Coastal risks in the Saloum Delta (Senegal) in a context of climate change: focus on Bétenty

Source: Think Tank “INTERFACE” of the Cheikh Anta Diop University of Dakar (UCAD) on climate finance

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This group was established following several discussions between researchers, public and private stakeholders. The group's leader is Professor Alassane SARR, director of the University Institute of Fisheries and Aquaculture (IUPA) at UCAD. The group is composed of 15 people, including five women. The group also includes several young researchers (doctoral and postdoctoral students).

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1 Introduction

The Bettenty Islands (or Bétanti, or Bétenty) are located 250 km south of Dakar, on the Petite-Côte, in the Saloum Delta (Figure 1). It is an archipelago of islands bordered to the north by Diomboss, to the west by the Atlantic Ocean, to the east by the forest and classified as a

Saloum Island, and to the south by Gambia. These islands are part of the Saloum Delta Biosphere Reserve (BDBR), and remain exposed to coastal risks, in a context of climate change. In order to study the risks of coastal erosion and marine submersion, the multi-decadal coastal dynamics are characterized, in a first step, before estimating, in a second step, the retreat of the shoreline and the levels of marine submersion induced by Sea Level Rise (SLR), by 2060, under the SSP5-8.5 scenario (fossil fuel-based development) of the IPCC AR6.

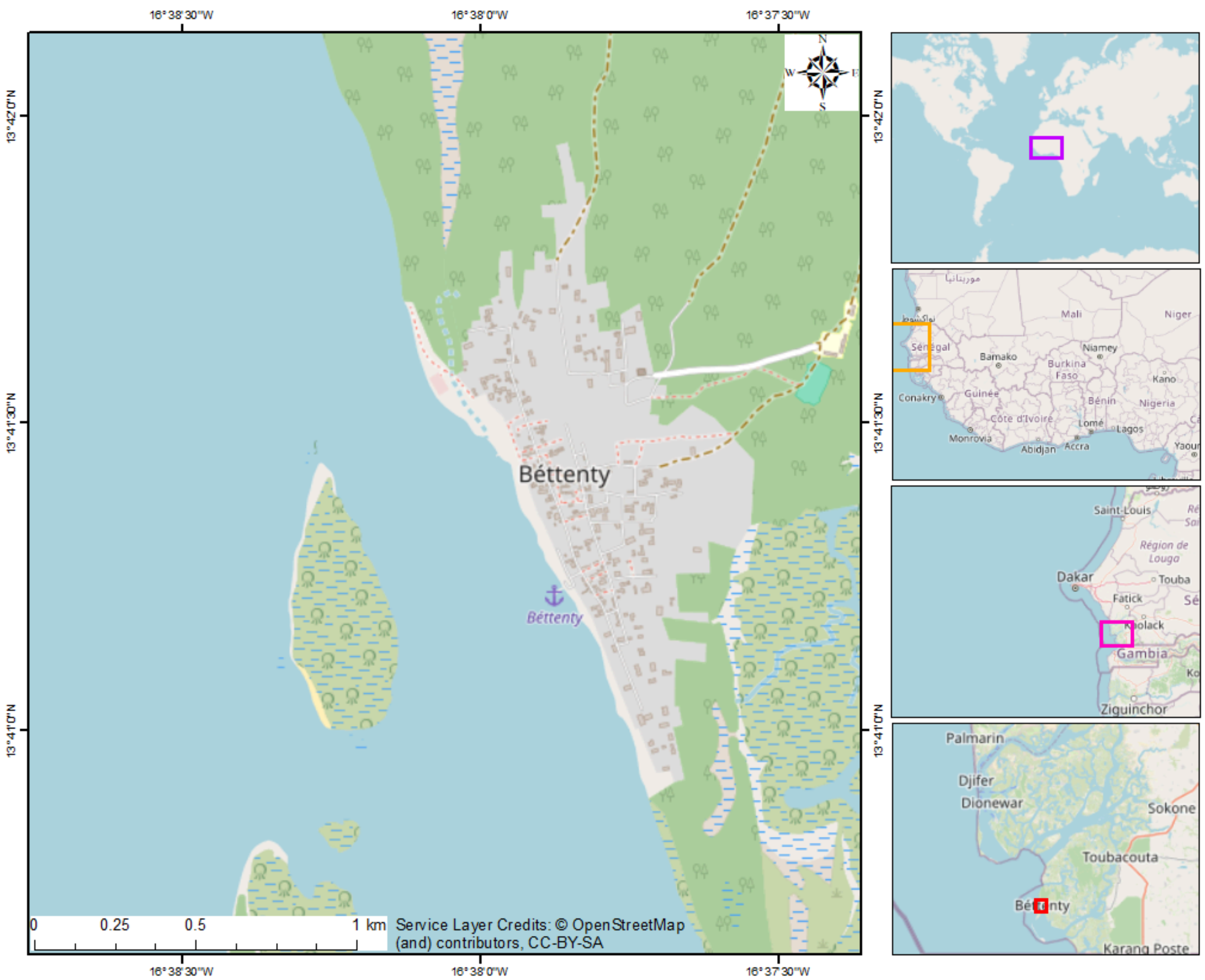

Figure 1: Study site

2 Methodology

2.1 Multi-decadal coastal dynamics

The characterization of coastal dynamics is based on an approach using remote sensing, geographic information systems (GIS) and statistical analysis, using ArcGIS GIS software and the application of the softwareDigital Shoreline Analysis (DSAS), with material mainly composed of LANDSAT satellite images.

Thus, after the production of composite strips, the execution of RGB (Red, Green, Blue) color compositions, the enhancement of the dynamics and the geometric verification of the satellite images, the instantaneous shorelines were subsequently extracted by digitalization from the GIS software ArcGIS. This was followed by a statistical analysis of the dynamics of the shoreline through the DSAS, with the calculation method *Linear Regression Rate* (LRR) or linear regression rate which is the most robust method for measuring historical trends in coastline evolution (FENSTER et al., 1993).

