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Monitoring Spatial and Temporal Scales of Shoreline Changes in Lahou-Kpanda (Southern Ivory Coast) Using Landsat Data Series (TM, ETM+ and OLI)

Abstract: Shoreline changes are crucial for assessing human-ecosystem interactions in coastal environments. They are a valuable tool for determining the environmental costs of socioeconomic growth along coasts. In this research, we present an assessment of shoreline changes along the eastern coast of Lahou-Kpanda of the Ivory Coast during the period from 1980 to 2020 by applying Digital Shoreline Analysis System method using Landsat Data Series. The measurement of the shoreline dynamics of the Lahou-Kpanda coastline is mainly described in three parts: the west straight cordon, the dynamics at the mouth and the east straight cordon. The findings show a drastic reduction in natural shorelines. The greatest transition occurred along the mouth segment of the coast, where the average erosive velocity approaches 90 meters each year and the average distance has decreased by around 2 kilometers. The Ivory Coast lost more than 40% of its biological shorelines between 1980 and 2020, according to this report, a worrying development because these are regions that were once biologically abundant and highly rich. In general, human operations on the Ivory Coast's shorelines have never had such an impact. The effects of these changes on habitats, as well as the vulnerability of new shoreline investments to increased human activity and sea-level rise, must be measured.

Keywords: shoreline change, remote sensing, DSAS, Landsat, Lahou-Kpanda

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1. Introduction

A coastal zone is a transition area between the land and water. It represents a very important natural and economic resource [1–3], despite the fact that it is constantly changing. In addition, this microcosm is a highly complex environment in which erosion phenomena, and therefore the retreat or advance of the coastline, are influenced by a wide range of meteorological, geographical, biological, and anthropogenic influences [4–6]. Monitoring the coastal zone is important in a variety of applications, including sustainable development, cartography, and environmental protection [7–9].

As with most coastal areas around the world, the coastal zones of West Africa have been marked in recent decades by a natural process that shapes the shores. The coastal zone of Ivory Coast, part of the West African coastal zone, is subject to marine erosion (Fig. 1). In fact, two-thirds of the Ivorian coastline is destabilized by coastal erosion, and this will continue to increase given the amplification of socio-economic pressure on the coast and global projections relating to the impacts of climate change, suggesting an increase in sea level rises and leading to the reinforcement of erosion processes on the low-lying coasts [10]. In Grand-Lahou, the most important fishing sector, coastal erosion threatens Lahou-Kpanda, a fishing village, and is characterized by the destruction of infrastructure, tourist sites and habitats. Given the real danger that coastal erosion poses to this village, and given the need to prevent coastal risks in a context of climate change, it is essential to characterize the spatial and temporal evolution of the line on the coastline of Lahou-Kpanda (in the south of the Ivory Coast).

Fig. 1. Pictures of the eroding coastline of Ivory Coast

Remotely sensed data plays an important role in the identification, monitoring and delineation of coastline change at regional or global scales [11–14]. The availability of multi-band, multi-temporal and multi-sensor images and advances in digital treatment and analysis have allowed scientists to gather information on spatial and temporal changes and on the sensitivity of alterations due to natural and anthropogenic events. In this research, Landsat satellite data from 1980, 1987, 2000, 2015, 2017 and 2020 were used to examine the shoreline changes that have occurred during the past 40 years in the coastal area.

The study has the following specific research objectives (i) to examine the shoreline changes in shoreline along the coast over the past 30 years (1980 to 2020) and (ii) to explain the mechanism(s) that caused these changes. Aside from its local implications (Grand-Lahou, southern Ivory Coast), the current study could add to the literature and research domain more broadly in terms of shoreline change analysis at the local, international, and global levels. Also, it might be utilized for subsequent research, particularly in coastal dynamics and the management of shore erosion and vulnerability mitigation [15, 16]. Using multi-temporal Landsat satellite images, the study explores shoreline alteration, coastal erosion, and accretion heterogeneity in a long-term scenario. The study's findings can be useful for erosion threat management in Grand-Lahou, which is one of Ivory Coast's most vulnerable coastal region, as well as a guide for future research and coastal hazard management at the local, international, and global levels.

