vertical expansion

As "Santos is full!", it does not establish scope for accommodating demographic growth in wider spatial terms – demographic growth is directed vertically.



The hill area is exposed to landslides

The zoning system of the city progressively attempted to capture risk areas but development was always of advance. The municipality has developed specific plans for landslide risk (the latest being the PMRR 2012). The PMRR has been largely successful in directing development, although in many cases people still settle in risk areas.

East Santos has a complex drainage system that protects

East Santos has a complex drainage system built in the early 1900s that allows tidal and rain water movement through the channels, protecting against floods. However, during storms in 1999, 2006 and 2012, there were reports of traffic interruption due to storms surges in some roads.

Figure 5.1 Predominant features of the built environment in Santos that impact upon flood and landslide hazard risks.

Institutional vulnerability in Santos

The institutional architecture of a city plays a central role in shaping the risk and vulnerability experienced by urban populations to natural hazards. It determines the distribution, accessibility and quality of critical services and physical infrastructure available to residents, and the provision of a safe and healthy environment. The institutional architecture refers to formal structures of government management such as legislation, planning guidance, and public organizations, as well as the more informal aspects of governance such as transparency and accountability, which characterise the social contract between citizens and the state. In small and medium sized cities, the capacity of urban management and governance institutions to identify and respond to current and future climate vulnerability defines not only the resilience of the urban system, but also its potential for future growth and sustainable expansion.

Institutional capacity for adaptation

Santos has a robust institutional structure for managing disaster risk and climate related hazards. The city's systems for risk management are considered to be one of the best in Brazil, with a strong focus on preparedness and risk reduction. Changes at the federal level are instrumental in influencing risk regulation at the city level (for example new federal guidelines on methodologies for risk assessment have altered the parameters of risk classification) but city level institutions are the drive force behind risk reduction.

Santos has developed comprehensive plans and procedures for risk reduction and management and investments have recently been made to improve government processes of risk management along with traditional efforts for technical and engineering-led mitigation actions. The municipality, led by the mayor, has developed an integrated process of disaster management that has a clear chain of command and engages all relevant government actors on a regular basis. In contrast, the role of the Civil Defence authority in Santos is focused primarily on risk prevention, preparedness and adaptation activities. Along with risk monitoring and strategic planning for flood and landslide hazards (operationalized in part through the annual contingency plan for excess rainfall), the Civil Defence undertakes public education campaigns and direct community engagement in high risk areas. The organization works in a pre-emptive manner by removing at risk populations both in advance of and during the impact of events. The focus on risk prevention and reduction activities before the onset of a disaster, rather than the response phase, characterizes the progressive and adaptive approach to risk planning in Santos.

The availability of qualified staff and resources is clearly observable across city level institutions involved in risk management activities. There appears to be a good amount of capacity within municipal organizations to undertake risk management operations. Each government department or secretariat engaged in risk monitoring and response across the city has a pre-designated member of staff responsible for planning and liaison on risk management issues with other government departments, and is on call 24 hours a day from December to April when the rainfall contingency plan is in effect. Such availability of dedicated professionals and services for risk management and coordination enables the municipality to effectively plan and respond to existing risk, and indicate strong capacity within the institutional system for adapting to future risk scenarios.

The presence of the Port has a significant socio-economic and geophysical impact on the city. As yet, there appears to be no coordination between the city and the Port on issues of risk management and planning because the Port functions as a private entity. The risk map for the city does not cover the areas within the port and although the Port has risk management and planning procedures, there is currently very little exchange of information or expertise between the two entities. The geographical proximity and economic interdependence of the city and the port makes greater collaboration a potential means of strengthening planning for climate change adaptation.

The location of Santos within the BSMR also presents specific institutional issues. The neighbouring cities of Saint Vincente, Guaraja and Cubitao are part of the same urban conglomeration as Santos, often with nothing but a street separating one city from the other. Despite this proximity, the municipal governments and civil defence organizations for each city do not formally collaborate or exchange resources for risk management. Each municipality can only initiate risk management procedures within its own boundaries and no mechanism for coordination exists to deal with climate change and disaster risk across BSMR as a whole, and the weaker standards of municipal planning and civil defence resources in the neighbouring cities pose a potential source of risk to Santos itself, particularly for flood hazards.

There is evidence of learning and adaptive capacity for risk management within the institutional framework in Santos. Policy strategies and risk management practices have been revised over time to better address changing risk contexts. When necessary, the municipality has demonstrated capacity to effectively change local laws and regulations to reflect changing regulatory needs. The institutional willingness to plan and coordinate is in part a reflection of the overall culture of planning and risk management in the city, which is built on swampy mangrove land and has a history of proactive engagement with drainage and land use planning.

The Civil Defence has established NUDECs and engaged with local leaders as a means of engaging with local communities in high risk areas (Gandini, 2012). Partnerships are also being forged with universities and private sector actors to engage them in the planning and risk management processes of the city. Despite on-going community engagement and public consultations, most of the decision-making on adaptation planning takes place within the institutional hierarchy of the municipality. There is a heavy focus on relocation as the principal strategy for risk reduction in Santos. Moving at risk populations is a lengthy and politically complicated process and local stakeholder engagement is vital for the success of such risk reduction initiatives. Further input and participation by citizens and at risk communities is needed to develop more resilient systems for climate change adaptation and planning.

Overall institutional assessment

Overall, Santos has strong policy frameworks and planning systems for improving climate change adaptation and risk management. The institutional framework is progressive in addressing the root causes of risk, but the overall approach to risk has, thus far, focused on planning for existing hazards and vulnerability, with little consideration of future climate variability and its potential impacts. The municipal outlook is now changing as the global import of climate change becomes clearer, reflecting an overall change in national priorities from a focus on mitigation to adaptation.

5.3 Landslides and floods vulnerability and risk in Santos

Santos is susceptible to both flooding and landslides. Floods have not caused any casualties but have resulted in traffic disruption in the city, while landslides have claimed lives and destroyed houses and infrastructure. Due to climate change, precipitation patterns are projected to change in the future, possibly resulting in a decrease in precipitation-induced floods, though coastal flooding from storm surge and high tide may increase. There may be a decrease in the overall frequency of landslides, but an increase in the occurrence of extreme landslide events. Understanding these future changes can help inform the development of protection mechanisms of existing neighborhoods and aid in the future planning of new or expanding neighborhoods.

This analysis considers which areas are exposed to floods and landslides, how that exposure may change in the future, and the associated vulnerability of the neighborhoods in each of the districts to these hazards. The information provided here summarizes and overlays the findings across the hazard and socioeconomic hazard assessments. Due to the fact that social and economic census data disaggregated at the neighborhood scale was not available to us, constructing a neighborhood-scale vulnerability assessment was not possible.

5.3.1 Approach

This section synthesizes information on Santos's landslide and flood vulnerabilities by district, focusing on the current physical exposure, urban social and economic conditions, and institutional arrangements. Due to the lack of available data as discussed below, the results of this analysis should be viewed as an informative screening of which neighborhoods are more likely to be affected by and be vulnerable to landslides and floods by mid-Century.

A vulnerability analysis of critical infrastructure was not possible as this would require an analysis by infrastructure category (e.g., inspection of building codes, damages associated with past events, and other indicators to determine how sensitive the infrastructure is when exposed to the hazard). The current analysis does, however, overlay the critical infrastructure with the hazard exposure, providing an indication of the infrastructure that is located in hazard prone areas. This vulnerability analysis can then inform decision makers as they consider climate adaptation options and provide recommendations regarding the combination of hazards, neighborhoods, and facilities that would benefit from a more intensive risk analysis.

A vulnerability analysis considers the exposure, sensitivity, and adaptive capacity of the neighborhood to the hazard (see Figure 5.2). Each of these components is discussed in more detail below.

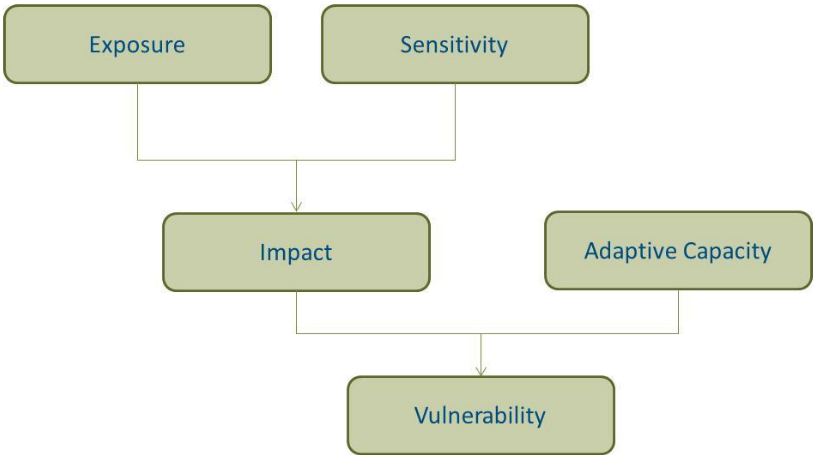


Figure 5.2 Schematic of the vulnerability analysis for landslides and floods.

- **Exposure.** Exposure considers whether a neighborhood and/or facility is located in an area that is considered susceptible to the hazard. For this analysis, this is simply a "yes/no" determination based on the findings in the hazard analysis. The hazard analysis identified the regions and neighborhoods that were exposed to a landslide and/or flood hazard and considered through the use of climate projections whether the exposure may increase or decrease by mid-Century (see Box 5).

> **Box 5 Projected changes in hazards**
>
> Due to climate change, Santos's exposure to precipitation-induced floods is projected to decrease in the 2040s, though coastal flooding associated with storm surge and high tide may increase due to sea level rise.

Given the hazard analysis does not include a more intensive modeling effort (e.g., new hydrologic and hydraulic modeling driven with projections of precipitation to investigate how exposure may change or drilled-down analysis of changes by precipitation event), this analysis is constrained to simply considering whether the existing hazard will worsen or reduce in areas already exposed to the hazard. Because of this, this analysis cannot provide a quantitative number describing the change in flooding or landslide exposure.

However, it can provide a high-level description of which neighborhoods are exposed to the hazard and a qualitative description based on quantitative data as to how climate change may impact future exposure. Climate projections were developed to reduce various components of uncertainty (e.g., an average from an ensemble of climate models was developed for two plausible socioeconomic futures). As with any projection, there is inherent uncertainty. In addition, new climate data that is shown to produce more rigorous results should be considered to augment the results presented in this report.

The two additional considerations in the vulnerability analysis include:

- **Sensitivity.** Sensitivity describes the degree to which a district that is exposed to the hazard might be affected. This step can rely on design standards, historical and geographic analogues, and/or expert opinion. The sensitivity of each neighborhood was ranked based upon two available metrics: the population density and the percentage of households in slums. The population density indicates how many people may be affected by the hazard. The percentage of households in slums is used as a proxy to suggest the proportion of housing where the construction is likely least able to withstand landslides and suffer more damage during a flood. Future work would benefit from the incorporation of detailed housing information (e.g., raised height of doorways).
- **Adaptive capacity.** Adaptive capacity considers how an impacted neighborhood (i.e., one that is exposed to and potentially harmed by the hazard) may be able to cope or adapt. This may include considering what technological, economic, and social means are available to help the neighborhood deal with the hazard. The adaptive capacity within each neighborhood was based upon two metrics: the literacy rate of the population aged 10 years and older and percentage of home ownership. These metrics suggest the potential income of the population within a neighborhood.[20]

Table 5.1 details the rankings used for sensitivity and adaptive capacity. The two metrics for sensitivity are ranked from 0 to 4. The sensitivity ranking is then computed by applying a one-third weight to the population density ranking and two-third weight to the households in slum ranking. Though both metrics are useful, the ranking of households in slums is assigned a greater weighting as it is a proxy regarding the potential housing quality – and thereby damage to the housing that could be incurred during a flood or landslide. The adaptive capacity is computed by applying equal weights to each of the two adaptive capacity metrics. The numerical divisions for each of the rankings were based upon data inspection and expert judgment. These divisions were discussed during the workshop presenting the results of this study. The neighborhoods in the Santos study area are ranked according to the information provided in the *Urban, social and economic assessment*.

Table 5.1 The rankings of sensitivity and adaptive capacity.

Rank	Sensitivity	Adaptive Capacity
0	Population density less than 500 people/km^2; no households in slums	Literacy rate greater than or equal to 99 percent; Home ownership greater than or equal to 99 percent of the houses
1	Population density between 500 and 5,000 people/km^2; less than 50 households in slums	Literacy rate between 95 and 99 percent; Home ownership between 95 and 99 percent of the houses
2	Population density between 5,000 and 10,000 people/km^2; between 50 to 100 households in slums	Literacy rate between 90 to 95 percent; Home ownership between 90 to 95 percent of the houses
3	Population density between 10,000 and 15,000 people/km^2; between 100 to 400 households in slums	Literacy rate between 75 to 90 percent; Home ownership between 75 to 90 percent of the houses
4	Population density above 15,000 people/km^2;	Literacy rate less than 75 percent; Home

[20] Other metrics such as income were not readily available at the neighborhood level. Two other metrics were considered: electricity within the house and toilets; however, these metrics were well below one percent across all neighborhoods.