2.2 Shoreline retreat induced by Sea Level Rise (SLR)

To estimate the coastal retreat caused by Sea Level Rise (SLR) by 2060, BRUUN's law (1962) was used:

$$R = S*G*L / (b + h)$$

where R is the retreat due to sea level rise, S is the sea level rise, G is the proportion of eroded material that remains in the active profile, L is the width of the active profile, b is the dune height, and h is the closure depth.

This Bruun rule is the most applied method (e.g. EUROSION, 2004; Cowell, 2006; Hinkel and Klein, 2009; Zang et al., 2004) to assess shoreline retreat caused by sea level rise (Yates-Michelin et al., 2011). It has been used in Senegal by Niang-Diop (1995), Niang et al. (2005), SADIO et al. (2019) and SAKHO et al. (2022).
Bruun's law is applied from S = 0.33 m (scenario SSP5-8.5: development based on fossil fuels); G = 1 (when the sediments are sands (Niang et al., 2005); h = 5.56 m; and L = 1831.

2.3 Assessment of the level of marine submersion

One of the first consequences of sea level rise is the increase in flood risk associated with storm surges in low-lying coastal areas. Nicholls et al. (1999) defined the risk zone as the land area between the shoreline/coastline and the maximum expected water level. It can be calculated using the equation of Hoozemans et al. (1993):

$$Dft = MHW + St + Wf + Pf$$

where Dft is the flood level, MHW the mean high water level, St the relative sea level rise, Wf the storm wave height and Pf the sea level rise due to a lowering of atmospheric pressure.

The mean high water level (MHW) is obtained from hourly data from the Dakar tide gauge, in particular station 223. It is 1.38 m. The relative sea level rise (St) by 2060 at the study site is estimated at 0.33 m., from NASA IPCC AR6 Sea Level Projection Tool. Regarding storm wave height (Wf), three different wave climates relative to the study area were used:

- a swell climate from ERA5 data over 40 years (from 1979 to 2019), with storm swells of 2.60 m to 3.75 m (Sakho, 2020);
- a swell climate resulting from Wave Watch III (ww3) data, with a storm swell of 4 m; and
- a swell climate used by Dwars, Heederik and Verhey Ingenieurs Conseils (1979), SOGREAH Ingénieurs Conseils (1981), Nardari (1993), Gueye (1997) and Niang et al. (2005), whose storm swell reaches 6.2 m, with a return period of 1/100.

The rise in sea level due to a lowering of atmospheric pressure (Pf) remains negligible in Senegal (Niang et al., 2005).

2.4 Estimation of areas at risk of marine submersion and environmental and socio-economic impacts

To identify areas at risk of marine submersion and their potential environmental and socio-economic impacts, the resulting submersion levels were extracted from a Digital Elevation Model (DEM) with a resolution of 1 arc second (approximately 30 m). The exposed areas were then overlaid on the ESRI Imagery base map.

3 Outcomes

3.1 Multi-decadal coastal dynamics

The multi-decadal dynamics of the coastline show erosion along the entire coastal line of Bettenty, with rates varying from -0.16 to -3.05 m/year (figure 2).

