Statistical Simulation of Sea Level-Rise on the Port-Bouet Coast (Ivory Coast)

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Abstract
The in-depth analysis and knowledge of the variation of weather-marine factors (tidal and wave heights, wind speeds) is a major challenge in understanding the physical processes of erosion and marine submersion on Ivorian coastal areas. Indeed, this coastal area has undergone several episodes of storms in particular in August 2011 and May 2014), which had negative impacts on environmental, socio-economic and human resources. For this purpose, an analysis of the data was carried out on the simultaneous variation of predicted tidal heights at the Port of Abidjan, by the SHOM, of wave heights and wind speeds, acquired by satellite altimetry by NOAA/PMEL during the period September 2009-February 2016. The objective is to carry out statistical simulations of extreme marine levels using the generalized method of extreme values, using the software R. The threshold values recorded are 1.01 m, 1.87 m and 5 m/s for tidal heights, waves and wind speeds respectively. Extreme heights range from 1.01 to 1.17 for the tide, 1.87 to 2.8 m for the waves, and 5 and 9.09 m/s for the wind speeds, with a 95% confidence bands. Storms on the Port-Bouet coast in 2011 and 2014 would have caused flooding areas of 0.72 sq.m for a 10-year return period. But from a 20-years return period, 0.9 sq.m of the coast are flooded, including the neighborhood Derrière Warff.

Key words : *weather-marine factors, statistical simulations, return period, flooding areas, Port-Bouet*

INTRODUCTION

Understanding how coastal systems work is a fundamental issue because almost all of the world's low coasts are now affected by marine submersion/coastal erosion (IPCC, 2007, Eurosion, 2004). In the current climate warming environment, erosion and marine flooding are likely to increase (IPCC, 2007). Indeed, global warming leads to a eustatic rise in the sea level and therefore submergence of the coasts. It could also lead to increased climate instability and increased frequency of storms (Lozano and Swail 2002) that could contribute to increased coastal erosion. In the Gulf of Guinea, for example, short-lived storms have been locally observed over the past 25 years. Those described as regional were the most significant because of their impact on the entire region and their relatively long duration (1 to 2 days) (Tomety, 2013). In Côte d'Ivoire, the storms of August 2011 and May 2014 caused erosion and exceptional flooding of the coasts of Port-Bouët, causing important consequences on this Ivorian coastal area. As this sector is located 160 m from the Abidjan International Airport (the country's second largest economic), a statistical study of the evolution of marine levels and its impact on this sensitive coastal area has become necessary, from high spatial-temporal resolution satellite data.

1. LOCATION OF THE STUDY AREA

The study concerns the coastal zone of Port-Bouet (a district of Abidjan), between the Vridi Canal and the airport. It is a densely urbanized area, located between the latitudes 30N 5770000-5830000 and the longitudes 385000-4050000 W, where are located from west to east, the Vridi Canal, an industrial area, the Lighthouse, the Derrière Warff district and the International Airport of Abidjan. The location of the study area is shown as indicated in figure 1 (Appendix).

2. MATERIAL AND METHODS

The data of significant wave heights and wind speeds used are taken from the Centre National Européen Spatial (CNES) satellite altimetry data site, las.aviso.altimetry.fr/las/getUI.do/. They were acquired from the satellite NOAA/PMEL (National Oceanic and Atmospheric Administration/Pacific Marine Environmental

Laboratory), which measures these heights by satellite altimetry on a daily basis. Tidal heights, for their part, were daily acquired at the SHOM site (Service Hydrographique et Océanographique de la Marine), via http://www.shom.fr/les-services-en-ligne/predictions-de-maree/presentation/ (www.shom.fr). The data set was acquired during the period of September 2009-February 2016. The determination of extreme marine levels was made by statistical analysis of time series of data over the period studied. The extreme values generalized method, using R. software, was used to perform these simulations. The analysis of the time series made it possible to determine the threshold values, in order to identify the extremes and their impact on the coastal zone concerned.

3. RESULTS AND DISCUSSION

3.1 Marine Level Time Series

Observed tidal heights

The change in tidal heights between September 2009 and February 2016 shows a cyclical observation of observed water levels. Several tidal cycles are observed and separated by water levels occurring during the May-June season of each year. The highest tidal heights are observed during the August-October, 2011, October, 2013 and 2015, May-June, 2014 seasons, with values of 1.2 m. The lowest tides are observed in the early years, that is, around the months of January and February, with heights of 0.77 m.

