BC3 POLICY BRIEF

PB 2021-02
www.bc3research.org

REPORT

bc3
BASQUE CENTRE FOR CLIMATE CHANGE
Klima Aldaketa Ikergai

Sustainability, that's it!

COASTAL FLOODING AND EROSION UNDER CLIMATE CHANGE: A RISK ASSESSMENT FOR DAKAR

Authors: *Íñigo Aniel-Quiroga[1,2], Elisa Sainz de Murieta[1], Íñigo Losada[2], Alexandra Toimil[2], Saúl Torres[2], Ambika Markanday[1] and Andrea Briones[1]*

[1] Basque Centre for Climate Change (BC3).
[2] IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain.

1. Introduction

The African continent faces many socio-economic and environmental challenges. The concentration of population in urban areas is a global trend, but in developing countries, this implies increased hardships due to existing informal urban development, pollution and insufficient infrastructures and services to deal with a fast-growing population. Moreover, countries in West Africa suffer from severe coastal hazards, experiencing erosion rates above 1 metre per year in certain areas. This affects communities, livelihoods and infrastructures while hindering progress and economic growth. Climate change is expected to exacerbate this baseline situation (World Bank, 2013).

The Senegalese coastal area is not indifferent to these challenges and represents a clear example of vulnerability to the effects of climate change (DEEC, 2015). Indeed, it consists of a multitude of activities (economic, social, cultural) and specific ecosystems that are exposed to climate change, including coastal erosion. Exposure to these risks also increases the vulnerability of certain human settlements and coastal sites, which already face heavy marine intrusions in the form of flooding and tidal waves.

Studies on the vulnerability of Senegalese coastal areas to climate change (e.g., Dennis et al., 1995; Niang et al., 2010) have shown that rates of sea-level rise could lead to acceler-

HIGHLIGHTS

- Dakar is exposed to coastal erosion and flooding. These risks are expected to increase in the future due to climate change.
- The areas most at risk of coastal flooding are the canal of Ngor, the flat areas around the Port and the chemical industrial facilities (ICS) in Mbao.
- As for coastal erosion, the areas most at risk are the long beach of Hanika in the Grand Côte and the narrow beaches from Hann to Mbao.
- The population at risk of coastal flooding due to sea-level rise and extreme events is expected to increase by 20-30% in 2050 and by more than 80% in 2100 unless adaptation measures are implemented.
- Economic damages, in the absence of adaptation, could increase by 30% in 2050 and by 80% in 2100, considering a middle of the road sea-level rise scenario.

This policy report includes the main results of the risk assessment, which considers coastal flooding and erosion in the study area.

ated coastal erosion, flooding in low-lying coastal areas (especially mangrove estuaries) and increased salinization of soils as well as surface and ground waters.

This report is part of the Governadapt project, funded by the Basque Cooperation Agency and whose aim is to understand current and future coastal risks to support climate adaptation in Dakar. Governadapt addresses these goals by developing a coastal risk assessment that was next discussed in a participatory approach with stakeholders from the region. **This policy report includes the main results of the risk assessment, which considers coastal flooding and erosion** in the study area, comprised by three out of four departments of the Dakar Region, namely **Dakar, Pikine and Guédiawaye** (Figure 1).

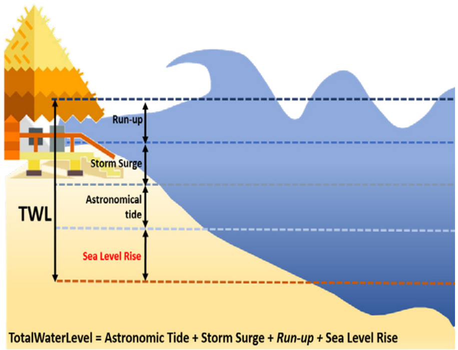
The assessment of coastal risks in Dakar has been developed based on the IPCC's risk framework, in which climate risk is the result of combining climate hazards, exposure and vulnerability (Figure 2). Climate hazard is the occurrence of potentially dangerous weather or climatic events. In the case of the Governadapt project, climate hazards are sea-level rise due to climate change and extreme storm surge leading to coastal flooding and erosion[1].

