Wouri River Estuary and Coastal Mangrove Forests near Douala

Coastal Diversity under Threat

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17.1 INTRODUCTION

Mangrove forests, located in estuarine environments of tropical regions between 30° N and 30° S latitude, are vital and sensitive ecosystems that offer a unique array of essential ecosystem services. Globally, these forests cover an estimated area of about 15 million ha (FAO, 2007). However, they are increasingly facing degradation due to a combination of climatic changes and anthropogenic pressures (Ellison, 2014; Bryan-Brown et al., 2020). Key disruptors of the estuarine system's equilibrium include storms, sea level rise, temperature fluctuations, and variations in precipitation. Research indicates that mangrove regression is estimated to be between 10% and 15% worldwide (Alongi, 2008). For instance, drought episodes can significantly alter salinity levels in estuarine environments, leading to high mortality rates among mangrove species, as observed in the Lower Casamance estuary in Senegal (Sakho et al., 2011).

In developing countries, the degradation of mangrove ecosystems is particularly pronounced. This is often due to chaotic land occupation, a lack of effective environmental protection laws, and the overexploitation of biological resources. Mangroves provide crucial livelihoods for coastal communities, including fisheries and tourism, yet human activities simultaneously contribute to their decline (Rönnbäck, 1999; Manson et al., 2005). The impacts of pollution and overexploitation severely affect the marine food chain and seafood production, threatening the well-being of local populations (Rönnbäck, 1999). The degradation of mangroves is even more pronounced near large urban centers, where urbanization has led to the loss of approximately 50% of mangroves in Southeast Asia (Wilkinson et al., 1994). Moreover, the degradation of these vital ecosystems significantly affects coastal geomorphology, exacerbating erosion and increasing the risks of flooding (Mazda et al., 2002; Thampanya et al., 2006).

In Cameroon, the mangrove coast of the Wouri estuary, which borders Douala—the country's economic capital and a key port for the CEMAC sub-region—exemplifies these pressing challenges. The Wouri estuary is characterized by a rich biodiversity and serves as a crucial habitat for numerous species. With mangrove coverage representing a significant portion of the Cameroonian coastline, estimated at around 20%, this region is undergoing rapid transformation driven by urbanization, infrastructure development, and port expansion. As urban sprawl encroaches on natural spaces, substantial losses of mangrove areas are being observed, threatening the ecological balance of the region (Ellison and Zouh, 2012).

This chapter aims to map high-resolution landscape changes related to this urbanization, focusing on the mangrove forest located south of Douala. By utilizing high-resolution satellite images covering the period from 2001 to 2020, we will analyze land use changes and assess the disturbances they generate in the hydro-sedimentary cycle. Furthermore, we will explore the implications of these changes on the evolution of the coastline and the increasing risks of flooding. Through this comprehensive analysis, we hope to highlight the urgent need for conservation efforts and sustainable management practices to protect these vital mangrove ecosystems and the communities that depend on them.

17.2 LOCATION AND GEOGRAPHICAL CONTEXT

The study site is located in the southern part of the city of Doula, where the area can be divided into two parts separated by a wide tidal inlet (Figure 17.1). To the north of the tidal inlet, there is a mixed urban landscape in full mutation that is still partially forested by mangroves (Figure 17.2), while to the north there is a mangrove forest undergoing uncontrolled deforestation. Illegal logging from these mangroves is directly related timber sales (Nfotabong-Atheull et al., 2009).

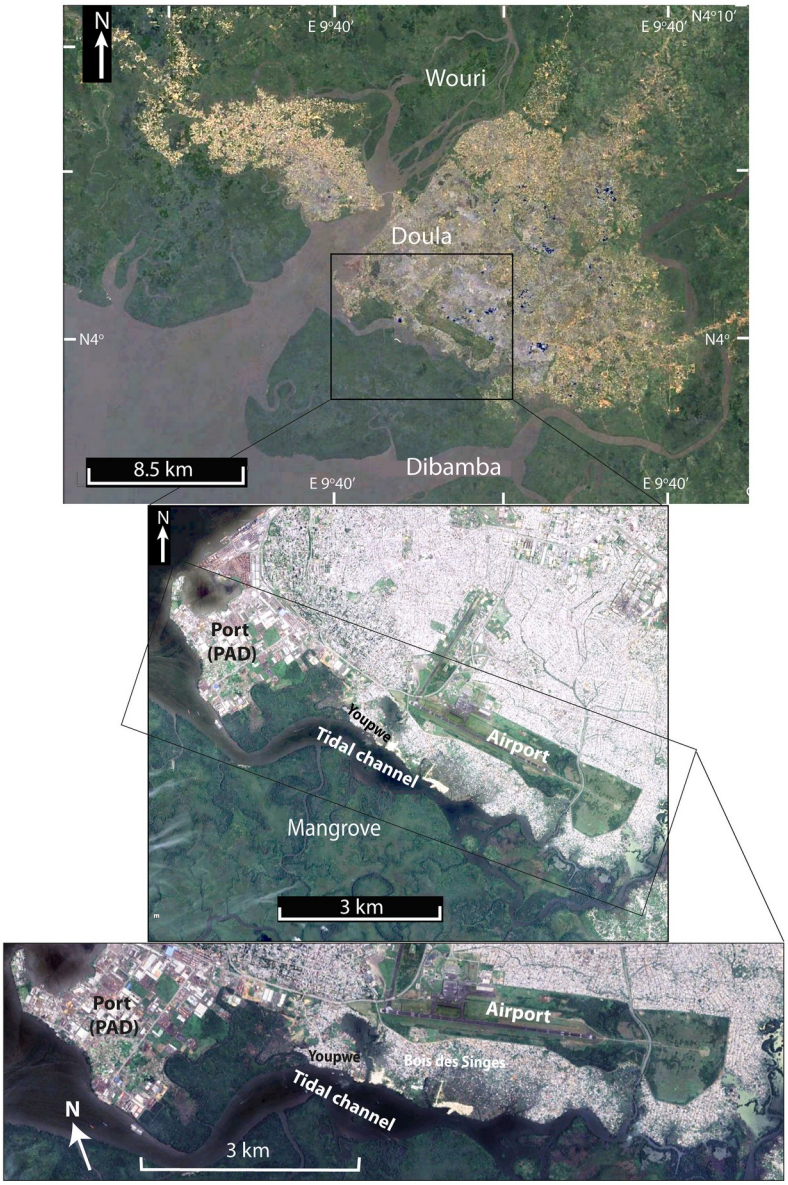


Figure 17.1 Location of the study area, south of Douala City, with a tidal channel separating the mixed urbanized landscape to the north from the mangrove landscape to the south. The three main economic hotspots in the area: the Autonomous Douala sea port, Youpwe, and the airport are indicated.