2. Study Area Description

2.1. Geographic Situation

Lahou-Kpanda is a village in the Grand-Lahou commune in the Ivory Coast's south-west region. It is bordered by the Gulf of Guinea, at the mouth of the Bandaman River, and is situated between 5°07′37″ and 5°08′12″ N and 4°59′01″ and 5°08′12″ W (Fig. 2b). The lagoons' (administrative) area includes Grand-Lahou. The geography of the area is characterized by thick woodland, with vast swaths of low-lying land and marshland. With temperatures ranging from 20 to 30°C, the sub-equatorial atmosphere is hot and humid. There are two major seasons (dry and rainy) and two shorter seasons that are somewhat similar. The annual rainfall is 2000 mm.

2.2. Geological Context

The Ivory Coast is split into two geological structures that are of unequal significance and separated chronologically [17–20]. In the one side, in the south, there is a late secondary to quaternary sedimentary basin that occupies 2.5% of the region and covers 30,000 km^2. This basin stretches from Sassandra (in the west) to the Ghana frontier (in the east) (Fig. 2a).

This portion of the basin (onshore) is very narrow in the west, but it widens to 35 kilometers at the level of Abidjan level. A large fault, known as the "lagoon fault", runs through the basin from west to east, dividing it into two parts: To the north, the fault's formations are finer, made up of clays, clayey soils, and more or less ferruginous sandstones of "terminal continental" age [21, 22]. The outcropping rocks in the south are thicker, and they are dominated by quaternary deposits made up of white sands and continental clayey beaches, sandy cordons, sands, fluvio-lagunar argillites, and maritime sands. However, the remaining 97.5% is taken up by a Precambrian basement. The research area is a part of Ivory Coast's coastline, precisely Grand-Lahou.