Finally, vulnerability is the propensity or predisposition for a system, person, asset or species to be adversely affected. Vulnerability is the result of diverse historical, social, economic, political,

Box 1. Components of total water level (TWL)

Coastal inundation occurs when the total water level (TWL) on the coast in any instant is higher than the land elevation of the coastal area. The TWL on the coast is the result of combining several components: tide, meteorology and breaking waves, as shown in the figure below. Eventually, projections of sea-level rise are an additional component that can also be added to the TWL to reflect future climate change scenarios.

Components of TWL:



- **Astronomical tide** refers to the periodic rise and fall in the level of the water in oceans and seas as a result of the gravitational attraction of the sun and moon and the rotation of the Earth.
- **Storm surges** lead to the rise in water level on an open coast due to meteorological reasons, the combined impact of the wind stress on the water surface, the atmospheric pressure reduction, decreasing water depth and the horizontal boundaries of the adjacent water.
- **Wave run-up** is the maximum onshore elevation reached by waves, relative to the shoreline position in the absence of waves.
- **Sea Level rise** due to climate change.

Figure 1. Dakar Region. The study area includes the departments of Dakar, Pikine, Guédiawaye (modified from Maximilian Dörrbecker's figure).

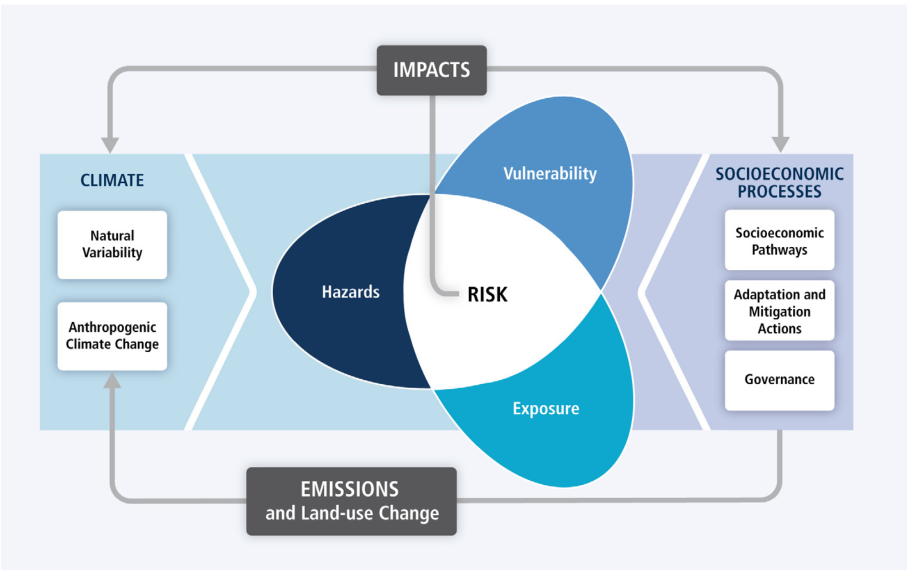


Figure 2. IPCC's risk assessment framework.

[1] *The methodological approach follows the methodology defined by Toimil et al. (2017). The data has been obtained from Perez et al. (2017) and Vousdoukas et al. (2016).*

cultural, institutional and environmental conditions and processes that influence the capacity to anticipate, cope with, resist and recover from the adverse effects of a hazard. The assessment of vulnerability was carried out through the use of vulnerability functions that describe the damage at a certain water depth of coastal flooding. The damage to buildings was obtained from Huizinga et al. (2017) and the population is considered to be "adversely affected" if flood depth is larger than 30 cm.

2. Modeling coastal risks in Dakar

Coastal risks are an existing problem of variable intensity along the coast of Senegal that will be exacerbated by climate change. In some areas of Senegal, like in Saint Louise and Rufisque (Ndour et al., 2018, Niang-Diop, 1995), the consequences of these hazards are already serious, and in some cases, unfortunately, a disastrous problem.

