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Mapping of Coastal Hazards in the South-West of Côte d'Ivoire on SRTM Images

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Abstract

Finding a solution to the coastal risks that are becoming recurrent in Côte d'Ivoire, including the risk of flooding, data collection has been undertaken on the entire coast. High spatial resolution images such as the SRTM images were used to be processed in the Qgis software to evaluate with high precision the overflow hazards of the coastal courses from Tabou to Sassandra, located on the west coast of the country. To do this, the layers of the processed slopes were superimposed on those of the rivers to assess the risks of overflow in the coastal areas concerned. It appears that these areas are marked by low slopes (<16.3%), or even none, likely to increase the intensity of the hazards of overflow of the Sassandra river in Sassandra and the Djiboué lagoon in San-Pédro. The foreseeable risks associated with simulations of overflow distances of 100 to 500 m of the rivers constitute threats to the port activities of San-Pédro that can cause big economic losses for the country, businesses, tourism activities and lodge complexes, coastal resources, and housing. An interactive cartography interface could make it possible to better visualize the results of the processing carried out in a Websig with a view to proposing sustainable solutions for the development of the Integrated Coastal Development and Management Plan of the Ivorian coastal area.

Keywords

SRTM Images, Flooding, Overflow Hazards, Sassandra, San-Pédro

1. Introduction

Remote sensing and GIS are particularly effective tools for the study of natural risks [1]. Indeed, earth observation data is a powerful tool for monitoring coastal phenomena. They make it possible to identify the affected areas and also help to set up risk prevention plans [2] [3]. Many risk mapping studies (floods, landslides, avalanches, etc.) in urban and rural areas exist but have not specifically focused assessment work on the risks of river overflow in the environment coastal. This is the example of [4] that used DEMs and thematic data to develop maps of hydrological hazards, slopes, in France, etc. Mapping studies of landslide hazards have also been carried out in Montrodat [5]. In Africa, [6] have developed a web mapping for the management of natural risks on the Cameroonian coast to assess the risks of vulnerability to floods and landslides with relief images from Google map. The question of the use of slopes images arises acutely given that they constitute a very important factor in the assessment of coastal risks and especially in the overflow of lagoon or river watercourses. A high spatio-temporal resolution of this type of data needs to be used to better manage the hazards of coastal flooding, particularly in Côte d'Ivoire which has already been confronted with several episodes of flooding in its 2nd port city (west of the Ivorian coast). Located between 4˚15'N and 5˚15'N and 6˚W and 7˚30'W, the western Ivorian coastal perimeter extends from Tabou to Sassandra, 215 km long. The area consists of several departments, including the departments of Sassandra, San-Pedro and Tabou. The coastal perimeter is drained by rivers of different natures. These watercourses are generally rivers (Cavally, San-Pédro, Sassandra) and lagoons (Djiboué) whose irregularity of regime depends on variations in rainfall. The distribution of rivers and lagoons in the study area is presented in **Figure 1**.

2. Data Sources and Methodology

2.1. Data Sources

Image data downloadable from the NASA website, as well as those from the Shuttle Radar Topography Mission (SRTM) satellite of the study area were used,