17.2.1 Mangrove Coast—Geographical Characteristics and Diversity

Our study site is located on the southern margin of Douala International Airport, flanking a west-east tidal arm of the Wouri estuary in Cameroon, which is historically dominated by mangrove forests and located within the tidal zone, less than 5 m above sea level (Figure 17.1). The Wouri estuary covers an area of 1200 km² and is formed by the convergence of the Wouri, Mungo, and Dibamba rivers and the Atlantic Ocean (Gabehe and Smith, 2002; Ndongo et al., 2015; Fossi Fotsi et al., 2019). The tidal regime is semi-diurnal with an amplitude of two to three meters, which can increase during storms (Onguene et al., 2015; Atekwana et al., 2022; Fotsi et al., 2023). The hydrodynamics within the estuary is thus characterized by moderate tidal currents and by a

strong sediment accumulation, with two accumulation zones (Gabehe and Smith, 2002). The first accumulation zone is located in the center of the estuary, where seawater and fresh water meet, resulting in the accumulation of suspended materials and solids. The second accumulation zone is found along the banks of the estuary and consists of a lateral deposition of sediments composed of clay (kaolinite) and silt. Fluvial sediments transport to the estuary in the rainy season, estimated to be close to 1 million tons per year with over 70% transported during the rainy season (Olivry, 1974; Gabehe and Smith, 2002). Our study site is located in the inner part of the river along a tidal arm.

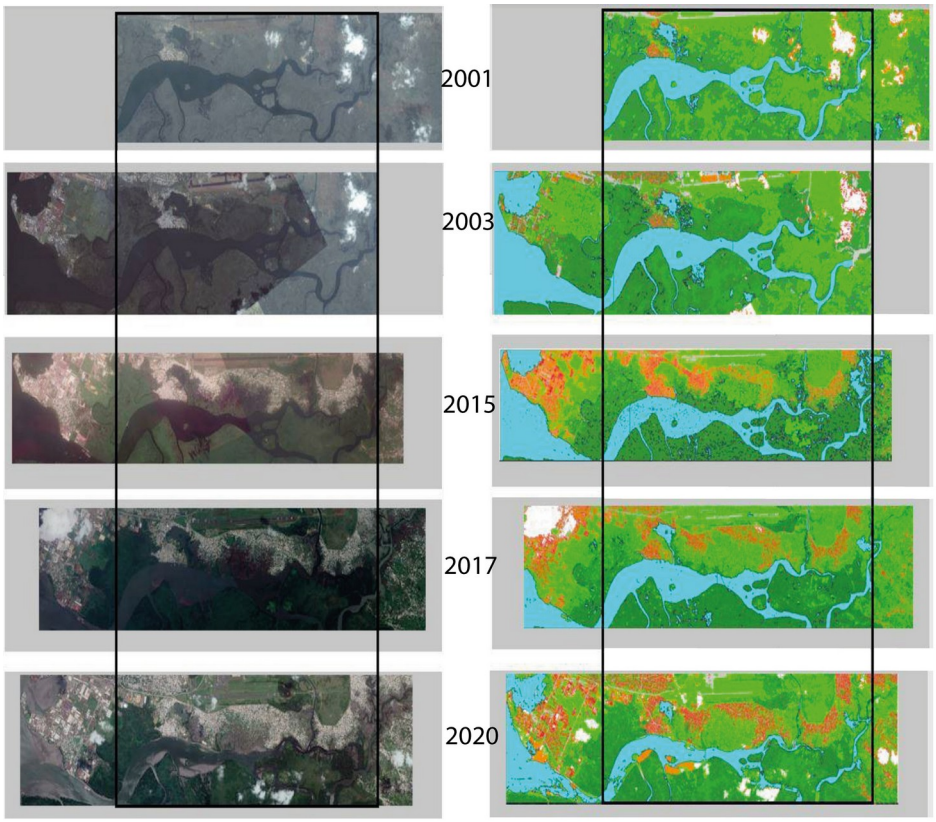


Figure 17.2 Examples of classifications of selected GE images, considering seven land cover classes: mangrove, water, built-up areas, asphalt roads, low vegetation, degraded mangrove, and bare soil.

The mangrove forest occupies an area of 1000 km² of the estuary and is home to more than 63 species, 54 genera, and 29 families of mangroves, of which seven species are indigenous to the Cameroonian mangrove, and distributed according to salinity (Nfotabong-Atheull et al., 2013). The mangrove forest is composed mainly of Rhizophora and Avicennia, including all their subspecies (Zogning, 1993; Din et al., 2002, 2016). Rhizophora is the dominant pioneer species, occupying the accretion zones at the edge of the tidal arms and on the banks of the river over a distance of about 100 meters, characterized by individuals over 40 m high (Din, 2002). Further inland, Avicennia germinans and Nypa fruticans dominate along with small trees such as Conocarpus erectus, Hibiscus tiliaceus (Din et al., 2017; Jean-Hude et al., 2016). The mangrove forest also supports a rich fauna of fish, birds, reptiles, primates, and other aquatic invertebrates (Macintosh et al., 2002; Ngo-Massou et al., 2012). The invertebrates, primarily mollusks and crabs, play a critical role in the food chain by decomposing litter and aerating the substrate (Smith, 1987; Nielsen et al., 2003; Kristensen and Alongi, 2006; Ngo-Massou et al., 2014). This diverse estuary structures its food chain along its horizontal and vertical profiles (Mauris, 2005). It is particularly known for its shrimp, which was the reason for its nickname “Rio dos camaroes” given by Portuguese explorers (Fernado Pô) in 1472, which translates to “River of Shrimps” in French “la rivière des crevettes,” and later became “Kamerun” during the German protectorate in 1884, “Cameroon” and “Cameroun” during the Franco-British condominium in 1918.

The growth of mangroves is favored by a climate characterized by long rainy seasons, which last for an average of 202 days/year, with abundant rainfall of approximately 4850 mm/year (Ndongo et al., 2015). The dry season is short and lasts from December to February. Salinity in the estuary varies seasonally, but generally remains below 20 ppt (parts per thousand) for most of the year (Baltzer et al., 1995; Van de Laar,

1980; Atekwana et al., 2022), which never reaches lethal extremes for the mangroves. The average annual temperature is approximately 26°C, and humidity reaches a maximum of 99–100% (Ndongo et al., 2015; Din et al., 2017). The low wind speed gives a regular direction to the coastal longshore currents, which carry large amounts of sediments, including clays and sands coming from the Sanaga Delta.