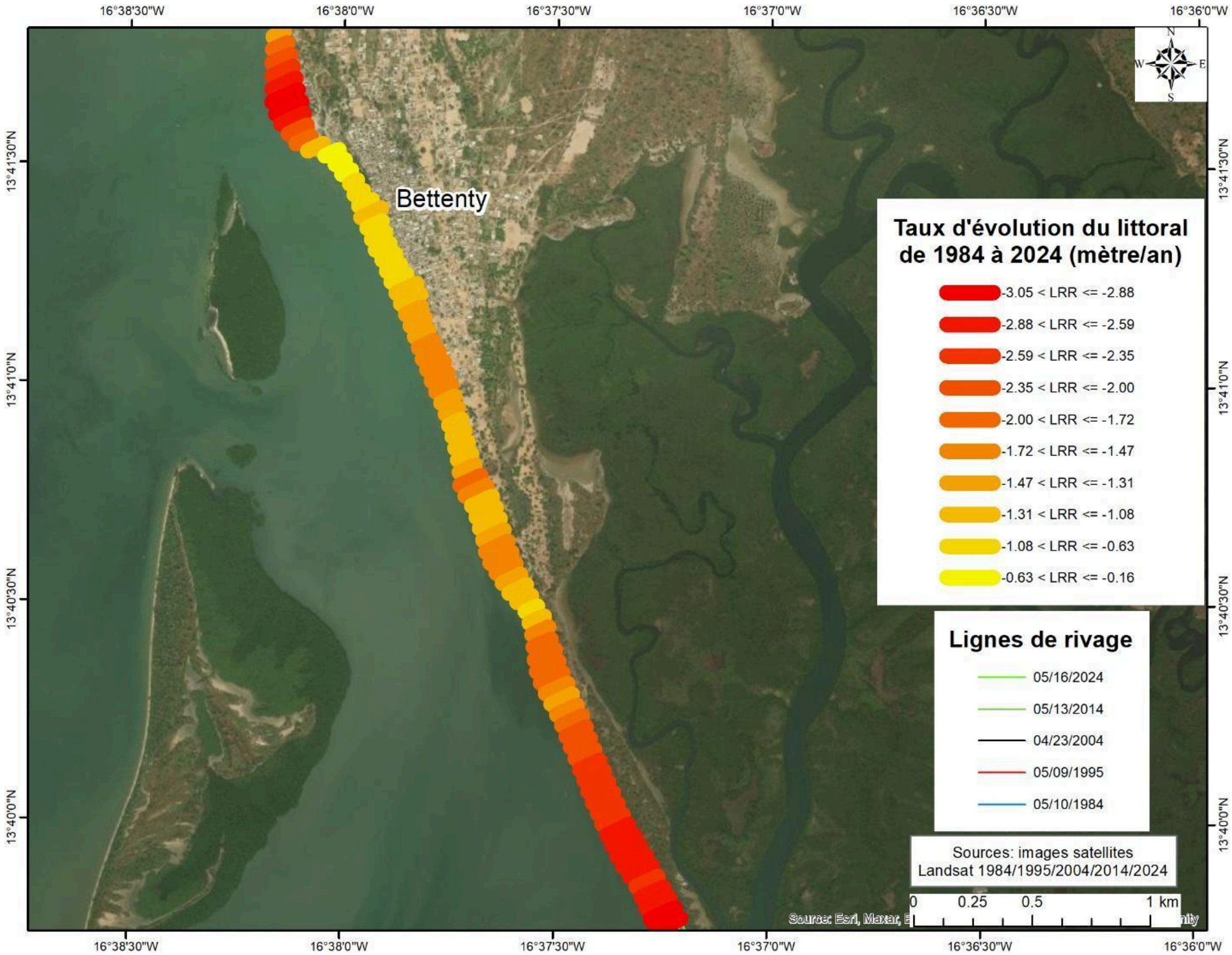

Figure 2: Dynamics of the Bettenty coastline from 1984 to 2024

Coastal erosion, which is very high in the north and south of Bettenty where it reaches its maximum rate (-3.05 m/year), remains low to moderately high in the center of the coast, with rates of -0.16 to -2.42 m/year. The average rate of change along the coast is -1.67 m/year. This erosion could be explained by natural and anthropogenic factors. The natural factors are related to a sediment deficit, a significant part of the sediment load of the littoral drift being sequestered by the various mouths located a little further upstream, notably the Lagoba, the mouth of the Saloum, and that of the Diomboss. This results in insufficient longshore transport to ensure the nourishment of the Bettenty coastline with sand. The anthropogenic factors are linked to the negative effects (such as sediment blockage) of the coastal and port protection structures of the site.

Furthermore, the erosion observed on the Bettenty coastline could also be explained by climate change. The importance of this forcing coastal erosion will increase in the future, depending on the acceleration of the sea level rise trend.

3.2 Risk of coastal erosion caused by sea level rise by 2026

The application of BRUUN's law (1962) shows that the Bettenty coastline would retreat by -88.47 m by 2026, which is equivalent to a rate of erosion of -2.46 m/year (figure 3).

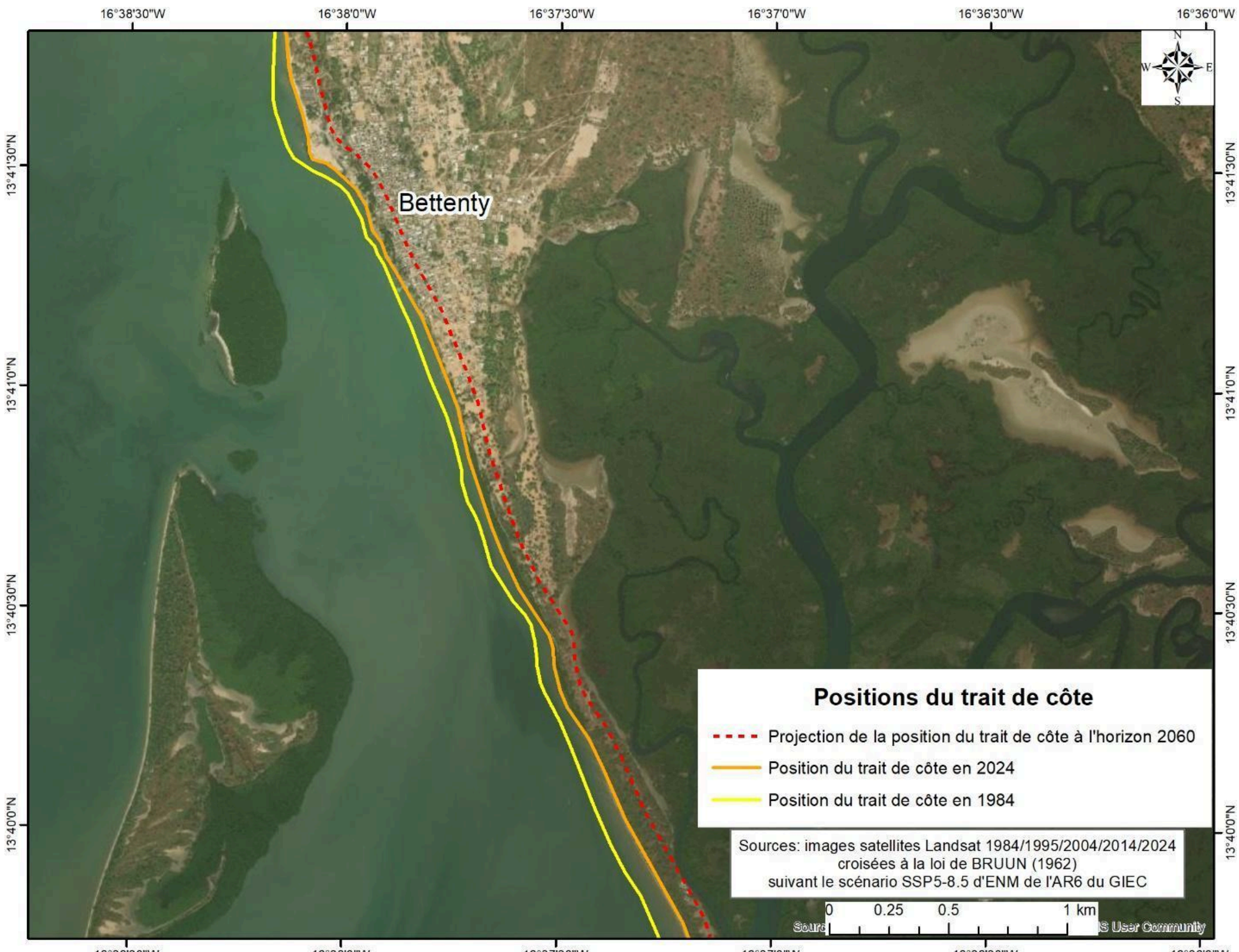

Figure 3: Potential coastal erosion induced by sea level rise athorizon 2060

As the projected coastline position shows, this erosion will have significant socio-economic impacts, especially along the densely populated coastal segment of Bettenty.

The shoreline retreat mentioned above corresponds to a loss of surface area of 389,905.51 m2 (figure 4).