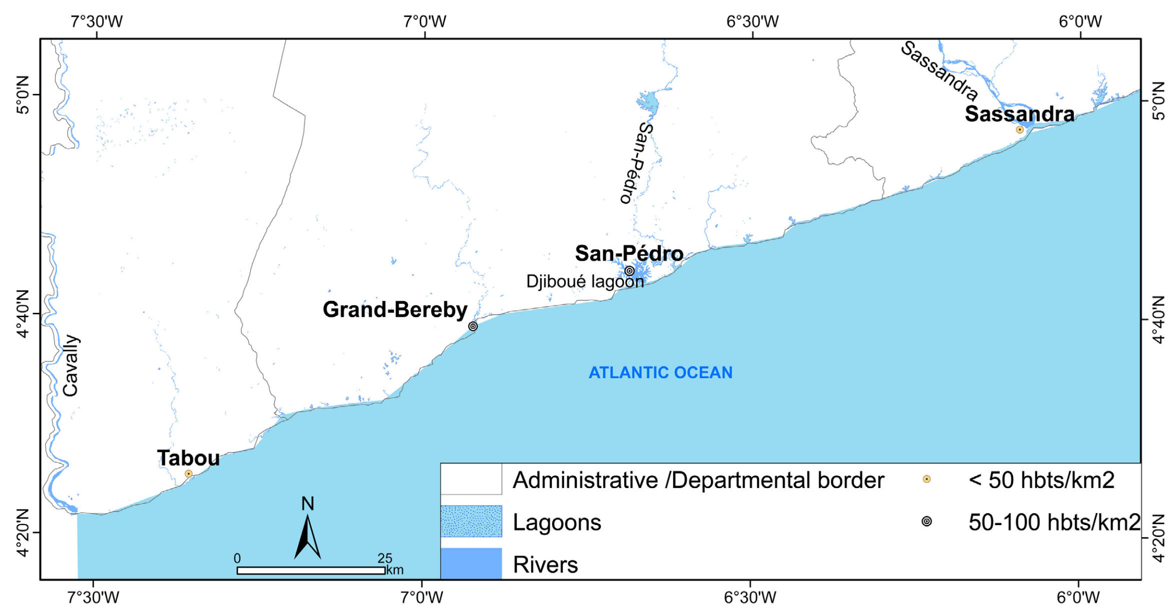


Figure 1. Coastal perimeter from Tabou to Sassandra.

namely, images N04W006_1, N04W007_1, N04W008_1, N05W006_1 and N05W007_1, all taken on November, 2019. Spatial resolutions range from 15 to 90 m. Land use data for the coastal perimeter are vector files (health centers, protected areas, road networks, schools, bodies of water, etc.) from the National Committee for Remote Sensing and Geographic Information (CNTIG).

2.2. Methodology

2.2.1. Slope Mapping

The mapping of this hazard was done through SRTM images which were processed in order to extract the map of the slopes. Given that the studied coastal perimeter is covered by five SRTM images, the first step was to make a mosaic of the five images to constitute a single one. The second was to cut out the study area in the mosaicked image. The last step was to apply the "slope" algorithm from GDAL in QGIS 3.4 with the required parameters.

2.2.2. Overflow of Rivers

To better appreciate the hazards of overflowing of rivers, the vector file of water bodies of Côte d'Ivoire was used to determine the buffer zones, beyond which there would be overflows, via the algorithm QGIS 3.4 Multi Ring Buffer. A mosaic of images made it possible to assess the slopes of the perimeter studied and the identification of the issues was done through the highlighting of the various infrastructures contained in the vector files of land use. The superimposition of hazard maps and stakes made it possible to map the coastal risks of flooding in the perimeter studied. Figure 2 presents the diagram of the hazard mapping methodology.

