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Projection and evaluation of the physical impacts of sea level rise in the year 2100 in the urban area of Grossos

Projeção e avaliação dos impactos físicos decorrente da elevação no nível do mar no ano de 2100 na zona urbana de Grossos

Jucielho Pedro da Silva[1]; Paulo Victor do Nascimento Araújo[2]; Marco Túlio Mendonça Diniz[3]; José Yure Gomes dos Santos[4]

[1] Federal University of Rio Grande do Norte, Laboratory of Geoprocessing and Physical Geography, Caicó/RN, Brazil. jucyelho@hotmail.com
ORCID: https://orcid.org/0000-0003-0445-5945

[2] Federal Institute of Education, Science and Technology of Rio Grande do Norte, Macau/RN, Brazil. paulo.araujo@ifrn.edu.br
ORCID: https://orcid.org/0000-0002-0625-0946

[3] Federal University of Rio Grande do Norte, Department of Geography of CERES, Caicó/RN, Brazil. tuliogeografia@gmail.com
ORCID: https://orcid.org/0000-0002-7676-4475

[4] Federal University of Rio Grande do Norte, Department of Geography of CERES, Caicó/RN, Brazil. jose.yure.santos@ufrn.br
ORCID: https://orcid.org/0000-0001-9840-8132

Abstract: The present study aimed to carry out a situational analysis of the city of Grossos in relation to sea level projections for 2100 based on the IPCC AR6. To this end, sea level modeling was carried out in a static hydraulic bathtub-type model, with an altimetric reference standardized at normal altitude and adjusted to the local level (zero on the Areia Branca tide ruler). To represent the terrain, it was made in MDT, using digital stereoscopic UAV images and adjusted to the Brazilian Geodetic System. The results demonstrate that the urban area is predominantly between 2.44 and 12.92 m in altitude, beyond the reach of current maximum tides and will have between 3.18 and 8.10% of its territory affected by 2100. Therefore, it can be concluded that the city is in a safe area with a relatively low risk of future flooding from rising sea levels.

Keywords: Inundation; Climate changes; Sea level.

Resumo: O presente estudo teve como objetivo realizar uma análise situacional da cidade de Grossos frente as projeções do nível do mar para 2100 com base no AR6 do IPCC. Para tanto foi realizada uma modelagem do nível do mar em modelo hidráulico estático do tipo banheira, com referencial altimétrico padronizado a altitude normal e ajustado ao nível local (zero da régua de maré de Areia Branca). Para representação do terreno, foi confeccionado um MDT, por meio de estereoscópia digital em imagens de VANT e ajustado ao Sistema Geodésico Brasileiro. Os resultados demonstram que a área urbana está predominantemente entre 2,44 e 12,92 m de altitude, ficando fora do alcance das máximas marés atuais e terá em 2100 entre 3,18 a 8,10% do seu território afetado. Com isso, conclui-se que a cidade se encontra em área segura e com relativamente baixo risco a inundações futuras provenientes do aumento do nível do mar.

Palavras-chave: Inundação; Mudanças climáticas; Nível do mar.

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1. Introduction

On the geological timescale, it is a fact that both the temperature and the sea level and the other elements that make up the climate have had and will have increases and decreases. However, on the human timescale, these variations would be imperceptible if not for paleo records. However, at the end of the 20th century and the beginning of the 21st century, the Intergovernmental Panel on Climate Change (IPCC) brought out reports that bring together and summarize various perceptions, through scientific articles, of this accelerated and perceptible climate change (e.g. IPCC, 2023).

According to the IPCC reports, the climate began to accelerate in a warming process from the beginning of the industrial revolution (1750), and the greater the mechanization and energy use of fossil fuels, the more this acceleration is accentuated, the fact is that from 2011 - 2020 an increase of 1.1 °C has been quantified compared to the variation from 1850 - 1900 (IPCC, 2023).

Rising temperatures due to climate change result in drastic impacts, such as melting polar ice caps, rising sea levels and more frequent extreme weather events. These changes threaten ecosystems, coastal communities and global food security. Urgent mitigation is essential to limit future damage. In South and Central America alone, there are already 690,000 people exposed to the risks of rising sea levels in 2020 and this number could increase by up to 35% by 2040 (IPCC, 2023).