Rank	Sensitivity	Adaptive Capacity
	more than 400 households in slums	ownership less than 75 percent of the houses

The rankings of sensitivity and adaptive capacity are then used to assess potential vulnerability, as shown in Table 5.2. The suggested responses to the potential vulnerabilities are as follows:

- Low ("L"): Stay attentive to the hazard but not necessarily change current planning and management
- Medium ("M"): Consider developing strategies to curtail impacts and consider enhancing warning systems
- High ("H"): Develop strategies to curtail impact and consider hazard vulnerability in planning.

This evaluation is applied for both the landslide and flood vulnerability analyses. Additional discussion is provided regarding the number of facilities located in each neighborhood.

Table 5.2 Index of potential vulnerability for hazards based upon the rankings of sensitivity and adaptive capacity.

Sensitivity						
Sensitivity	4	M	M	H	H	H
	3	M	M	M	H	H
	2	L	M	M	M	H
	1	L	L	M	M	M
	0	L	L	L	M	M
		0	1	2	3	4
		Adaptive Capacity				

5.3.2 Vulnerability results

A number of climatic and anthropogenic factors play a role in whether and where a landslide and/or flood may occur. This report has considered how changes in climate may impact landslides and floods, but future changes associated with the neighborhood stressors will also play a key role in reducing or exacerbating the impact. Table 5.3 provides an overview of anthropogenic and climatic impacts that affect floods and landslides. How this region continues to develop will have a direct impact on the susceptibility of the region to landslides and floods.

Table 5.3 Summary of anthropogenic and climatic stressors of landslides and floods, and a description of the projected change in climate by the 2040s.

	Stressors		Projected climate change
	Anthropogenic Activities	Climatic	
Landslides	■ Slope loading with housing and infrastructure. ■ Deforestation and land clearing for urban expansion of informal neighborhoods.	■ Slope saturation from intense rainfall ■ Prolonged intense precipitation	■ By the 2040s, though the annual and monthly rainfall may decrease, the precipitation indices associated with the threat of landslides is projected to increase.

	Stressors		Projected climate change
	Anthropogenic Activities	Climatic	
Floods	■ Poor drainage infrastructure	■ Prolonged periods of rain ■ Intense rainfall ■ Higher high tides ■ Storm surge	■ The climate projections suggest that the threat of precipitation-induced floods may be reduced as seasonal and extreme rainfall is generally expected to decrease or experience no change in the area. ■ Coastal flooding associated with storm surge and high tide may increase.

The discussion and results of the vulnerability analysis are presented by (1) neighborhoods, and the (2) facilities and critical infrastructure.

Neighborhoods

This section considers the vulnerability of the neighborhoods potentially exposed to landslides and floods.

Landslides. The urban and socioeconomic assessment describes the neighborhoods prone to landslides (i.e., may potentially be exposed to landslides). These neighborhoods are listed in Table 5.4 which presents the findings of the vulnerability assessment. Though a reduction in overall rainfall is projected in the 2040s, the landslide indices used to forecast potential landslide activity suggest an increase in future landslide exposure.

Table 5.4 Summary of neighborhoods that are potentially vulnerable to landslides.

Neighborhood	Population	Vulnerability				
		Exposure Today	Future Exposure	Sensitivity	Adaptive Capacity	Vulnerability Score
Jabaquara	2,586	Y	↑	0	2	**L**
Jose Menino	7,714	Y	↑	3	2	**M**
Morro Monte Serrat	1,623	Y	↑	1	2	**M**
Morro Nova Cintra	4,171	Y	↑	0	2	**L**
Morro Santa Maria	1,657	Y	↑	2	1	**M**
Morro Sao Bento	8,117	Y	↑	1	3	**M**
Morro Marape	1,596	Y	↑	0	2	**L**
Saboo	11,737	Y	↑	3	2	**M**
Vila Progresso	3,814	Y	↑	1	3	**M**
Morro Santa Terezinha	260	Y	↑	0	1	**L**
Morro Caneleira	1,118	Y	↑	0	2	**L**
Morro Fontana	799	Y	↑	1	3	**M**

Figure 5.3 illustrates the neighborhoods vulnerable to landslides and suggests the degree of the vulnerability. The figure illustrates that those within the hilly region of Santos are exposed to landslides. Of the exposed neighborhoods, low vulnerability neighborhoods tend to represent areas that are not as populated nor as concentrated with slums as the other more vulnerable areas. Based upon the metric used, no neighbourhood was considered highly vulnerable to landslides.

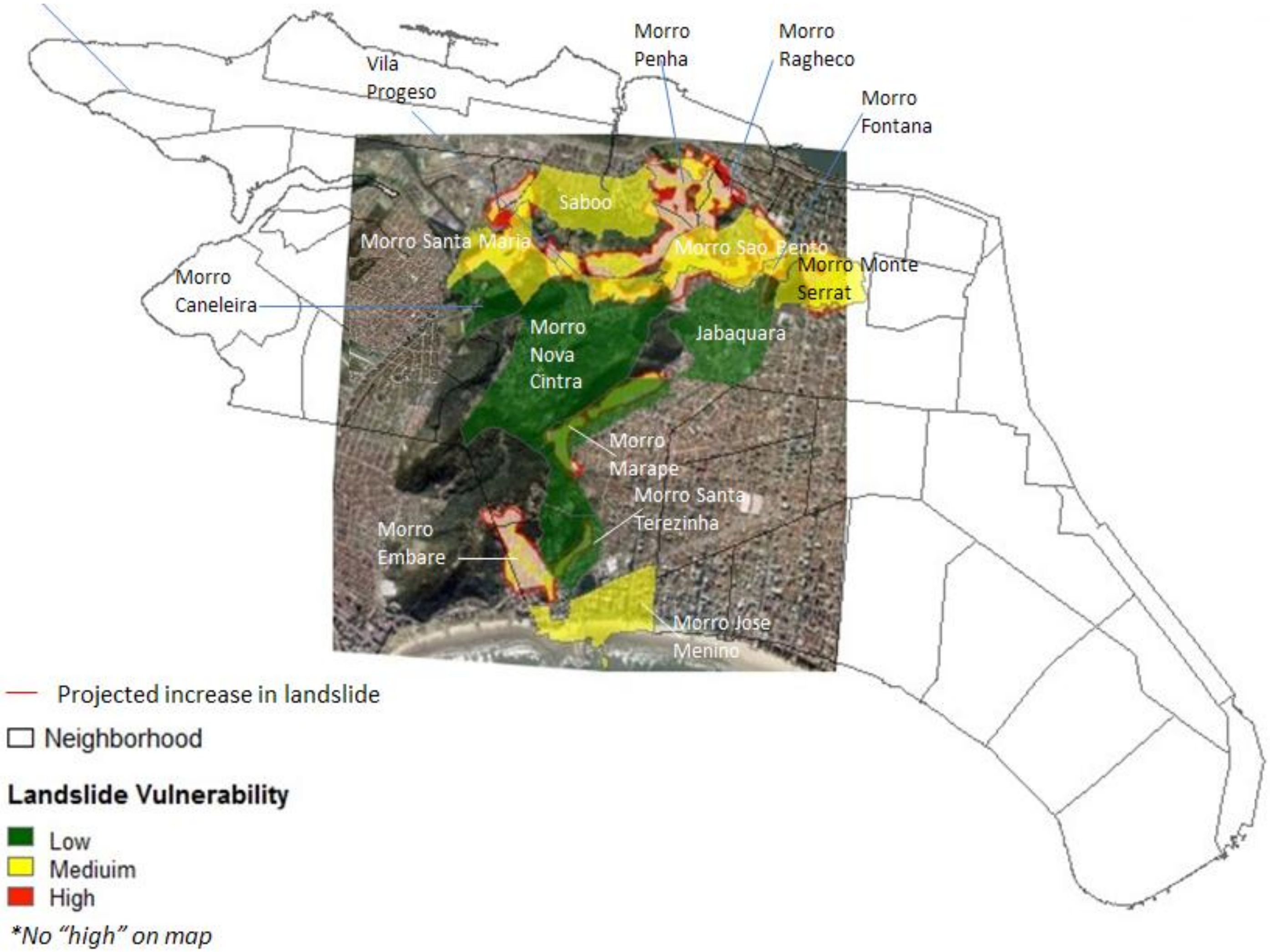


Figure 5.3 Illustrates the projected increase in exposure to landslides and the potential vulnerability of neighborhoods prone to landslides, Sources: Adapted from IPT, 2012 and using shapefiles provided by the Municipality of Santos.

To reduce the vulnerability of the population, one of the activities of the Santos Novos Tempos Project lead by the Municipality with the financial support of the World Bank is to transplant many of the vulnerable populations away from landslide locations. Though this does not decrease the occurrence or impacts associated with landslides, it will decrease population exposure. Reducing informal neighborhoods in landslide prone areas will also contain future landscape transformation thereby reducing the landslide risk associated with anthropogenic changes in the vegetation.

Floods. The *Urban, social, and economic assessment* identified the neighborhoods prone to flooding; these are listed in Table 5.5. The table further provides the findings of the vulnerability assessment.

The future exposure to coastal floods in the 2040s may be increased as the sea level rises leading to increased damage associated with storm surge. Future projections suggest that - without intervention such as the Novos Tempos project - the inland flooding in Santos may remain consistent or worsen compared to that experienced today. The Ponta Da Praia neighborhood is considered to be at greatest vulnerability to coastal flooding.

Table 5.5 Summary of neighborhoods that are potential vulnerable to flooding (primarily coastal flooding).

Neighborhood	Population	Vulnerability				
		Exposure Today	Future Exposure	Sensitivity	Adaptive Capacity	Vulnerability Score
Alemoa	570	Y	↑	2	1	**M**
Aparecida	36,940	Y	↑	4	1	**M**
Areia Branca	6,740	Y	↑	1	2	**M**
Boqueirao	9,212	Y	↑	1	2	**M**
Castelo	30,869	Y	↑	3	2	**M**
Chico De Paula	11,260	Y	↑	1	2	**M**
Embare	3,535	Y	↑	3	2	**M**
Gonzaga	36,812	Y	↑	0	2	**L**
Pompeia	11,333	Y	↑	3	2	**M**
Ponta Da Praia	30,448	Y	↑	4	2	**H**
Saboo	11,737	Y	↑	3	2	**M**
Santa Maria	6,043	Y	↑	1	2	**M**
Vila Haddad	205	Y	↑	2	2	**M**

Figure 5.4 illustrates the neighborhoods vulnerable to floods and suggests the degree of the vulnerability. The threat of coastal flooding is anticipated to worsen by the 2040s as global sea level rises. These southern regions of Santos may become areas of concern over the coming decades and experience an increase in the frequency of floods. The southern coastline will likely experience an increase in flooding which may impair the use and integrity of infrastructure along the coastline. Additional study is warranted that would investigate the potential future exposure of the city of Santos to storm surge under given sea level rise scenarios.

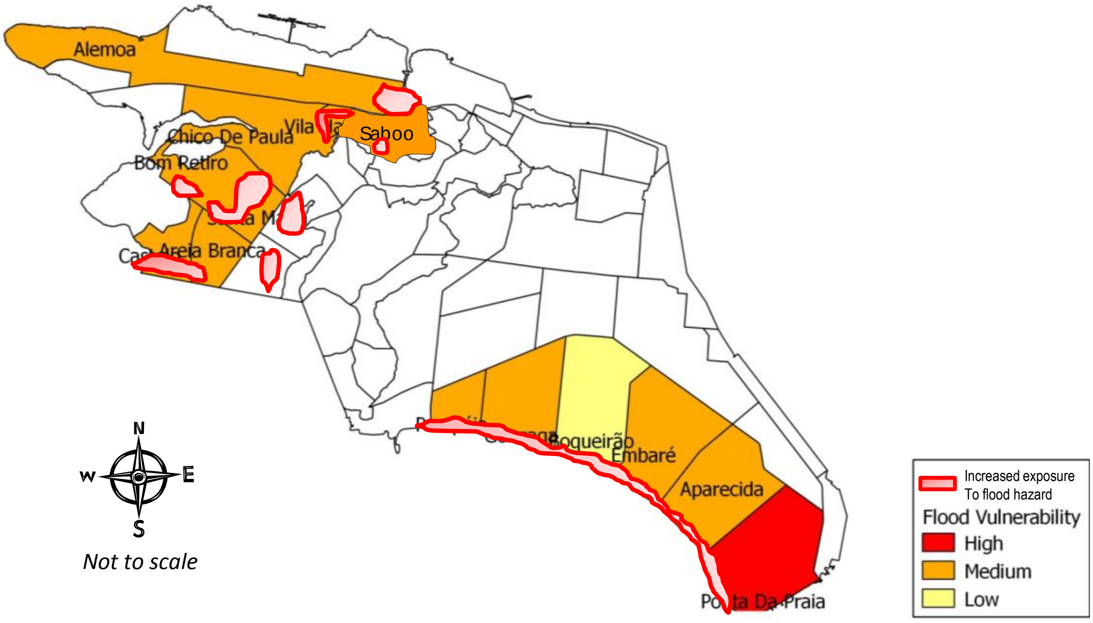


Figure 5.4 The projected increase in exposure to coastal flooding and the potential vulnerability of neighborhoods prone to flooding, Source: Adapted using shapefile provided by the Municipality of Santos and flood map provided by the Prefeitura Municipal.