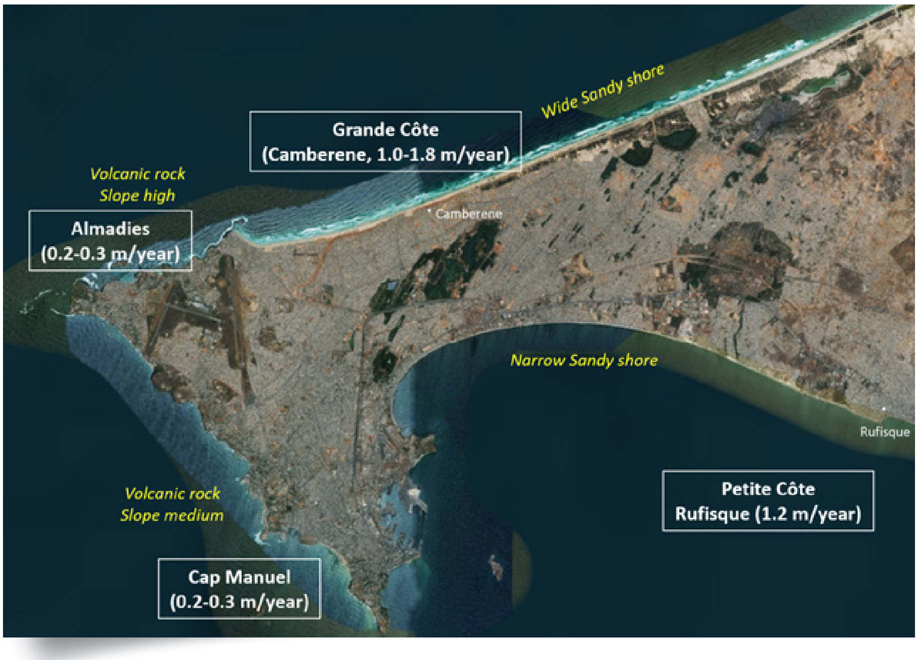


Figure 4: Current erosion rates from previous works in the region of Dakar. Source: Ndour et al., 2018; Niang et al, 2010; Birame Diadhiou et al, 2016; Faye et al (2010); Bakhoun et al (2017).

2.1. Coastal inundation

Coastal inundation in this report refers to saltwater floods caused by sea level, tides and storm surge combining to raise the ocean high enough to spread over adjacent land. The current coastal flood hazard in the Dakar region is shown in Figure 3. In general, areas at risk of flooding coincide with already existing water bodies that spread onshore due to the sea action. In addition, the extent of coastal inundation varies together with the typology of the coast. This is because the response of the coast is different in the Grand Côte, which is characterised by long sandy areas, the Petite Côte formed of successive series of small sandy areas and capes, and the Cap Vert rocky areas, consisting of mainly cliffs, with small beaches.

Figure 3. Current coastal flood risk in the Dakar region.

In the Grand Côte, from Malika to Yoff, the existing long open beach and dunes work to protect the coast and are currently able to defend it from flooding. Only in the cape in front of Yoff Islands, where the land is flat and used by local fishermen to leave their boats, does relevant flooding occur.

Between Yoff and the limit of Cap Vert (the westernmost point of Africa's mainland), the coast is characterized by an irregular shape, with rocky areas and small pocket beaches. In this area, no relevant flooding is observed. The only exception is the coastal area of Ngor where the canal represents a potential entrance point for the waves to penetrate and flood the surrounding urban area. On the west coast, from Ngor to Cap Manuel, the existence of cliffs and rocky areas in the first few meters behind the coastline keep the area safe from flooding.

The Port of Dakar, as is common for these kinds of critical infrastructures, is located in a very flat area. Consequently, in the case of an extreme event reaching the port level, the surrounding areas could be flooded. In the north of the port, the flattest areas of Bel Air are flood-prone as well.

From there to Cap Des Biches, at the border with Rufisque, there is a succession of narrow sandy areas. In Hann, the water finds a way to penetrate onshore in some places, but inundation is not signif-