With this in mind and knowing that in 2022, according to the census of the Brazilian Institute of Geography and Statistics (IBGE), more than half of the Brazilian population will live along the coast (around 54.8% of the population) (IBGE, 2022), there is a need to know which areas are already or will become susceptible to flooding if the predictive modeling of the IPCC's sixth assessment report (AR6) comes true.

With this problem in mind, the aim of this study was to carry out a topographic survey of the urban area of Grossos, Rio Grande do Norte State, Brazil, and to project possible sea level rises based on the AR6 Shared Socio-Economic Pathways (SSP) scenarios.

2. Method

The work was carried out in the ubano section of the municipality of Grossos, in the state of Rio Grande do Norte, Brazil. This region belongs to the estuarine zone of the Apodi-Mossoró River (Figure 01).

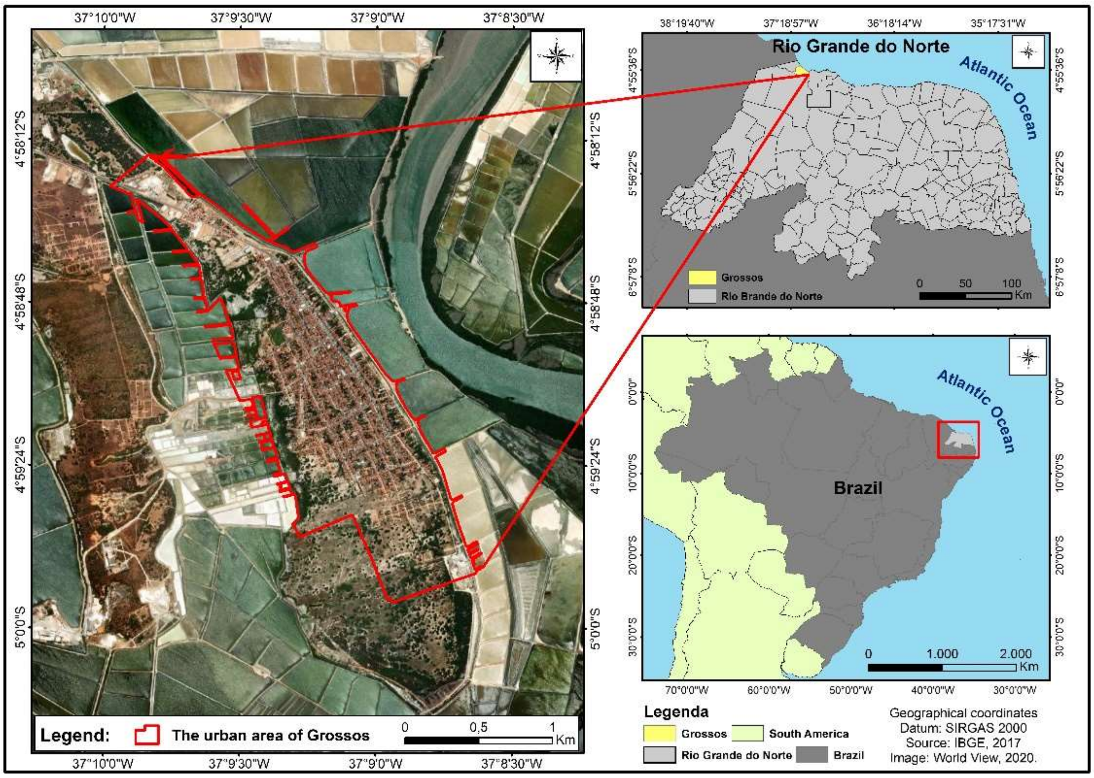


Figure 01 – Location map of the urban area of Grossos - RN.
Source: Authors (2024).

According to Figure 01, the study area is geographically in a favorable spatial context (sheltered region), suffering only from the influence of the tide, with average daily amplitudes of around 1 to 2m (Aguiar et al., 2019).