The northwest zone, however, may be armed against the potential sea level rise due to the engineering infrastructure project currently underway. Santos is currently undergoing a substantial and critical engineering infrastructure project to reduce the frequency and intensity of floods in the northwest. Upon successful completion of this engineering project, the flood hazard in the Northwest Zone of Santos may be substantially reduced. Growth in this area, however, may be limited due to the soil characteristics (i.e., substantial layers of mud that deter a structural foundation from effectively supporting significant structural weight). In other words, the city is aware of the vulnerable populations to the flood and landslide hazards and has taken measures to protect them, demonstrating the city's high adaptive capacity, assuming the availability of external funding.

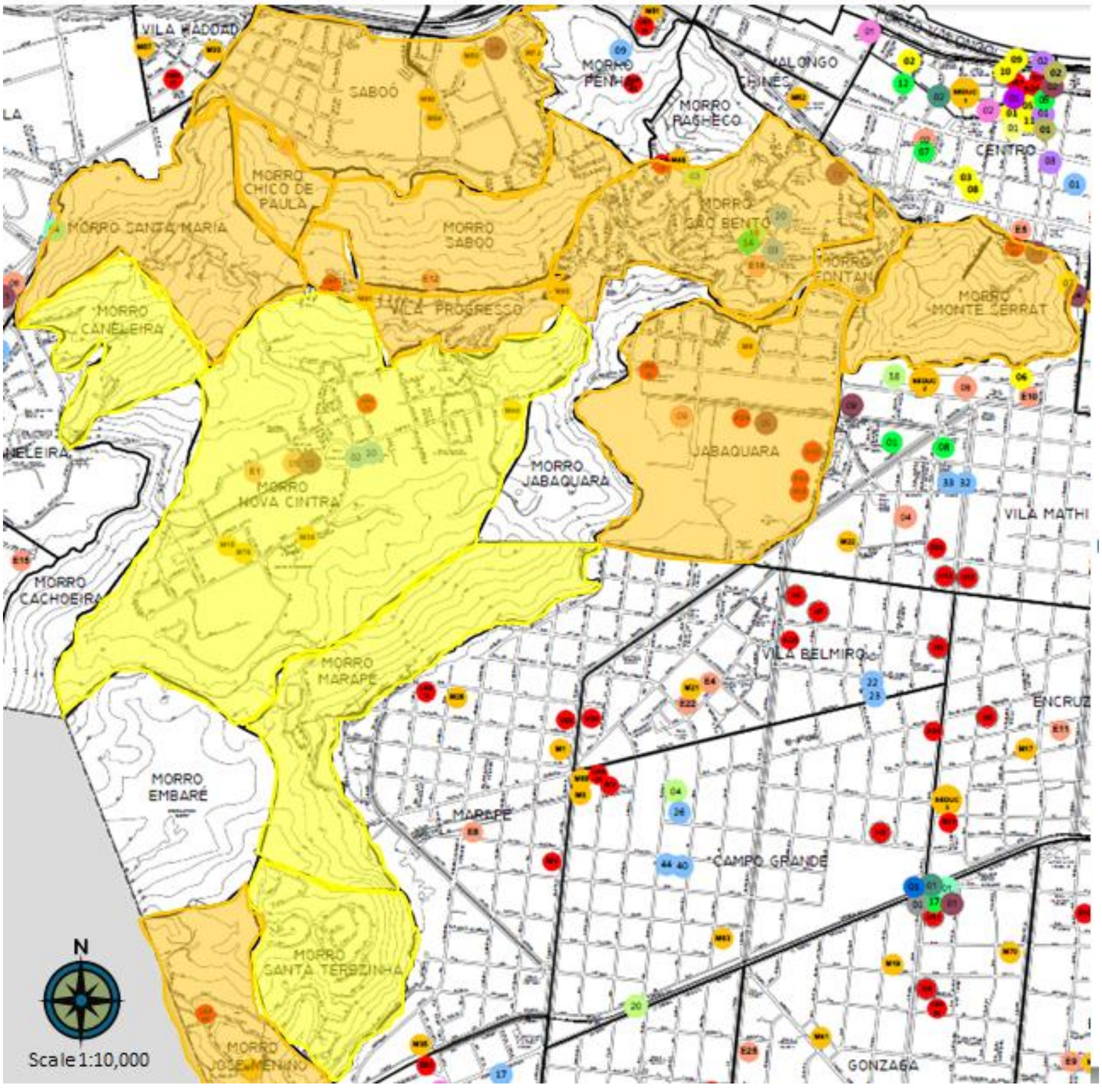
Facilities and Critical Infrastructure

Infrastructure that is located in areas prone to floods and/or landslides is provided in Figures 5.5, 5.6, and 5.7. For each figure, the vulnerability scores are based upon neighborhood characteristics and, hence, are not appropriate in describing the vulnerabilities of individual facility (see Box 6). To provide facility vulnerability scores, each type of facility would need to be considered, with respective sensitivity and adaptive capacity rankings determined.

Box 6 Overlaying infrastructure and settlement vulnerability

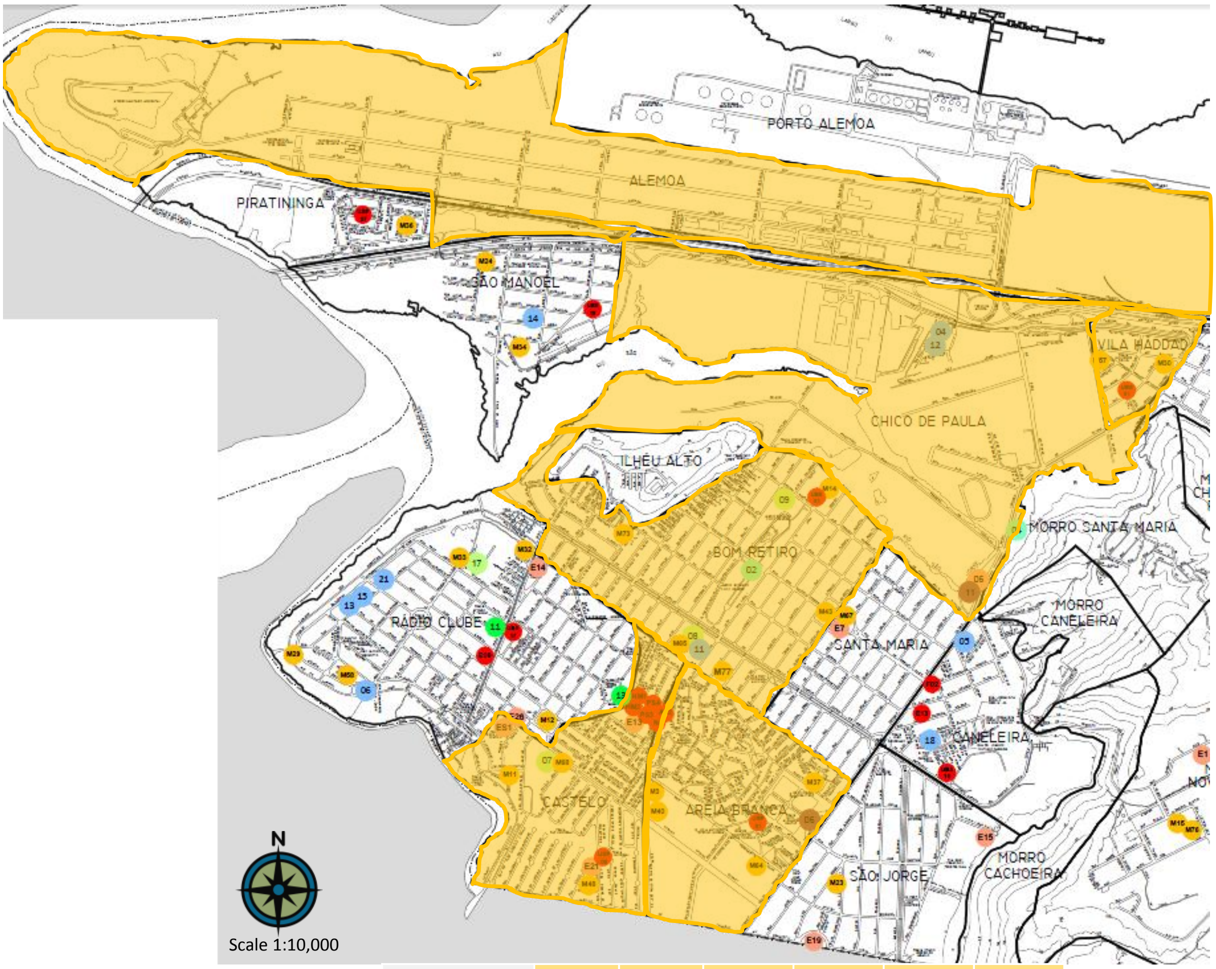
Flood and landslide events can damage infrastructure, leading to financial losses. It is important to realize that two similar types of infrastructure may suffer differently in response to an event. This is because the potential damage and associated costs to infrastructure – particularly infrastructure built to last many decades or more – is affected by many complex factors such as building materials and design, maintenance, age of the infrastructure, past damage, and the strength and dynamics of the particular event. Therefore to analyze infrastructure vulnerability, a detailed database of these factors for each critical infrastructure is needed. Additionally, discussions with infrastructure stakeholders assist in understanding the level of difficulty in building protective resilience into the infrastructure.

The overlay figures provided simply identify which infrastructure is located in an area prone to landslides and/or floods. The settlement vulnerability to the event is also included in the figure to demonstrate the potential 'social' severity if an event were to occur. For example, if a flood were to occur in a settlement highly vulnerable, there is a higher potential need for specific infrastructure – e.g., a hospital – to support the population compared to a settlement ranked at lower vulnerability. In addition considering the criticality of the hospital to the local population is important; Is it the only hospital within a given radius of the settlement? Are other hospitals not vulnerable to the event reachable during an event? Will necessary staff be available to support the hospital needs? These types of overlays can provide key talking points for decision makers when considering how to identify which infrastructure is critical to the local population and thereby warrant further study.



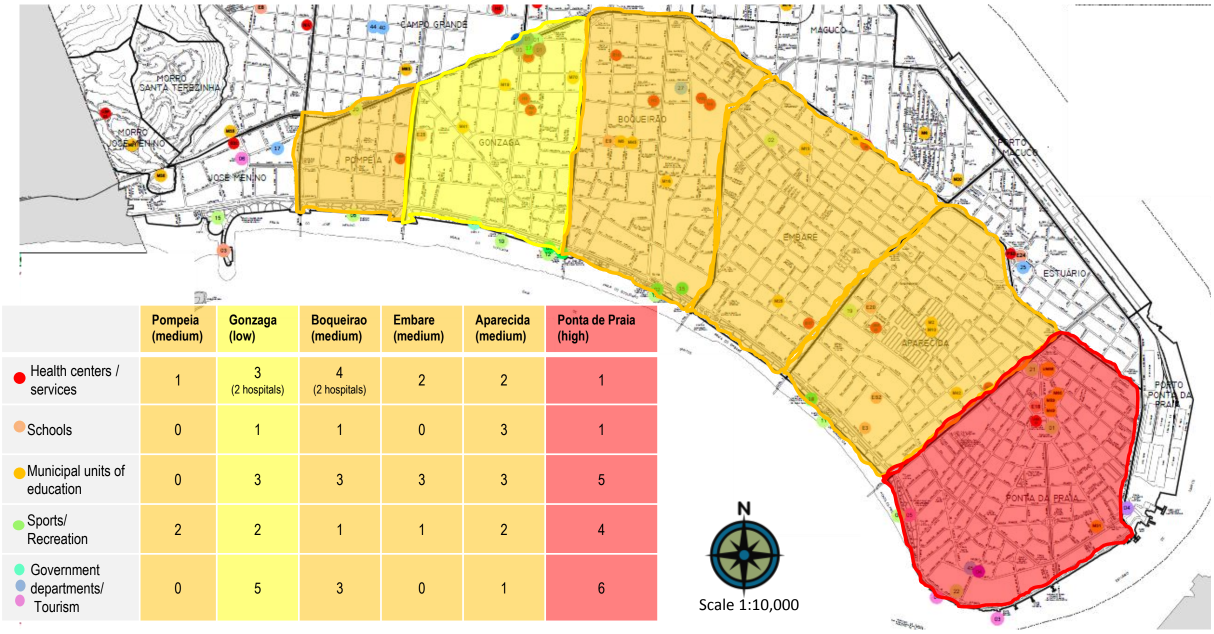
	Medium vulnerability									Low vulnerability			
	Saboo	Morro Santa Maria	Morro Saboo	Morro Sao Bento	Jabaquara	Morro Monte Serrat	Jose Menino	Morro Fontana	Vila Progreso	Morro Caneleira	Morro Nova Cintra	Morro Marape	Morro Santa Terezinha
Health centers / services	0	0	0	1	5 (1 hospital)	1	1	0	1	0	1	0	0
Schools	1	0	1	1	1	0	0	0	1	0	2	0	0
Municipal units of education	5	0	0	1	1	0	1	0	1	0	4	0	0
Sports/ Recreation	0	0	0	2	0	0	0	0	0	0	0	0	0
Government departments/ Tourism	1	1	0	4	1	1	0	0	0	0	3	0	0

Figure 5.5 Infrastructure located in the neighborhoods that may be vulnerable (low, medium) to landslides in the 2040s. Source: Shapefiles provided by the Municipality of Santos.