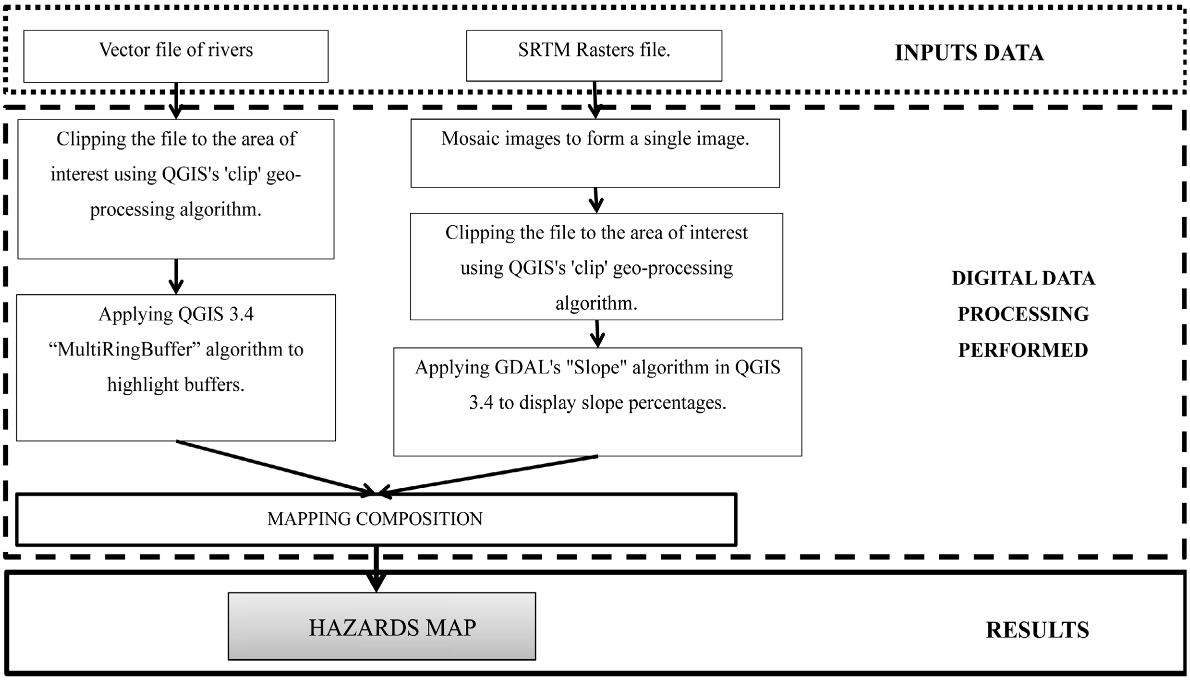


Figure 2. Diagram of the hazard mapping methodology.

3. Results and Discussion

3.1. Mapping of Issues in the Study Area

The main issues identified on the coastal perimeter are waterways, classified forests, degraded forests, agricultural developments, housing, industrial plantations such as coffee, cocoa and rubber. Let us not forget that these cultures are the main ones of the country and thus constitute the country's economic wealth. They are therefore a major issue. Watercourses are rivers, rivers and lagoons. Forests are biotopes to be protected and are home to many endemic plant and animal species or those with special conservation status. Industrial plantations are represented by industrial processing units in the sub-prefectures of Grand-Béréby and Tabou. This is the case of SOGB (Grand-Béréby Rubber Company). The map of coastal issues is presented in Figure 3.

3.2. Mapping of River Overflow Hazards

The digital processing of the data collected has shown that overflows of rivers are likely to occur in the sub-prefectures of Sassandra and San-Pédro. This could be explained by the presence of major rivers in these departments, in particular the Sassandra river and Djiboué lagoon in San-Pédro.

3.2.1. Coastal Area of Sassandra

The areas are also marked by flat to very low slopes (<16.3%) distributed in the northern and eastern parts and low slopes (between 16.3% and 32.5%) located in the southwestern parts, marking their vulnerability to flooding. Figure 4 shows the overflow hazards of the Sassandra.