17.2.2 Environmental Degradation of the Mangrove Coast due to Social and Economic Factors

The mangrove forest of the estuary has sustained a strong degradation around Douala city with an estimate of ~7450 ha in the past 30 years (Kana et al., 2019). This is also the case in the study area located south of Douala in the southeastern part of the Wouri River estuary, along an E–W tidal arm can be divided in two areas having different economic pressure (Figures 17.1 and 17.3). To the south lies a mangrove forest without any human settlements and infrastructure, while to the north lies arrondissements 1 and 2 of Douala, and is an important economic center close to the historical center of Douala as described below.

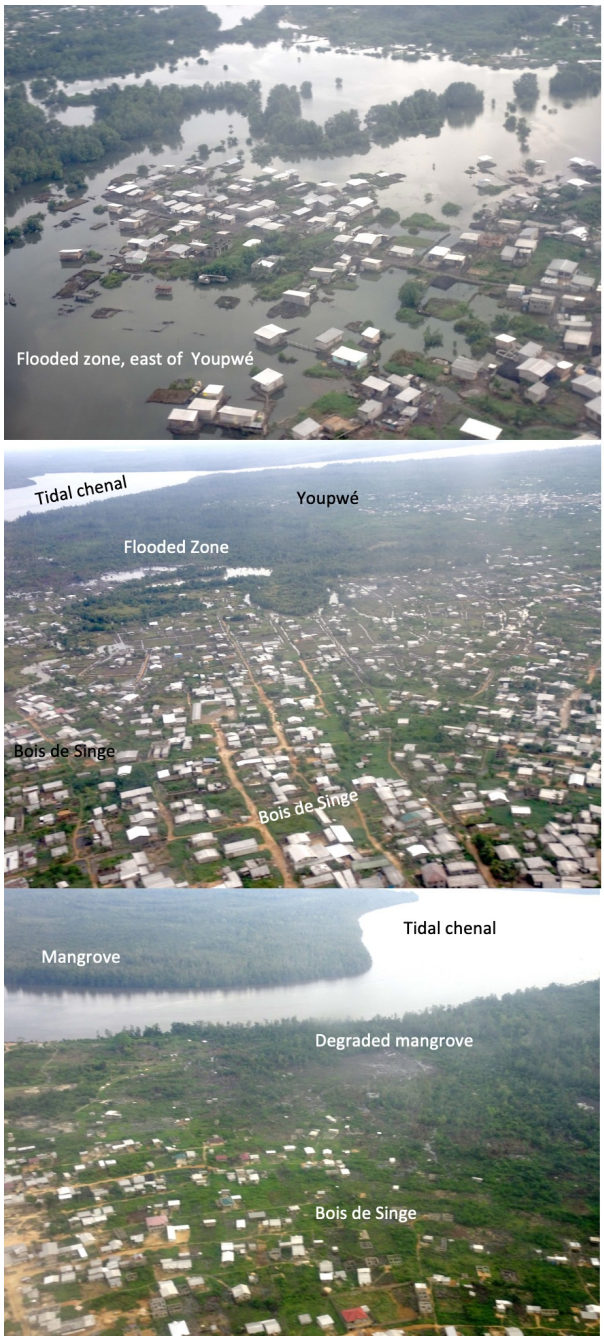


Figure 17.3 Photos of the mixed landscape urban-mangrove in 2010 to the south of the airport of Douala city.

The northern part of the studied site was first partially deforested to create the Douala port of the city of Douala in the 19th century (Figure 17.1). The port grew rapidly, with container traffic starting in 1970, resulting in the establishment of the Port Autonome de Douala in the late 1990s. This strategic infrastructure handles 75–80% of the trade for Cameroon, Chad, and the Central African Republic, amounting to 12–13 million tons annually.

Further east is the local port of Youpwé, which is directly linked to the large local market of Youpwé, where fishing products from the estuary and nearby land are sold. This port also serves the island communities of the Cap Cameroun estuary and Manoka by pirogue (Ajonina et al., 2015).

The northern portion of the study area comprises the Douala International Airport, which began operating in 1977 and necessitated the clearance of approximately 200 ha of forest (Figure 17.1). The southern part of the airport is a forest reserve, where no housing or roads should be constructed, but the uncontrolled urbanization of Douala has led to the development of the informal Bois des Singes district on this land (Ngoran, 2014; Ngoran et al., 2015). This urban sprawl also functions as Douala's sole excreta disposal site, making it a septic tank. The issue of fecal matter management in African cities is a recurring problem that creates concerning health situations (Ngoran et al., 2015; Evan and Kantrowitz, 2002), exposing populations to diseases like cholera or malaria (Pimenta de Castro Fonseca, 2014). This pollution combined with other contaminant sources causes the progressive degradation of wetland environments, resulting in the disappearance of spawning grounds and reproduction areas of fish species in marshy areas (Manson et al., 2005; Ngoran et al., 2015; Mbusnum et al., 2020).

Anthropic pressure on the mangrove to the south of the central tidal inlet (Figure 17.1) is still very high, as it is a direct wood resource used for export or local consumption of Doula City as construction material or energy resource (Feka et al., 2009; Walters et al., 2008; Atheull et al., 2009; Angoni et al., 2015).

17.3 DATA AND METHODS

Our analysis was performed mainly using a dataset consisting of two Pleiades images, five Google Earth (GE) images, and a digital terrain model (DTM). The Pleiades images used were multi-spectral images of 0.5 m resolution acquired on 27/05/2013 and 24/03/2017. GE provided also high-resolution (1 m) images of the study area from 2001 to 2022. A subset of GE images was used for classification purposes (Figure 17.2), and another set was used to compare changes between low tides and high tides, and to infer flooded and accretion areas.

The DTMs were extracted from Pleiades images. We used MicMac software, an open-source software developed by the French geographic agency for obtaining high-quality DSMs and DTMs from this type of image (Sofia et al., 2016).