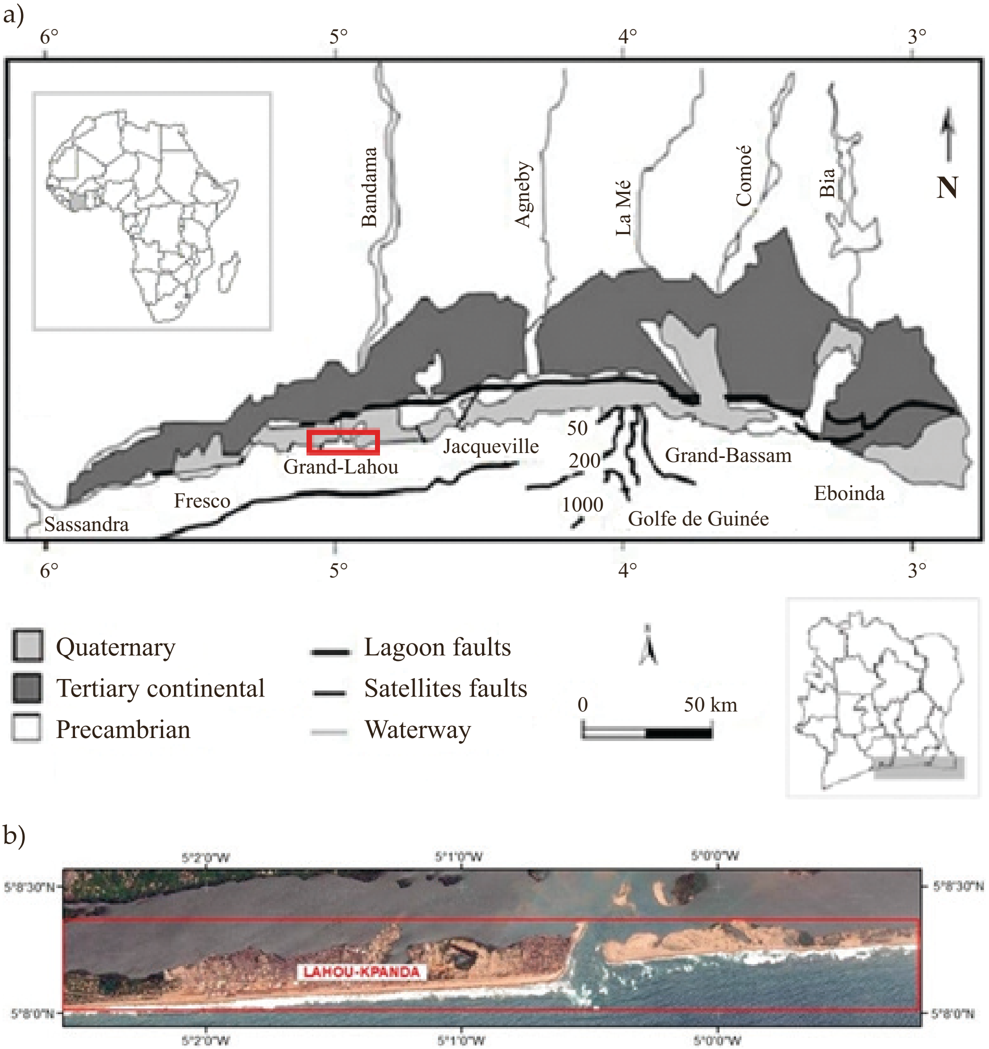

Fig. 2. Map of the Ivorian onshore sedimentary basin (a) and location of Lahou-Kpanda (b)

Source: [23] (Fig. 2a)

3. Materials and Methods

3.1. Data Used

Remote sensing data is a valuable tool for detecting coastline changes. It is crucial in the interpretation and mapping of data, since water absorbs infrared wavelengths and vegetation and soil reflect them strongly, multispectral images are an excellent combination for mapping the spatial distribution of land and water. Landsat satellite images represent the longest continuously acquired collection in the world of space-based earth remote sensing data. In this context, a series of Landsat images between 1980 and 2020 were used to determine of coastline changes in the study area, as presented in Table 1. These multispectral images were obtained by the United States Geological Survey (USGS).

Table 1. Dataset of Landsat images used for coastline changes of the Ivory Coast

Dates	Satellite/sensor	Path/Row	Spatial resolution [m]	Radiometric resolution [bit]
11/03/1980	Landsat TM	196/056	30 × 30	8
10/04/1987	Landsat TM	196/056	30 × 30	8
20/11/2000	Landsat ETM+	196/056	30 × 30	8
03/12/2015	Landsat OLI	196/056	30 × 30	12
30/05/2017	Landsat OLI	196/056	30 × 30	12
05/01/2020	Landsat OLI	196/056	30 × 30	12

3.2. Methodology

Landsat data series (TM, ETM+ and OLI) from 1980 to 2020 were used to track and discern shoreline changes, and have thus proven useful for studies relevant to coastal zone management [24–26]. The Landsat satellite images downloaded are in UTM projection, zone 30, and WGS 84 datum. A scheme was set up to analyze the shoreline change along the Lahou-Kpanda coastal strip, as shown in Figure 3.