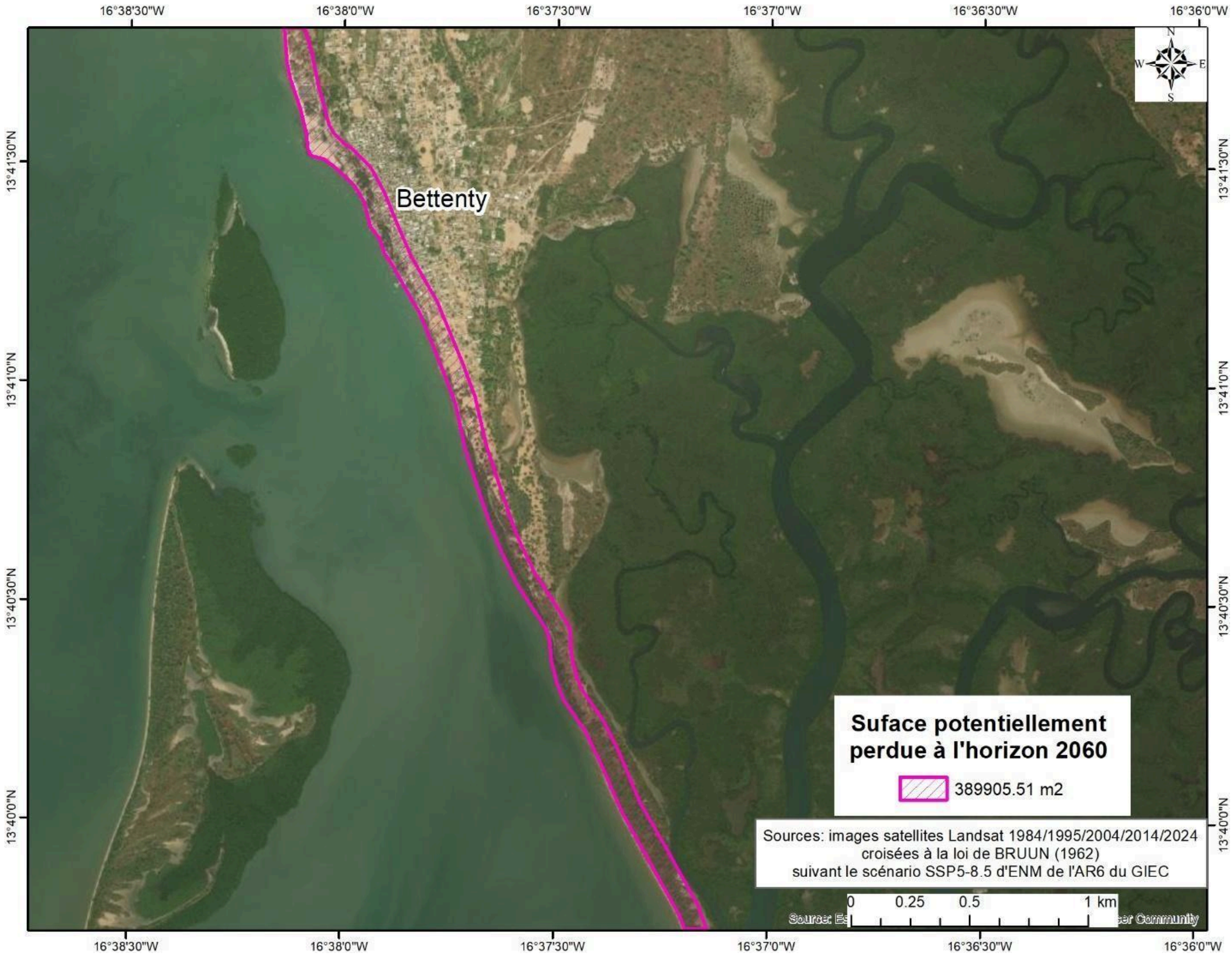

Figure 4: : Potential loss of land area due to sea level rise by 2060

The extent of this land area that would be lost by 2026 shows the impact of the climate factor on the risk of coastal erosion in the Bettenty Islands and raises the question of adaptation options.

3.3 Risk of marine submersion

The study site displays a topography characterized by altitudes varying from 1.16 to 10.43 m (Figure 5).

