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Morphological Forecast of the Grand-Bassam Shoreline by the Kalman Filter Model (Ivory Coast)

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Abstract: This study presents a high spatial resolution morphodynamic numerical simulation of the Grand-Bassam shoreline, located est of Abidjan. Indeed, for several years, this area has been confronted with receding coastlines causing significant material damage and flooding, which has made it possible to consider investigations in this area. However, these investigations have not always made it possible to accurately predict the morphological dynamics of the future shoreline of this area. This explains the use of MultiSpectral Instrument (MSI) 2A sentinel images from 2015 to 2020 (spatial resolution is 10m) to extract the shorelines. Digital processing was performed using the Digital Shoreline Analysis System (DSAS), compatible with ArcGis 10.5 software. The End Point Rate (EPR) and Linear Regression Rate (LRR) methods were used to calculate the statistical evolution of the Grand-Bassam shorelines between 2015 and 2020. To improve the forecast, including updating the rate and uncertainties, the Kalman filter approach is initialized with the linear regression rate calculated by DSAS. The treatments allowed to generate 9758 transects (4853 transects west of the mouth, 2550 east of the mouth and 2355 transects after Asséoufoué) for 2 m steps. During the period indicated, the Grand-Bassam shoreline has receded by -0.47 m /year. The west areas of the mouth and after Asséoufoué show negative balances with erosion rates of -0.97 m per and -0.22 m/year respectively. On the other hand, the eastern sector of the mouth presents a positive balance with a rate of 0.24 m/year. The simulations made on the evolution of the future dynamics of the coastline show a fattening of 21.49 m or 2.15 m/year in 2030 and a fattening of 30.4 m or 1.53 m/year in 2040.

Keywords: Sentinel Image, Shoreline, DSAS, Kalman Filter, Forecast, Grand-Bassam

1. Introduction

The process of coastline retreat is a natural phenomenon that affects more than 70% of beaches on the planet (Bird, 1985) [1]. In Côte d'Ivoire, like the other coastal countries of the Gulf of Guinea, the coastline is confronted with major environmental problems, both natural and anthropogenic, and coastal erosion is an illustration of this (Hauhouot, 2008; Touré, 2009; Konan, 2012; Yao et al., 2010) [2-5]. In addition, this area is subject to various attacks, including pollution of all kinds, marine submersion, strongly impacting the lives of populations, economic, tourist and cultural activities. For this work, the research focused on the coastal of Grand Bassam area. Indeed, several forecast studies of the evolution of the coastline exist but present relatively long approaches. This is the case of the LX-Shore model for longshore and crossshore processes coupled with spectral wave models (Robinet, 2017; Robinet et al., 2018) [6, 7]. Thus, to simplify the forecasts of the dynamics of the coastline of the Grand-Bassam area, it appears necessary to test other powerful tools requiring little calculation time and better spatial resolution of the data.

Presentation of the study area

Located between 3° and 3°94' west longitude and 5° to 5°13' north latitude, the municipal territory of Grand-Bassam has a coastline of 12.5 km (figure 1). It is bounded to the north by the sub-prefecture of Alépé, to the west by that of Bingerville, to the south by the Atlantic Ocean and to the east by the sub-prefecture of Bonoua. It covers an area of approximately 1,000 km^2 and a population of 50,000 inhabitants. This former capital of Côte d'Ivoire is 40 km from Abidjan, and is one of the main coastal cities of southeastern Côte d'Ivoire. Geomorphologically, the coastal strip is located on a plain of the coastal sedimentary basin (Tastet, 1972) [8]. It extends between the coasts of the localities of Azuretti and Asseouffouè, separated by the mouth of the Comoé river.