For the development of this work, primary and secondary databases were used. For the topographic survey, a photographic survey was carried out using the DJI - Mavic Air 2S Unmanned Aerial Vehicle (UAV) and a survey of control and check points using CHCNAV - I90 Global Navigation Satellite System (GNSS) receivers, based on the SIRGAS 2000 horizontal datum and the geoHNOR_IBITUBA Modeled Vertical Datum. With the data from these two surveys, the topographic model of the study area was produced using Agisorft MetaShape digital stereoscopy software, thus generating a Digital Elevation Model (DEM), corrected by the control points, which was then transformed into a Digital Terrain Model (DTM) by classifying the dense point cloud, using the following criteria: maximum angle of 20º; maximum distance of 1 m; maximum slope of 8º; cell size of 100 m. The final MDT had a horizontal error of 11.7 cm and a vertical error of 6.9 cm.

However, in order to project the future IPCC scenarios and find out which areas would be affected, it was necessary to obtain the local mean sea level and astronomical and meteorological tide records for the region. To do this, we used data from the Brazilian Navy, specifically the Directorate of Hydrography and Navigation (DHN), third-party work carried out in the vicinity and bibliographic research into possible flood records. With these searches, it was possible to obtain the average local sea level and the tidal record, and thus project onto the MDT the levels that will be reached in 2100 based on the values provided by the IPCC for each scenario chosen.

To carry out the sea level modeling for 2100, a static hydrological model of the "bathtub type" or "GIS-based flood model" was used, using ArcGis software. According to Anderson et al. (2018), this type of model can be defined as the projection of a flood surface onto an MDT, being easy to implement and providing the necessary spatial specificity. And in the case of a sheltered region, the model is of great value.

3. Results and Discussion

Figure 02 shows the coordinates of the tide gauge used for this study, located in the municipality of Areia Branca-RN. It should be noted that the local mean sea level is pre-calculated by the DHN according to the illustrative diagram shown in Figure 02.

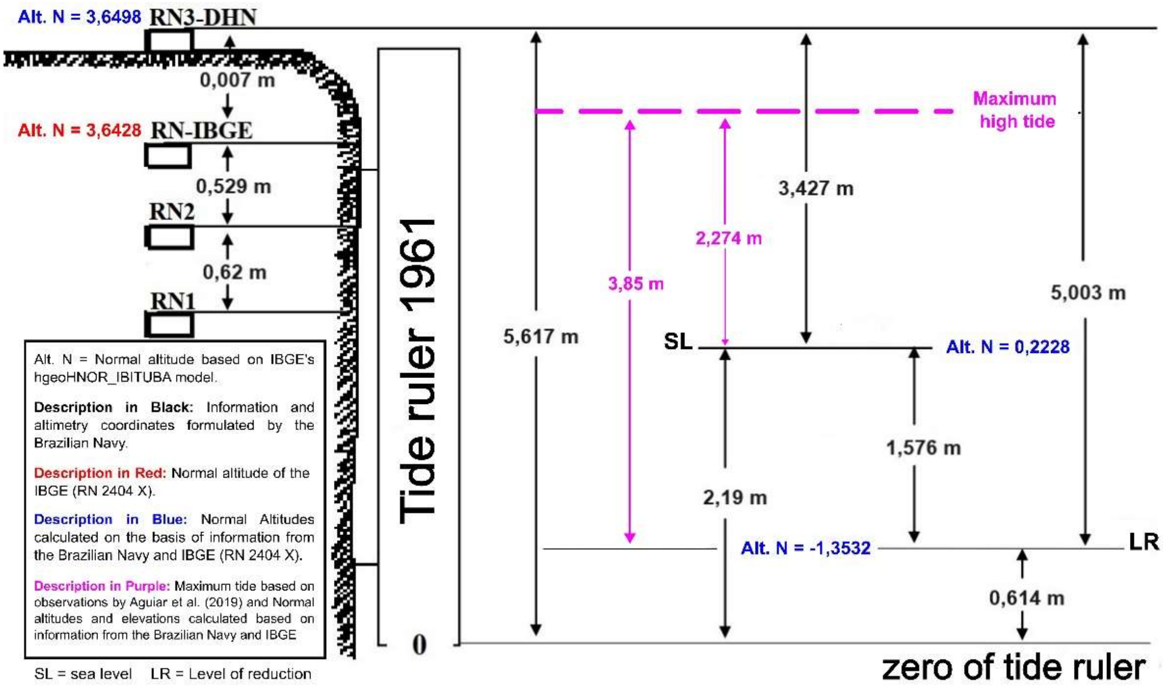


Figure 02 – Diagram illustrating the geometric leveling of the Areia Branca tidal ruler and orthometric leveling based on the IBGE horizontal and vertical datum.
Source: Adapted from DHN (2010); Aguiar, et al. (2019) and IBGE, (2023).