After pre-processing (geometric correction, radiometric calibration, and atmospheric correction) of the images, shorelines were extracted by digitizing all satellite images of different time periods as shapefiles and used as input to the Digital Shoreline Analysis System (DSAS) tool. This is a tool for calculating the rate of change of the shoreline from a time series of multiple shoreline positions. It provides a robust suite of regression rates in a consistent and simply repeatable method so as to be run on large volumes of data collection at different scales [27–30]. Transects were developed using DSAS after the buffer was created with a margin of 15 meters to analyze the changes along the Lahou-Kpanda coast, and shoreline change statistics were determined in the form of Linear Regression Rate (LRR), Weighted Linear Regression, and End Point Rate (EPR). The LRR is calculated by fitting a least-squares regression line to all shoreline locations for a given transect. The uncertainty value is not taken into account when computing the shoreline change rate. The WLR technique is used to calculate the shoreline change rate. The approach for calculating shoreline rates of change is based on measured changes in coastline locations over time. The EPR is a straightforward technique that calculates change rates by dividing the distance between the oldest and youngest shorelines by the time interval between them.

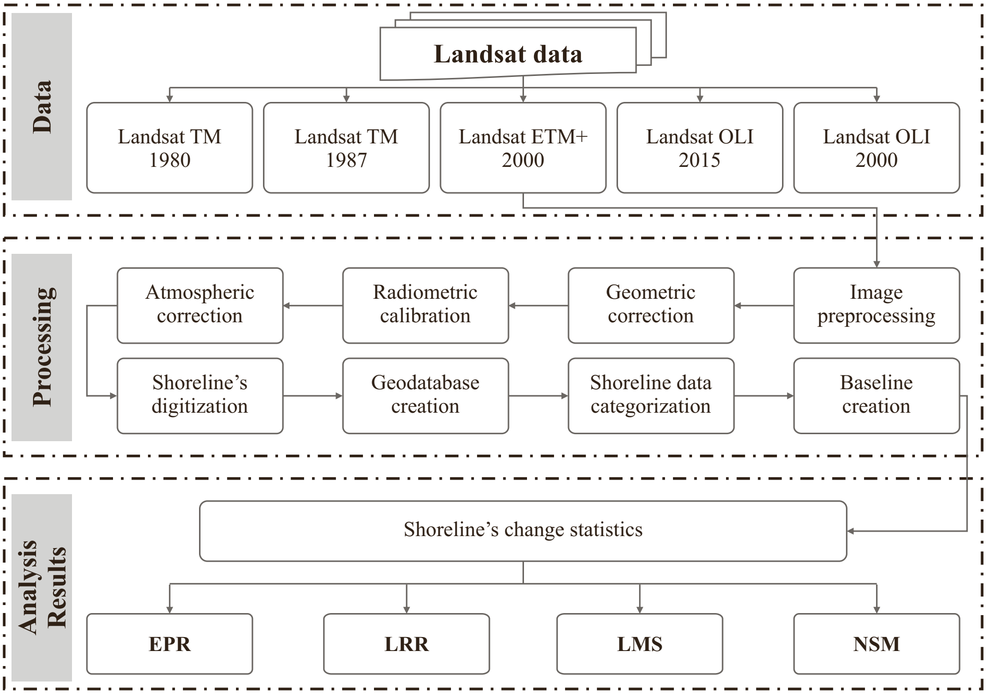

Fig. 3. Flowchart of the shoreline extraction process

4. Results and Discussion

4.1. Morpho-dynamic Evolution of the Coastline of the Lahou-Kpanda Cordon

The Lahou-Kpanda perimeter is composed of three trend parts (A, B and C). Part A (Fig. 4a) consists of all the straight zones of the perimeter's coastline. It is composed of the straight zone of the West Barrier and the straight zone of the East Barrier. It is an irregular zone because the coastline varies little over the period 1980–2020.

The 1980–1987 coastline is perfectly prograded along the western barrier reef shoreline. However, its two variants overlap as it approaches the mouth and gradually leads to erosion. This evolution is certainly not the same on the eastern barrier beach. The coastline has two characteristics, but the priority is given to erosion. On the western barrier, the trend is the same and is repeated for the periods 1980–2000, 1980–2015, 1980–2017 and 1980–2020. From 1987 to 2000, the coasts are very often straddling, favoring either accretion or erosion zones. A fairly identical description for the 1987–2015, 1987–2017, and 1987–2020 periods. The 2000 and 2015 coastlines also straddle each other, but erosion is always observed near the mouth.