The very high-resolution GE and Pleiades images (0.5–1 m) enabled us to conduct a classification covering the period from 2001 to 2020 and allowing us to observe the evolution of urban expansion on the mangrove and potential retreat of the coastline. The Pleiades images contained more information than the GE images. The four bands of the Pleiades image allowed us to calculate the Normalized Difference Vegetation Index (NDVI) directly and to better identify the mangrove. GE images have poor spectral characteristics and are not classically used for classification, but to validate the results of classifications (Simon and Raffaelli, 2012). However, Hu et al. (2013) demonstrated their potential for land cover analysis by comparing object-oriented classifications of a GE image and a Quickbird image. We followed their processing methodology and performed an object-oriented classification on 2001, 2003, 2015, 2017, 2020 GE images (Figure 17.2) and 2015, 2017 Pleiades images.

We then used the GDAL and ORFEO Tool Box libraries as well as the R environment, and follow the subsequent steps. First, we selected a common area and resolution of 1m for all images (Figure 17.2). Second, for the Pleiades images, we calculated the NDVI (Rouse et al., 1973) using the "BandMathX" function of the Orfeo Tool Box (OTB) to identify mangrove, degraded mangrove, and low vegetation (gardens). As the GE images did not have the individualized near-infrared band, we could not calculate the vegetation index (NDVI) for them. Third, for the Pleiades images, we created a virtual raster by resampling the red, green, blue (RGB), near-infrared (NIR), NDVI, and mean normalized difference (MNS) bands as six mono-bands with

adapted weights for image segmentation. In the case of GE images, the virtual raster we used three spectral bands red 1, green 2, and blue 3. Then we performed a segmentation using the “MeanShift” algorithm of the OTB and the different bands of the virtual raster. The segmentation depends on two main parameters: the spatial radius that represents the distance and the range radius that represents the spectral signature. The range radius assigns to each pixel the average value of a group of homogeneous pixels, while the spatial radius allows identifying neighboring pixels with similar average values. We performed a sensitivity analysis to determine optimal values of the spatial and range radius. The best segmentation was obtained with spatial radius of 10 for the 2 types of images, and range radius of 20 for Pleiades images and 10 for GE images. The cloud cover, including mists, posed a challenge during the segmentation process. Finally, object-oriented classification was performed based on six defined land cover classes, which were mangrove, water, built-up areas, asphalt roads, low vegetation, degraded mangrove, and bare soil. The presence of clouds resulted in confusion in the classification, so we created a new class “cloud or cloud shadow” and manually modified it. The “otbcli_ TrainVectorClassifer” function provided by the OTB library was employed to assign the class of the training points to each adjacent segment, and a training model was developed to classify all the segments. Training models used 100 training points for the Pleiades images and a minimum of 150 training points for the GE images to obtain accurate classification.

Our database of high-resolution images enabled us to compare the Pleiades and GE images directly (Figures 17.2 and 17.4). The classification of the GE images was similar to that obtained with the Pleiades images, which validated our use of GE images, particularly for the years 2001 and 2020.

It was not possible to retract a reliable high-resolution coastline from GE images, because of the very poor orthorectification of the images in Google Earth Pro, which made reliable and multi-date statistical analysis of the coastline dynamics in the Wouri estuary impossible. Therefore, a manual inspection of the different coastlines from 2001 to 2022 at high tide and low tide was necessary.

17.4 RESULTS AND DISCUSSION

17.4.1 Evolution of the Landscape

The analysis of high-resolution images from GE and Pleiades satellites over a period of more than 20 years reveals a dramatic transformation of the landscape in the northern part of the tidal arm close in relation with the expansion of Douala city (Figure 17.4).

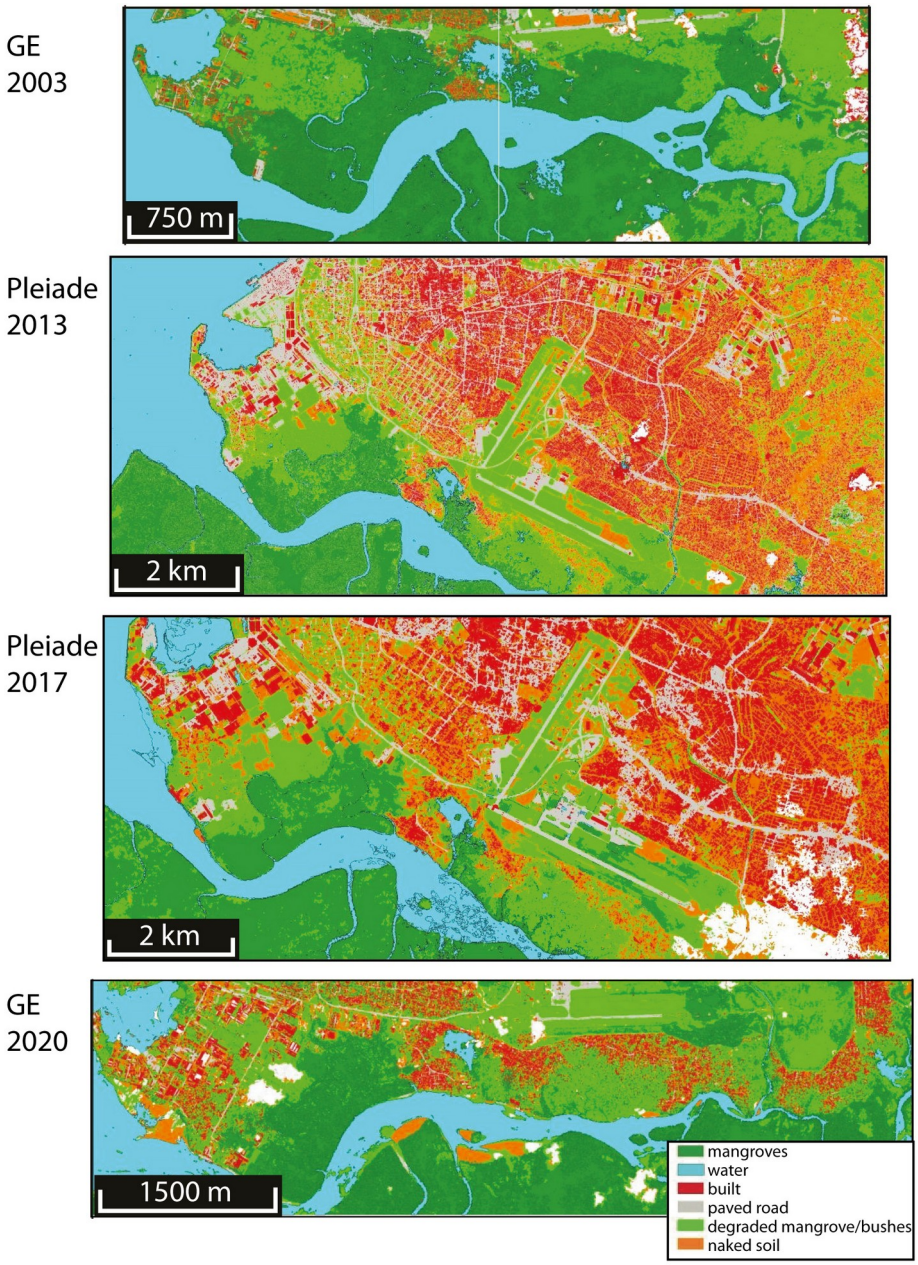


Figure 17.4 Classifications using GE and Pleiade images showing the progressive urbanization south of Douala airport, the development of the PAD, Youpwe and the informal neighborhood of Bois des Singes.