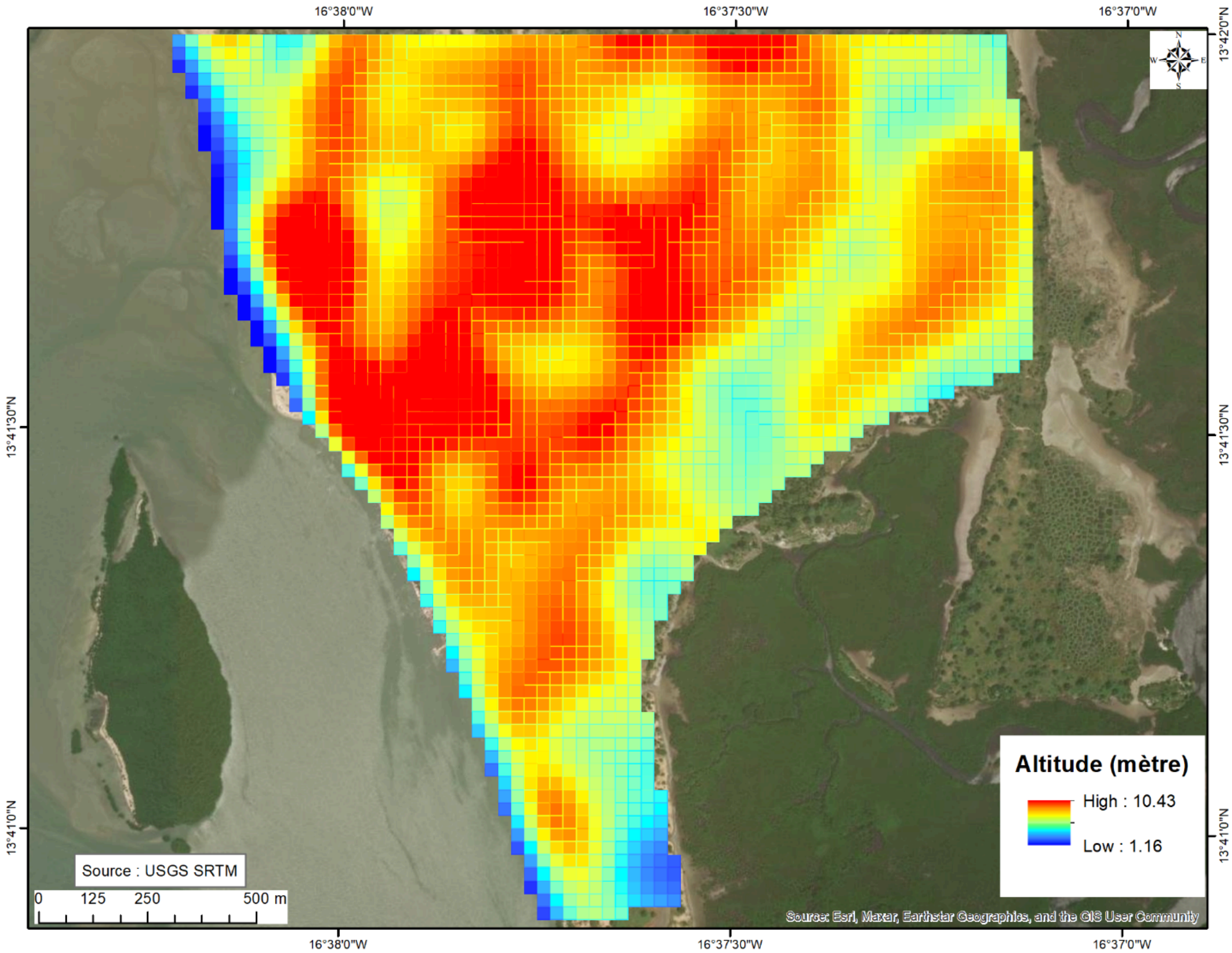

Figure 5: Digital Elevation Model (DEM) of the study site

The highest elevations are generally located in the north, centre and west, and gradually decrease towards the coast, as well as towards the east and south. The application of the formula developed by Hoozemans et al. (1993) reveals different levels of marine submersion: 4.31, 5.46, 5.71 and 7.91 m, depending on the reference storm.

With a submersion level of 4.31 m, only the coastal area and a few riverbeds to the east, south-east and north-west would be flooded by seawater ((Figure 6).

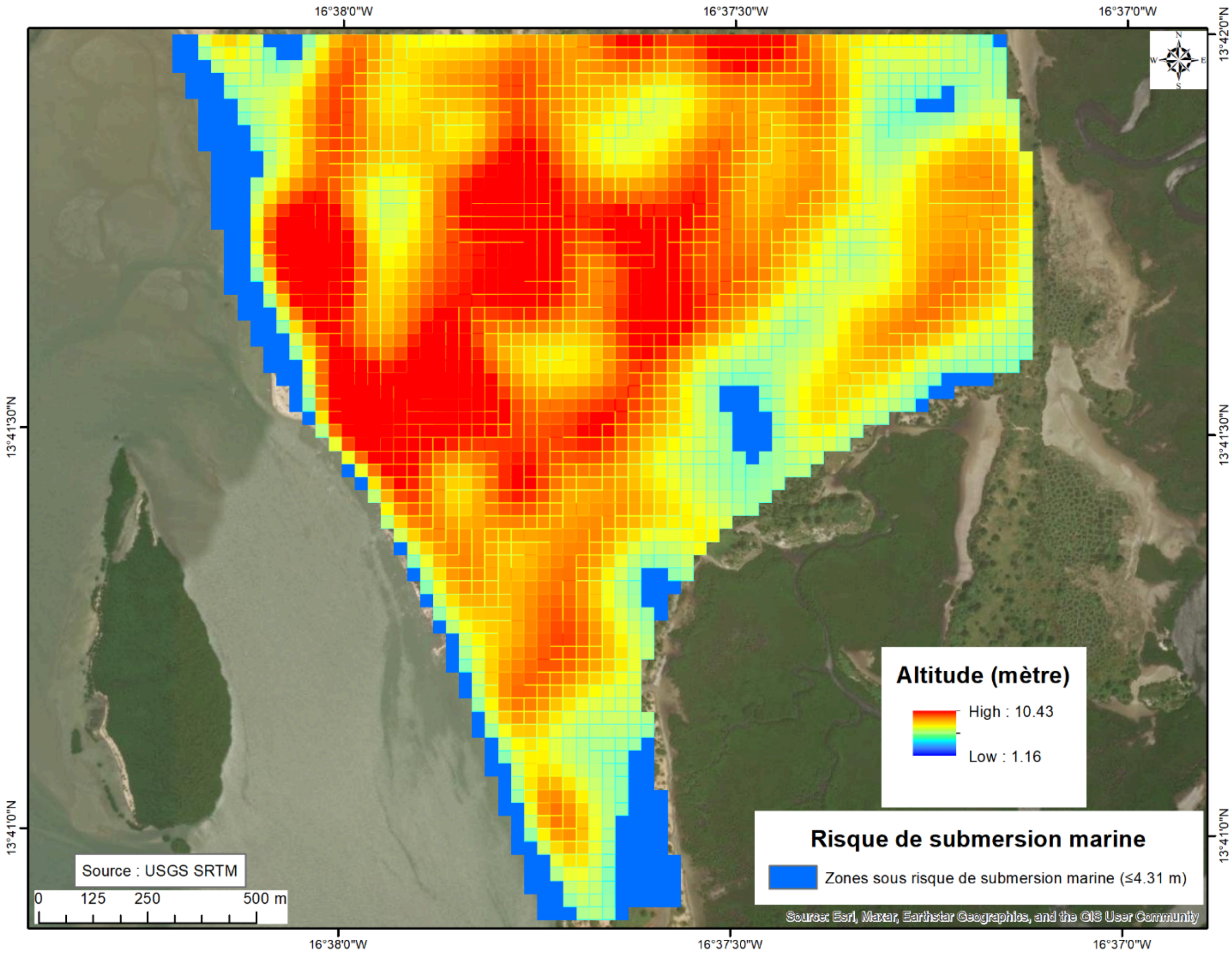

Figure 6: Marine submersion level of 4.31m and areas at risk

With a submersion level of 5.46 m, seawater would spread further across the site, starting in particular from the coastal area, then bordering it from the south and moving north-eastwards, depending on the topography (figure 7).