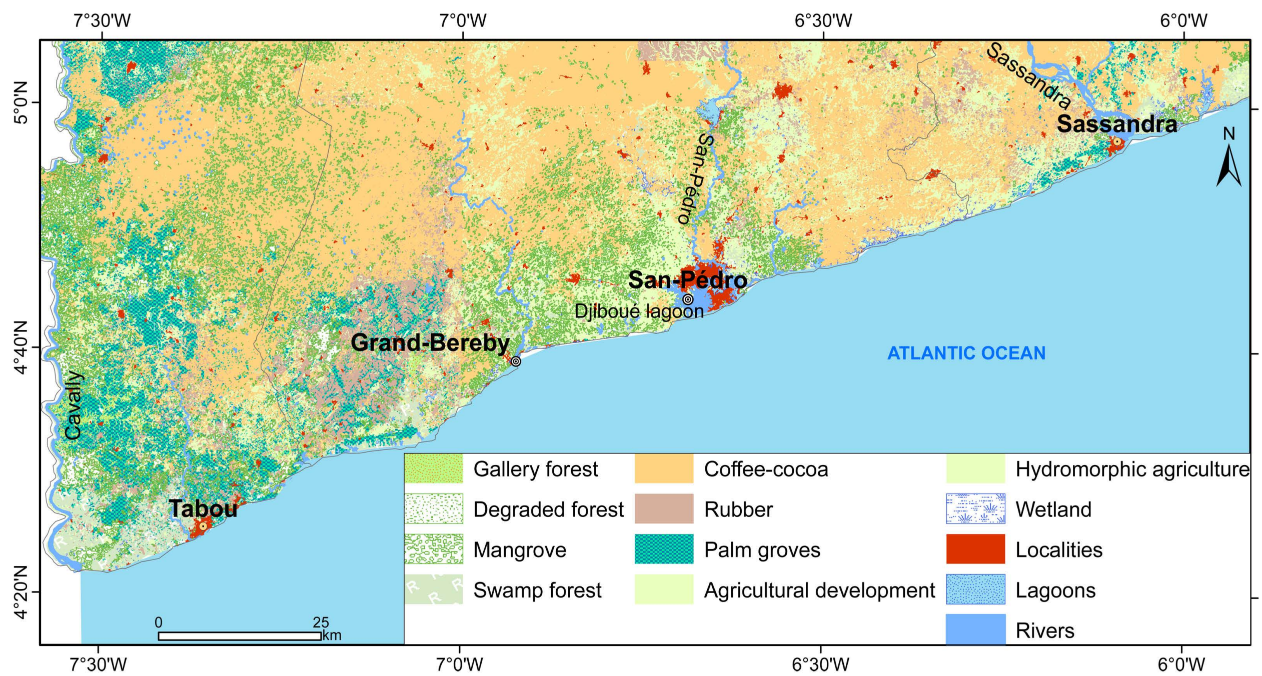
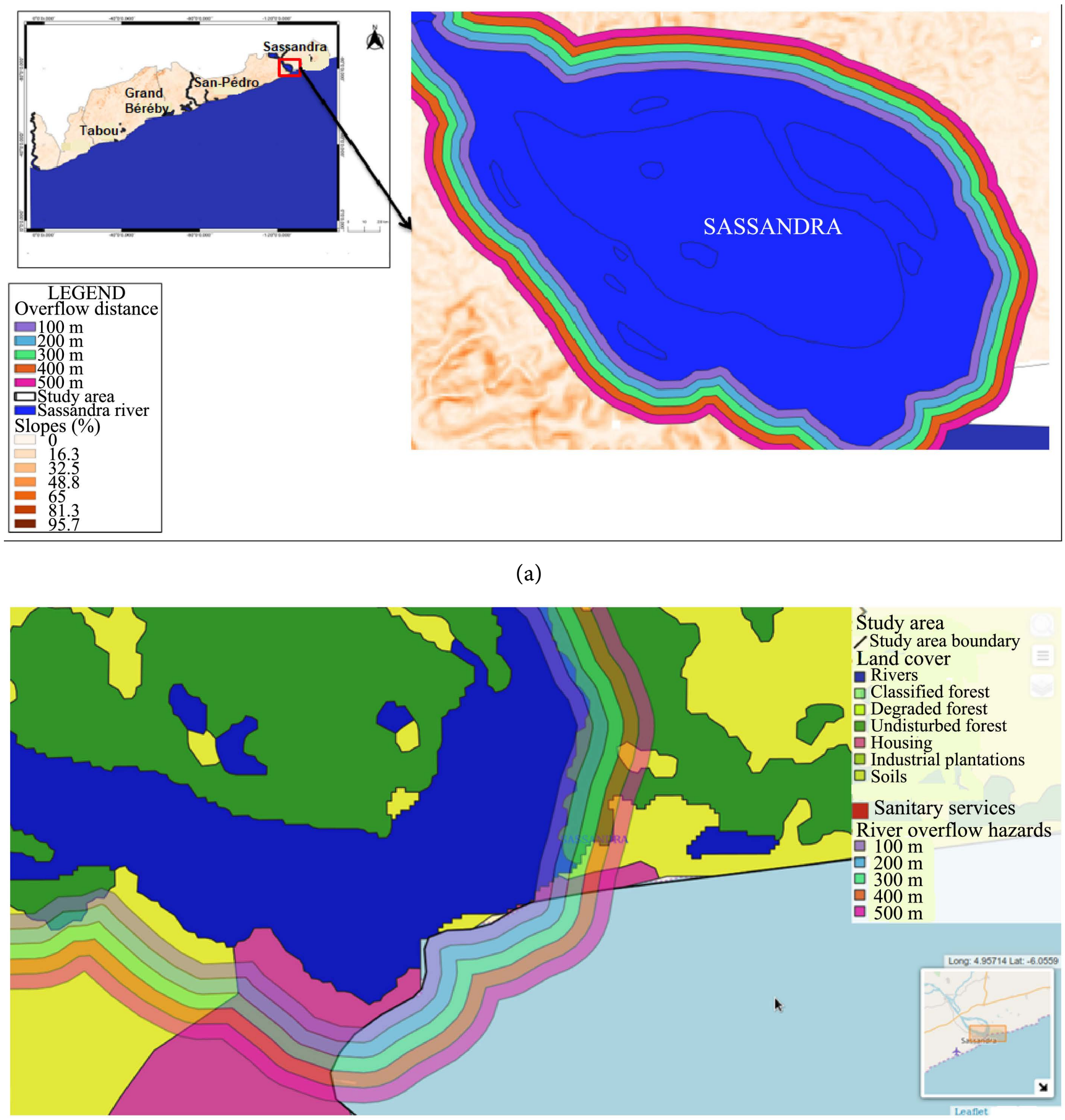