Despite being approximately 3km away from the study area, the ruler is located in an identical context to Grossos (in a sheltered region within the Apodi-Mossoro River estuary). It is important to know that in the descriptions in bold are the information and calculations from the DHN to calculate the local mean sea level, in blue are normal (geometric) altitudes tied to the IBGE vertical Datum (geoHNOR_IBITUBA) and in purple is the highest tide level ever recorded, according to Aguiar et al. (2019). You can see that the topographic data is tied to a vertical plane (IBGE - hgeoHNOR) and the tidal data is tied to another vertical plane (DHN local plane measured from the NR - Reduction Level). Therefore, the tide gauge data was linked to the hgeoHNOR altimetric reference, leaving all the data in the same altimetric reference (normal altitude).

This shows that there is a discrepancy between the zero level of the horizontal plane of the hgeoHNOR model and the zero level of the DHN of 0.2228 m. Therefore, in order to adjust and equalize the two horizontal planes, this value was subtracted from the topographic model (MDT) using the “raster calculator” tool.

After this correction, it was possible to continue with the modeling, which consisted of the stackings shown in Figure 03.

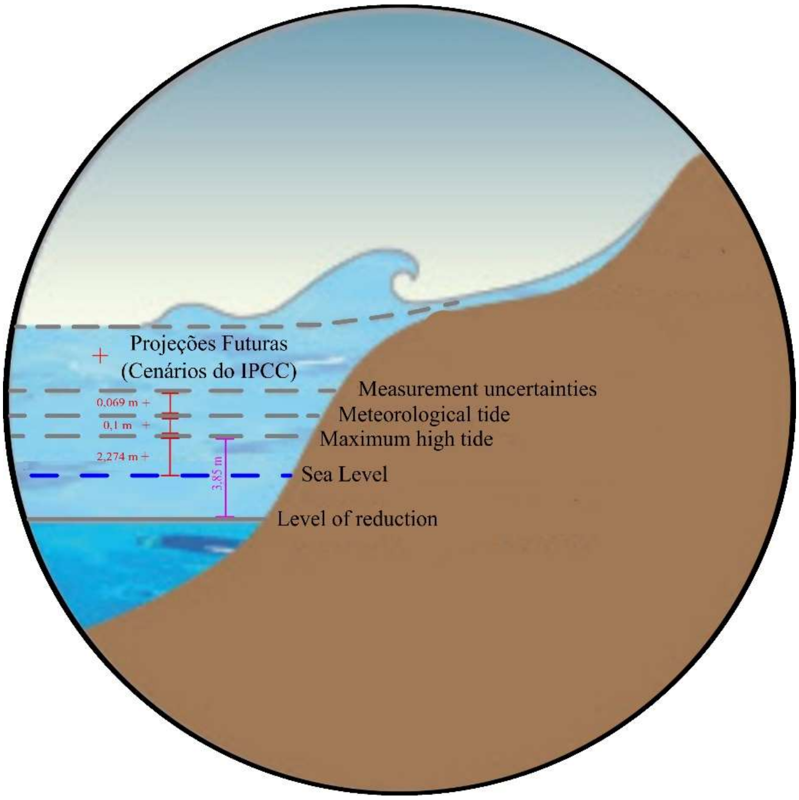


Figure 03 – Illustrative stacking scheme of the parameters considered in the sea level rise modeling for the city of Grossos - RN.
Source: Adapted from IPCC (2023).

As can be seen in Figure 03, the flood level consists of the sum of the highest sizigia tide ever recorded, which according to Aquiar (2019) was 3.85 m from the reduction level, i.e. 2.274 m in the topographic model (from mean sea level), plus the meteorological tide of 0.1 m, according to observations made by Frota et al. (2016), plus the uncertainties of the measurements (0.069 m), i.e. the Root Mean Squared Error (RMSE) between the point generated by the software in the MDT and the point measured with the GNSS, plus the values of the IPCC scenarios.