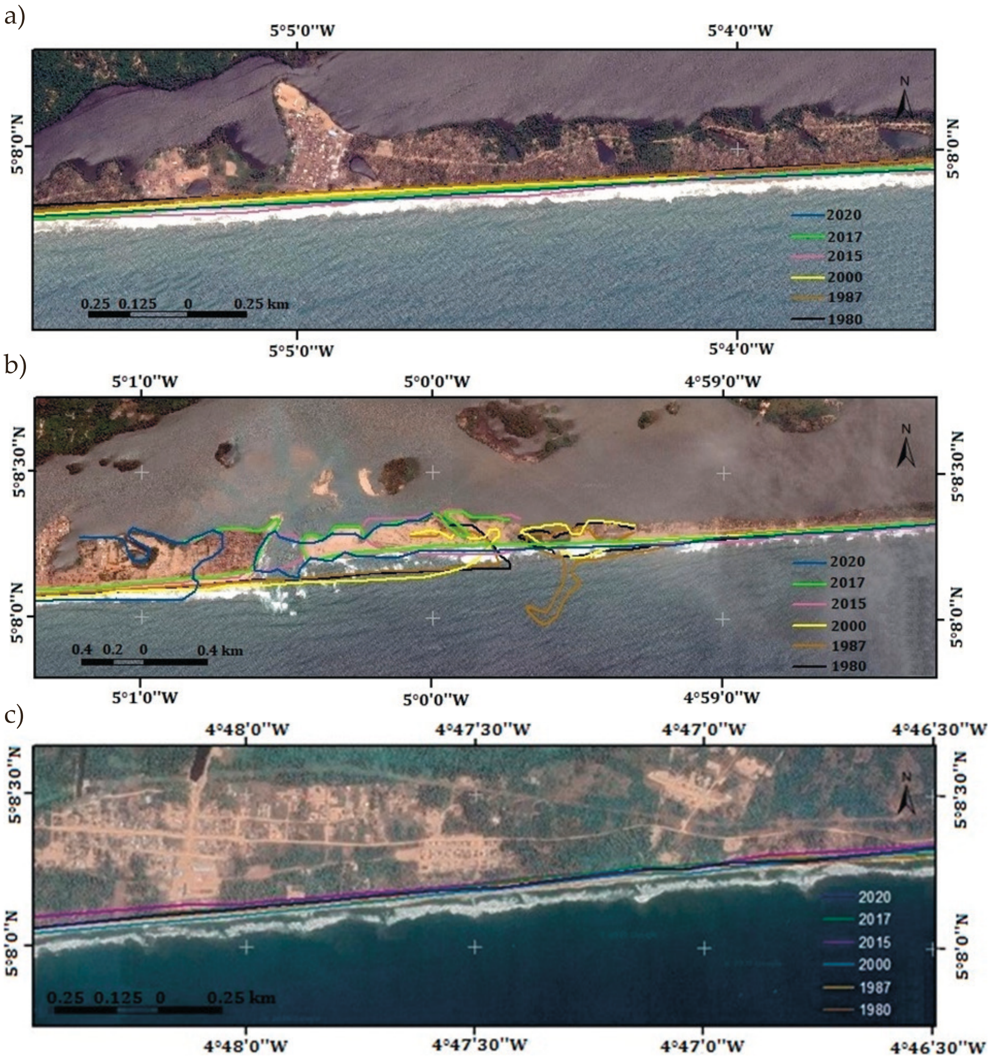

Fig. 4. Coastline kinematics from 1980 to 2020

Part B is that which characterizes the littoral zone at the mouth (Fig. 4b). It is a zone of instability, and quite tumultuous instability at that. It is an area with a dual trend: erosion and accretion. From 1980 to 1987, the western barrier experienced slight erosion while the eastern barrier experienced slight accretion, frequently changing its environment. From 1980 to 2000, the erosion of the western barrier beach increased, while the eastern barrier beach for this period also experienced shoreline erosion. From 1987 to 2015, the erosion of the western barrier beach was very pronounced, with a significant accumulation on the eastern barrier beach. The retreat of the coastline intensified again from 1980 to 2017 on the western barrier, with an accretion identical to the rate of erosion observed on the western barrier. From 1980 to 2020, the different barriers interpenetrate, the position of the channel is very distant between 1980 and 2020.