Initially, in 2001 or 2003, the area presented a mixed landscape with patches of heavy urbanization around various economic poles of attraction (Figure 17.4), that is, the Autonomous Port of Douala (PAD), the local port of Youpwé, and the Douala international airport, as well as areas with partial urbanization such as the informal settlement of Bois des Singes and patches of mangrove forests. These landscape features persisted into the 2010s, as shown in Figure 17.3. However, our time series analysis and associated classifications indicate that mangrove patches had almost completely disappeared by 2022, replaced by low residual vegetation, bare soil that is flooded during the rainy season at high tide, and scattered habitats often located around informal traffic axes within the informal neighborhood of Bois des Singes.

Over the 19-year period, land use change has been dynamic, with different dynamics of land use change observed for each of the years 2001, 2003, 2015, 2017, and 2020 (Figures 17.2 and 17.4). In 2001 and 2003, the classification poorly distinguished mangrove from degraded mangrove/low vegetation, which together occupied approximately 70% of the total classified area. Built-up areas, roads, and bare soil covered 0.7%, 1.7%, and 3.6% of the area, respectively. During the 2000s, the country was still recovering from the economic crisis of the previous decade, and there was little investment in the region. The various poles (PAD, Youpwé, airport) showed little change. However, the following decade was marked by significant

deforestation around the three economic poles, as observed in images from 2013, 2015, and 2017. The degradation dynamics accelerated in 2020. This recent evolution is described in more detailed in the following.

Firstly, the PAD has continued to expand eastward along the banks toward the port of Youpwe (Figures 17.2 and 17.4). In 2007, the port occupied 4000 ha, or 40% of its surface area. Currently, the port occupies nearly 98% of its surface area and plans to acquire more land for its expansion (Rahman et al., 2012). Urban densification also occurred around the PAD associated with improved road infrastructure. This expansion automatically results in the degradation and disappearance of mangroves, as the port is located in a mangrove area.

Another urbanization axis focused around Youpwé and the N–S axis connecting this port to the N3 road, which links the PAD and the airport (Figures 17.2 and 17.4). The fishing port of Youpwe, which was the first urbanized site detected on our images in 2001, has grown rapidly. Youpwe is a significant economic zone for the natives, offering a multiplicity of resources to exploit, including transportation, fishing, agriculture, and wood sale (Atheull et al., 2009; Angoni et al., 2015). It is also a platform for various local commercial exchanges, including the transport of goods and people between Douala, neighboring islands (Manoka), and even neighboring countries (Nigeria) (Ajonina et al., 2015). The population flow toward Youpwe began in the 1970s due to expropriations carried out on the site of the Douala naval base, and the arrival of migrants in the 1990s amplified the anarchic urbanization and abusive exploitation of resources (Beni, 1991). As a result, mangrove areas have disappeared over time, replaced by buildings, roads, bare soil, or degraded mangrove.

The imagery also highlighted the development of the informal neighborhood of Bois des Singe to the east of Youpwé and to the south of the airport (Figures 17.2 and 17.4). There was an amplification of urbanization between 2015 and 2017, which corresponds to the period of renovation of the runway of the Douala airport. The neighborhood development occurred in an anarchic manner, without paved roads, to the detriment of the mangrove, which was directly exploited by the local population as a source of energy. Consequently, the landscape in this area is characterized by insalubrious houses surrounded by a surface mainly of naked ground that is eroded during the rainy season, posing a risk of flooding by the sea at the time of high tides and strong rains that saturate the surface layers of the ground, whose permeability decreases strongly with deforestation and urbanization. The discharge of excreta pits multiply, increasing the insalubrity of the zone and the propagation of pathogens. The dynamics of degradation of the mangrove in this sector accelerated in 2020, and we can consider its almost complete disappearance in 2022. The green islands of the mangrove have almost disappeared, but the massive use of embankments is visible on the imagery of 2022 and suggest a development of this area in a less anarchic way. This transformation goes hand in hand with significant investment in the PAD and the airport, so that the city of Douala can continue to compete with the deep water port of Kribi, located 150 km to the south.

The imagery analysis finally provides evidence that most of the studied area that was occupied by mangrove areas is at risk of flooding related to high precipitation/low infiltration and tidal cycles. Indeed, mangroves are systematically located in swampy areas that are frequently flooded by tides (Ellison, 2015). Destroying mangroves to build homes and infrastructure, despite filling them in, exposes people to flooding. Amanejieu (2018) identified an upsurge in flooding between 1984 and 2018 in Douala. Bruckmann et al. (2019) identified the appearance of new flooded neighborhoods, including Bois des Singes. These floods can also spread waterborne diseases such as cholera caused by insalubrity in precarious neighborhoods (Amanejieu, 2018). The poor management of wastewater also exposes populations to worrisome health situations (Ngoran et al., 2015).

17.4.2 Coastal Dynamics

The set of high-resolution satellite GE and Pleiades images with a scale of 0.5–1 m was also used to analyze the changes in the coastline between 2001 and 2020, that is, its stability, erosion or accretion. We first look at the impact of mangrove deforestation visible without urbanization south of the tidal inlet (Figure 17.5), then at the impacts of urbanization associated with mangrove deforestation and use of embankments (Figures 17.6–17.8).

The 2003 GE images south of the tidal inlet show an active deforestation area of 5 ha, not present in 2001, which grew to over 9 ha in 2005 (Figure 17.5). This deforested area is located about 100 m south of the boundary between the tidal inlet and the mangrove; it is not directly visible from the main north-south oriented tidal inlet. This illegal deforestation not followed by replanting allows us to assess the long-term impact of this anthropogenic impact on the landscape, since we have more than 20 years of high-resolution images. The deforested area, even after 20 years, does not show a return to equilibrium in 2020 at low tide and in 2022 at high tide. It is characterized by a still low shrub density, bare soils visible at low tide and new, very convoluted creeks and channels completely submerged at high tide (areas 1 in 2008 and 2022 in Figure 17.5).