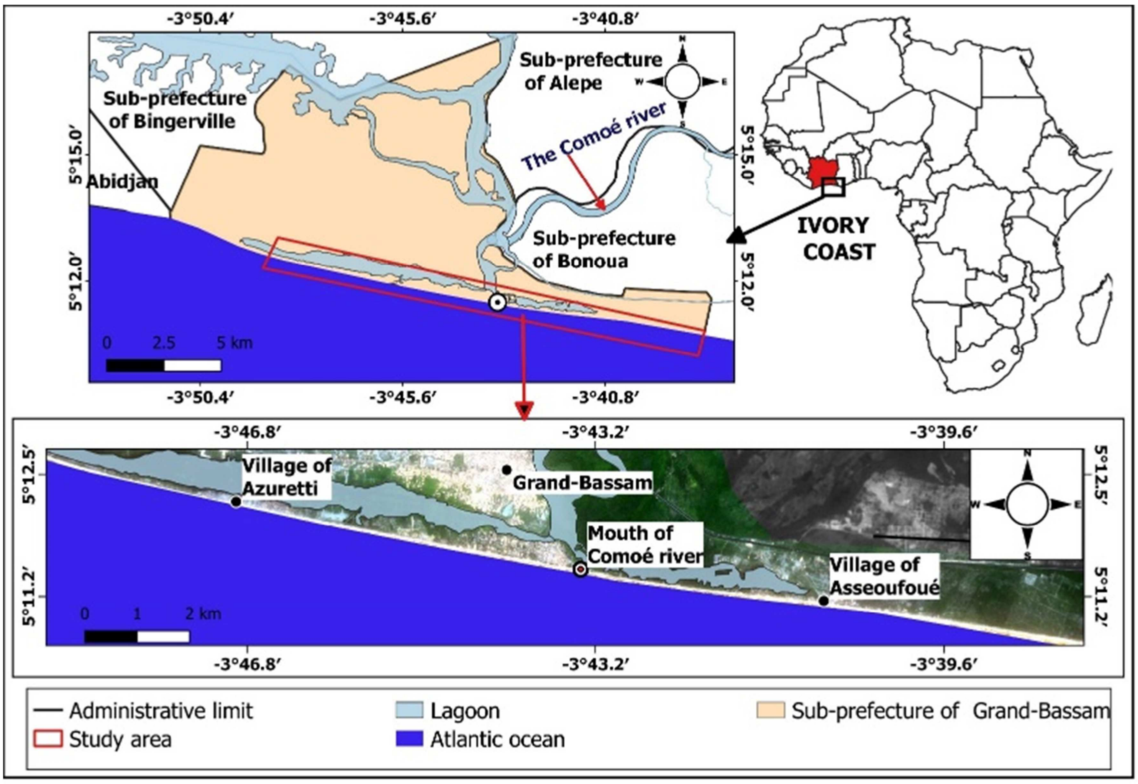


Figure 1. *Location of the study area.*

2. Methodology

2.1. Statistical Calculation of Shoreline Rates of Change

As part of this study, several sentinel satellites images, in particular the sentinel 2A MSI 1LC images of the years 2015, 2018, 2019 and 2020 were acquired on the Copernicus site (https://scihub.copernicus.eu/dhus/# /home), to undergo digital processing in appropriate software. First, the SNAP software made it possible to perform atmospheric, radiometric and resampling corrections in order to calculate the indices Modified Normalized Difference Water Index (MNDWI). Then the ENVI 5.3 software was used to perform the thresholding by clearly distinguishing the limit between the dry soil and the wet soil and the isolation of the waters of the continent. The ArcGIS 10.5 software meanwhile, made it possible to digitize the coastlines and to make the cartographic layout. Finally, the Digital System Analysis Systems (DSAS 5.0) extension was necessary to perform statistical calculations of erosion rates (EPR, LRR) and the evolution of shorelines. Calculations were performed on 9758 automatically generated transects between shorelines. As for the prediction calculations of the future dynamics of the shorelines, they were carried out via an algorithm, called Kalman filter (Himmelstoss et al., 2018) [9].

2.2. Kalman Filter Model

The Kalman filter approach is initialized with the linear regression rate calculated by DSAS.

The model begins at the first-time step (the date of the earliest survey) and predicts/forecasts the shoreline position for each successive time step until another shoreline observation is encountered. Whenever a shoreline observation is encountered, the Kalman Filter performs an analysis to minimize the error between the modeled and observed shoreline positions to improve the forecast, including updating the rate and uncertainties (Long and Plant, 2012) [10]. When the prediction is displayed, it is strongly recommended that the uncertainty band is also displayed to responsibly visualize the uncertainty associated with the prediction.

3. Results

3.1. Current Dynamics of the Coastline of the Coastal Zone of Grand-Bassam

Azuretti area

The Azuretti sector presents a linear regression rate with an average of -0.97 m/year. Out of 4853 transects generated in this sector, 98% of the coastlines are clearly receding while 2% are getting fatter. Erosion is estimated at -1m/year and the fattening rate is 0.12 m/yr.

The mouth of the Comoe river area

The mouth sector shows a linear regression rate of 0.24 m/year. Out of 7404 cumulative transects generated in this area, 38.47% of the coastlines are under erosion and 61.53% under growth.

Asséoufoué

The Asséoufoué sector shows a linear regression rate of -0.22 m/year. Out of 9757 cumulative transects generated in this area, 60.55% of the coastlines are eroded while 39.45% are accredited. Figure 2 shows the evolution of the erosion and progradation rates of the coastlines of the Grand-Bassam coastal zone between 2015 and 2020.

Figure 2 presents current dynamics of the coastline of the coastal zone of Grand-Bassam.