These IPCC values (Figure 04) correspond to the increase in global mean sea level, which can vary from 0.28m to 1.01m depending on the socio-economic responses to each scenario, where there is a maximum, minimum and average margin. For this research, the maximums for each scenario were used as a reference: SSP1-1.9 (0.55m), SSP1-2.6 (062m), SSP2-4.5 (0.76m), SSP3-7.0 (0.90m) and SSP5-8.5 (1.01m).

	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP5-8.5 *Low Confidence*
Total (2030)	0.09 (0.08–0.12)	0.09 (0.08–0.12)	0.09 (0.08–0.12)	0.10 (0.08–0.12)	0.10 (0.09–0.12)	0.10 (0.09–0.15)
Total (2050)	0.18 (0.15–0.23)	0.19 (0.16–0.25)	0.20 (0.17–0.26)	0.22 (0.18–0.27)	0.23 (0.20–0.29)	0.24 (0.20–0.40)
Total (2090)	0.35 (0.26–0.49)	0.39 (0.30–0.54)	0.48 (0.38–0.65)	0.56 (0.46–0.74)	0.63 (0.52–0.83)	0.71 (0.52–1.30)
Total (2100)	**0.38 (0.28–0.55)**	**0.44 (0.32–0.62)**	**0.56 (0.44–0.76)**	**0.68 (0.55–0.90)**	**0.77 (0.63–1.01)**	**0.88 (0.63–1.60)**
Total (2150)	0.57 (0.37–0.86)	0.68 (0.46–0.99)	0.92 (0.66–1.33)	1.19 (0.89–1.65)	1.32 (0.98–1.88)	1.98 (0.98–4.82)

Figure 04 – Projections of global mean sea level rise by SSP scenarios - Shared socio-economic pathways.
Source: IPCC (2021).

Based on an analysis of the IPCC's discussions on these SSP scenarios (Figure 05), it was observed that of the five scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5), the first and most optimistic (SSP1-1.9) will be highly unlikely to materialize, as it depends on a reversal of warming and CO^2 emissions from 2050 and in 2100 remaining at the limit of 1. 5ºC; the second (SSP1-2.6), also considered an optimistic scenario, depends on a reversal of greenhouse gas emissions, especially CO^2, and a slowdown in warming until 2070, reaching a limit of 2ºC by 2100; the third scenario (SSP2-4. 5) is considered intermediate and more realistic, as it considers the upward curve of warming and GHG emissions around two current levels reaching the threshold of 3°C in 2100; the fourth scenario (SSP3-7.0) is considered more pessimistic and considers that by 2100 CO^2 levels could double and warming be around 4°C. the fifth and final scenario (SSP5-8.5), considered to be the most pessimistic, but with more than a fifty percent (>50%) probability of coming true, considers that GGE levels, mainly CO^2, will double by 2050 and warming will be around 5°C.