Part C characterizes the straight zone of the eastern barrier beach. This zone is very irregular and dominated by periods of erosion (1987–2007, 2015–2020). On the other hand, a trend of strong accretion can be seen at the approach to the mouth (Fig. 4c).

Part A of Lahou-Kpanda is characterized by an erosive trend and a progradation trend, despite being dominated by the accretion period. The reference year 1980 is characterized by two periods of accretion (1980–2000, 1980–2020) and three periods of erosion (1980–1987, 1980–2015 and 1980–2016). The average velocities vary between 0.80 and 1.81 m/yr for the accretion periods and between −0.91 and −1.7 for the erosion periods, respectively. The periods 1987–2000 and 1987–2020 are the accretion periods for the base year 1987. Its average velocities are 1.68 and 1.04 m/yr. It is also characterized by erosion periods (1987–2015 and 1987–2017), with average velocities of −1.06 and −0.73 m/yr, respectively. Two periods of erosion and one period of accretion characterize the reference year 2000. They are: 2000–2015 and 2000–2017 for the erosive periods and 2000–2020 as the accretion year. The average velocities are −4.00, −2.65 and 0.94 m/yr, respectively. The base year, 2015, is exclusively accretionary periods with average velocities of 9.17 and 14.70 m/yr. The 2017–2020 period is an accretionary period with an average velocity of 20 m/yr.

4.2. Interpretation of the Sensitivity of the Coastline at Lahou-Kpanda

The analysis of the dynamics of the Lahou-Kpanda shoreline was done in three (3) sequences: the western straight bar (Fig. 5a), the eastern straight bar (Fig. 5c) and the dynamics at the mouth (Fig. 5b).

The western right barrier (Fig. 5a) is essentially characterized by a significant accretion zone. Average velocities reach 2.5 m/yr and accumulation distances can evolve up to 100 m. Groguida is the only locality in this section. Its coastline in particular evolves at an average speed of 1 m/yr, with an accretion distance reaching about 50 m/yr.

The eastern barrier of the coastline is an alternation of erosive and accretionary zones. Thus, the sandy accumulation of the entire eastern shoreline (from the mouth to the eastern straight zone) is estimated at 363,066.07 m² or 36.29 ha (Fig. 5c)