The identified typical morphology of illegally deforested areas allows prior and posterior deforested areas to be identified systematically in the study area. Prior to 2003, there was a first deforestation creating an initial convoluted network of creeks (zone 2 in the 2003 image in Figure 17.5), followed by a second significant deforestation further west in 2003 (zone 2 in Figure 17.5), expanding south in 2005. In 2020–2022, new deforested areas are seen farther west along the tidal inlet (area 1 on both the 2020 and 2022 GE images in Figure 17.5).

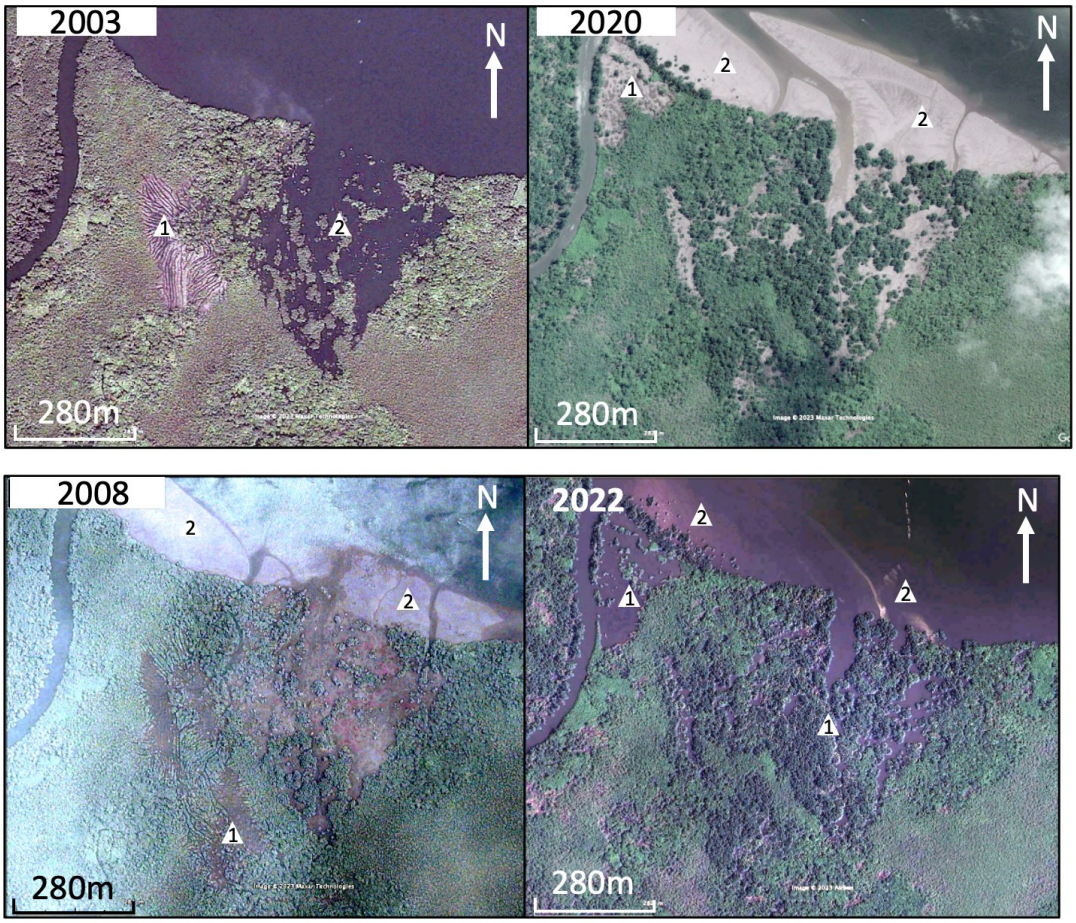


Figure 17.5 A consequence of deforestation on the coastline (zone 1) with an increase in bare areas at low tide and flooded areas at high tide without trees forming creeks and tortuous channels. Increased erosion leads to increased suspended load and accretion (zone 2) at the contact between the mangrove and the tidal arm, and difficulty of re-growth of the mangrove by itself.

The 2008 and 2022 low-tide GE images highlight another phenomenon at low tide, that is, significant sediment accretion in the vicinity of the deforested area (area 2 in the 2008 and 2020 images in Figure 17.5), that is not evidenced in other parts of the estuary. We interpret it in direct relation with the much larger soil erodibility after deforestation. The disappearance of the tree canopy leads to a high erosivity of the intense tropical rain on a non-cohesive soil not anchored by tree roots that is also susceptible to be eroded by tidal currents. Erosion of the top soil is also evidenced by the sedimentary plumes visible at high tide on the 2022 GE image shown in Figure 17.5 (symbol 2). The sediments remobilized are then deposited close to the mangrove shoreline resulting in accretion. This accretion allows locally a punctual visible advance of some mangrove trees (Figure 17.5).

The following landscape evolution model related to deforestation can be proposed. Deforestation leads to significant sedimentary reworking caused by rain and tidal currents, which results in a relative increase in sea level. This process occurs progressively and can be decelerated if the root network is left undisturbed for a period of time or if the deforested area is reduced (Simon and Raffaelli, 2012) However, if the deforested area is substantial like in our study area, the erosion products are not retained locally, but instead exported toward the permanently flooded tidal arms downstream. This erosional process causes a permanent increase in the periods of flooding linked to the tidal cycle, making it challenging for the mangrove to recover the entire affected area naturally. Consequently, the marks of deforestation persist for more than a decade, indicating a permanent decrease in the shrub density and increase in free water creek area. Therefore, replanting policies within this ecosystem are crucial to mitigate the adverse impacts of deforestation (Kumara et al., 2010).

We also look at the impact of mangrove deforestation in relation to urbanization, north of the tidal inlet (Figures 17.6–17.8). We expect more complex dynamics of shoreline evolution would be more complex due to greater human interventions. However, onland soil erosion similar to the one south of the tidal inlet in the deforested area was observed. To better evidence the processes at play, we closely examine several coastal areas.



Figure 17.6 Sedimentary consequences of urbanization: increase in runoff, erosion of loose soils previously fixed by mangrove roots and accretion in proximal areas with development of sandbanks (1) in tidal arms.