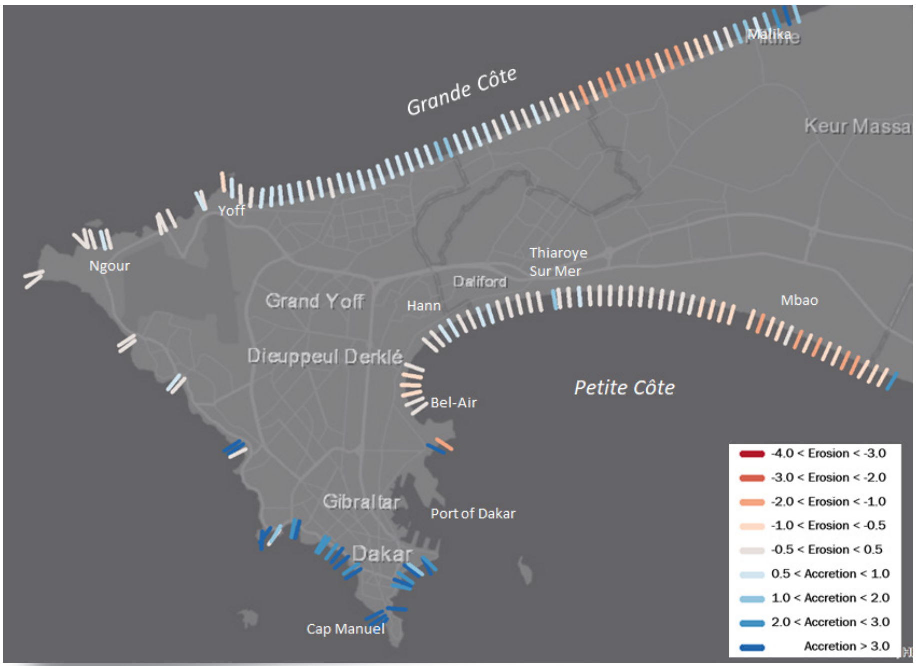


Figure 5. Estimates of current erosion in the Dakar region.

icant. In Thiaroye Sur Mer, the built area is so close to the shoreline that any small amount of flooding has the potential to be significant. Finally, the Mbao beach and flat areas around the chemical industrial facilities (ICS), represent places where the action of incoming waves in cases of extreme events could affect the surrounding areas.

2.2. Measuring coastal erosion

Coastal erosion, or shoreline retreat, is the loss of coastal lands due to the net removal of sediments or bedrock from the shoreline. Erosion can be either a rapid-onset hazard that occurs very quickly, in a period of days to weeks; or a slow-onset hazard, occurring over many years, or decades to centuries. Coastal erosion is the result of a natural process that occurs whenever the transport of material away from the shoreline is not balanced by new material being deposited onto the shoreline. Erosion results in a changing position of the shoreline.

The problem of coastal erosion has been widely described in Senegal. There are areas, like Saint Louis and Rufisque (Niang-Diop, 1995; Bâ et al., 2007), in which erosion is a critical issue, but Dakar is not indifferent to this problem. In Dakar, coastal erosion has been studied extensively. See, for example, the thesis by Faye (2010) or the more recent work by Bakhoun et al. (2017, 2018). The World Bank has also developed several assessments within the West Africa Coastal Areas Management Program (WACA). These previous works reveal an overall recession of the coast that ranges between 0.5 and 2 m (Figure 4). Governadapt builds on all of these valuable works and updates the analysis applying a state-of-the-art methodology (Toimil et al., 2020), widely validated numerical models (Miller and Dean, 2004), and currently available data (Vitousek et al., 2018).

The current state of coastal erosion has been evaluated by analysing satellite imagery, focusing on the position of the shoreline from year to year at locations every 300 m along the sandy beaches of the coast of Dakar. With that information, the erosion and accretion trends along the coast across the different years were obtained (applying DSAS, Himmelstoss et al., 2018). Results for the current erosion rates are presented in Figure 5, where each bar represents a profile and its colour describes the state of erosion or accretion[2], as well as the annual rate in meters.

The results expose a relevant erosion trend in Guediawaye, which diminishes towards Yoff. Based on the satellite imagery analysis, the sandy areas between Yoff and Cap Manuel are more stable. From the port to the border with Rufisque, along the coast of Pikine, accretion and erosion appear mixed in the area from Hann to Mbao, depending on local conditions and coastal typology.

The origin of these changes on the coastline is both natural and anthropogenic. On one hand, natural processes can appear due to sea-level rise, sand deficit, etc. On the other hand, anthropogenic processes are due to sand extraction from beach areas, inadequate design, urban planning, etc. These processes are linked to massive coastal occupation and also affect other hazards, for instance, triggering problems of salt intrusion.

Finding the origin of the erosion (natural or anthropogenic) is essential to understanding the evolution of an area,

Figure 6. Anthropogenic origin of the erosion in Mbeubeuss (SEYLLOU/AFP via Getty Images). Source: Google Earth.

Figure 7. Thiaroye Sur-Mer. The construction of a breakwater leads to an accretion zone that has been urbanised. Source: Google Earth.