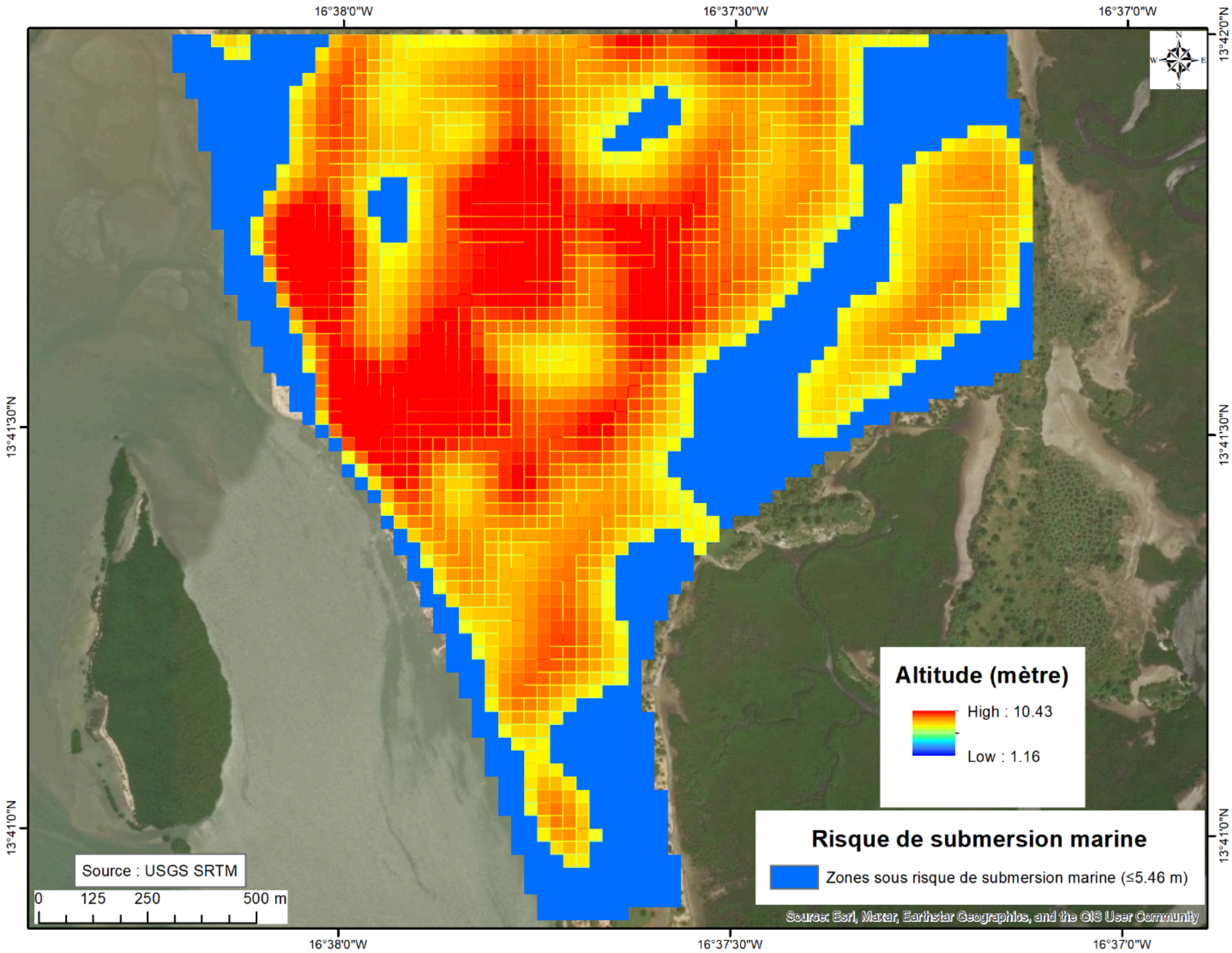

Figure 7: Marine submersion level of 5.46m and areas at risk

With a submersion level of 5.71 m, ocean waters, having already flooded the coastal front, the south and north-east of the area would begin to encroach on certain sectors located in the centre and north (figure 8).