Observed wave heights

The time series of wave heights also shows that the appearance of strong and weak waves on the coast is cyclically observed. The highest wave heights appear between June and October of each year while the lowest wave heights occur between January and March and between November and December. Two peaks are observed during the period:
• observed heights of 3 m on August 25 and 26, 2011;
• observed heights of 2.9 m on May 30 and 31, 2014.

Observed wind speeds

Contrary to tidal and wave heights, the observed wind speeds show a general non-cyclic trend that oscillates between 0.5 and 8 m/s. The highest wind speeds were around 7.55 m/s in August 2011 and 7.2 m/s between May and July 2014. Speeds oscillating around 7 m/s are present in May 2012 and August 2013. The lowest wind speeds (< 1 m/s) were observed in January 2010, May 2011, between May 2012 and July 2013, and in April 2014. Figure 2 (appendix) shows the different variations observed in marine levels over the period 2009-2016.
From the observed thresholds, the tidal heights, waves and wind speeds related to return periods are determined and recorded in table 1 (appendix). The analysis in table II (appendix) shows that extreme marine levels increase with return periods. They range from 1.01 to 1.17 for extreme tidal heights. Wave speeds are between 1.87 and 2.8 m and wind speeds between 5 and 9.09 m/s.

3.3 Flooding areas

The storms that occurred on the Port-Bouët coast in 2011 and 2014 would each have resulted in several submerged surfaces. The elevation profiles of the Port-Bouët coastline show an altitude of more than 11 m in the areas of the Airport, Derrière Warff and part of the Lighthouse and less than 11 m before the Lighthouse. These results show that in Port-Bouët, the submersible area is close to 0.72 km^2 for a 10-year return period (Figure 3). However, from the 20-year return period, the heights of the coastline are between 10 and 11 m. Derrière Warff is then subject to the hazards of flooding and the areas are estimated at 0.9 km^2 for these periods (Figure 4).

3.4 Discussion

The statistical study of extreme marine levels allowed to determine the tides and waves extreme heights and winds during the period September 2009-February 2016. However, it is important to note that the tidal data observed are not in situ and do not come from the tide gauge "Appontement" located at the West Pier of the Vridi Canal. The tidal data used are from previous predicted SHOM data and have been reconstructed. They can already be a source of error and constitute a limitation of this study. The statistical wave set-up resulting from observed and calculated tidal heights remains very low (15.7 mm) for the short time series of our study. Kergadallan (2013) believes that the dependence between the wave set-up and the tide is an amplitude and non-seasonal dependence. According to Woodworth et al. (2011), variations in mean sea level rise are almost similar around the world if long-term trends in water levels are taken into account. This statement could be contrary to the realities of the ivorian coastal zone which have a low tidal range (around 0.4 m) except for specific areas. Adjustments to these extreme marine levels are made in 95% confidence bands with margins of error of tidal heights, waves and wind speeds of 10 cm, 55, 44 mm, 29, 74 cm/s, for standard deviations σ of 0.079, 0.3 and 0.6.

CONCLUSION

The standard deviation results obtained of this study show an adjustment in data quality and can therefore be used in numerical hydrodynamic modelling. The wave heights and wind speeds observed on August, 25 and 26, 2011 and on May, 30 and 31, 2014 recalled the last storms occurred on the Port-Bouët coast, and thus mark the extreme sensitivity of this coastal zone to marine flooding. Flooding areas of 0.72 sq.m and 0.9 sq.m related to return periods were estimated. They confirm the sensitivity of the coast to stormy events and can thus serve as a model of marine wave set-up on the ivorian coasts.