[2] *Accretion refers to the opposite of erosion, the process of coastal sediment on a beach.*

at a local scale, and helps to determine the causes of the erosion in order to act adequately. For instance, according to satellite photographs, the Mbeubeuss area appears to be subject to irregular erosion, since the dry beach is narrower and different from the surrounding areas. The evidence (Figure 6 below) suggests that erosion is caused not by natural events but by the extraction of sand for construction works (Figure 6). In Thiaroye sur Mer the net sediment transport eastwards is retained by the constructed breakwater, diminishing the sand availability on the east, and increasing deposition on the west. The result is a newly generated area caused by accretion triggered by the breakwater, which has then been urbanised (Figure 7).

3. Mapping coastal inundation and erosion under climate change

Sea-level rise due to climate change sets a new baseline wherein the waves and tides can increase, exacerbating coastal inundation. The way to account for future climate change is done by using climate scenarios, each one of them is defined by certain parameters that derive an associated Total Water Level (see Box 2). The combination of these parameters provides a range of cases, from most optimistic to most pessimistic. In other words, each scenario is reflected on the components of the Total Water Level (see Box 1) and it translates into a certain hazard level, which in turn implies different coastal inundation and erosion outcomes. No future socio-economic scenarios have been considered in the assessment.

3.1. Coastal flooding under climate change

Future coastal flood risk was obtained following the combination of the parameters presented in Box 2. Some results for coastal flood risk are depicted in Figure 8: (i) Baseline, as presented in section 2; (ii) coastal flood risk in 2050, which accounts for an extreme event with a return period of 100 years; (iii) a scenario for the year 2100 considering the middle-of-the-road scenario (RCP4.5); and (iv) a scenario for the same year (2100) considering the worst scenario (RCP8.5), including the effect of a 100-return period.

Box 2. Selecting climate change scenarios

Several parameters have been considered to estimate coastal flooding and erosion under future climate change: the evolution of CO_2 emissions, the year in which the situation is assessed, and the coincidence of extreme events, such as storm surges.

Representative Concentration Pathways

Representative Concentration Pathways (RCPs) represent a range of possible future emission trajectories over the century, which correspond to a certain increase of the level of total radiative forcing (W/m^2) in the year 2100 with respect to the preindustrial period.

In Governadapt, two RCPs, which account for two different CO_2 emission pathways, have been applied: RCP4.5, which is a medium-low emission scenario that can be considered a middle-of-the-road pathway. The second scenario is RCP8.5, which considers that emissions continue to rise throughout the 21st century. RCP8.5 is commonly recognized as a worst-case scenario. Note that until 2050, differences across RCPs remain small. From 2050 onward, pathways diverge and this difference increases with time.

Sea-level rise projections

Projections for climate-induced sea-level rise under RCP4.5 and RCP8.5 were taken from Vousdoukas et al. (2017).

Time horizon of the assessment

Two-time horizons were considered in the Governadapt project: one until the year 2050, which provides information that can support adaptation planning in the short to mid-term, and the other until the year 2100, which allows understanding the potential evolution of sea-level rise and coastal flooding in the long run.

Extreme event return period

Extreme events are commonly featured by what is called a return period (TR). Return periods estimate the time interval between events of a similar size or intensity. For example, an extreme storm event with a 50-year return period can be expected to happen once every 50 years.

Figure 8. Coastal flooding (in blue) in 2050 and 2100 under different climate change scenarios and compared to the baseline (current flood risk).

The total population living within the calculated flood-prone areas was estimated for the current situation and future scenarios.

Focusing on the same areas affected by current risks (baseline), the potential floods observed on the Grand Côte are not severe, even in the worst-case scenario. In this area, the long beach acts as a barrier which is able to adequately stop flooding. The presence of dunes in some areas strengthen this protective performance of the coast.

In the area of the Canal of Ngor, the effect under extreme conditions, linked to extreme return periods, becomes more and more significant, wherein flooded areas become larger as scenarios become more severe. While this trend is seen all along the coastline, it is more prevalent in flat areas.

In the case of the Port of Dakar, although the affected area increases with more severe scenarios, flooding does not increase as much as in the case of the Ngor Canal. The elevation of the areas surrounding the port facilities is higher and therefore is harder reached by the action of the sea. The flood extent does not increase as in other areas, even under the most extreme scenario.

Finally, in the area of Mbao, flooding follows the very same pattern. Flooding takes advantage of the already existing water bodies to penetrate inland. This phenomenon is exacerbated under the worst case scenario, where the affected area spreads to the surrounding areas of those water bodies.