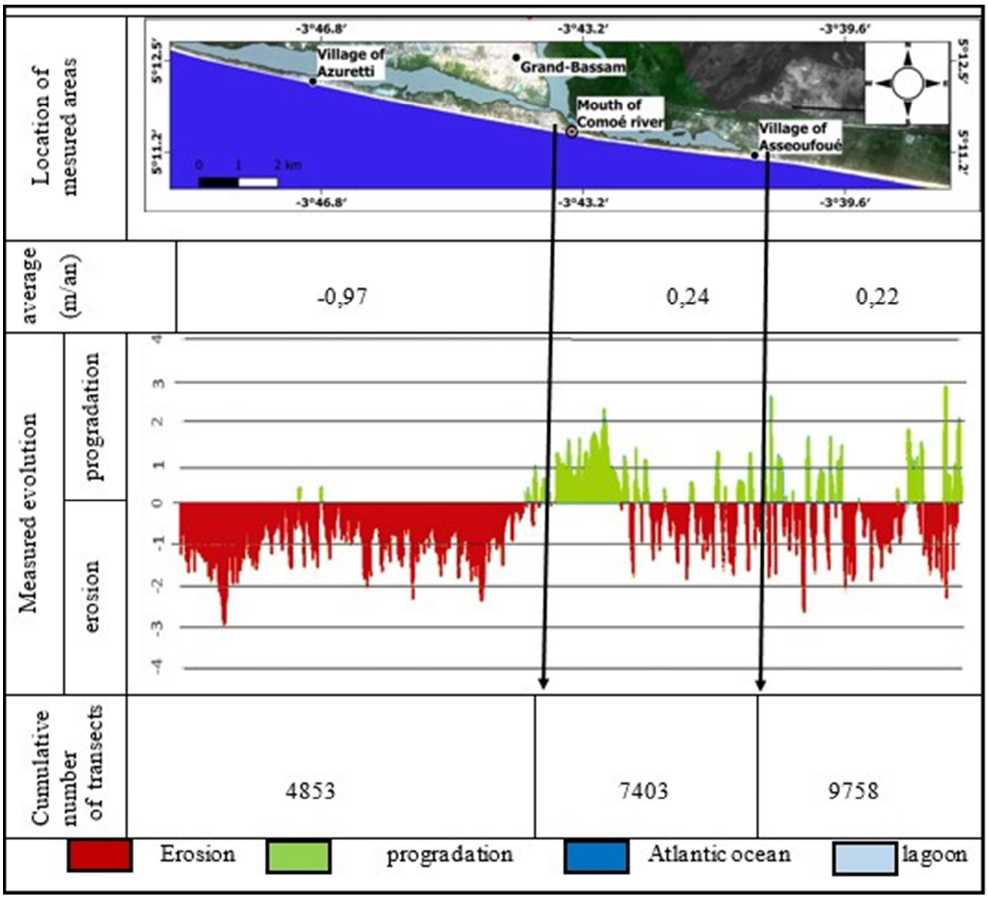


Figure 2. Current dynamics of the coastline of the coastal zone of Grand-Bassam.

3.2. Morphological Forecasts of the Future Dynamics of the Coastal Zone of Grand-Bassam

3.2.1. Forecast for 2030

The statistical calculations carried out for the forecast of the future dynamics of the coastline for 2030 have made it possible to present a positive balance for the entire coastal zone. Thus, a fattening of 21.49 m is expected in the area, i.e. an average speed of 2.15 m/year during the period of 2020-2030. However, the morphological forecasts in the specific sectors of the Grand-Bassam area show the following results:

Azuretti area

The forecasts in the Azuretti sector show a retreat of -0.37m, i.e. a speed of -0.037 m/year, which results from an alternation between erosion (-0.47 m/year) and fattening (0.58 m/year). over the whole period.

Mouth of the Comoé river area

The mouth sector shows a gain of 13.88 m during the period, i.e. an average speed of 1.38 m/year, distributed between a decline of -0.35 m/year against a gain of 1, 67 m/year.

Asséoufoué

The Asséoufoué sector also shows a gain of 7.98 m, i.e. an average speed of 0.79 m/year, with an alternating decline of -0.69 m/year against a fattening of 1.39 m/year.

Figures 3 and 4 present the morphological forecasts of the Grand-Bassam shorelines and their assessment for 2030 respectively.

3.2.2. Forecast for 2040

The statistical forecasts made on the morphology of the coastline for 2040 have shown an advance of 30.4 m, i.e. an average speed of 1.53 m/year, during the period of 2020-2040. The eroding sectors are estimated at -11.84 m with an average speed of -0.59 m/year. However, the accredited quantities show a gain of 19.98 m, i.e. an average speed of about 1 m/year. The morphological forecasts in the specific sectors of the Grand-Bassam area show the following results.

Azuretti area

Overall, this sector shows a decline of -2.78 m, i.e. an average speed of -0.14 m/year, divided between a decline of -0.6 m/year against an increase of 0.41 m/year.