	Castelo (medium)	Areia Branca (medium)	Bom Retiro (medium)	Chico de Paula (medium)	Vila Haddad (medium)	Alemoa (medium)
Health centers / services	7	1	1	0	1	0
Schools	3	0	0	0	0	0
Municipal units of education	4	2	4	0	2	0
Sports/ Recreation	1	0	2	0	0	0
Government departments/ Tourism	0	1	1	4	0	0

Figure 5.6 Infrastructure located in the neighborhoods in the Northwest Zone of Santos that may be vulnerable to flooding (medium) in the 2040s. Source: Underlying figure was provided by the Municipality of Santos.



	Pompeia (medium)	Gonzaga (low)	Boqueirao (medium)	Embare (medium)	Aparecida (medium)	Ponta de Praia (high)
Health centers / services	1	3 (2 hospitals)	4 (2 hospitals)	2	2	1
Schools	0	1	1	0	3	1
Municipal units of education	0	3	3	3	3	5
Sports/ Recreation	2	2	1	1	2	4
Government departments/ Tourism	0	5	3	0	1	6

Figure 5.7 Infrastructure located in the neighborhoods in south Santos that may be vulnerable (low, medium, high) to coastal flooding in the 2040s. Source: Underlying figure was provided by the Municipality of Santos.

The Port of Santos, a critical infrastructure to the city's economy, has some terminals that may be affected by sea level rise and storm surge, but most sections are built to withstand water levels of 3 meters above mean sea level. No direct damage to the Port from past weather events has been reported, though heavy rainfall during an El Niño event in 2010 forced ships to wait weeks to load sugar into their holds, as rain falling into ships' holds can damage the consistency of sugar.

Overall, there appears to be minimal critical infrastructure in most flood-prone areas and no critical infrastructure within landslide prone areas. The infrastructure likely to be most vulnerable to future hazards is located along the coastline of the south-eastern coastline. This is an area where fortification by sea walls against ocean waves exists, but the sea walls may not be strong enough to arm against future beach erosion and rising sea levels.

5.3.3 Considering risk

A risk assessment considers the likelihood of a hazard event occurring (typically expressed in terms of probability) and the magnitude of the consequence if the hazard event occurs. Some studies define likelihood as the probability of the occurrence of a climate hazard (NYCPCC 2009). The vulnerability analysis incorporated limited primary and secondary data. In order to expand this analysis to consider risk, additional data is needed to develop a quantifiable baseline understanding of the frequency, severity, and triggers of landslides and floods and how these hazards may change over time. In addition, no information was available to consider the impact of these hazards on specific critical infrastructure.

The following studies and data collection activities are suggested to continue the development of pertinent risk information for Santos:

- The development of long-term publically assessable data of tidal gage stations of Santos Bay along with the introduction of additional meteorological stations is critical in informing future studies.
- The development of inundation maps susceptible to future sea level rise and potential storm surge would increase the robustness of these results. Further simulations estimating how the inundation from storm surge and waves may change under rising sea levels were not available to inform this assessment. To understand how storm surge and waves may impact coastal locations, an intensive coastal storm surge analysis using

models such as SLOSH or ADCIRC would reveal how the coastline may be inundated in response to various historical storms with and without projected sea level rise. This effort would demonstrate regions susceptible to multiple scenarios of possible inundation. This information could be aligned with sensitivity and adaptive capacity infrastructure information to identify key infrastructure vulnerable to future sea level rise and storm surge.

- Hazard maps of various flood return periods (e.g., 100 year) linked to precipitation would be beneficial in identifying areas at risk to more extreme events.
- The city would benefit from an intensive modelling effort drawing on future climate conditions (e.g., new hydrologic and hydraulic modelling driven with projections of precipitation to investigate how exposure may change or drilled-down analysis of changes by precipitation event).
- Extreme precipitation events will also affect landslide risk, but there is a high level of uncertainty in how this relationship may be influenced by the likely decrease in storm intensity. Further examination of specific historical events and landslide hazards may help increase understanding in how individual extreme events contribute to landslide hazard.
- The vulnerability assessment could be enhanced by incorporating additional metrics describing sensitivity and adaptive capacity. For example, the height of the doorway floorboard may be useful in determining susceptibility to floods. In addition, considering how the values of these metrics changed with future time would create a more dynamic analysis.
- Conducting a drilled-down vulnerability analysis of carefully selected critical infrastructure would serve to identify which infrastructure is most vulnerable and arm decision makers with recommendations on how to build resilience into the system. Within this effort, outlining the costs of damage and adaptation would be particularly useful.

The choice of which activities to undertake depends on the concerns and stakeholder understanding of the hazards within Santos.

6 Strategic climate adaptation investment and institutional strengthening plan

6.1 Introduction

Santos is susceptible to both flooding and landslides. Due to climate change, precipitation patterns are projected to change in the future, possibly resulting in a decrease in precipitation-induced floods, though coastal flooding from storm surge and high tide may increase. There may be a decrease in the overall frequency of landslides, but an increase in the occurrence of extreme landslide events.

In particular, for coastal locations in Northwest Santos, climate projections suggest that the threat of precipitation-induced floods may be reduced. On the other hand, the area may experience an increase in coastal flooding associated with storm surge and high tide as sea level rises. The Southeast regions may become areas of concern over the coming decades and experience an increase in the frequency of floods. The southern coastline will likely experience an increase in flooding which may impair the use and integrity of infrastructure along the coastline. With regards to landslides in the hilly environs of the city, decrease in monthly and seasonal precipitation may lead to an overall decrease in soil saturation, but the projections also suggest an increase in landslide indices used to determine if conditions are favourable to landslide events.

While absolute population growth in Santos has slowed down, the city is characterized by complex spatial dynamics. Santos is attracting a higher income population while a lower income population is, of necessity, settling in other neighboring areas and cities, where land is cheaper and informal residential conditions predominate. While the city has benefited overall from substantial investments in urban infrastructure, the Northwest area still concentrates a great number of informal, low income and low quality neighborhoods (including palafitas, stilt-housing neighborhoods in the water).

Since 1968, the zoning system of the city progressively attempted to capture risk areas but development was always ahead of planning (irregular occupation begun before 1968). The municipality has developed specific plans for landslide risk, the latest being the 2012 Municipal Plan for Risk Reduction (PMRR). The PMRR has been largely successful in directing development, although in many cases people still settle in risk areas.

Santos has a robust institutional structure for managing disaster risk and climate related hazards. The city's systems for risk management are considered amongst the best in Brazil, with a strong focus on preparedness and risk reduction. This forward-looking approach offers a contrast to the largely reactive and response-led institutional frameworks for risk management found in other cities. More recently, investments have been made to improve government processes of risk management along with a traditional focus on technical and engineering-led mitigation actions. The focus on risk prevention and reduction activities before the onset of a disaster, rather than the response phase, characterizes the progressive and adaptive approach to risk planning in Santos.

The purpose of the Santos *Strategic climate adaptation investment and institutional strengthening plan* is to identify and then to prioritize short-, medium- and long-term adaptation interventions aimed at enhancing resilience to flooding and landslides in Santos.

6.2 Approach and tools for adaptation planning

The preceding *Climate-related vulnerability assessment* provides the basis from which to identify and prioritize a set of strategic climate adaptation investments and institutional strengthening interventions that can be linked or incorporated into existing priorities, sector plans and planning instruments in Santos.

Engagement with national and local level stakeholders and decision-makers during the execution of the assignment was a very important feature which helps ensure coherence with national and local priorities and to tailor measures to fit needs.

The plan draws accordingly on the conclusions and the feedback obtained during a workshop held in Santos in March 2013. The feedback served to validate assessment findings, update or readjust them and establish a set of specific actions to be proposed based on the needs and major issues identified by stakeholders. This process helps ensure that the proposed climate change adaptation measures can be mainstreamed within the policy and institutional framework, and form part of an overall climate change adaptation strategy for Santos.

Climate change adaptation planning is a key element of urban planning since it sets out a range of responses that can be implemented to enable communities to 'adapt' and become more resilient to climate-related change. Resilience is broadly defined as the 'ability to absorb or off-set damage and so avoid lasting harm and recover to pre-disaster status.' (da Silva et al., 2012) In the context of climate change, a more resilient system (i.e., a city) has the ability to withstand higher threshold limits in specific events, such as floods and landslides.

The steps taken to develop the *Strategic climate adaptation investment and institutional strengthening plan* for Santos were:

6. Identification of urban planning, physical, socio-economic and institutional challenges and shortcomings related to flooding and landslides, drawing from the four assessments carried out under the project.
7. Definition of planning themes that create the foundation for a climate change adaptation strategy.
8. The planning themes lead to specific structural and non-structural measures which can be implemented in Santos to manage and reduce flooding and landslide vulnerability and risk. These measures are presented in Table 6.1 and Table 6.2. Table 6.3 positions the measures within the disaster risk management (DRM) cycle.
9. Finally, a set of specific actions that can be undertaken to implement adaptation measures are proposed. These actions are presented in Table 6.4, which specifies:
   - The targeted area in the city: the area/s where the action can be enacted.
   - The institution responsible for enacting the action: this identifies the institution or institutions that have a responsibility for the proposed action.
   - The timeframe for its implementation: this allows providing a prioritization spectrum. Short-term actions are the issues with the highest priority; long-term actions are the issues with lower priority, or with high priority but with longer-roll out times.
   - An estimation of its relative cost: this is meant to give estimation on the resources to be allocated for the implementation of the action.

In the process of planning and implementation, the uncertainty associated with climate projections and its implications requires addressing, as Box 7 below describes.

Box 7 Dealing with uncertainty: addressing the risk of maladaptation

Ranger et al (2011) point out that as a degree of uncertainty is incorporated in climate projections, uncertainty is also embedded within the climate change adaptation process.

If policy-makers need to make investment decisions that will have a direct impact in the future capacity of a city to adapt to climate change, and uncertainty is embedded within the decision-making process, policy-makers face a significant challenge: *How to plan and decide on what will best help in constructing the city's resilience to climate change when the information available to advise on decision-making is limited and/or unclear?*

The major risk of not taking uncertainty into account is to take decisions that expose a society to maladaptation. This occurs when unsuitable investments are made for addressing the climate changes that actually do happen.

There are two forms:

- Under-adaptation: when the actions and adjustments made are not enough to deal with the climatic changes that do occur. For example, needing significant financial resources for replacing infrastructure built prematurely and found unsuitable to address climatic changes can be regarded as under-adaptation.

- Over-adaptation: when the adjustments made initially prove to be unnecessary, but later on they are either not adaptive or counter-adaptive. For example, when considerable financial resources are put into building a sea defense meant to withstand a sea level rise of 4 meters, but this change does not happen and the infrastructure is found unsuitable.

In dealing with maladaptation, the integration of adaptation considerations into existing planning and policy priorities can be seen as a major asset. Incorporating adaptation into the overall development process can allow the proper addressing of the existing needs of a city. The rationale is to focus on principles rather than projections. If adaptation is integrated not as an independent characteristic but as a constitutive element spanning across an integrated development strategy, the possibility of delivering an appropriate strategy taking into account present uncertainties is increased.

Furthermore, a core feature of integrated planning is to build flexibility into adaptation strategies by prioritizing long-term adaptive capacity while avoiding inflexible decisions: here, the need to have a decision support tool allowing stakeholders to make “robust” investment choices in a context of uncertainty has been advanced (Lempert et al., 2010).

“Optimal” solutions stand in contrast to “robust” ones. An “optimal” solution is only adapted for an expected future, but might be inappropriate if conditions change. “Robust” solutions might not be optimal, but they are appropriate no matter the conditions that are encountered in the future. Allowing the incorporation of new information to guide decision-making allows the effective design of an adaptation strategy in which flexibility and robustness are embedded as core elements.

6.3 Strategy and adaptation measures

Overall goal

The overreaching goal of the strategic plan is to increase resilience to floods and landslides in Santos. On the basis of planning themes, specific measures to address particular urban development challenges as well as institutional shortcomings are identified. These measures also promote a more sustainable and resilient urban development process.

From goal to planning themes

The potential planning themes that create the foundation for a climate change adaptation strategy to help Santos build its resilience against floods and landslides, both now and in the future, can be outlined as follows:

- **Horizontal and vertical (cross-scale) integration of risk management practices:**
  - Coordination with disaster management organizations from the surrounding cities to ensure a more robust and effective strategy for adapting to climate-related hazards.
  - Coordination with the port authorities over disaster response strategies, as well as long term environmental planning for long term business continuity, as well as for a more effective approach to planning for transport and coastal management.
  - Initiatives to engage the public and local stakeholders in adaptive actions and to improve citizen awareness regarding floods and landslides to consolidate institutional and local adaptation and provide a more holistic approach to climate change planning.
- **Mechanisms for data collection, storage and dissemination to be created and/or improved for better climate monitoring, risk planning, and information sharing:**
  - Improvement of information, communication and policy relevant technical knowledge for assisting local actors to identify and understand impact, vulnerability and adaptation responses in order to effectively select and implement practical and high priority adaptation measures.