We first examined the northeastern end of the W–SE oriented tidal arm, which converges into a 100–200 m wide channel and extends upstream into an urban river running in the north-south direction (see Figure 17.6). In the channel, the low-tide GE images of 2008 and 2020 reveal the growth of intra-channel sandy islands and sandy banks in the convexities (areas 1 in Figure 17.6). We interpret this accretion to be a consequence of increased soil erosion, like in deforested areas south of the tidal inlet.

Then we examine the coastline in the informal settlement of Bois des Singe further west. The linear coastline, despite deforestation, is relatively stable and accretion is promoted in certain areas (see Figure 17.7). The low-tide GE image of 2020, compared to other images, illustrates significant and systematic accretion in the concave littoral zone (area 3 in Figure 17.7) adjacent to areas with almost complete deforestation and some human occupation (area 2 in Figure 17.7). This sedimentary input is attributed to the high erosivity of this humid tropical zone on bare soils during the prolonged rainy season characterized by high intensities that can easily reach 100 mm/h (Robert, 1951). The bare soils are formed of sands and clays that were previously fixed by the root network of the mangrove, and they are easily remobilized during the runoff accentuated by the partial impermeabilization of the soils by urbanization. The excreta pits are also reworked during flooding directly polluting water and enhancing the unsanitary conditions in this neighborhood (Mbida et al., 2016). In addition, soil reworking and infilling used during construction provide easily remobilized materials during flooding that may have a double origin, coming from the sea and/or from the land. In fact, large-scale embankments like the one in 2022 in Figure 17.7 are generally indispensable to prevent flooding.

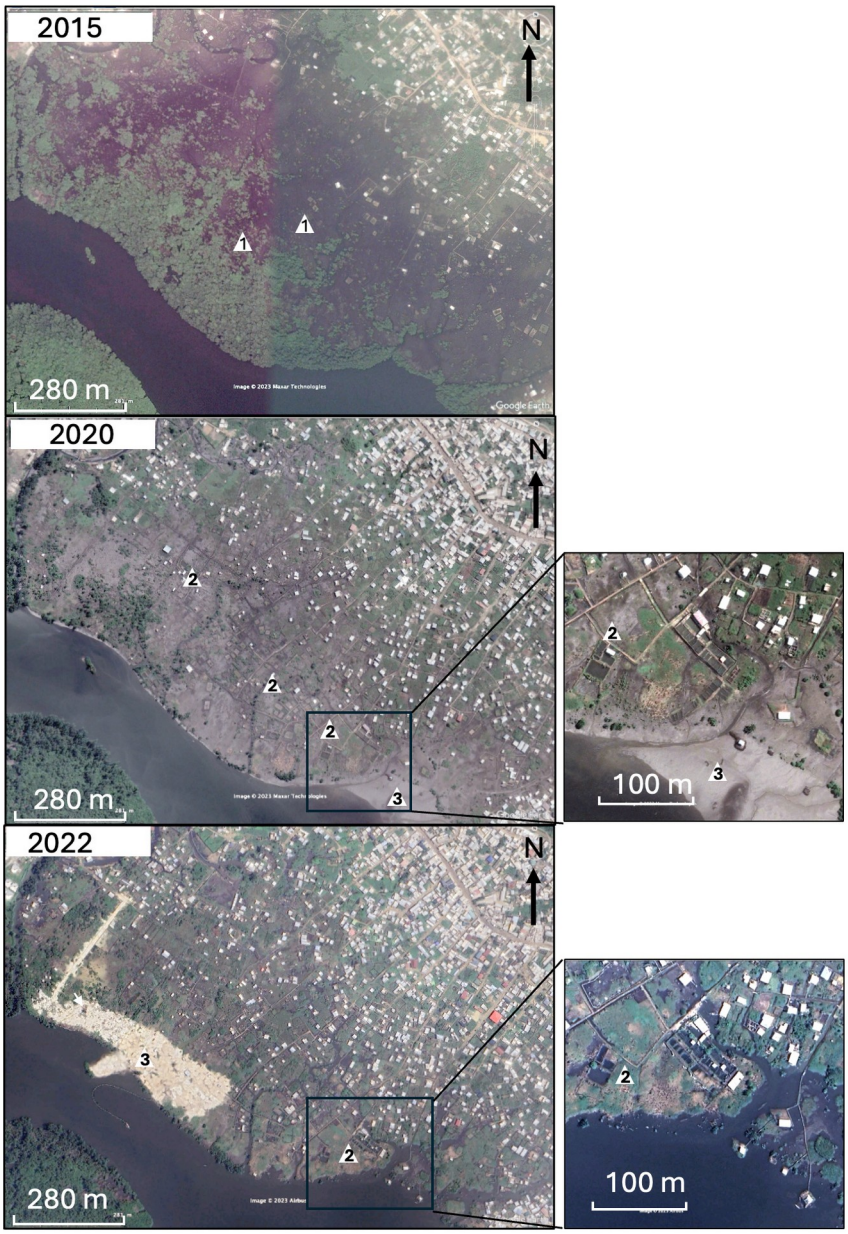


Figure 17.7 Development of neighborhood of Bois des Singes with in 2015: (1) heavily deforested high tide floodplain with significant soil erosion during the rainy season; in 2020, increased urbanization, concentrated along unpaved roads and also scattered, (2) open dumping pits for excrement; (3) sedimentary cone linked to soil erosion; in 2022: (1) strong urbanization; (2) pits (3) filling and destruction of the last remaining mangroves.

Finally, we look at the Youpwé neighborhood further east where the dynamic of mangrove forest disappearance is also visible (Figure 17.8). The neighborhood is limited to the east by a small north-oriented tidal arm and by a flood zone that was occupied in 2015 by a remnant of mangrove forest (zone 2 in 2015 on Figure 17.8). Deforestation leads to the expansion of bare floodable soils during high tides and rainy seasons (zone 1 in 2022 in Figure 17.8), followed by filling and construction. Fills are associated with the expansion of the port of Youpwé (zones 3 in 2015 and 2022 in Figure 17.8). They can be remobilized during heavy erosive rains and contribute to the high turbidity of the water near the shoreline, visible in the 2022 GE image. Similarly, the GE images illustrate the sediment plume associated with the urban river NE of Youpwé (area 1 in Figure 17.8) and associated with a micro-delta visible at low tide (area 1 in 2020 in Figure 17.8).