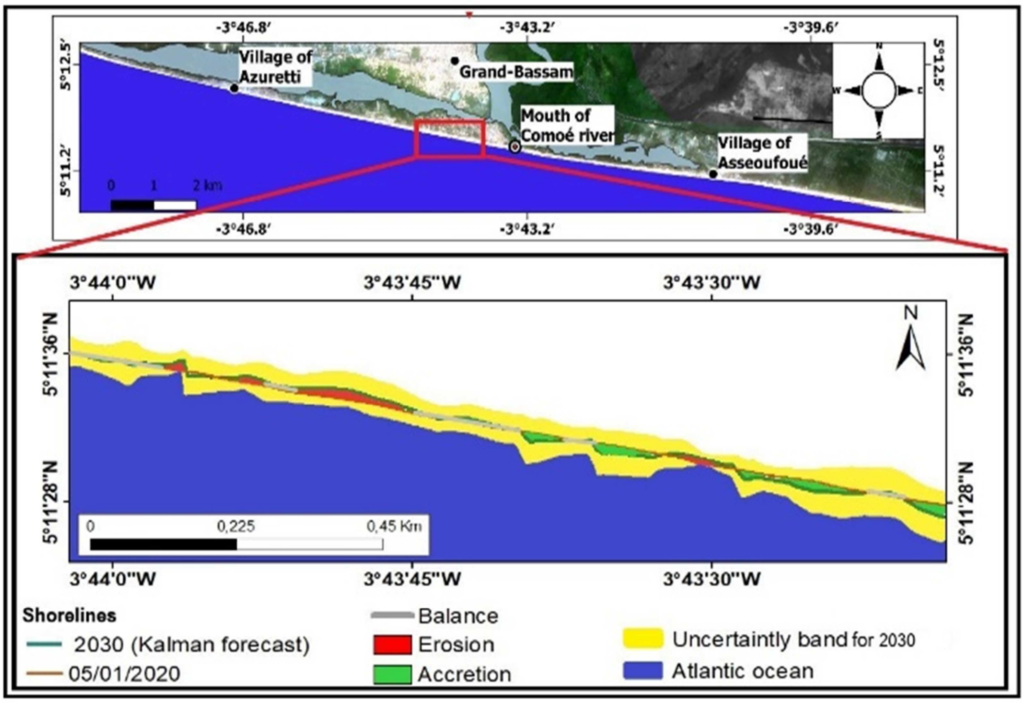
Mouth of the Comoé river

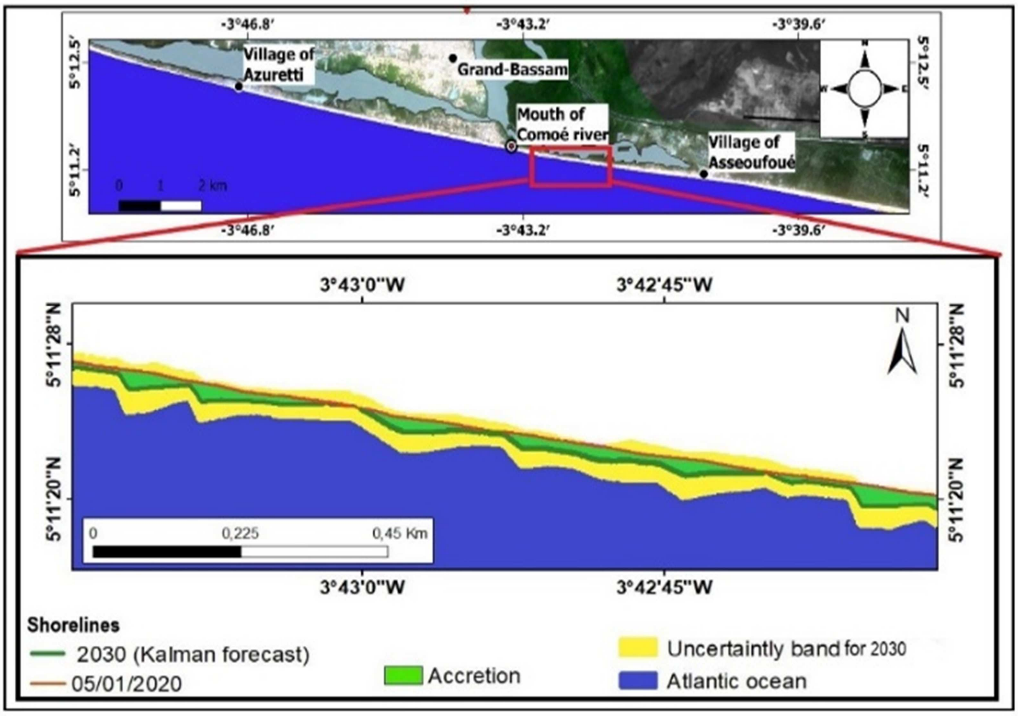
The mouth area shows an overall gain of 22.59 m, i.e. a fattening rate of 1.13 m/year. This fattening is the result of a gain of 1.43 m/year followed by an eroded quantity of -0.39 m/year.

Asséoufoué

In this zone, an advance of 10.59 m, i.e. an annual speed of 0.53 m/year has been identified and is distributed as a decline of -0.68 m/year against 1.11 m/year accredited.

Figures 5 and 6 present the morphological forecasts of the Grand-Bassam coastline and their assessment for 2040 respectively.