- **Improved insurance mechanisms and climate financing for long-term recovery and building resilience against floods and landslides:**
  - Formalized structures of cooperation with the private sector in planning and risk reduction phases for sustained and meaningful engagement.
- **A shift from disaster management to long term risk reduction and climate change adaptation to ensure a proactive and forward-looking system of risk governance:**
  - Supporting efforts towards mainstreaming climate change adaptation from policy into development practice and programmes.

From planning themes to measures

An integrated strategy requires the use of both structural and non-structural measures for "getting the balance right" (Jha et al., 2012).

Flood and landslide risk management measures can be either structural or non-structural. In broad terms, structural measures aim to reduce risk by controlling physical processes – such as the flow of water – both outside and within urban settlements. They are complementary to non-structural measures which aim at keeping people safe from flooding or landslides through better planning and management of – in this case, urban – development. More narrowly:

- **Structural measures:** refer to physical investments that a city can institute in order to prepare its built environment for the expected effects of climate change. Structural measures are often costly investments in hard-engineered infrastructures.
- **Non-structural measures:** refer to investments other than the improvement of physical infrastructure. These measures are often less costly than structural measures, and span a wider spectrum, covering urban (for example, planning), socio-economic (for example, poverty reduction) and institutional (for example, educational campaigns) dimensions.

Tables 6.1 and 6.2 which follow present a series of disaster and climate change-related adaptation measures which can be implemented in Santos to manage and reduce flooding and landslide risk and vulnerability to these hazards – and, in so doing, enhance overall urban resilience.

Each measure is briefly described and the anticipated co-benefits over and above their flood and landslide management role are sketched.

In order to present a forward-looking view and allow the prioritization of adaptation options, two ratios are also considered:

- **Benefits relative to costs:** to allow an understanding of how the costs inherent to the measure compare with the expected benefits.
- **Robustness to uncertainties:** robustness refers to the way in which the benefits of an adaptation measure might vary with climate projections. It can be regarded as the risk of maladaptation. For example, on the left hand-side of Figure 6.2 are found "no-regret measures" (measures that will have a positive effect on adaptation, no matter the accuracy of climate projections, as for example, with awareness campaigns). On the right hand-side are located "higher-regret" measures, whose benefits are dependent on the accuracy of climate projections (for example, drainage systems or flood defences).

It is important to highlight that the robustness and cost-benefit ratios of measures are established on a case-by-case basis. It is also acknowledged that costly, long-term projects should seek "no-regret" ways to build in flexibility in order to address potential uncertainty.

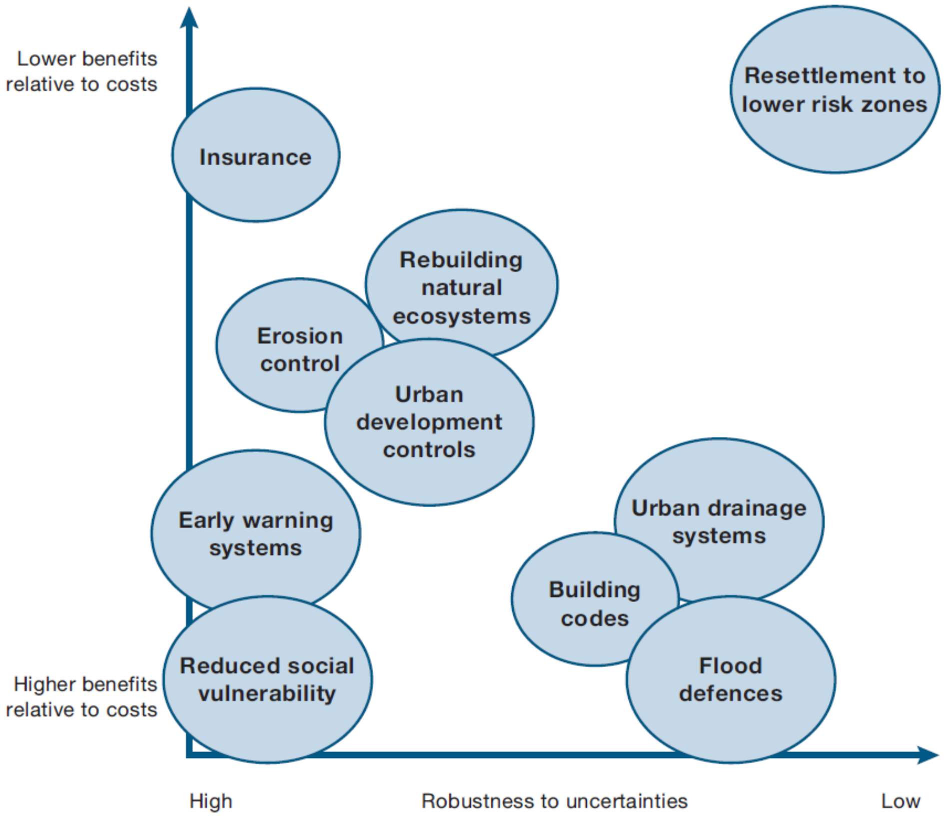


Figure 6.1 **Relative costs and benefits of flood management options (based on findings for Guyana, Mozambique and UK). Source: Adapted from Ranger and Garbett-Shields 2011, in Jha, A., Bloch, R., and Lamond, J. (2012).**

Table 6.1 Structural measures

Climate changes	Potential impacts	Measure	Challenge – and response	Co-benefits	Benefits relative to costs	Robustness to uncertainties
FLOODING & LANDSLIDES						
■ Slightly prolonged and intensified rainy season ■ Increased chance of drought during the dry season	■ Flooding ■ Landslides	**Incentivize green infrastructure projects**	Measures for reducing the amount and speed of rainwater runoff in urban areas can include green infrastructure projects. These ’greening’ measures can be at a micro level, such as creation of green roofs, landscaping around buildings, and tree-lined streets. Within the context of wider urban planning, policies can be drawn up which address the need to zone natural or man-made buffer zones within and around urban areas, such as urban parks, riverside corridors, and buffers around roads in sloping areas. The creation of green spaces indirectly further reduce flooding and landslides in urban areas. From the flood management point of view the key purpose of green infrastructure projects is to act as flood retention basins and hence reduce the flood risk to built-up urban areas. Green infrastructure projects can also help control the soil and stabilize stream banks providing protection against substantial erosion and landslides. The success of such initiatives will depend on considerable support from local communities and businesses. In Santos, green infrastructure investments could be used to improve the city’s urban landscape and identity, while contributing to increased adaptive capacity. Rapid urban development linked to tourism in the 1960s and 1970s lead to a degradation of the urban identity of Santos through the massive construction of high-rises, saturating all available space. As such, efforts in green infrastructure investment, such as urban parks, the plantation of trees along streets and waterfront corridors would contribute not only to the improvement of Santos quality of life, but also to its resilience through indirectly reducing flood and landslide hazard.	■ Reduction of the ‘urban heat island’ effect ■ Benefits to flora and fauna habitats ■ Reduction of the level of CO2 ■ Reduction of run-off together with the enhancement of ground water storage by more infiltration through the soil	High	High

FLOODING					
	Rebuilding natural ecosystems	Rebuilding natural ecosystems and protection of mangroves has come to describe a basis for considering how communities are dependent upon the condition of the natural environment. Natural ecosystems contribution extends beyond the provision of goods such as food, to services which support processes such as flood and coastal erosion risk management. Mangroves, for example, have been reported to be able to help buffer against cyclones and other storms. Wetlands that provide flood protection may be valued on the basis of the cost of building man-made defenses of equal effectiveness. Given that Santos is a port, and is located on an island, the preservation of the surrounding natural ecosystem and mangroves is of extreme importance for both environmental protection and flood control. In this, appropriate institutional channels need to be established to bring together stakeholders from the city and port authorities. This would help improve governance and adaptive capacity through reinforcing the interrelation between the port and the city and the formulation of a common strategy for mangrove and natural ecosystem preservation.	■ Ecosystem goods, such as fisheries ■ Recreation and tourism ■ Climate change mitigation co-benefits	High	High

	Incorporation of projected precipitation and SLR levels into drainage system in North-West	A new drainage system is being developed through the Santos Novos Tempos Program supported by the World Bank. Part of this program is to restructure the urban macro drainage system, installing new channels and pumps, along other drainage infrastructure. Considering future weather events, the new drainage system may be vulnerable under extreme precipitation events and/or sea level rises. Given the information collected during our interviews, the northwest zone may be vulnerable to flooding after the new system is built if the tide is above 1.5 m and the rainfall is above the 100-year precipitation return period. Sea level rise as a consequence of climate change was not considered on the project design. Urban drainage systems need to be able to deal with both wastewater and stormwater whilst minimizing problems to human life and the environment, including flooding. Maintenance is vital, not only to remove obvious obstructions, but also cleaning out deposited sediment, and then disposing of the material so that it does not go back into the drain. The cost of operation and maintenance is a critical aspect in the long term. Realistic ways of revenue generation for sustainability and general awareness from the public and local authorities will be key issues.	■ Prevention of water pollution ■ Providing valuable habitats for wildlife in urban areas ■ Addresses landslide causes by reducing infiltration into the soil	High	Medium

	Sustainability of existing drainage systems in East Santos	Blocking the canals during high tide does not create flooding conditions even during precipitation events since the canals are deep enough for substantial water storage. During our interviews with representatives from the municipality, there were some concerns regarding the state of the canal infrastructure, including: the iron gates within the canal being susceptible to corrosion over time and needing to be replaced, and some revisions to the channels may be needed to accommodate the beach erosion along the southern beach and sedimentation in the northern side. Urban drainage systems need to be able to deal with both wastewater and stormwater whilst minimizing problems to human life and the environment, including flooding. Maintenance is vital, not only to remove obvious obstructions, but also cleaning out deposited sediment, and then disposing of the material so that it does not go back into the drain. The cost of operation and maintenance is a critical aspect in the long term. Realistic ways of revenue generation for sustainability and general awareness from the public and local authorities will be key issues.	■ Prevention of water pollution ■ Providing valuable habitats for wildlife in urban areas ■ Addresses landslide causes by reducing infiltration into the soil	High	Medium

Table 6.2 **Non-structural measures**

Climate changes	Potential impacts	Measure	Challenge – and response	Co-benefits	Benefits relative to costs	Robustness to uncertainties
FLOODING & LANDSLIDES						
■ Slightly prolonged and intensified rainy season ■ Increased chance of drought during the dry season	■ Flooding ■ Landslides	**Prioritize and enhance civil society's awareness to risk**	Flood risk awareness is the cornerstone of non-structural flood and landslide risk management. All actions to minimize the impact of flooding and landslides hinge upon stakeholders becoming aware these are both necessary and desirable. Various measures can be advanced to enhance flood and landslide risk awareness: ■ *Using means of communications, notably television, radio and newspapers, as well as new media, like Twitter, Facebook*: targeting to ensure the 'message' reaches a large proportion of the population. ■ *Enhancing environmental awareness campaigns*: improve citizen awareness on hazardous practices such as illegal waste disposal and construction in high risk zones ■ *Public awareness in school system*: education is the first step for a better understanding of risk, the possible consequences it can have, and the deployment of attached prevention and mitigation strategies.	■ Better understanding of risk ■ Improved environmental conditions ■ Increased deployment of risk prevention and mitigation measures	Very High	Very High

	Creation of a City-Region Observatory	The municipal boundaries of Santos within the larger urban conglomeration of Baixada Santista also present specific institutional issues. Most of the land within city limits is already constructed, limiting the scope for new construction. As such, zoning and land use laws are not very relevant for regulating risk for most of these areas, although the master plan for the city is revised every five years. New construction is controlled through the implementation of risk maps and regulations, making risk management an important aspect that shapes urban development. Additionally, the neighbouring cities of Saint Vincente, Guaraja and Cubitao are part of the same urban conglomeration as Santos, often with nothing but a street separating one city from the other. Despite this proximity, the municipal governments and civil defence organizations for each city do not formally collaborate or exchange resources for risk management. Each municipality can only initiate risk management procedures within its own boundaries. In reality, the surrounding cities act as suburbs that contain the population overflow from Santos. No mechanism for coordination exists to deal with climate change and disaster risk across all cities within Baixada Santista, and the weaker standards of municipal planning and civil defence resources in the neighbouring cities pose a potential source of risk to Santos itself. Stakeholders saw as a challenge the improvement of data collection and dissemination: critical information and data to orient decisions at the sub-national and local level. Without this information, it is impossible to undertake local adaptation activities that rely on the downscaling of climate change models and climatic data. The creation of a City-Region Observatory is proposed as a partnership between local universities, Baixada Santista Metropolitan Region, Santos Municipality and other municipalities. The Observatory can help to build the knowledge base that government, private sector, the civil society and citizens all need to make their cities and the region spatially integrated, environmentally sustainable and socially inclusive. In particular, the Observatory will collect data and benchmarks for the city-region, provide policy analysis and support, and undertake applied research.	■ Better information sharing ■ Better climate monitoring ■ Better flood and landslide risk planning	Very High	Very High