Figure 3. Mapping of issues in the study area.



(a)

(b)

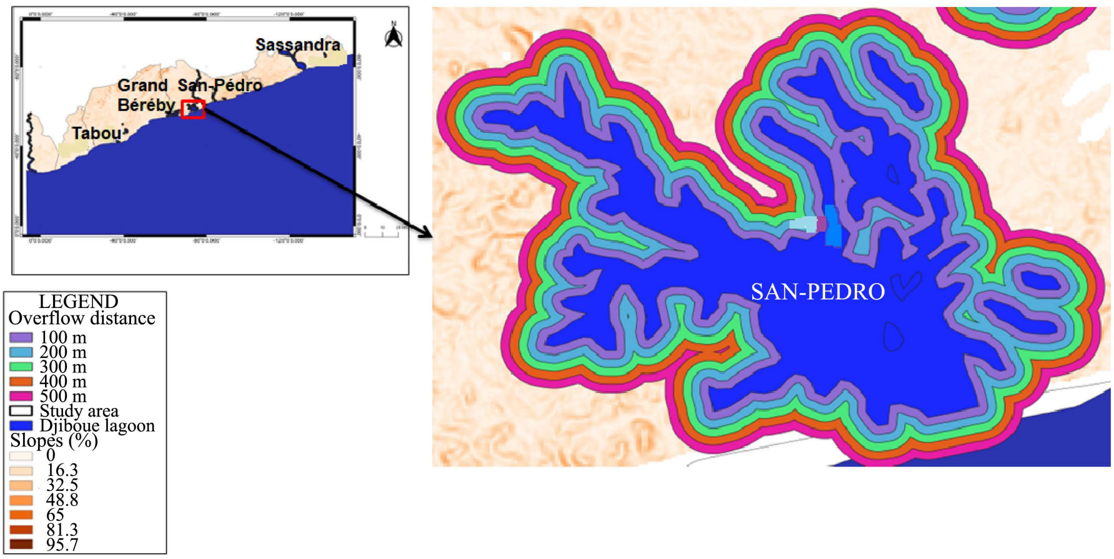
Figure 4. Overlay of the overflow hazards of the Sassandra River with the slopes (a) and land use (b) of the area.