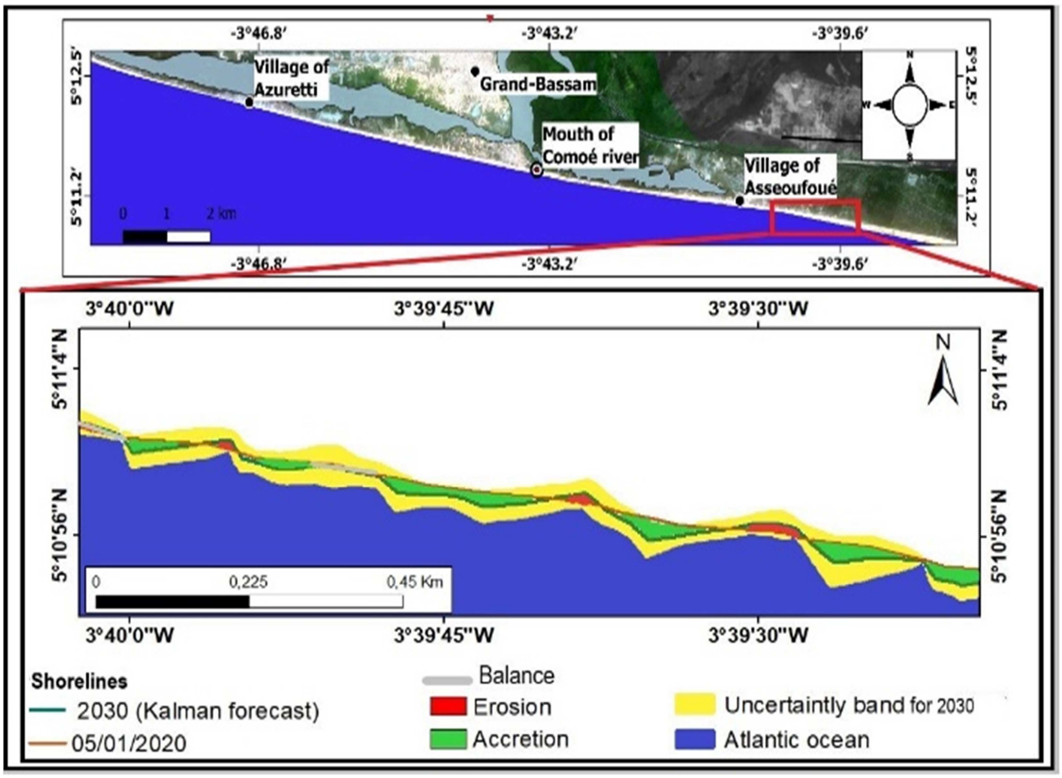


Figure 3. *Morphological forecasts of the Grand-Bassam shorelines for 2030.*

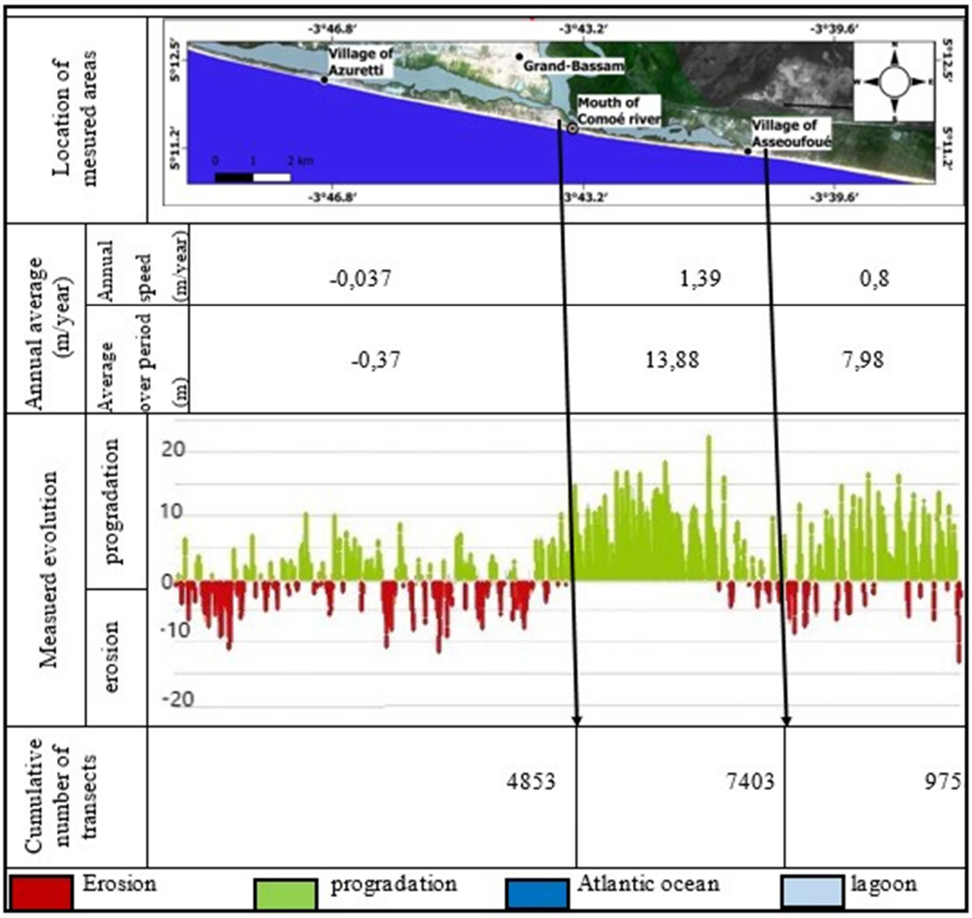
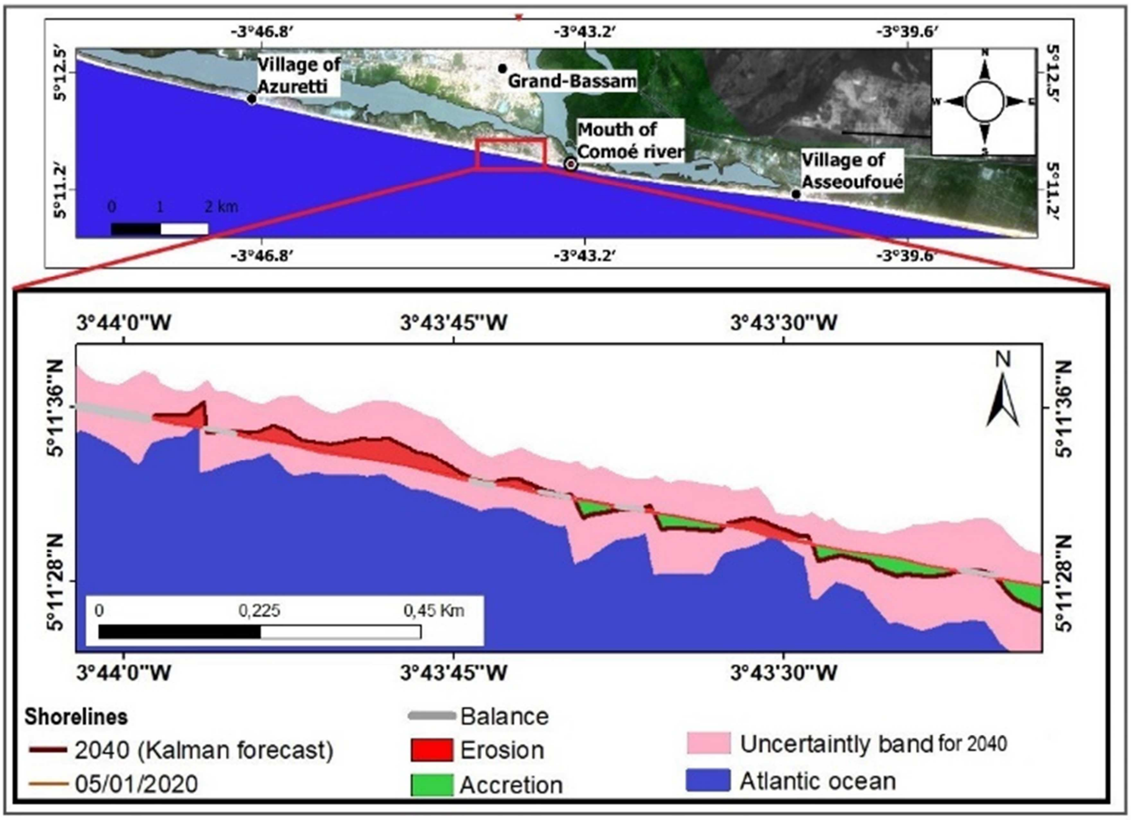