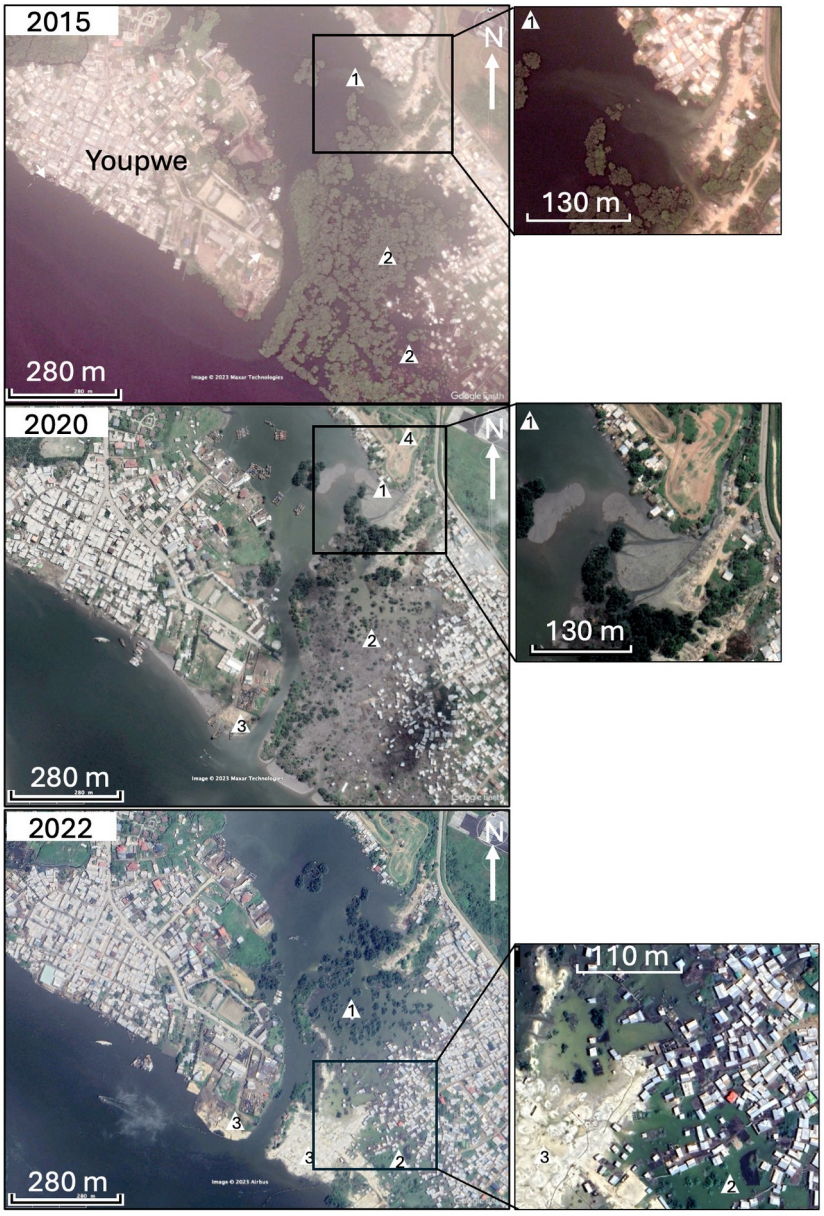


Figure 17.8 Transformation and enlargement of Youpwe area. In 2015, at high tide, the Youpwe area to the west and its dugout port; in (1) sediment plume from the small channel illustrating the increased sediment inputs related to urbanization, and in the east (2) a flood zone at high tide partially occupied by mangrove partly deforested. In 2020, at low tide, in (1) the sediment cone coming from the channel, (2) the more intensive deforestation area east of Youpwé with its bare soil subject to erosion especially in the rainy season, (3) filling in on the coastline for the Youpé harbor expansion, (4) housing area razed to the bull-dozer (airport expansion?). In 2022, flood zone in (1), (2) expansion of urbanization to the east of Youpwé on the edge of the flood zone following filling, (3) expansion of Youpwé port by filling.

Our finding evidence that the destruction of several hectares of mangroves due to anarchic urbanization has modified the sediment balance in the tidal arm. The removal of the mangrove canopy leads to soil exposed to more intense rainfall and tidal currents, which triggering the erosion of surface layers that are less cohesive

than before due to the disappearance of the mangrove roots. The increased sediment load from the runoff was transported into adjacent urban rivers and tidal arms, leading to further accretion (Whitehouse et al., 2000), even if sand mining is prevalent in the area (Fusi et al., 2016). This human-induced estuarine sedimentary change is not the only one, as the deepening of the Douala port channel also plays a role.

Our results are consistent with the overall dynamics of the estuary, demonstrating accretion upstream of the estuary near highly urbanized areas and erosion downstream of the estuary dominated by marine currents (Ondoa et al., 2018). So urban expansion has played a role in promoting the stability of the northern coastline in the tidal arm of the Wouri estuary. This evolution is different from most deforested mangrove areas that are usually the locus of coastal erosion (Ellison, 2014). Urbanization is responsible for increasing runoff which leads to erosion of urbanized soils (Beni, 1991).

17.5 CONCLUSION

This study presents the landscape transformation due to urban expansion and degradation of the mangrove. South of Douala, mangroves have been rapidly declining due to the ever-increasing needs of human populations for space and resources. The presence of three major transportation infrastructures—the PAD, the fishing port of Youpwè, and the airport of Douala—has contributed to the anthropogenic pressure on mangroves, making human activity the primary cause of degradation (Nfotabong-Atheull, 2013). These infrastructures are all close to the city centers and also made urban sprawl called Bois des Singes, a magnet for anarchic illegal occupation event though this flooding prone area is unsanitary. Mangrove deforestation is also driven by commercial purposes, such as construction of dugouts, houses, as well as by household use, such as wood for heating and cooking, and also for export (Beni, 1991; Atheull et al., 2009; Ajonina et al., 2015; Angoni et al., 2015). This degradation of mangrove areas and the increase in urbanization pose significant challenges for land use management and highlight the need for effective measures to ensure sustainable development, especially within a context of global sea level rise (Din et al., 2016; Jean-Hude et al., 2016).

Paradoxically, we show that the disappearance of mangrove has not produced uniform coastal retreat. In some sectors—particularly along the urbanised northern bank—runoff-driven sediment fluxes have stabilised or even advanced the shoreline. Nevertheless, such accretion is a geomorphological side- effect that does not compensate for the ecological loss, declining fisheries potential or heightened contamination of estuarine waters (Fusi et al, 2016). The contrast between local shoreline gain and broader environmental degradation highlights the importance of sediment-budget assessments in coastal- vulnerability studies.

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