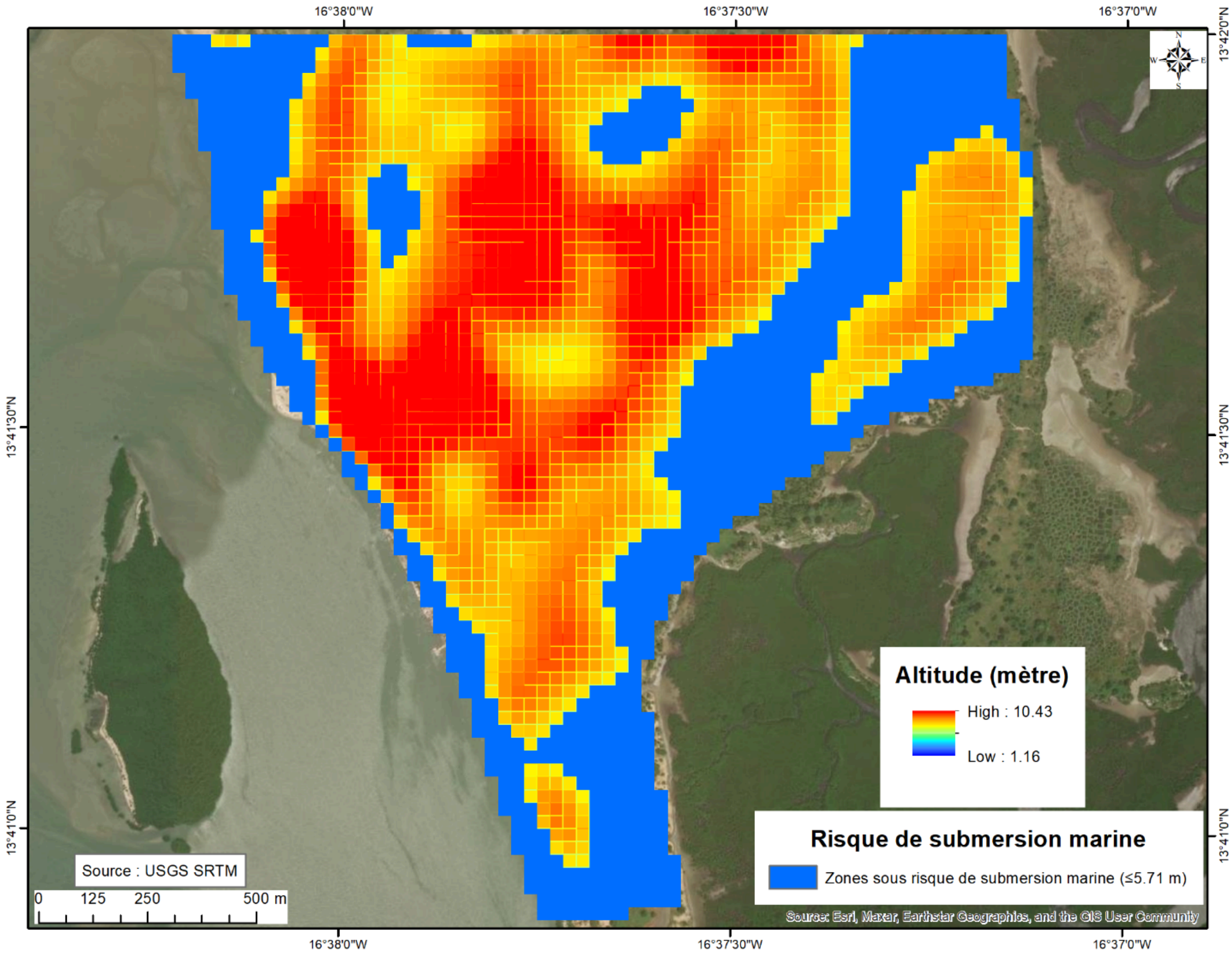

Figure 8 Marine submersion level of 5.71m and areas at risk

With a submersion level of 7.91 m, seawater would cover the entire site, with the exception of a few areas rising above the risk level, located specifically in the west, centre and north-east (Figure 9).

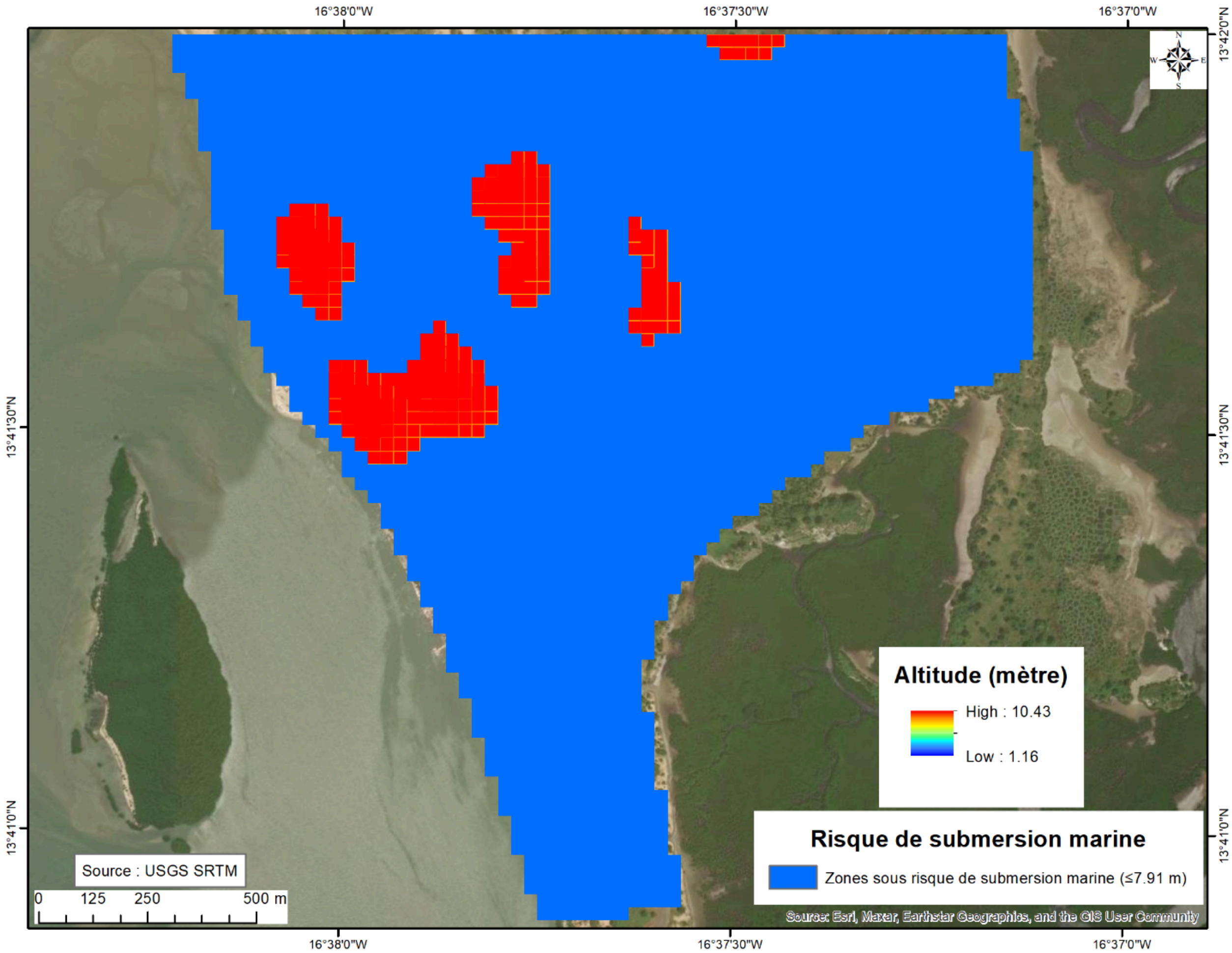

Figure 9: Marine submersion level of 7.91m and areas at risk

3.4 Potential environmental and socio-economic impacts

The analysed levels of marine submersion would have potential environmental and socio-economic impacts of varying magnitude.