	Integrated land use planning and risk-sensitive zoning	While risk *per se* is not taken into account in land use (zoning), for landslide risk in particular, the municipality considered risk when categorized an area as preservation zone or *Zona de Preservação Paisagística* (ZPP) (Figure 3.10). For example, the land use plan preserves the vegetation of the slopes based on environmental criteria: this indirectly addresses landslide risk-related issues. Zoning is now a strong tool for reducing climate-related hazards risk and is very important that the municipality enforces that category. Future development in inappropriate areas will also be dealt by a new cross-institutional decree that will allow the municipality to demolish encroachments in ZPP areas. Land use planning provides a policy and regulatory mechanism that enables diverse and often conflicting objectives to be integrated and addressed in a development framework – with this process and its output referred to as 'integrated land use planning'. Integrating flood and landslide risk management objectives and principles into land use planning is an essential component of contemporary flood and landslide risk management. Through its formulation and implementation, land use planning: ■ Identifies appropriate area(s)/location(s) for specific land uses ■ Determines what risks are associated with specific land uses in specific locations ■ Determines and identifies sensitive or important societal or environmental features ■ Details minimum requirements/expectations of particular land use types. ■ Put simply, it determines what urban development is required and where it should go. The interaction between land use planning and flood and landslide risk management is mutual. Urban land use plans should ideally be integrated within a suite of flood and landslide management plans which may include river basin management plans, coastal management plans and surface water management plans. Such plans are likely to be the responsibility of different governmental departments or agencies and the urban use plan will be informed by these dedicated flood and landslide management tools.	■ Increased resilience and establishment of a pattern of sustainable urbanization	High	High

	Improved budgetary allocation for climate-related activities	Specific municipal budget allocations in climate change would enhance the city's capacity in designing strategies targeting a particular output in climate change adaptation action. Given Santos already sound existing institutional system in DRM and adaptation, Santos could prioritize efforts into mainstreaming climate change investments across budgets in all municipal departments. This would elevate climate adaptation considerations in the institutional system and create a platform for action in all sectors of municipal activity. As such, improved budgetary allocation for climate-related activities would result in the establishment of an integrated approach in climate adaptation, ultimately increasing institutional adaptive capacity.	■ Enhanced capabilities in designing and implementing climate change adaptation actions – risk identification, risk reduction, adaptive governance	High	High
	Formalized structures of cooperation with the private sector in planning and risk reduction	Further attention needs to be paid to the level of engagement and liaison between the government and private sector in both risk management and climate change adaptation. Stakeholders acknowledged that the involvement of various private sector actors could be improved. This would allow the establishment of a more integrated and participatory strategy in climate change adaptation and the DRM system overall. Stakeholders specifically targeted: The private sector could also be engaged in climate change adaptation through Corporate Social Responsibility (CSR) schemes. Private companies, notably in the port and tourism industries, can undertake innovative measures in climate change adaptation and mitigation.	■ Improved integration of the DRM and climate change adaptation system ■ Elaboration of a more integrated approach in climate change adaptation action taking into account lessons and ideas from various stakeholders	High	High

	Increased insurance mechanisms	Increased insurance mechanisms for supporting resilience and recovery to climate change hazards. Insurance has two main purposes in the management of flood and landslide risk. Firstly, and most obviously, the provision of these financial mechanisms can be used by those at risk to offset their financial risk from flooding and landslide. Although these financial tools obviously do not prevent flooding or landslides, they allow recovery without placing undue financial burdens on those impacted by flood and landslide disasters. Purchase of insurance is highly dependent on a number of factors, including its availability and cost, the level of the provision of disaster relief, general risk awareness, and attitudes to collective and individual risk. Micro-insurance can be a solution offered to the urban poor. Below the poverty line, micro-insurance schemes will need some government or donor intervention. Expansion of insurance coverage and financial instruments, such as those outlined above, could thus contribute to alleviate financial pressure on the government during recovery and adaptation phases. Given Santos's high level of development and good social indicators, institutional efforts could be put into establishing insurance schemes. Local authorities could supervise and monitor the use of insurance mechanisms amongst the city's middle class, as well as open option channels for marginalized groups. In order to assure accurate monitoring and establishment of an insurance scheme, efforts could be put into incorporating it into the municipal housing strategy.	■ Disaster recovery can be expedited and funds are not diverted from other priorities such as development	Medium	High

Proposed measures and the disaster risk management (DRM) cycle

Under the disaster risk management (DRM) cycle, the structural and non-structural measures above can also usefully be classified as: (i) risk reduction, (ii) risk transfer or share, (iii) preparedness, and (iv) response and recovery (Mitchell and Harris, 2012). Table 6.3 below locates the proposed structural and non-structural measures in the DRM cycle.

Table 6.3 Risk management options

Risk reduction (preventing hazard/shock, reducing exposure and vulnerability)	Risk transfer or share	Disaster preparedness	Disaster response and recovery
Incentivize green infrastructure projects	Increased insurance mechanisms	Creation of a City-Region Observatory	
Integrated land use planning and risk-sensitive zoning	Improved budgetary allocation for climate-related activities	Prioritize and enhance civil society's awareness to risk	
Sustainability of existing drainage systems in East Santos		Formalized structures of cooperation with the private sector in planning and risk reduction	
Incorporation of projected precipitation and SLR levels into drainage system in North-West			
Rebuilding natural ecosystems			

6.4 Action Plan

Table 6.4 presents a set of specific actions that can be undertaken to implement climate change adaptation measures. It illustrates the areas targeted by the action, the institution responsible for putting it in place and give it life, the expected time-frame (short, medium, or long-term), as well as the relative costs. The purpose of this is to present strategic planning initiatives that the city could consider and how these could be implemented.

Table 6.4 Santos action plan

Measure	Action	Targeted neighbourhoods (or broader locations)	Institutional responsibility	Schedule: Short-term (1-5 years)	Schedule: Medium-term (5-10 years)	Schedule: Long-term (10-20 years)	Relative costs
Incentivize green infrastructure projects	Incentivize 'greening' measures at the micro level, such as creation of green roofs, landscaping around buildings, and tree-lined streets	City-wide; prioritize low-income high-risk neighborhoods	■ Municipal Secretariat of Planning ■ Strategic Affairs and Development Ministry ■ Municipal Ministry of Infrastructure ■ Municipal Ministry of Public Works				High
	Zone natural or man-made buffer zones within and around urban areas, such as urban parks, riverside corridors, and buffers around roads in sloping areas						
Rebuilding natural ecosystems and protecting mangroves	Establish institutional channels to bring together stakeholders from the city and port	Coastal areas	■ Strategic Affairs and Development Ministry ■ Municipal Ministry of Infrastructure ■ Municipal Ministry of Public Works ■ Port of Santos ■ Maramar Institute				High
	Develop and implement ecosystems and mangrove protection policies and legislation to halt further degradation and promote mangrove restoration activities						
Incorporation of projected precipitation and SLR levels into drainage system	Carry out detailed studies for the other water basins of the city to assist decision making for future drainage infrastructure investments	North-west area	■ Strategic Affairs and Development Ministry ■ Municipal Ministry of Infrastructure ■ Municipal Ministry of Public Works				High
	Develop a comprehensive maintenance strategy to sustain the overall condition of the drainage infrastructure						
Sustainability of existing drainage systems in East Santos	Carry out detailed studies for the other water basins of the city to assist decision making for future drainage infrastructure investments	East Santos	■ Municipal Secretariat of Planning ■ Strategic Affairs and				Medium

Measure	Action	Targeted neighbourhoods (or broader locations)	Institutional responsibility	Schedule			Relative costs
				Short-term (1-5 years)	Medium-term (5-10 years)	Long-term (10-20 years)	
	Develop a comprehensive maintenance strategy to sustain the overall condition of the drainage infrastructure		Development Ministry ■ Municipal Ministry of Infrastructure ■ Municipal Ministry of Public Works				
Prioritize and enhance civil society's awareness to risk	Define target audience(s), for example, the public, professionals, hard to reach groups	City-wide	■ Civil Defense Department ■ Strategic Affairs and Development Ministry, Santos Prefecture ■ NGOs and private sector organizations				Medium
	Choose the message and determine communications channels. Use more than one channel						
Creation of a City-Region Observatory	Devise a schedule and mechanism for relevant key officials from the Municipalities conforming the Baixada Santista and adaptation experts to engage with one another to share understanding, experience and visions for urban adaptation planning	Region-wide	■ Civil Defense Department ■ Local governments in the Baixada Santista: Saint Vincente, Guaraja and Cubitao ■ Municipal Secretariat of Planning ■ Local universities				Low
	Create mechanisms of data collection and information sharing and dissemination in climate change adaptation knowledge.						
	Support strategic capacity building for urban adaptation planning and knowledge exchange through practitioner networks and global events						
Integrated land use planning and risk-sensitive zoning	Database generation using actual event data, historical data, socio-economic and physical data	City-wide	■ Municipal Secretariat of Planning ■ Strategic Affairs and				Medium

Measure	Action	Targeted neighbourhoods (or broader locations)	Institutional responsibility	Schedule			Relative costs
				Short-term (1-5 years)	Medium-term (5-10 years)	Long-term (10-20 years)	
	Develop a computer-aided well-integrated system of data collection, monitoring and information dissemination		Development Ministry, Santos Prefecture ■ Civil Defense Department ■ Baixada Santista Housing Corporation (COHAB-ST)				
Improved budgetary resources and climate financing	Integrate climate risk reduction across the budgets and projects of government departments or crate a distinct budget for climate risk reduction	City-wide	■ Cross-municipal effort: all ministries and municipal departments.				High
	Identify and assess possible ways for climate finance, including through private sector contributions						
Formalized structures of cooperation with the private sector in planning and risk reduction	Inclusion of the private sector in flood and landslide risk management may involve the utilization of the financial and human resources of businesses	City-wide	■ Civil Defense Department ■ Private Sector				Low
	Identify and assess possible climate change adaptation solutions through Corporate Social Responsibility (CSR) schemes, for example in the tourism and port related industries						
Increased insurance mechanisms	Identify and assess possible market-based insurance products for individuals and communities, or businesses	City-wide	■ Strategic Affairs and Development Ministry ■ Baixada Santista Housing Corporation (COHAB-ST)				High
	Identify and assess possible micro-insurance schemes for low-income individuals and communities, or micro-businesses						
	Incorporate insurance mechanisms and priorities into the municipal						

Measure	Action	Targeted neighbourhoods (or broader locations)	Institutional responsibility	Schedule			Relative costs
				Short-term (1-5 years)	Medium-term (5-10 years)	Long-term (10-20 years)	
	housing strategy						

6.5 Conclusions

Climate change adaptation is a continuous process: the resilience of a city can be enhanced over time through various measures in different time-scales (short-term, medium-term, long-term).

The *Santos Strategic Climate Adaptation Investment and Institutional Strengthening Plan* presents an overview of measures that the city can implement to enhance disaster risk management and adaptation planning. This is done following a holistic approach that focuses on provision of infrastructure, such as drainage, on the one hand, and by taking into account local environmental, social and economic issues on the other hand, in order to address the complex challenges of socio-spatial development in Santos and BSMR.

For Santos we fully consider the potential for utilizing the output of this project for inclusion in current and future urban planning and management activities in Santos, notably the potential links with the World Bank-funded program Novos Tempos and the social housing programs financed by the Regional Housing Department for Baixada Santista (COHAB-ST) which incorporate components for guiding development in no-risk areas.

In particular, these programs aim to relocate people from high and very high landslide risk areas, as well as from the *palafitas* which are exposed to flooding. Key indicators of the Novos Tempos program include the provision of urban services to households in slum areas and the rehabilitation and improvement of the existing macro-drainage system in the Northwest Zone with sufficient capacity to handle 25-year flood levels, directly impacting its 90,000 residents.

In the hillside adjacent to the Northwest area, the Novos Tempos program includes preventive measures, such as construction of retaining walls and micro-drainage infrastructure, to avoid erosion caused by inadequate drainage in the hilly topography. Finally, the program includes 'greening' measures, such as planting of street trees and creating green spaces in the Northwest area, both as a means to enhance the attractiveness of the urban area and further promote tourism opportunities in the region, as well as provide additional surface area for infiltration and absorption of rainwater, thus helping decrease the flow of storm water into drainage systems.[21]

Overall, Santos has strong policy frameworks and planning systems for improving climate change adaptation and risk management. The city's systems for risk management are considered amongst the best in Brazil, with a strong focus on preparedness and risk reduction. This forward-looking approach offers a contrast to the largely reactive and response-led institutional frameworks for risk management found in the other four city sites for this study. The institutional framework is progressive in addressing the root causes of risk, but the overall approach to risk has, thus far, focused on planning for existing hazards and vulnerability, with little consideration of future climate variability and its potential impacts. The municipal outlook is now changing as the global import of climate change becomes clearer, reflecting an overall change in national priorities from a focus on mitigation to adaptation.

Actions decided and implemented in the present can play a central role in shaping the future exposure to climate hazards, such as floods and landslides. Understanding the linkages between conventional urban development and climate change adaptation is key in reducing climate-related vulnerability in Santos.