Figure 4. *Shorelines forecasts assessment for 2030.*


-3°46.8′
-3°43.2′
-3°39.6′
5°12.5′
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Village of Azuretti
Grand-Bassam
Mouth of Comoé river
Village of Asseoufoué
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3°44'0"W
3°43'45"W
3°43'30"W
5°11'36"N
5°11'28"N
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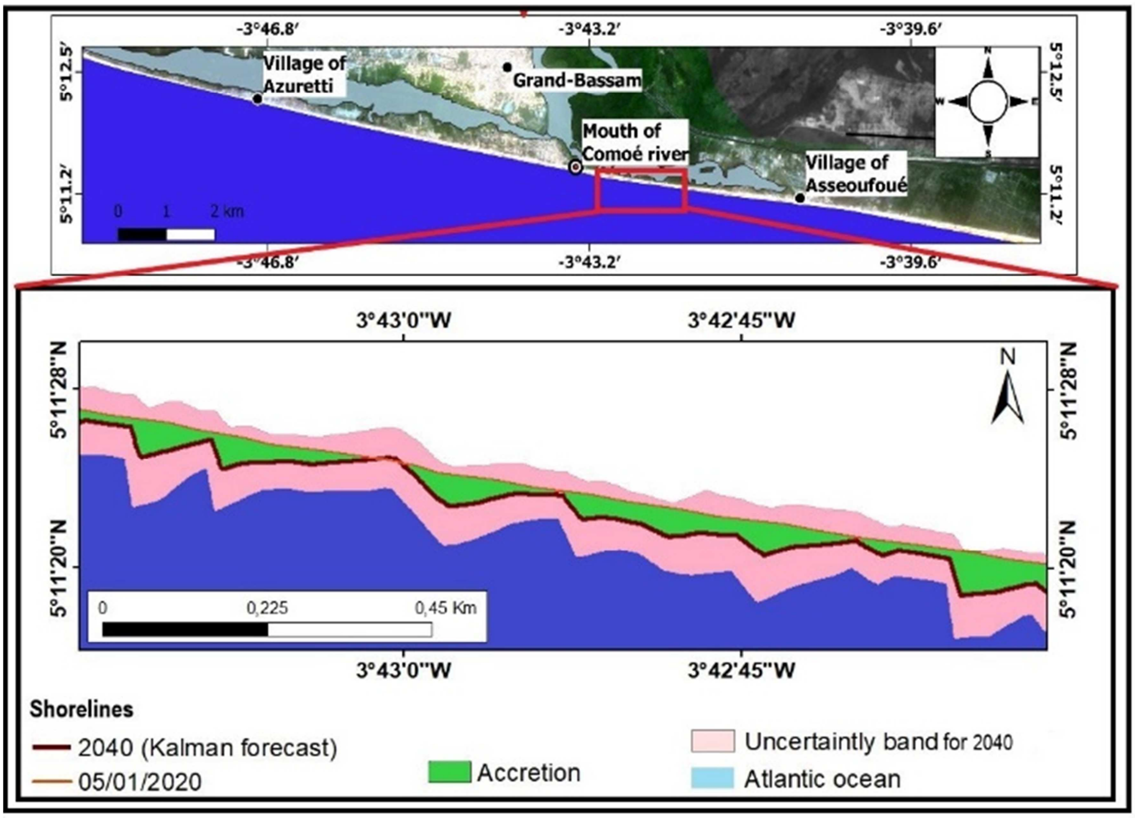
Shorelines
2040 (Kalman forecast)
05/01/2020
Balance
Erosion
Accretion
Uncertaintly band for 2040
Atlantic ocean