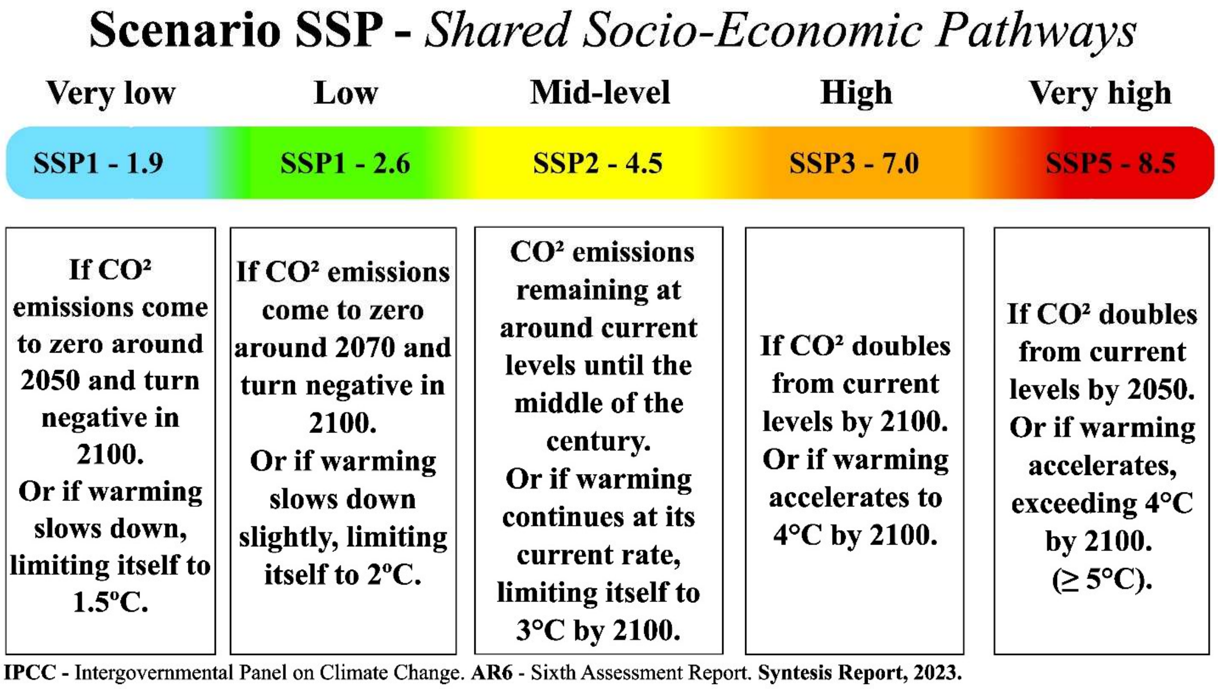
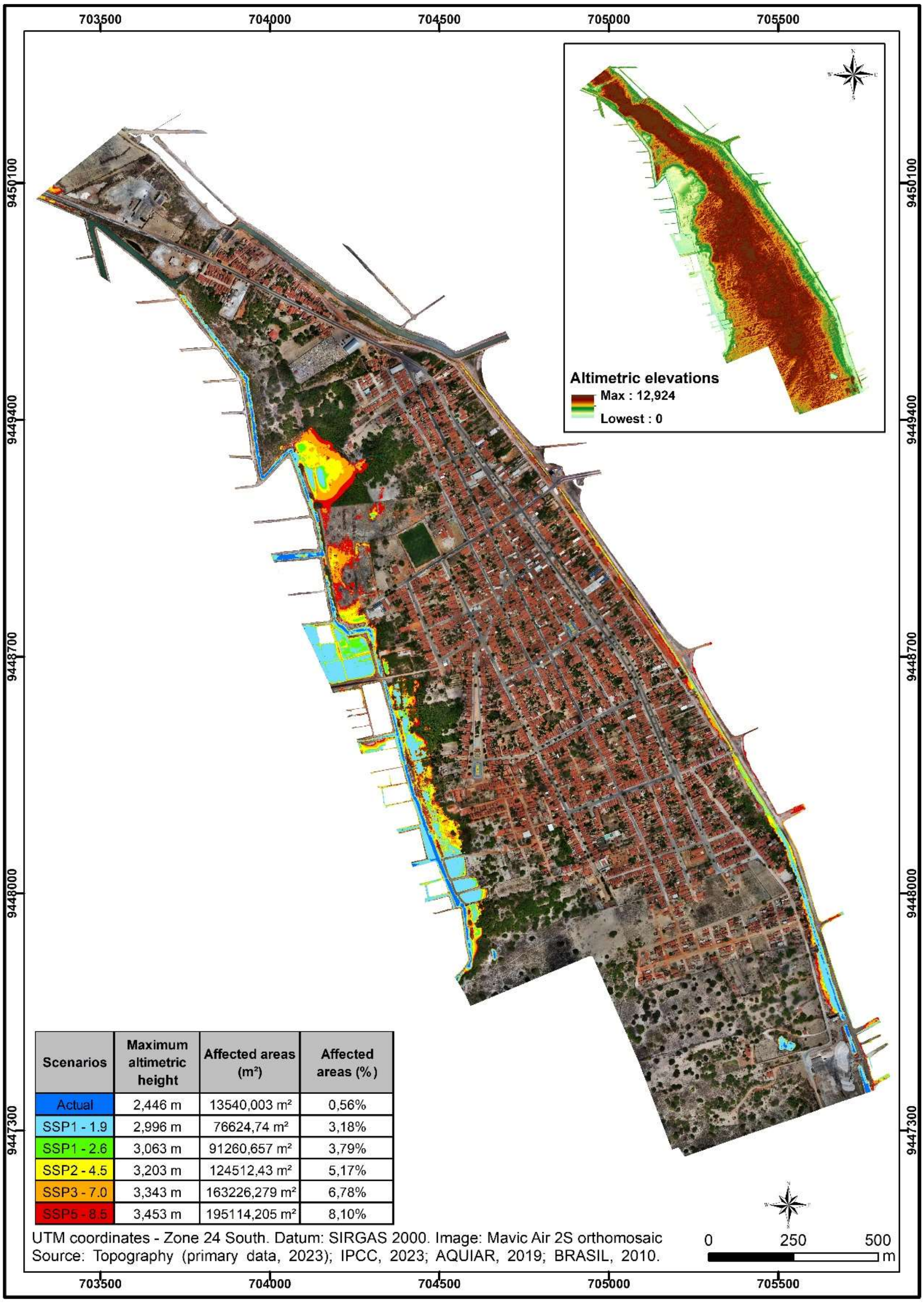