3.2. Coastal erosion under climate change

Following the same principle as in the case of coastal inundation, the future scenarios of coastal erosion are estimated considering the waves and tides until a certain year, incorporating sea-level rise projections. As a result, Figure 9 presents

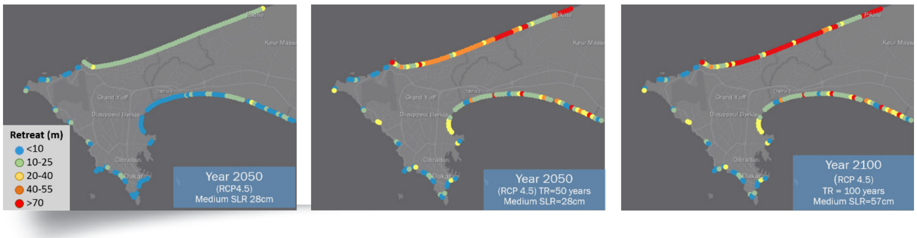


Figure 9. Coastal erosion in 2050 and 2100 under different climate change scenarios.

the total retreat that would occur under various climate change scenarios. Total retreat refers to the distance that the shoreline retreats under a given scenario under each analysed profile.

In 2050, under the middle-of-the-road scenario (RCP4.5) the Grande Côte displays larger net retreats. In the Petite Côte, the retreat is not as large but there are certain areas where the beach width is very narrow, thus, certain small retreats can result in a high percentage of the beach lost (Figure 9, top left).

The second scenario considers the effects of a 50-year return period extreme event, in addition to sea-level rise (Figure 9, top right). In terms of erosion, a return period of 50 years is extremely high, meaning that erosion increases substantially. In a coastal erosion assessment like this one, potential anthropogenic actions and specific local effects, like those observed in Figures 6 and 7 cannot be included in the analysis, and therefore, the main result is the general natural trend observed at this regional level. The third map (Figure 9, bottom) presents the situation with a return period of 50 years (extremely high) and a time horizon until 2100 (instead of 2050). The observed trend is a reduction in beach extension, specifically in the areas where the beach width is not very large, such as in the Petit Côte.

4. Estimating population at risk and economic damages due to coastal flooding

Once the analysis of the coastal hazards has been developed and flood maps are available, the population exposed to such coastal risks can be estimated, as well as the monetary damage resulting from flood risk.

4.1. Population exposed to coastal risks

The total population living within the calculated flooded areas was studied for both the current situation (baseline) and the different climate change scenarios considered. Under the current situation, results show that the total affected population due to coastal inundation in Dakar could be between 1500 and 2000 people per year, out of a population of 2.98 million[3].

1500-2000
Affected people annually
By coastal flooding

Comparing the affected population across climate change scenarios, the number of people affected by coastal inundation in Dakar is expected to increase

Increase of 20% by 2050...

80% in 2100...

170% in 2100 in the worst scenario.

Figure 10. Expected annual affected population across the same four scenarios considered in the coastal inundation assessment.

[3] *World Urbanization Prospects 2018*

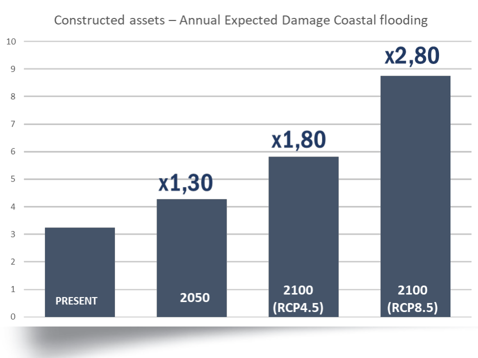
by 20 % in 2050, and between 80% and 170% in 2100, depending on the severity of future climate change.

4.2. Coastal flood risk and economic damages

Current expected annual economic damage to buildings was obtained by superimposing the calculated flooded areas and the constructed stock information, independently of the building types, that is available through the UNISDR global exposure dataset of the built environment. Results suggest a total annual average economic damage of approximately 3-4 million USD. This calculation is based on the baseline coastal risk together with the evaluation of extreme events, by means of return periods.

3-4 M USD
stock constructed annually damaged
by coastal flooding
AED

Comparing the economic damage across climate change scenarios, an increase of 30% is observed by 2050. By the end of the century, expected damages could increase between 80% and 180% depending on the sea-level rise scenario and assuming no adaptation is undertaken (Figure 11).



Increase 30% in 2050...

del 80% in 2100...

del 180% in 2100 in the worst scenario.

Figure 11. Annual expected economic damage (M$) for the baseline and future climate change scenarios.