-3°46.8′
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Village of Azuretti
Grand-Bassam
Mouth of Comoé river
Village of Asseoufoué
0 1 2 km
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3°42'45"W
5°11'28"N
5°11'20"N
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Accretion
Uncertaintly band for 2040
Atlantic ocean

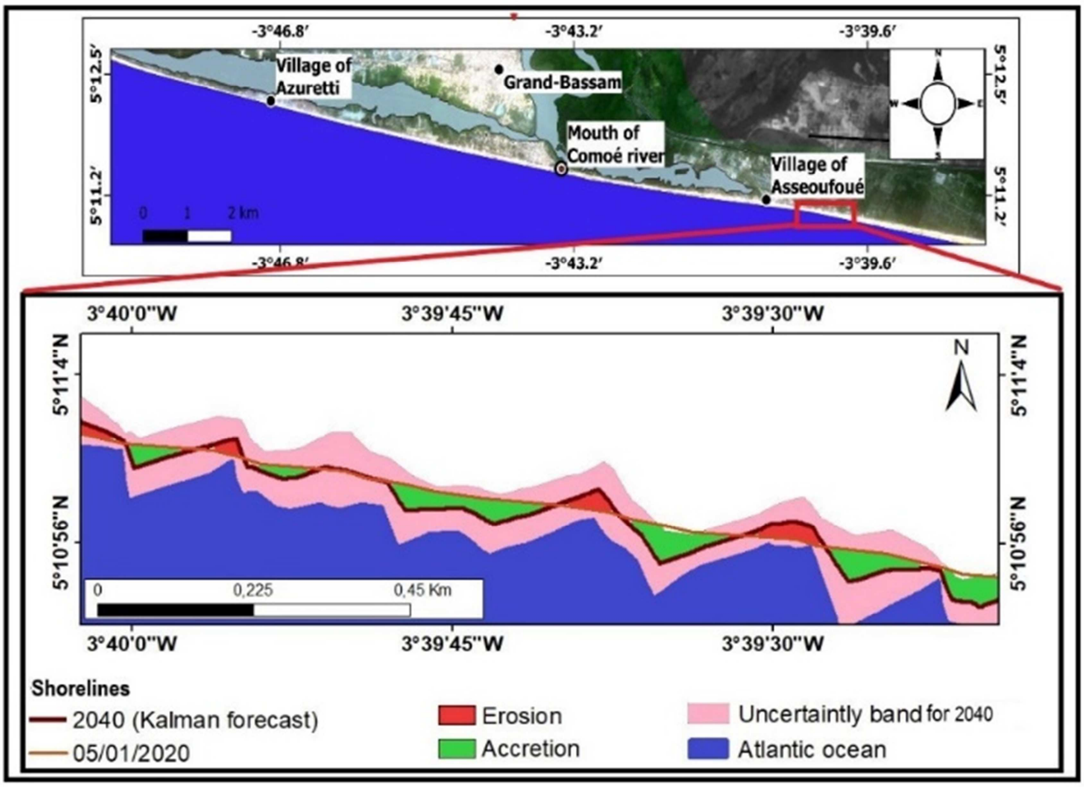

Figure 5. Morphological forecasts of the Grand-Bassam shorelines for 2040.