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APPENDIX

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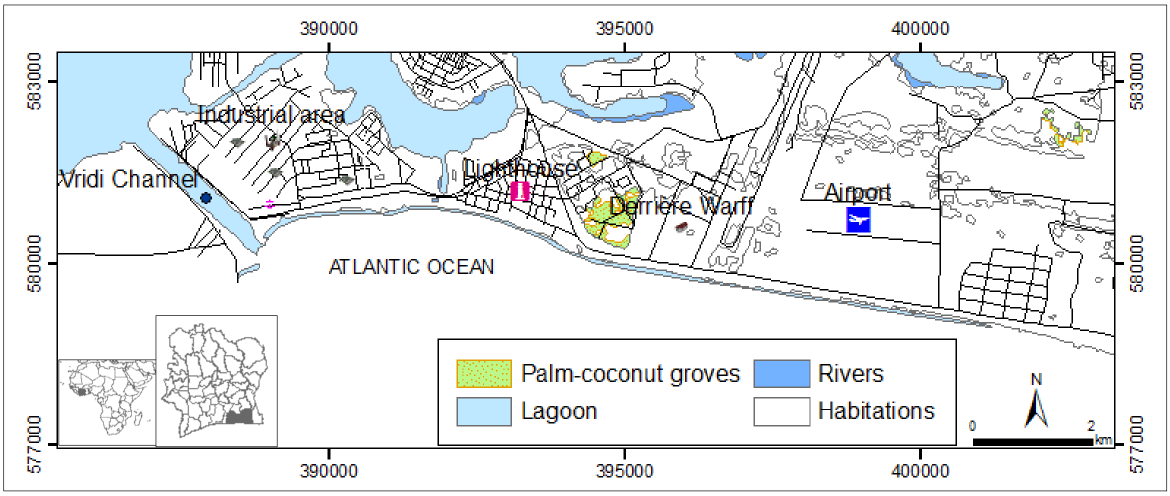
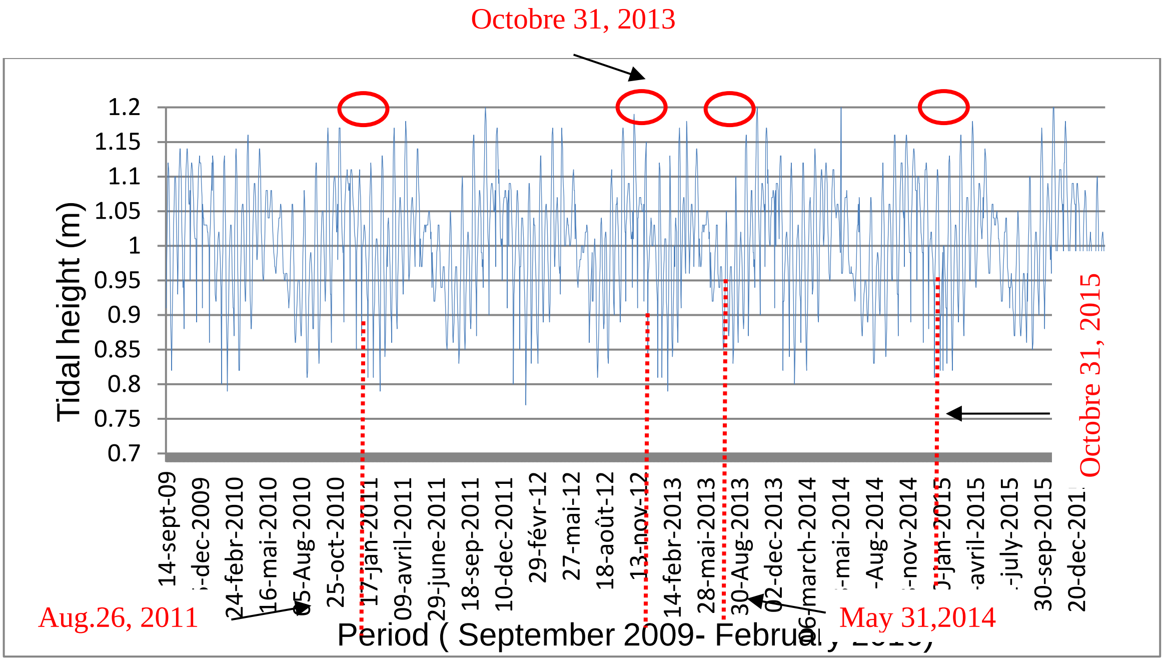