Figure 05 – Schematic of the SSP scenarios - Shared socio-economic pathways.
Source: IPCC (2023).

Based on these scenarios, correlated with the local topography, it was possible to map and quantify the possible areas to be affected in 2100 and the current flood areas from extreme events, as shown in Figure 06.



Scenarios	Maximum altimetric height	Affected areas (m²)	Affected areas (%)
Actual	2,446 m	13540,003 m²	0,56%
SSP1 - 1.9	2,996 m	76624,74 m²	3,18%
SSP1 - 2.6	3,063 m	91260,657 m²	3,79%
SSP2 - 4.5	3,203 m	124512,43 m²	5,17%
SSP3 - 7.0	3,343 m	163226,279 m²	6,78%
SSP5 - 8.5	3,453 m	195114,205 m²	8,10%

Figure 06 – Map of the location and situation of Grossos/RN in 2024, with modeling of the IPCC scenarios for 2100. Source: Authors (2023).

Currently, the city's urban area is surrounded by salt pans, with no direct contact with the ocean, and with elevations between 0 and 13 m, more than 90% of which are above 3.5m. In this sense, according to the projection for 2100, the area liable to flooding varies between 3.79 and 8.11 % in extreme cases (taking into account only the influence of the tide), bearing in mind that the modeling was carried out based on the maximums of each scenario and with the maximum sizígia tide.

In more detail, it can also be seen that the risk areas are not in built-up areas, except for the observation of only three houses affected. One to the east only in the SSP5-8.5 scenario and two to the west being affected in the SSP3-7.0 and SSP5-8.5 scenarios. It is important to emphasize that possible extreme flood events from the Apodi-Mossoró River have worsened the modelled scenarios.

The main factor for its greater occurrence on the west side is the topography of the terrain. The region has a slight decrease in elevation towards the west. In addition, it is important to mention that the floods that occur in areas of topographic discontinuity are the result of a rise in the water table.

Many coastal cities in Brazil are topographically vulnerable to a rise in mean sea level, which is not the case with the city of Grossos, which was built on a relatively elevated site, considering that the Costa Branca is mostly made up of low-lying coastal land.

4. Final considerations

Based on this work, it was possible to conclude that the urban area of the city of Grossos in the state of Rio Grande do Norte - Brazil is located in a safe area in relation to current flooding and at low risk (3.79 % to 8.11 %) of future flooding from rising sea levels by 2100. This work can serve as a guide for future local land-use planning. It is suggested that future coastal flooding studies take into account the combined effect of coastal flooding and river flooding, denoting a maximum extreme event for the region.

Although the municipal seat of Grossos is sheltered from the danger of flooding, other communities in the same municipality may be vulnerable, which makes it necessary to expand the study.

Acknowledgements

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