Thus, for a marine submersion level of 4.31 m (Figure 10a), the potential environmental and socio-economic impacts would be:

- the submersion and degradation of some rain-fed farming areas in the southeast, northeast and northwest; and

- the invasion on the coast and related structures, in particular the fishing quay and/or port, as well as mangroves on the southern part of the coastline.

With regard to sea level rise levels of 5.46 and 5.71 m (Figures 10 b and c), the potential environmental and socio-economic impacts would be:

- flooding and destruction of some rain-fed farming areas in the south-east, north-east, north and north-west

- the submersion of the coastal zone and related structures, including the fishing quay and/or port, built-up areas, dwellings, public, private or tourist establishments or structures backing onto the coast from the middle segment of the coastline to the south, as well as the mangrove population located on the southern part of the coastline.

Regarding the marine submersion level of 7.91 m (Figure 10 d), the potential environmental and socio-economic would be:

- the submersion of almost all built-up areas, homes, public and private structures and establishments, transport routes, leisure areas, conservation areas and places of worship;

- the invasion and demolition by seawater of the entire coastline and the structures and/or establishments within it, such as the quay or port, and the collapse of existing protective structures.

- the flooding and devastation of all rain-fed farming areas, wooded savannahs and mangroves.

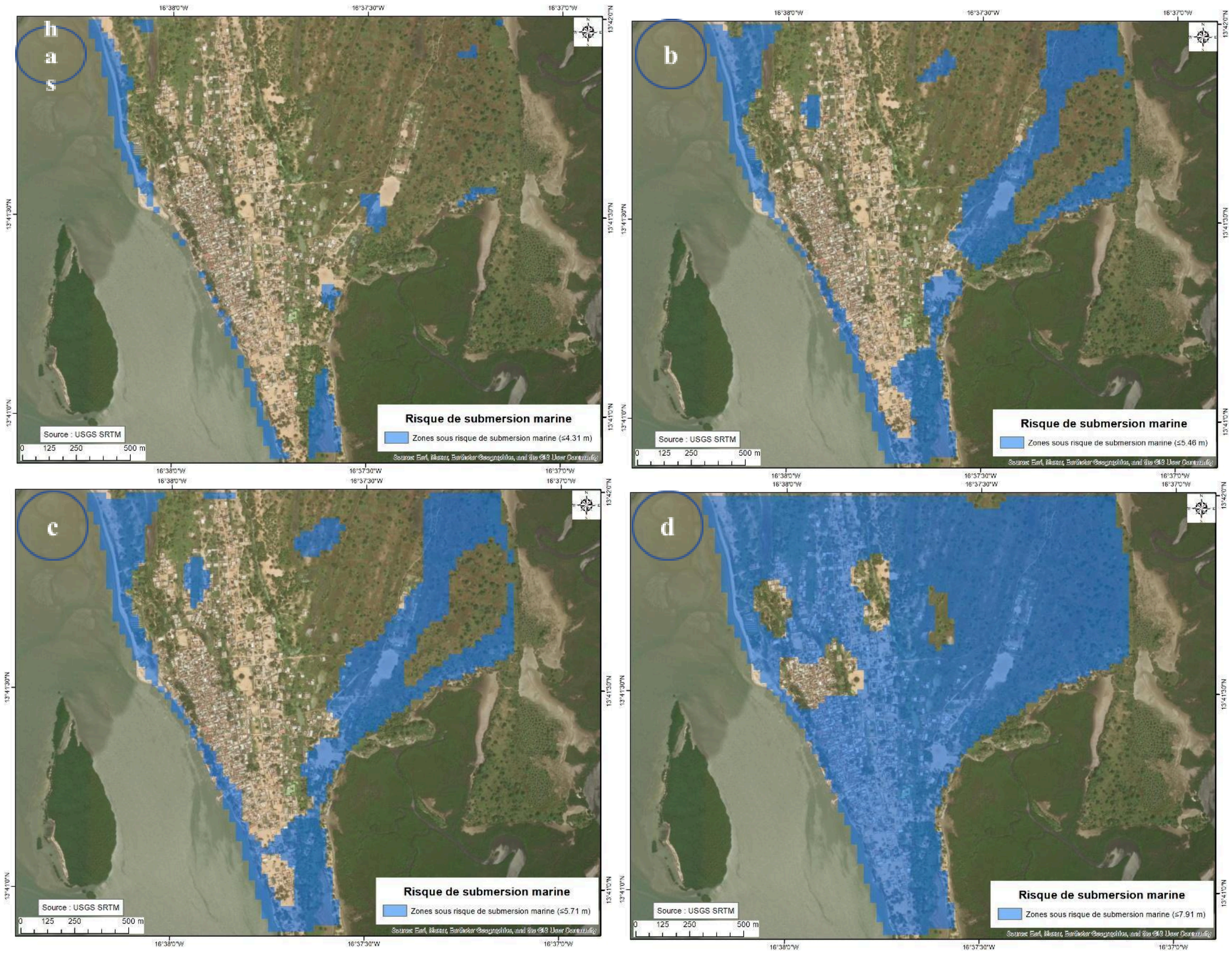

Figure 10: Potential environmental and socio-economic impacts of marine submersion

4 Conclusion

The study of the risks of coastal erosion and marine submersion on the Bettenty Islands coastline reveals a multi-decadal coastal dynamic characterized by erosion along the entire coastline, with an average rate of -1.67 m/year. It also shows that in the context of rising sea levels, this erosion would reach -88.47 m by 2026, or -2.46 m/year, with marine submersion levels of4.31, 5.46, 5.71 and 7.91 m.

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