Figure 1 : Location of the study area



A

B

C

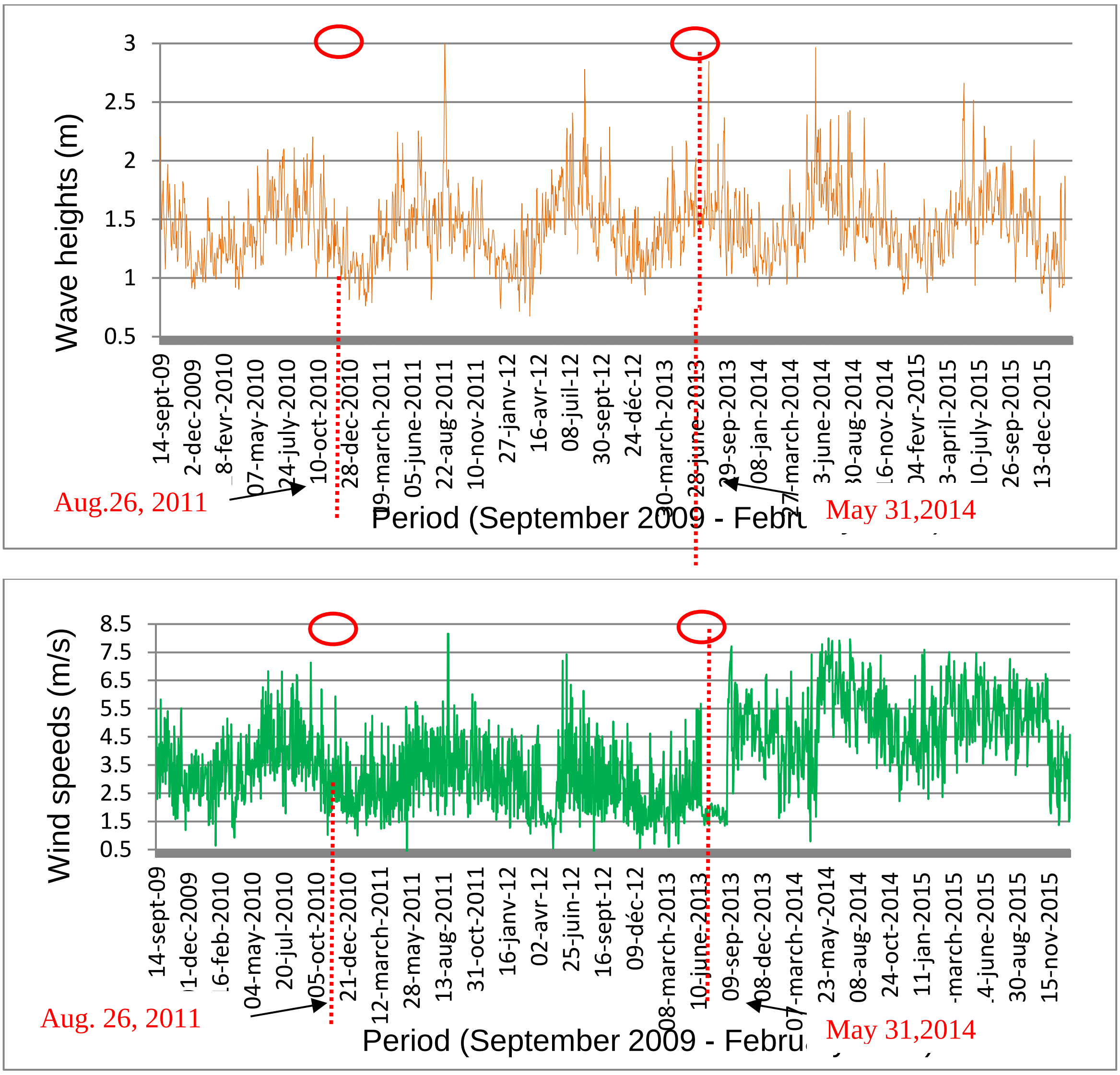


Figure 2: Time series of tidal heights (A), wave heights (B) and wind speeds (C) from September 2009 to February 2016