The main challenge for policy- and decision-makers is to implement a climate change adaptation process that considers the trade-offs between current development priorities and long-term climate risks and embraces uncertainty, as the timing and scale of local climate change impacts affects the types of measures to be adopted and prioritization of investments and action. In the end, the ability and willingness of key actors to address climate change impacts will be of utmost importance.

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ANNEXES

Annex 1 Methodology of Hazard Assessment

This analysis utilizes existing tools used by the Santos government to consider how flood and landslide hazards may change in the study area by mid-Century (2040s). To effectively inform future urban planning, it is important that our approach be appropriately aligned with the available local data and tools. The steps taken to consider how climate changes by the 2040s may impact the timing and frequency of future landslide and flood events included:

1. Review available information describing the physical system such as hydrology and geomorphology to understand the drivers that affect landslides and floods.
2. Collect and investigate data on past landslide and flood events in Santos to assess the degree of impact per event and the conditions that precipitate events.
3. Assess available resources used by the municipality to describe zones vulnerable to landslides and floods, and inform emergency planning.
4. Assess available future precipitation and temperature data for the 2040s.
5. Assessing and performing the application of three distinct approaches that consider how climate change may impact the resources investigated in Step 3.

Each step is discussed in greater detail below.

Step 1: Review the physical system. It is important to first understand the physical system specific to Santos that affects the nature and location of landslides and floods. A literature review was conducted to identify relevant thematic maps that describe the physical system. To investigate local climate, two data sources were analysed:

- WorldClim data was processed to develop a baseline of observed mean monthly precipitation and temperature (Hijmans et al., 2005). WorldClim data was generated through the interpolation of average monthly climate data from weather stations at a 1 km^2 resolution.[22]
- The Civil Defense provided daily precipitation observations from 1940 to 2012 for the station in Santos (02316279).

CODESP is responsible for the port and has long-term records of tide gage data. This data was not made available for this study; instead, the discussion of local sea level rise is based upon information provided in the scientific literature. The results of this step are presented in Section 2.3.

Step 2: Catalogue of past events. A collage of past flood and landslide events was compiled based on: (1) discussions with stakeholders during the field visit; (2) government reports; and (3) online material including local newspaper reports. This information was collected to explore answers to these specific questions: Do floods and/or landslides occur concurrently? Is the hazard more apt to occur during specific times of year? Is there regularity to the occurrence of the events or is the time series of events punctuated by a few events over a long time period? Answers to these questions helped illuminate the flood and landslide trends in Santos.

The results of this step are presented in Sections 2.4 and 2.5.

Step 3: Review resources that inform flood and landslide management. As this analysis is to inform planners, planning and emergency management, a survey of available information led to the collection of materials (e.g., maps, weather indicators) which are used by the local stakeholders to gage landslide and flood hazards. Incorporation of these tools allows this analysis to be developed drawing from sources of information that local planners are intimately knowledgeable with. In addition, these materials may have defined spatial and temporal scales for the precipitation data that were

[22]For observation data, this dataset uses a number of major climate databases such as the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, among others. It also uses the SRTM elevation database. The ANUSPLIN program interpolates noisy multi-variate data using thin plate smoothing splines (using latitude, longitude, and elevation as independent variables). At a minimum, averages were calculated for 1960 to 1990 where at least 10 years of data where available. After removing stations with errors, WorldClim used precipitation records from 47,554 locations.

deemed acceptable, and, as such, replicating future projections as close to the scales of data as possible ensures the results of this analysis are within an acceptable scale of uncertainty to inform future plans (understanding that working with climate projections introduces additional uncertainty as discussed in Step 4). A review was conducted to investigate if precipitation data informed these collective materials. For example: Is the flood and/or landslide early warning system triggered by a specific precipitation threshold? Were the flood and/or landslide hazard maps developed based on precipitation metrics?

For this analysis, the materials available include flood hazard maps, landslide hazard maps, emergency management, and stakeholder knowledge. The meteorological and oceanographic parameters used in these maps were identified.

Discussion of the findings of this step is presented in Sections 2.4 and 2.5.

Step 4. Assess climate projections. We reviewed sources that provide precipitation and temperature projections. For replicability across other cities and as no locally tailored data was available, data sources that provide global projections of climate were considered.

Considerations in identifying and developing appropriate projections. The following approach was adopted to develop robust projections from the available projections to inform this analysis (see Box 6 for term definitions and additional discussion of uncertainty in climate projections):

- **Time period:** The 2040s were chosen as the relevant time period for this analysis.
- **Spatial scale:** Statistically downscaled data were used supplemented by dynamically downscaled results from the literature. Given Santos topography and coastal location, downscaled data is preferred; however, it is not clear if the downscaled methodologies used produces additional accuracy in replicating today's climate.
- **Natural Variability:** To reduce this uncertainty, 30-year averages were used centered at the 2040s.
- **Model uncertainty:** To reduce the contribution associated with model uncertainty, projected change is calculated as an average for the climate model ensemble (i.e., the average values across all climate model results for a given emission scenario). This is consistent with the approach recommended by the broader community of climate scientists the most robust indication of how climate may change in the future when considering adaptation responses (Knutti et al., 2010). The maximum, and minimum projections from the individual climate models were also provided To illustrate the range of values projected across the climate models,
- **Scenario uncertainty:** Given it is unclear how global society may evolve over the coming decades, this analysis considers low (B1) and moderately-high (A2) greenhouse gas emission scenarios for developing potential futures.

Given the disagreement amongst climate models regarding the direction of future precipitation (i.e., will precipitation increase or decrease), additional tools were used to assess confidence in the climate model ensemble mean used in this analysis. The following ranking was applied (this example is based on a total of 15 climate models) to consider how many of the models agreed in the direction produced by the climate model ensemble average: "very high" if 13 or more climate models were in agreement, "high" if 11 or 12 climate models were in agreement, "medium" if between 6 and 10 climate models were in agreement, "low" if between 3 and 5 climate models were in agreement, and "very low" if less than 3 climate models were in agreement. This ranking was applied in our evaluation of precipitation projections in the 2040s where there can be strong directional disagreement across the models.

Box 8 Uncertainty in Climate Projections

There is considerable confidence in the capability of climate models to simulate temperature projections, particularly at the continental scale, but less confidence in climate models ability to project precipitation. This difference in confidence should be qualitatively considered when incorporating vulnerability and risk assessments results into future planning.

There are three main sources of uncertainty in climate model simulations:

1. Natural variability (the unpredictable nature of the climate system)
2. Model uncertainty (the ability to accurately model the Earth's many complex processes)
3. Scenario uncertainty (the ability to project future societal choices such as energy use)

The relative contribution of each uncertainty component to the climate model simulation's overall uncertainty varies with time. In the near term, Hawkins and Sutton (2009) suggest scenario uncertainty is relatively minimal while model uncertainty and natural variability are dominant contributors by near-term and mid-Century. These uncertainties also change relative to each other for projections on different spatial scales. Natural variability becomes a greater source of uncertainty at finer scales. This is one reason why incorporating downscaled projections expands the potential uncertainty in climate projections.

There are a few methods adopted within the climate modelling and impact science community to capture the breadth of uncertainty associated with each of the three main sources. To understand the uncertainty associated with natural variability, climate model results may be averaged over long-term periods of time (e.g., 30 years) or driven with variations in input data to simulate various sources of natural variability differently. A collection of results across climate models that rely on variations in parameterizations and other components within climate models can provide some breadth of the uncertainty component associated with climate models. And considering various emission scenarios reflecting differences in how our society may change in the future provide some degree of quantification of the scenario uncertainty.

Modelling the climate in Santos is particularly challenging given it’s a small coastal area surrounded by mountains. Global climate models are not at a fine enough resolution to include small-scale processes like local wind patterns. This suggests downscaled data may be preferred to capture smaller scaled processes.

Climate datasets used in the analysis. Two scenarios were developed for this analysis. For simplicity, this analysis refers to the climate model ensemble mean under the B1 emission scenario as Scenario 1 and the climate model ensemble mean under the A2 emission scenario as Scenario 2 (see Box 7).[23] These emission scenarios were chosen as they provided projections for low and moderately-high emission scenarios and were readily available from a number of sources across a number of climate models. For this analysis, all projections are considered equally plausible.

Box 9 Scenarios for this Analysis

Scenario 1. The climate model ensemble average under the low (B1) emission scenario

Scenario 2. The climate model ensemble average under the moderately-high (A2) emission scenario

Table A1.1 presents the climate projections considered for Santos. Projections under two emission scenarios were available including: low (B1) and moderately-high (A2) emission scenarios.[24] For this analysis, we collected two sets of projection data:

- Monthly projections of precipitation and temperature were gathered from Climate Wizard for the 2040s relative to a 1961 to 1990 baseline (Girvetz et al., 2009).[25] This data provides projections of 15 climate models under two emission scenarios.[26]
- Drawing from recent reports, projections of how rainfall events may change in the 2030s were also incorporated.

[23] The A2 emission scenario family has population that continuously increases and regional economic development with technology change more fragmented than other scenarios. The B1 emission scenario describes a global population that peaks in mid-century and declines thereafter, and an emphasis on global solutions to economic, social, and environmental sustainability (IPCC, 2007).

[25] Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), were downscaled as described by Maurer et al. (2009) using the bias-correction/spatial downscaling method (Wood et al., 2004) to a 0.5 degree grid, based on the 1950-1999 gridded observations of Adam and Lettenmaier (2003). This dataset is for the 2040s (averaged from 2030 to 2059) compared to a 1961 to 1990 baseline.

[26] As recommended by the scientific community, this analysis considers the average across model grid cells around the Santos study area (i.e., not just at the grid cell that overlays Santos). This increases the statistical confidence of the results (Girvertz et al., 2009).

Table A1.1 Catalogue of climate projections for the 2040s used for this analysis.

Dataset / Report	Precipitation Projections	Downscaled?	Spatial Resolution	Emission Scenarios	Climate Models
Climate wizard[27], a dataset *(Girvetz et al., 2009)*	Monthly (2040s)	Yes	0.5 degree	■ B1 ■ A2	15 global climate models used to inform the IPCC Fourth Assessment
Climate Change and Extreme Events in Brazil, a report *(Marengo, n.d.)*	Extreme precipitation	Yes	Regional results provided	■ A1B	Eta-CPTEC/ HadCM3

The projected changes in climate based upon these datasets are provided in Section 2.6.

Step 5. Assess approaches to consider climate change impacts on floods and landslides. As described below, we considered three approaches and tested the viability of implementing each one based on available information:

- **Approach 1.** This approach identifies and investigates the development of flood and landslide hazard maps used by local stakeholders in planning and emergency management. Any precipitation metrics used to develop the flood and landslide maps are identified. An analysis is done to quantify how these precipitation metrics may change in the future and a discussion of the implications of these changes on the frequency and/or intensity of future flood and landslide events is provided.
- **Approach 2.** Using regional meteorological events that have caused floods and/or landslides can be a useful approach in developing precipitation event thresholds. How floods and/or landslides may change in the future can then be investigated by looking at future daily precipitation projections to see how often these thresholds might be crossed in the future.
- **Approach 3.** When observational data and/or records are very limited, global datasets of precipitation projections can provide insight as to how changes in the nature of precipitation may impact future floods and landslides in Santos.

Table A1.2 provides a succinct discussion of each approach along with a description of the data requirements, the assumptions and limitations for applying the approach in the Santos study area. The level of detail in the findings for use by the municipality reduces from the first approach to the third approach, moving from a more quantitative analysis to one that is more qualitative. Given the constraints on the available information, we largely adopted Approach 1 supplemented with additional information from Approach 3 to investigate how landslides and floods may change in the future.

As this study was not intended as an intensive vulnerability and risk analysis, we did not consider a sophisticated and time-consuming model-intensive approach for Santos. This would include conducting hydrologic and hydraulic modelling driven by projected changes in precipitation to consider changes in the flood hazard. Additionally, analysis to better understand today's relationships between storm events and hazards could also be conducted. This, for example, could potentially provide a robust statistical relationship between storm events and landslides that could be used to tailor future precipitation projections to consider changes in future landslide hazards. The findings of our analysis based on the more simpler approaches, however, can provide guidance regarding the best use of funds for conducting such a vulnerability and risk analysis (e.g., which hazards are likely to worsen, are there potential hotspots where hazards may get worse, etc.) for Santos.

[27] http://www.climatewizard.org

Table A1.2 Description and considerations of approaches to investigate how changes in precipitation may impact floods and landslides in Santos.