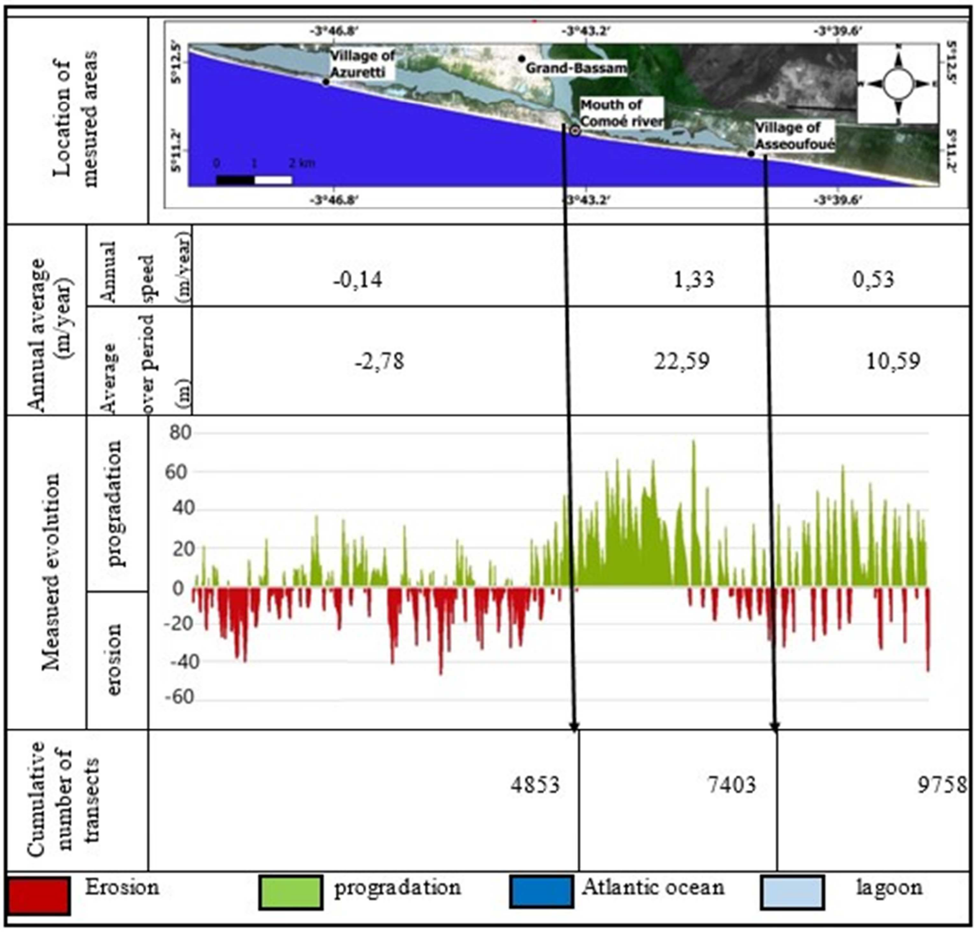

Figure 6. Shorelines forecasts assessment for 2040.

4. Discussion

In this study, the work was essentially based on the linear regression method, a method which made it possible to carry out the forecast calculations. Indeed, the current dynamics of the coastline of the study area shows an erosive trend during the study period. The erosion of the coastline could be explained by many human activities carried out in this area of the coast, in particular the extraction of sand which is used in real estate construction projects. During this time, episodes of accredited quantities are recorded between the mouth of the Comoé River and the Asseouffoue sector. This could be related to the deposition and clogging of sediments in this area during sediment transit, due to the closure of this mouth for several years.

These results present certain differences with some previous studies, in particular those carried out by Touré et al., 2018 and Djagoua et al., 2016 [11, 12]. Indeed, Touré et al., 2018 [11] used the MobiTC application to monitor the statistical evolution of the Grand-Bassam coastline between 1984 and 2016. The result is an overall increase in the coastline of 0.34 m/year with 62.79% accredited and 37.21% eroded. The difference in the results is clear because in our case, it is an average eroded rate of -0.47 m/year. These differences could be due first to the period of study, to the spatial resolution of the satellite images used to extract the coastlines, using the transects transects automatically generated to perform the statistical calculations of the evolutions of the coastline. Sentinel images offer good spatial image resolution (10 m) unlike the Landsat images used by these authors. The step used is 2 m between the transects generated during our work.

Our results are also different from those of Djagoua et al., 2016 [12], based on the use of the same tool (DSAS tool) for mapping the dynamics of the coastline in Grand-Lahou. The GIS approach was used during this study and consisted of a compilation of data from Landsat images from 1998 to 2014 for a 10m mesh. The result is an average accrediting of 2.09 m/year west of the mouth before Lahou-Kpanda and an erosion of 0.84 m/year on the rest of the shore after this same village. The methods used in this study being almost the same as in ours, except for the Sentinel images used, the difference in results can be explained by the difference between two study areas which are subject to different morpho-dynamic and hydrosedimentary phenomena.

Concerning the forecasts using the Kalman filter in this study, they should always be used with caution. The processes driving shoreline change are complicated and not always available as model inputs: many factors that may be important are not considered in this methodology or accounted for within the uncertainty. This methodology assumes that a linear regression thorough past shoreline positions is a good approximation for future shoreline positions; this assumption will not always be valid. By 2030, forecasts show a fattening of 2.15 m/year and in 2040 a fattening of 1.53 m/year.

The work to open the mouth of the Comoé River in Grand-Bassam (project in progress) could thus modify the morphological and sedimentary dynamics of this coastal zone. Our forecast results do not take into account the parameters and data of the current mouth opening works. Because there could be possibilities of building protective works (protection structure, by passing, reloading, etc.) at the end of the works.

However, forecasting work by Kouekam et al., 2019 [13] on the Cameroonian west coast was based on the evaluation of the position of the costline from the speed formula V=Distance/Time between 2018 and 2028, considering as origin the year 2018 with a speed of coastline retreat of -1.09 m/year. These results are quite different from ours for the 10-year forecast.

5. Conclusion

Knowledge and monitoring of the coastline is essential for the integrated management of coastal zones and the prevention of coastal risks such as erosion and marine flooding. This study on the morphological forecast of the coastline of the coastal zone of Grand-Bassam using the "Digital Shoreline Analysis System" tool had the main objective of carrying out, on a local scale, a provisional mapping of the dynamics of the coastline. The analysis of the data obtained thanks to the various digital processing of the Sentinel images from the DSAS 5.0 software made it possible to understand the current spatiotemporal mobility of the coastline in order to predict future dynamics.

The morphological simulations highlighted an eroded and fattened coastal zone alternately at the Azuretti zone but strongly fattened between the mouth of the Comoé river and the Asseoufoué zone. These results should be taken with caution, given that work to open the mouth of the Comoé river is currently underway.

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