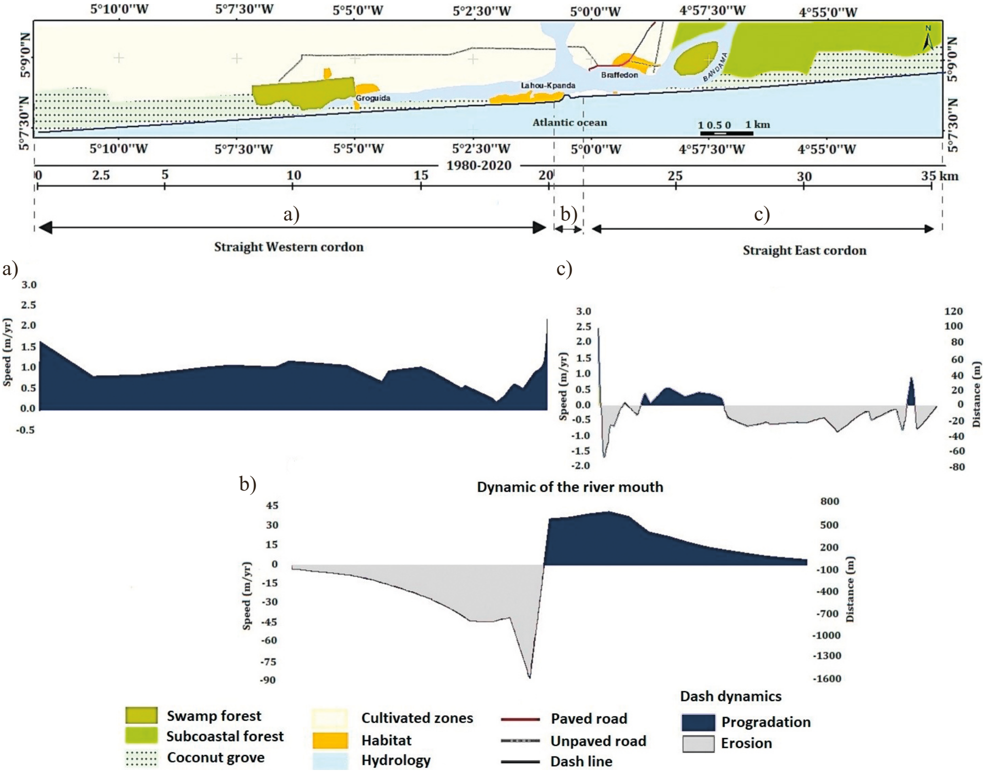

Fig. 5. Coastal segment development from Adiadon to Noumouzou

The mouth section is a very dynamic area, subject to strong erosion on its western side and strong accretion on the east. The average speeds are exorbitant considering the acceleration of the phenomenon on this part of the coastline. The average erosion speed reaches 90 m/yr, with an average distance reduced by about 2 km. The accretion zone, on the other hand, is of the order of 30 m/yr with a maximum distance of about 800 m. The locality of Lahou-Kpanda straddles these two pressures. This situation makes its barrier beach very vulnerable, as it is eroding at an unprecedented rate in all the areas studied (Figs. 4, 5).

4.3. Surface Analysis of the Coastline of Lahou-Kpanda

The cordon is made up of a first zone of significant accretion (Fig. 6a). This strong accumulation of earth is estimated at 656,541.46 m² or 65.65 ha. Part on Figure 6b is an alternation of erosive and accretionary zones. The total area under erosion is estimated at 538,465.74 m² or 53.84 ha, and the area under progradation is equivalent to 329,277.07 m² or 32.92 ha. The eastern coast cordon is also an alternation of erosive and accretionary zones (Fig. 6c). The area under erosion is estimated at 129,707.13 m² or 12.97 ha, and the area under progradation is 33,789.07 m² or 3.37 ha. The total surface dynamics for this perimeter is estimated at 168.77 ha.