Approaches to Investigate Future Changes in Floods and Landslides				
Approach	**Description**	**Requirements**	**Assumptions**	**Discussion/Limitations**
1. Identify precipitation metrics used in developing local flood and landslide hazard maps for local planners. Consider how these precipitation metrics may change in the future.	Investigate the methodology used to develop local flood and landslide hazard maps that inform local planners (e.g., 100 year flood, maps that identify areas that are prone to flooding, etc.). Determine what precipitation metrics were used in the map development. Identify appropriate source(s) for the projections of the precipitation metrics within the temporal and spatial resolution required and use these data to consider future change in hazard. In addition, through stakeholder discussions determine if additional anecdotal information or emergency flood and/or landslide warning systems are used and tied to precipitation thresholds.	■ Local flood hazard maps ■ Local landslide hazard maps ■ Information underlying the emergency flood warning systems ■ Information underlying the emergency landslide warning system ■ Local expertise in flood events ■ Local expertise in landslide events ■ Projections of identified precipitation metrics	The findings of this approach describing future conditions would not create new flood and landslide hazard locations. This method is constrained to consider whether the flood and landslide hazard locations identified by the flood and landslide maps are projected to intensify or lessen; though qualitative reasoning can be applied to broaden the identified future hot spots. As this analysis is intended to separate the climate change component from other influencing factors to consider how climate change may affect future hazard levels, it is assumed other future changes across the city remain static such as changes in land use, construction and maintenance in sewage/drainage systems, and housing.	Local stakeholders use flood and landslide maps as described in Sections 2.4, 2.5, and 2.6 to identify areas prone to floods and landslides. These maps are linked to meteorological and oceanographic thresholds that can be used in this analysis. The new drainage system in the Northwest is informed by the 100 year precipitation (mm/min) for events up to 240 minutes; however, using climate projections at this fine a temporal resolution would introduce a large amount of uncertainty.
2. Identify precipitation thresholds. Consider how these precipitation thresholds may change in the future.	Use past events described in research/academic/government literature and local newspapers to identify the dates of past flood and/or landslide events. Using these identified dates, construct a table with the daily precipitation observed at a local weather station. If there are enough events to consider, investigate the strength of the precipitation threshold(s) in predicting flood events (e.g., construct a	■ Collection of past flood events ■ Collection of past landslide events ■ Local meteorological data ■ Daily downscaled precipitation projections	This approach assumes that the identified precipitation thresholds represent a consistent indicator for floods and landslides. For example, if cumulative rainfall over a 5-day period is considered a reasonable indicator for a given hazard in today's climate, it is assumed it will	Observational data was not available to link past events with meteorological conditions and grey matter provided little discussion of the conditions leading to each event. Future work could include linking the past landslide and flood events on records with the precipitation amounts and storm surge to consider relevant meteorological and oceanographic thresholds. This option

Approaches to Investigate Future Changes in Floods and Landslides				
Approach	**Description**	**Requirements**	**Assumptions**	**Discussion/Limitations**
	scatterplot between precipitation and flood, investigate whether there were other days that crossed a specific precipitation thresholds but did not lead to flooding); similarly for landslide events. Use daily downscaled precipitation projections to consider how the frequency of the precipitation threshold(s) may change in the future.		still be a reasonable indicator under a potentially changed climate (i.e., the future stressor/impact relationships remain constant). As this analysis is intended to separate the climate change component from the other influencing factors to consider how climate change may affect future hazard levels, it is assumed other future changes across the city remain static such as changes in land use, construction and maintenance in sewage/drainage systems, and housing.	also is difficult to apply as it assumes daily downscaled precipitation data is available in a ready-to-use format for this analysis - this is not the case for Santos.
3. Construct / leverage future precipitation projections and qualitatively consider the impact on local flood hazard maps.	Identify sources of recent precipitation projections for Santos (i.e., projections developed ideally using modelling of IPCC AR4 or later) and the associated metrics (e.g., time periods, emission scenarios, climate models). Construct a catalogue of precipitation projections and determine the best projections to use for the flood and landslide analysis. Ideally, the data would include changes in annual, monthly, and daily precipitation. If daily is not available, then 'processed' projections that are available should be considered (e.g., changes in the 5-percentile of precipitation; changes in the 100 year precipitation return period).	▪ Precipitation projections	As this analysis is intended to separate the climate change component from the other influencing factors to consider how climate change may affect future hazard levels, it is assumed other future changes across the city remain static, including: land use, construction and maintenance in sewage/drainage systems, and housing.	The precipitation projections from recent reports were used to help supplement discussion of how climate may floods and landslides in Santos.

Annex 2 General description and associated risk of identified classes

Table A2.1 General description and associated risk of identified classes in Santos. Source: based on information provided in IPT (2012).

Class	Risk Level	Characteristics
Class VI	**R3/R4**	■ Areas explored for removal of material (e.g, quarries) ■ Evidence of scars of landslides, cracks in ground and houses ■ Areas with extremely irregular topography and locally cut by erosion and incipient occupation
Class V	**R2/R3/R4**	■ Steep slopes above, the area is the base of the slope generally thick and granulometry ■ Low consolidation of materials ■ Fragile areas potentially affected by dynamic upstream processes ■ High susceptibility to landslides triggered by concentration and infiltration of surface waters
Class IVa	**R2/R3**	■ Predominantly rectilinear slopes, with slopes between 30 and 40 degrees ■ Areas with shallow soils (1.5 m depth) ■ Rock exposures may occur locally ■ Presence of landslide scars ■ High susceptibility to mass movement processes ■ Prohibit occupation in this area
Class IVb	**R2/R3/R4**	■ Segments of straight slope and of slope greater than 40 degrees ■ Areas with steep slope are cut by landslide scars that may be occupied by banana trees, shrubs, and/or scrub vegetation ■ Predominantly characterized by rock exposures or thin soil (1.0m) ■ Strong evidence of instability ■ Potential for natural landslides is high due to the dynamic evolution of these slopes ■ Accelerated by anthropogenic factors
Class IIIa and IIIb	**R2/R3**	Segments of straight slope and of slope between 20 and 30 degrees Soil thickness may be less than 2.0 m Possibility of sliding caused by the concentration of surface water
Class IIb	**R2/R3**	■ Segments with concave or rectilinear slopes, with slopes less than 20 degrees, usually associated with accumulation zones ■ Mass movements are unlikely and are associated with detrital deposits which may occur with variable thickness and grain size ■ Segments of straight slopes may have erosion due to the removal of the top layer of soil (organic clay)
Class IIa	**R1/R2/R3**	■ Segments of straight or convex slope, with slope less than 20 degrees ■ Thicker soil (up to 10 m) ■ Subject to erosion due to the withdrawal of topsoil (organic clay) ■ Possibility of landslides on cutting embankment locations associated with removal of material

Annex 3 Data at neighbourhood scale

Area at Risk	Sector	Process	Likelihood level	No. of dwellings	Geotechnical Charter
ST-01 Jose Menino	ST-01-01	E	R3	81	IVa, IVb
	ST-01-02	E/S	R3	497	IVa, IVb
	ST-01-03	E	R2	45	IIIa, IIIb
	ST-01-04	E	R3	27	IVa
	ST-01-05	E	R3	59	IVa, IVb
Total				**709**	
ST-02 Santa Teresinha	ST-02-01	E	R3	59	IVb
	ST-02-02	E	R2	137	IVb
	ST-02-03	E	R3	11	IVb
Total				**207**	
ST-03 Marape II	ST-03-01	E	R4	17	IVb
	ST-03-02	E	R2	31	IIb
	ST-03-03	E	R3	47	IIIa, IVb
	ST-03-04	E	R2	83	IIIa
	ST-03-05	E	R3	263	IIIa
	ST-03-06	E	R2	69	IIa, IIIa
	ST-03-07	E	R3	92	IVa, IVb
	ST-03-08	E	R2	57	IVa, IVb
Total				**659**	
ST-04 Marape I	ST-04-01	E	R3	132	IIIb, IVa, IVb
	ST-04-02	E	R2	96	IIIa, IIIb, IVb
Total				**228**	
ST-05 Monte Serrat I	ST-05-01	E	R3	28	IIa, IVb
	ST-05-02	E	R2	179	IIa, IVb
	ST-05-03	E	R4	258	IVb
Total				**465**	
ST-06 Monte Serrat II	ST-06-01	E	R3	123	IVa, IVb
	ST-06-02	E	R2	59	IIa, IVb
	ST-06-03	E	R4	72	IVb
	ST-06-04	E	R2	46	IIIb
Total				**300**	
ST-07 Fontana	ST-07-01	E	R3	23	IIIb
	ST-07-02	E	R4	28	IVa, IVb
	ST-07-03	E	R2	17	IIIb
	ST-07-04	E	R3	18	IIIb, IVb
	ST-07-05	E	R4	04	IVb
	ST-07-06	E	R2	40	IIb

Area at Risk	Sector	Process	Likelihood level	No. of dwellings	Geotechnical Charter
	ST-07-07	E	R3	12	IIIb
	ST-07-08	E	R4	54	IIIb, IVb
	ST-07-09	E	R2	40	NA (no unstable slopes)
Total				**236**	
ST-08 Sao Bento Santas	ST-08-01	E	R2	09	IIa
	ST-08-02	E	R3	216	IIb, IIIb, IVa, IVb
	ST-08-03	E	R3	11	IIa, IVb
	ST-08-04	E	R2	348	IIa, IVa
	ST-08-05	E	R3	13	IVb
	ST-08-06	E	R3	121	IVb
	ST-08-07	E	R2	31	IIIa
	ST-08-08	E	R4	51	IVb
Total				**800**	
ST-09 Vila Sao Bento	ST-09-01	E	R2	319	IIa, IIb, IIIb, IV, IVa
	ST-09-02	E	R3	141	IIIb, IVa, IVb, Vb
Total				**460**	
ST-10 Pacheco	ST-10-01	E	R4	30	IIa, IIb, IVb
	ST-10-02	E	R3	500	IIa, IIb, IVb
	ST-10-03	E	R4	15	IVb
	ST-10-04	E	R2	327	IIb, IIIb
	ST-10-05	E	R3	08	IIIb
	ST-10-06	E	R4	77	IIIb, IVb
	ST-10-07	E	R2	100	IIa
Total				**1057**	
ST-11 Penha	ST-11-01	E	R4	53	IIIb, IVb
	ST-11-02	E	R3	19	IIIb
	ST-11-03	E	R2	360	IIa, IIb
	ST-11-04	E	R3	61	IIb, IIIb, IVb
	ST-11-05	E	R2	54	IIIa, IIIb
	ST-11-06	E	R3	14	IIIb
Total				**561**	
ST-12 Penha Lomba	ST-12-01	E	R2	274	IIa, IIb
	ST-12-02	E	R3	73	IIa, IIIa, IVb
	ST-12-03	E	R2	125	IVb
	ST-12-04	E	R4	96	IIIa, IVb
Total				**568**	
ST-13 Saboo	ST-13-01	E	R4	10	IIIb
	ST-13-02	E	R2	563	IIb, IIIa, IIIb, IVa

Area at Risk	Sector	Process	Likelihood level	No. of dwellings	Geotechnical Charter
	ST-13-03	E	R4	09	IIIa
	ST-13-04	E	R3	22	IVb
	ST-13-05	E	R3	04	IVb
Total				**608**	
ST-14 Sao Bento Santos	ST-14-01	E	R2	126	IIa
	ST-14-02	E	R3	15	IIa
	ST-14-03	E	R3	366	IIb, IIIb, IVb
	ST-14-04	E	R2	167	IIa
	ST-14-05	E	R2	13	IIa
Total				**687**	
ST-15 Sao Bento – Lindoia – Sao Roque	ST-15-01	E	R4	21	IVb
	ST-15-02	E	R2	445	IIa
	ST-15-03	E	R3	23	IIIb, IVb
	ST-15-04	E	R1	30	IIa
	ST-15-05	E	R3	74	IIa, IVa
	ST-15-06	E	R3	06	IVa
Total				**599**	
ST-16 Jabaquara	ST-16-01	E	R3	274	IIb, IIIb, IVb, Va, Vb, VIb
	ST-16-02	E	R2	253	IIb, Va
	ST-16-03	E	R2	28	IVb
	ST-16-04	E/S	R4	08	IIb
Total				**563**	
ST-17 Nova Cintra II	ST-17-01	E	R3	55	IIa, IVb
	ST-17-02	E	R2	106	IIa, IIIa, IVb
	ST-17-03	E	R3	05	IVb
	ST-17-04	E/S	R4	23	IVb
Total				**189**	
ST-18 Villa Progresso	ST-18-01	E	R2	507	IIIb, IVb
	ST-18-02	E	R3	172	IIIa, IIIb, IVb
Total				**679**	
ST-19 Nova Cintra I	ST-19-01	E	R2	471	IIa, IIIa
	ST-19-02	E	R3	33	IIIa
	ST-19-03	E	R3	22	IIa, IVb
	ST-19-04	E	R4	48	IIa, IVb, VIa
Total				**574**	
ST-20 Caneleira	ST-20-01	E	R3	232	IIa, IVb
	ST-20-02	E	R2	303	IIa, IIb, Vb
	ST-20-03	E	R2	59	IIa, IVb

Area at Risk	Sector	Process	Likelihood level	No. of dwellings	Geotechnical Charter
	ST-20-04	E	R2	34	IIa, Vb
	ST-20-05	E / S	R4	20	IIa, Vb
Total				**648**	
ST-21 Santa Maria I	ST-21-01	E	R2	122	IIa, IIIa
	ST-21-02	E	R3	174	IIb, IVb
	ST-21-03	E	R2	114	IIa, IVb
Total				**410**	
ST-22 Santa Maria II Curia	ST-22-01	E	R2	107	IIb, IVb, VIb
	ST-22-02	E	R3	17	IVb
	ST-22-03	E	R4	05	IVb
	ST-22-04	E	R4	32	IVb
	ST-22-05	E	R3	39	IIb, IVb, VIb
Total				**200**	

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