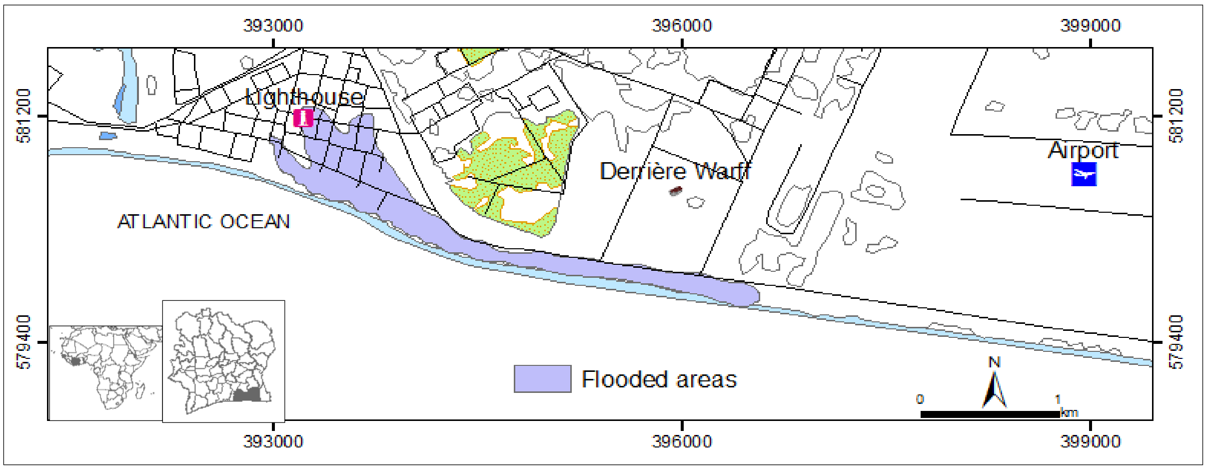


Figure 3 : Flooding surfaces on the Port-Bouët coast for a 10-year return period

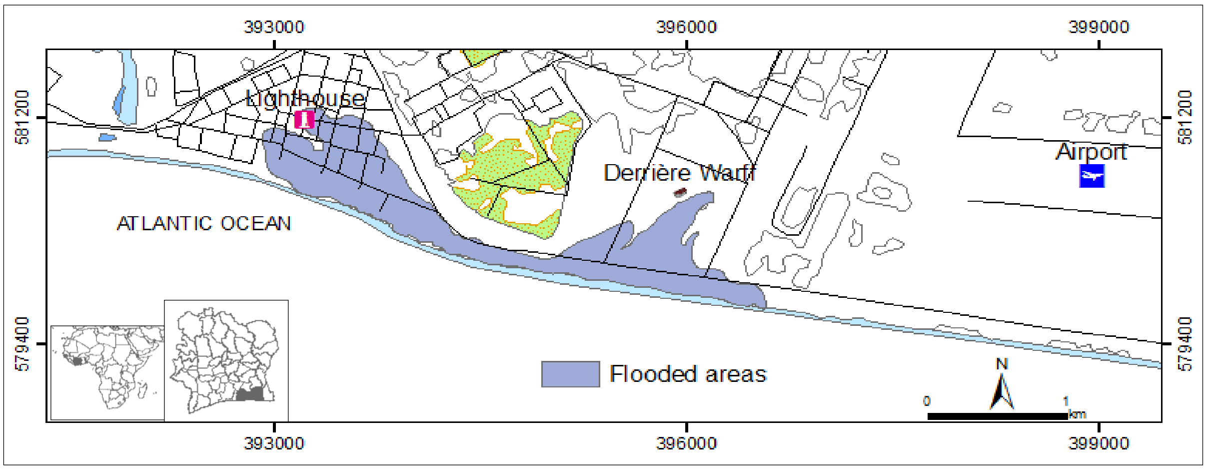


Figure 4 : Flooding surfaces on the Port-Bouët coast for 20, 50, 100-years return period

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Table 1 : Observed thresholds

Parameters	**Observed thresholds**
Tidal heights (m)	1,01
Wave heights (m)	1,87
Wind speeds (m/s)	5

Table II: Calculated Extreme Marine Levels

	Calculated tidal		**Calculated waves**		**Calculated winds**	
Return period (years)	**H (m)**	Conf.bands (95%)	**H (m)**	Conf.bands (95%)	**V(m/s)**	Conf.bands (95%)
100	**1,17**	1,16-1,17	**2,8**	2,75-2,85	**9,09**	8,82 – 9,37
50	**1,15**	1,15-1,16	**2,67**	2,63-2,71	**8,59**	8,38 -8,80
20	**1,13**	1,33-1,40	**2,48**	2,45-2,51	**7,82**	7,68 – 7,96
10	**1,11**	1,11-1,11	**2,32**	2,30-2,35	**7,15**	7,05 - 7,25
5	**1,08**	1,07-1,08	**2,15**	2,14-2,17	**6,37**	6,28 - 6,45
2	**1,01**	1,00-1,01	**1,87**	1,87-1,98	**5,00**	4,93 - 5,05