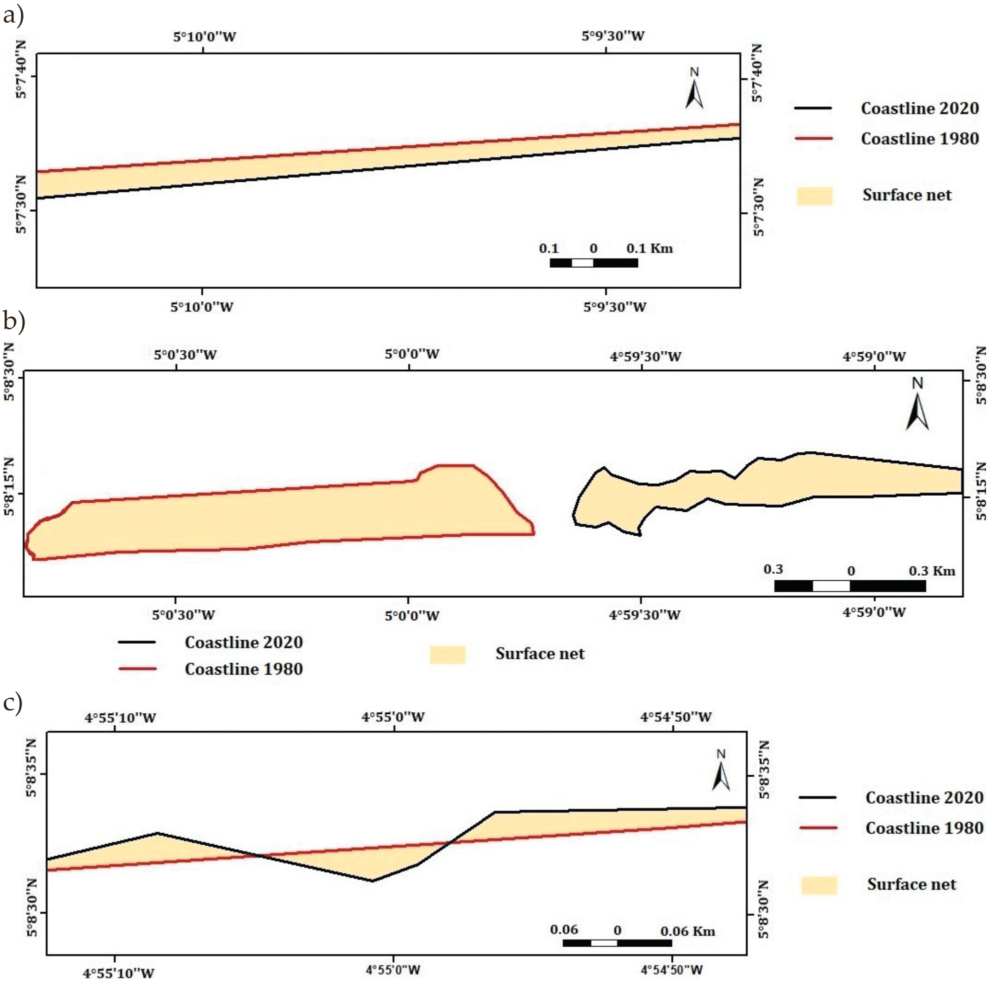

Fig. 6. Surface area assessment of Lahou-Kpanda

5. Conclusion

Landsat Data series images (TM, ETM+ and OLI) during the elapsed period from 1980 to 2020 were used to delineate and classify the shorelines along the coast of Lahou-Kpanda (southern Ivory Coast) using the Digital Shoreline Analysis System, an excellent approach for coastal zone planning, monitoring, and sustainable development in fast economically growing countries. According to our findings, major changes in the shoreline have occurred over the last 40 years. The share of natural shorelines has moved from a majority to a minority over time, with over 40% of the biological shoreline lost, showing dramatic changes in areas that comprised the richest areas of biodiversity in the Ivory Coast's littoral zones. The conversion of low-cost shorelines to higher-cost shorelines has shown a clear trend. Economic-oriented human behaviors are the primary driving force behind these shoreline changes. The human activity affecting the coastline is quite unique, and the implications of these developments will be far-reaching, particularly as more and more people are drawn to the coastline, underscoring the necessity to develop and execute suitable adaptive strategies. Rising human activity and growth along the coasts makes marine habitats more vulnerable, as well as the depletion of coastal infrastructure and natural resources due to sea-level rise and storm waves.

Author Contribution

Badjo Ruth Virginia Zonkouan conducted the image preprocessing, the methodology of the work and analyze the data. Imane Bachri provided important suggestion and reviews for improving the paper. Badjo Ruth Virginia Zonkouan and Imane Bachri wrote the manuscript. Abaze Henri Jöel Beda and Kpangba Aristide Meniansou N'Guessan provided suggestions for improving the paper. All authors approved the final version of the manuscript and agree to be held accountable for the content therein.

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