In Sassandra, it is important to note that the coastal slopes are almost homogeneous in places and vary between 0 and 65% throughout the area. The enlarged image in this figure is characteristic of the spatial evolution of the mouth of the Sassandra River. The slopes to the north-east of the stream are lower (<32.5%) than those to the south-west (<65%). There is therefore more risk of the river overflowing in the northern and eastern areas, marked by housing and forests. Thus, the overflow distance becomes high, and the flood hazards are high.

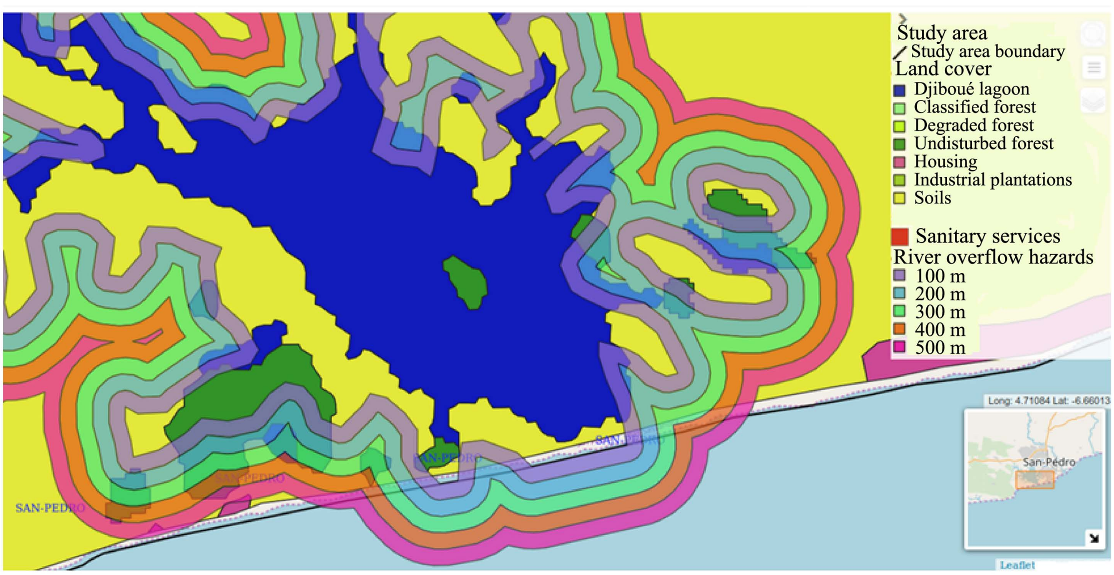
Indeed, 100 m beyond the shore, the rivers could flood the houses, part of the forests and some bare soil. From 200 to 500 m beyond the shore, the streams could flood a large part of the housing, bare soils and intact forests. **Figure 4** shows the overlay of the overflow hazards of the Sassandra River with the slopes (a) and land use (b) of the area.

3.2.2. Coastal Area of San-Pédro

In the coastal area of San-Pédro, the slopes are lower than those of Sassandra. They are almost zero in some places (in the west) and slightly in the area (0% - 16.3%). Only a few surfaces are in the west of the Djiboué lagoon of 32.5%. Thus, the same threats are present, but will be much higher due to strong anthropization of the coastal zone. More, this area is home to the Autonomous Port of San-Pedro, the country's second largest port, hotel complexes and many great restaurants. From 100 to 500 m beyond the shore, it is essentially bare soils and intact forests that could suffer from flooding. It is noted that the housings could be strongly impacted because they are located near the overflow hazard 500 m beyond the shore (**Figure 5**).