It is important to note that using global databases for population and buildings presents some limitations, particularly with regards to the accuracy of the specific values. Nonetheless, they can provide relatively good approximations that allow us to understand the magnitude, frequency and trends of climate change impacts. Moreover, these kinds of analyses allow us to understand how damages evolve as climate change becomes more severe.

Damaged stock (M$)				
Return period	Present	2050 RCP 4.5/8.5 Medium SLR	2100 RCP 4.5 Medium SLR	2100 RCP 8.5 Medium SLR
25	40-45	58-62	79-83	120-124
50	45-50	60-64	81-85	122-126
100	46-51	61-65	83-87	125-129

Figure 12. Damage (M$) for the baseline and future climate change scenarios under several return periods.

In this sense, results show that an event with a 100-year return period under the baseline is expected to occur more frequently in the future, once every 25 years by the year 2050, with damages almost doubling by the year 2100.

Concluding remarks

Coastal flooding and erosion are serious problems in many areas of Senegal, including the region of Dakar and climate change is expected to exacerbate this risk. The results presented in this report should be considered as conservative estimates. If other aspects are taken into account, such as population growth, economic growth in the region and future urban developments, then the overall affected population and level of economic damage can be expected to be much higher than these estimates suggest.

These results are a preliminary step to support the design of flood risk management strategies. The development and application of potential adaptation strategies, pathways and measures are key factors that has the potential to modify the trends presented in this report. By understanding the impacts, reducing exposure and vulnerability, we are able to reduce the risk. While adaptation cannot reduce the severity of a storm, it has the ability to diminish its consequences, reducing the number of affected people and the economic damage. Developing adequate adaptation strategies will entail compromise among all stakeholders: citizens, local regional and national governments, public and private sectors, etc.

The methodology and results presented here are replicable in other African cities and scalable to other levels of government.

Acknowledgements

We are very grateful to the Ville de Dakar, our institutional partner in the region, for its support during the development of the project. We would also like to acknowledge the technical support received from our partner in Dakar, the Centre de Suivi Ecologique (CSE), and, particularly, from Ousmane Bathiery.

Detailed information on references and methodology can be found in Aniel-Quiroga et al (Forthcoming).

Data repository: Governadapt project results, including GIS files are available under request in Zenodo. https://doi.org/10.5281/zenodo.4749593.

Disclosure of the use of these data: Note that the estimates are inherently uncertain due to the uncertainties in climate projections, the economic risk model applied and the input data. Thus, the actual figures should not be interpreted as predictions of future impacts for Dakar, but as a reference of the trends of sea-level rise and its associated impacts.