(a)



(b)

Figure 5. Overlay of the overflow hazards of the Djiboué lagoon with the slopes (a) and land use (b) of the area.

4. Discussion

The proposed method for identifying areas at coastal risk of flooding is a method applied in a good number of studies aimed at a coastal management plan. Several approaches have been used, including the simple index approach such as the Coastal Vulnerability Index (CVI) [7]. In his article on the study of coastal risks from the perspective of geomatics, [8] presents the approach of studying coastal risks by index based on several variables (multi-criteria approach by Saaty weighting). This approach has made it possible to identify the areas at risk on the island of Yeu requiring priority intervention. Considering the topographic criterion as the 2nd criterion of choice with a weighting value of 0.22 and a DEM that extends between 0 to 32 m, these results are almost similar to those presented in our study, although the two sites are different. Clearly, the use of SRTM images for the assessment of the slopes of estuaries finds its meaning here, given the techniques used for digital processing of these images. Multi-criteria analysis was also used by [9] in Algeria to map the vulnerability of municipalities in the Bay of Algiers to coastal risks through the coastal vulnerability index. This analysis made it possible to identify three (3) municipalities at high risk of coastal erosion, namely Hussein Dey, Mohammadia and Bordj El Kiffan, thus allowing the determination of priority intervention zones. These authors also used SRTM images to assess the Coastal Vulnerability Index, strongly influenced by socio-economic factors compared to physical factors (slopes, coastline, bathymetry, geomorphology). The evaluation of this area has nevertheless led to unfavorable physical characteristics (significant erosion, fragile sandy coastlines, etc.) as is the case on the west of the Ivorian coast. However, the techniques used in our case made it possible to simulate cases of flooding according to overflow distances. It is the same for [10] who also based their approach on the overlay/GIS to identify the sectors subject to marine flooding in the municipality of Guissény (France). These authors used a DGPS to build a Digital Terrain Model with a resolution of 0.5 × 0.5 m, superimposed on the extreme water levels (observed tide + wave setup) of the Guisseny coast to show that 120 ha of the coastal zone urbanized is highly exposed, 77 ha moderately exposed and 25 ha lowly exposed. The results are different from ours, given the difference in the data and the techniques used. Indeed, the marine weather data were not used in our case, but rather made forecasts based on river water overflow distances on the coast. On the other hand, [11] in his study on the vulnerability of the coastal city of San-Pedro, identified from the multi-criteria method that more than two-thirds (2/3) of the urban territory, 80% of the services socio-economic, 70% of households, *i.e.* 4 out of 5 individuals, have a high degree of vulnerability. These results are similar to those obtained in our study in that in the San-Pédro area, a large part of the slope assessment was estimated to be less than 10%. Otherwise, [12] implemented a flood model based on very high spatial resolution aerial images taken by a DJI Phantom IV® quadcopter type drone equipped with a fixed 4K image sensor to an integrated stabilization nacelle. This flood model was simulated from a Digital Terrain Model (DTM) produced using a DGPS and which made it possible to carry out topographic and photogrammetric surveys in June 2017. 54 ha of residential areas and 8 ha of farms would be directly impacted. These results are different from ours because we did not use weather-marine data to model.

5. Conclusion

The results of this study made it possible to show exposure to river overflow hazards in an estuarine area, such as the coastal areas of Sassandra and San-Pédro. Indeed, the superposition of coastal slope data from SRTM superimposed on issues made it possible to identify the hazards of overflowing courses and their impact on the country's economic activities. Today, other technologies are in full expansion to map coastal hazards with high precision. In Côte d'Ivoire for example, web mapping or web mapping solutions will have to be initiated to address the issue of coastal risk management, particularly flooding. These are the interactive mapping solutions, which most often use Mapserver because of its many features, its stability and its performance. By applying this technology completed to the evolution of slopes from SRTM, the country will be able to have a solid database to solve the problem of coastal flooding.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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