References

- Bâ, K., Wade, S., Niang, I., Trébossen, H., & Rudant, J.-P. (2007). Cartographie radar en zone côtière à l'aide d'images multidates RSO d'ERS-2: application au suivi environnemental de la Langue de Barbarie et de l'estuaire du fleuve Sénégal coastal zone radar mapping with multitemporal ERS-2 SAR data: application to the environmental monitoring of the Langue de Barbarie sand spit and the Senegal river estuary.
- Bakhoum, P. W., Ndour, A., Niang, I., Sambou, B., Traore, V. B., Diaw, A. T., Sambou, H., & Ndiaye, M. L. (2017). Coastline Mobility of Goree Island (Senegal), from 1942 to 2011. 7(1), 1–9.
- Bakhoum, P. W., Niang, I., Sambou, B., & Diaw, A. T. (2018). A peninsula in coastal erosion ? Dakar, the Senegalese capital city facing the sea level rise in the context of climate change. EWASH & TI JOurnal, 91–108. Dennis, K. C., Niang-Diop, I., & Nicholls, R. J. (1995). Sea-Level Rise and Senegal: Potential Impacts and Consequences. In Journal of Coastal Research (pp. 243–261). Coastal Education & Research Foundation, Inc.
- DEEC, Direction de l´Environnement et des Établissements Classés, 2015. Troisième Communication Nationale du Sénégal. À la Convention Cadre des Nations-Unies sur les Changements Climatiques (National Communication No. 3). Ministère de l´Environnement et du Développement Durable (MEDD), Dakar.
- Dennis, K. C., Niang-Diop, I., & Nicholls, R. J. (n.d.). Sea-Level Rise and Senegal: Potential Impacts and Consequences. In Journal of Coastal Research (pp. 243–261). Coastal Education & Research Foundation, Inc.
- Durand, P., Anselme, B., & Thomas, Y.-F. (2010). L´impact de l´ouverture de la brèche dans la langue de Barbarie à Saint-Louis du Sénégal en 2003: un changement de nature de l´aléa inondation ?The impact of the opening of the breach in the Langue de Barbarie (Saint-Louis du Senegal) in 2003: a change of flood hazards nature? Cybergeo.
- Enríquez-de-Salamanca, Á. (2020). Evolution of coastal erosion in Palmarin (Senegal). Journal of Coastal Conservation, 24(2), 1–11.
- Faye, I. (2010). Dynamique du trait de côte sur les littoraux sableux de la Mauritanie à la Guinée-Bissau (Afrique de l'Ouest): Approches régionale et locale par photo-interprétation, traitement d'images et analyse de cartes anciennes.
- Huizinga, J., Moel, H. de, & Szewczyk, W. (2017). Global flood depth-damage functions: Methodology and the database with guidelines. In JRC.
- IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.
- Miller, J. K., & Dean, R. G. (2004). A simple new shoreline change model. Coastal Engineering, 51(7), 531–556.
- Ndour, A., Laïbi, R. A., Sadio, M., Degbe, C. G. E., Diaw, A. T., Oyédé, L. M., Anthony, E. J., Dussouillez, P., Sambou, H., & Dièye, E. hadji B. (2018). Management strategies for coastal erosion problems in west Africa: Analysis, issues, and constraints drawn from the examples of Senegal and Benin. Ocean and Coastal Management, 156, 92–106.
- Niang, I., Dansokho, M., Faye, S., Gueye, K., & Ndiaye, P. (2010). Impacts of climate change on the Senegalese coastal zones: Examples of the Cap Vert peninsula and Saloum estuary. Global and Planetary Change, 72(4), 294–301.
- NIANG-DIOP, I. (1995). L´érosion sur la petite côte du Sénégal à partir de l´exemple de Rufisque. Passé - Présent - Futur [UNIVERSITE D´ANGERS UFR: ENVIRONNEMENT].
- Perez, J., Menendez, M., & Losada, I. J. (2017). GOW2: A global wave hindcast for coastal applications. Coastal Engineering, 124, 1–11.
- Toimil, A., Camus, P., Losada, I. J., Le Cozannet, G., Nicholls, R. J., Idier, D., & Maspataud, A. (2020). Climate change-driven coastal erosion modelling in temperate sandy beaches: Methods and uncertainty treatment. In Earth-Science Reviews (Vol. 202, p. 103110). Elsevier B.V.
- Toimil, A., Losada, I. J., Camus, P., & Díaz-Simal, P. (2017). Managing coastal erosion under climate change at the regional scale. Coastal Engineering, 128, 106–122.
- Vousdoukas, M. I., Voukouvalas, E., Annunziato, A., Giardino, A., & Feyen, L. (2016). Projections of extreme storm surge levels along Europe. Climate Dynamics, 47(9–10), 3171–3190.
- World Bank. (2013). Economic and Spatial Study of the Vulnerability and Adaptation to Climate Change of Coastal Areas in Senegal.

GARAPENERAKO LANKIDETZAREN EUSKAL AGENTZIA
AGENCIA VASCA DE COOPERACIÓN PARA EL DESARROLLO

EUSKO JAURLARITZA GOBIERNO VASCO
BERDINTASUN, JUSTIZIA ETA GIZARTE POLITIKETAKO SAILA
DEPARTAMENTO DE IGUALDAD, JUSTICIA Y POLÍTICAS SOCIALES

This work has been developed with the financial support of the Basque Cooperation Agency, eLankidetza.

bc3
BASQUE CENTRE FOR CLIMATE CHANGE
Klima Aldaketa Ikergai

Sustainability, that's it!

*BC3 Policy Briefs report on research carried out at BC3 and have received only limited review. Views or opinions expressed herein are responsibility of the authors and do not necessarily represent those of the Basque Centre for Climate Change. BC3 Policy Briefs are available on the internet at **http://www.bc3research.org/policybriefings.***

EUSKO JAURLARITZA GOBIERNO VASCO
HEZKUNTZA SAILA
DEPARTAMENTO DE EDUCACIÓN

EXCELENCIA MARÍA DE MAEZTU
jul. 2018 - jun.2022

AGENCIA ESTATAL DE INVESTIGACIÓN

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES