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Review on Coastline Change and Its Response Along the Cotonou Coast, Benin in the Gulf of Guinea, West Africa

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서아프리카 기니만에 있는 베냉 코토누의 해안선 변화와 대응에 대한 고찰

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Abstract : *The global surface temperature has risen critically over the past century and according to the IPCC Fifth Assessment Report 2014, existing risks in natural and human systems will worsen. Coastal erosion is mostly caused by climate change and among all the coastal areas at risk, Benin, which is part of the Gulf of Guinea, has been ranked very highly as a vulnerable region. Therefore, in this review, we focus on the evolution of coastline change in Cotonou of Benin, summarizing its resultant impacts and applied measures around the coast area by reviewing previous studies. Signs of coastal erosion in Cotonou appeared in 1963. After 39 years, the east shoreline of Cotonou has retreated by 885 m, resulting in the disappearance of more than 800 houses. To solve this problem, Benin authorities built seven groynes in 2013, and have increased the number of the structure as a way to interrupt water flow and limit the movement of sediment. Over the region, shorelines appeared preserved accordingly. In contrast, areas located further east, where groynes were not installed, have suffered from intensive erosion at a rate of 49 m/yr. In the future, as a next step, the effectiveness of groynes should be studied with local and broader perspectives.*

Key Words : *Cotonou, Benin, Coastline, Coastal erosion, Sea level rise*

요 약 : 지난 한 세기 동안, 지구 표면 온도는 급격히 상승했다. 급격한 기온 상승은 심각한 지구 기후 변화를 초래한다. 2014년 IPCC 5차 평가보고서에 따르면 현재 추세대로 기온이 계속 상승하면 해수면 상승 현상처럼 자연 및 인간 체계에 위험이 가해지는 것으로 조사되었다. 해안 침식의 위험이 있는 모든 해안 지역들 중에서 기니만에 위치한 베냉은 매우 높은 취약 지역으로 나타났다. 이 보고서에서는 선행 연구들을 참고하여 코토누의 해안선 변화의 진행과정에 초점을 맞추어 이와 같은 변화의 영향을 조사하고, 연안 침식 방지 조치들의 적용 결과를 요약하였다. 베냉의 코토누에 있는 해안 침식의 징후는 1963년에 나타나기 시작했다. 코토누 동쪽의 해안선은 39년간 약 885 m 후퇴했고, 토지 손실과 함께 800여 채의 가옥이 없어졌다. 이 문제를 해결하기 위해 베냉 당국은 2013년에 7개의 돌제를 건설했고, 이후 추가 설치를 진행하였다. 설치 지역의 해안선은 해변 보호가 되고 있었다. 반면 돌제가 설치되지 않은 돌제 동쪽 지역은 연간 49 m의 집중 침식을 겪고 있다. 따라서 다음 단계로 돌제의 효과는 국지적 관점뿐만 아니라 더 넓은 관점에서 연구되어야 한다.

핵심용어 : 코토누, 베냉, 해안선, 해안 침식, 해수면 상승

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1. Introduction

The world climate faces dramatic climate changes due to critical temperature rises. According to a new assessment of NASA's record of global temperature, the average global temperature has increased by approximately little more than 1°C since 1880 which means two-thirds of the warming has been processed over 40 years (NASA, 2019). If surface temperature rises as current trend, the global mean surface temperature would increase 3-5°C by the end of the 21st century as see in Fig. 1 (IPCC, 2014).

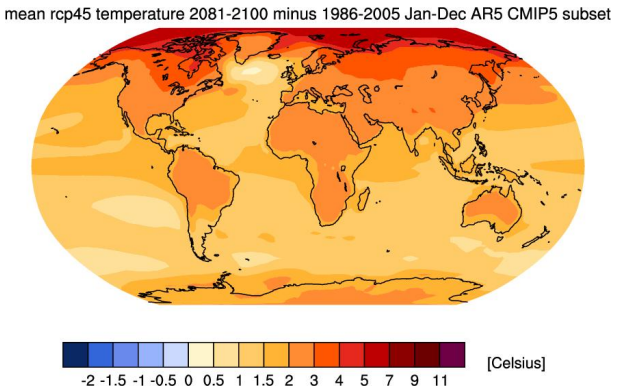

Fig. 1. Difference of global surface temperature between 1880 to 2100 based on the IPCC Fifth Assessment Report Climate Change Atlas: historical and RCP 4.5 scenarios from CMIP5-GCM (KNMI, 2021).

Effects of global warming are resulting in worldwide problems such as melting ice, extreme climate, severe heatwaves, changing the hydrological cycle, changing currents in the oceans, and rising sea levels which all can cause serious coastal erosion (NASA, 2019; Kang and Hong, 2016). Among many coastal regions affected by global climate change, the coastal area located on the Gulf of Guinea in West Africa is one of the most vulnerable areas to climate variability and change (Melet et al., 2016).

The Gulf of Guinea is the northeastern tip of the tropical Atlantic Ocean and extends westward from Cape Lopez in Gabon to Cape Palmas at longitude 7° west. Major tributaries that flow into the Gulf region include the Volta River, the Niger River, and the Congo River. The tropical water at the Gulf of Guinea has warm temperature (27.5-29.5°C) and relatively low salinity because of river effluents and high precipitation along the coast (Britannica, 2021). High precipitation at the gulf become heavier due to more frequent extreme rainfall in both coastal and inland zone as the global surface temperature rises (Mensah et al., 2017). The warm sea temperature is inducing faster erosion in the gulf region. In fact, approximately 930,000 m^2 of land and 800 houses at risk zone in Cotonou (Benin) disappeared in 2018 (Longueville et al., 2020).

Benin is a country in West Africa, and its capital is Porto-Novo. Current population in Benin is 12,368,551 (Worldometer, 2021). Benin is surrounded by Togo to the west, Niger to the north, and Nigeria to the east as see in the green area in Fig. 2. The southern part of Benin has a tropical rainforest climate, while the northern part of Benin has a tropical savanna climate.

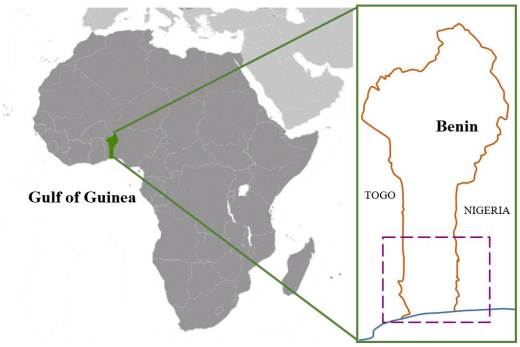

Fig. 2. Location of Benin in Africa (green area).

While Porto-Novo is capital of Benin, Cotonou represents the center of the Benin economy (Fig. 3). According to Worldometer (2021), population in Cotonou is 698,868 which is over half of Benin's population. It has the sub-equatorial climate with two rainy and dry seasons. The average minimum temperature is around 28.2°C, and it does not vary much throughout the year (WMO, 2021). Average annual sea temperature in Cotonou is 27.2°C (Sea Temperature.Net). Because Cotonou locates near the sea, its humidity is almost constant at 85 percent. The annual rainfall is 1,309 mm (Dossou and Glehouenou-Dossou, 2007).

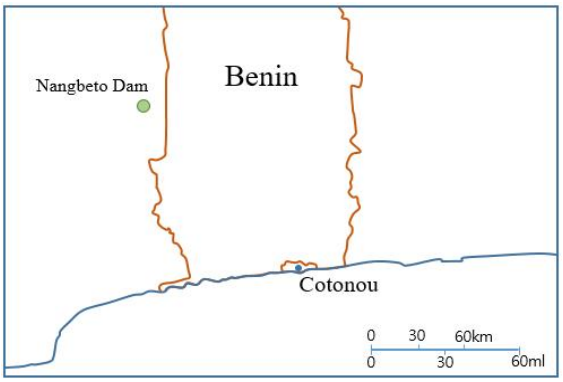

Fig. 3. Location of Cotonou in Benin (blue point) and Nangbeto Dam (green point).

Prevailing coastal winds blow southerly with speeds of approximately 3-7 m/s (Dossou and Glehouenou-Dossou, 2007). Ocean swells at Cotonou shore have 160-220 m long with arriving intervals between 10 and 16 seconds. In addition, the swells have oblique angles between 4° and 9°. Thus, coastal drift could be transported from west to east. As a result, 1,500,000 cubic meters of sand are reached from Lome in Togo to Cotonou every year. However, ports built-in the two cities disrupted sediment to be transported into Cotonou, and this reduced the sandy deposits.

As previously stated above, Cotonou is one of the most vulnerable coastal communities in the Gulf of Guinea and suffering from economic losses and settlement destruction due to coastal erosion (Gomez et al., 2020). Especially, east of Cotonou Port (Vulnerable Zone) displayed great coastal erosion compare to the west of Cotonou Port (Stable Zone) as see in Fig. 4. Therefore, in this review, we are going to take a look at how the east coastline of Cotonou has been changed, and how coastal erosion impacted to people who lives in the site by summarizing previous studies on the topic.

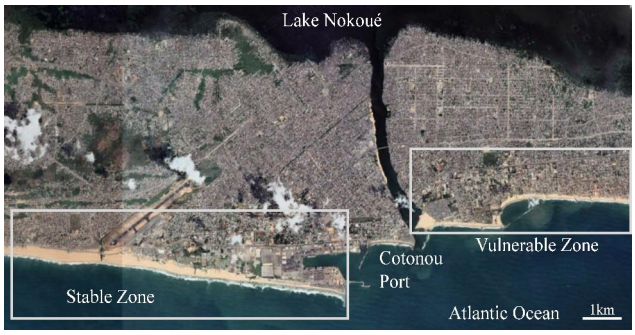

Fig. 4. Google image of Cotonou obtained in July 2021.

2. Methodology used in previous researches

In the previous studies, two main methods were mainly used to examine coastline change and its impacts: satellite images and fieldwork. High-resolution satellite data are often used to examine changes in the coastline. Using satellite imagery was a good way to compare and contrast the differences of the coastline because it allows to see large areas and images from different time periods at a time. However, limitations in the quality of optical satellite images, inaccuracy of images, and uncertainty of measurement methods created the margin of error.

Secondly, fieldwork helped to see the vivid effects of coastal erosion and hear local residents' stories. Because they interviewed residents in person, they could reduce misunderstandings and conduct more accurate analysis. The data collected from fieldwork were mainly used to analyze people's reactions and perceptions of the situation at the site.

3. The progress of coastal erosion in Cotonou

3.1 Causes of coastal erosion in Cotonou: nature and artificial structures

In general, reasons of coastal erosion are divided into two main categories: natural factors and the human influences.

Sea level rise is the main climate hazard that Cotonou is facing, and it likely causes coastal erosion. As an evidence, IPCC report (2007) proposed that sea level rise would bring harmful effects on the coastal system, especially in the Gulf of Guinea. A simulation modeled by IPCC suggested that the sea level in Benin would rise until 59 cm based on their extreme scenario (Table 1). Sea levels in the coastal countries, rose by 4 mm per year from 1993 to 2020 (https://uhslc.soest.hawaii.edu/). Boer et al. (2019) showed an areal change rate of Cotonou is 0.11 km^2 per year from the 1984-2018 data. Since Cotonou has some areas that are at, or below sea level, vulnerability is considerably high. Among 13 districts in Cotonou, the first and fourth districts were selected as the most vulnerable area to coastal erosion (Fig. 5). Estimated population who are in the threatened area (the first and fourth district) was 94,425 according to 2002 census. It is same as one-tenth of Cotonou population at the time. Now, it is estimated approximately 69,887 which is one-tenth of Cotonou population in 2021. We anticipate that decreasing in living space due to land loss has resulted in population outflows.

Table 1. Prediction of sea level rise in 2050 and 2100 based on IPCC scenario IS92a

	Sea level rise (centimeter)	
Scenario \ Year	Year of 2050	Year of 2100
Average	20	49
Extreme	39	59
Basic	7	20

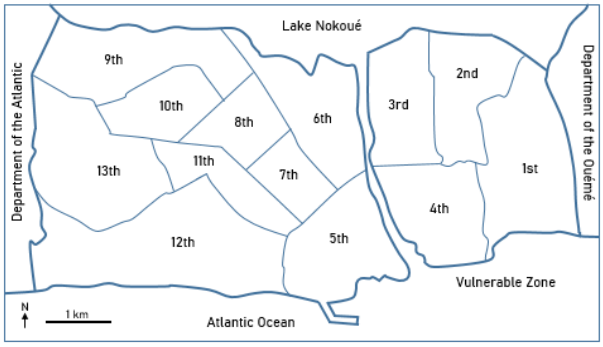

Fig. 5. Location of the first and fourth districts where are selected as vulnerable zones in rough past map. Modified from Dossou and Glehouenou-Dossou (2007).

Furthermore, Longueville et al. (2020) suggests three main causes of coastal erosion in Cotonou with a greater emphasis on the human influences. First, deep-water harbor and pier built in early 1960s hindered the littoral transit. Second, the decrease in the amount of sand flowing down from upstream due to the construction of the Nangbeto Dam built in 1987 (Fig. 3). Lastly, the reduction of inflow sediment from the west due to various protective facilities built in countries such as Togo (Ndour et al., 2018). Additionally, sand quarries and beach sand mining became other causes that aggravated the situation in Cotonou. For these reasons, coastal erosion in Cotonou has become more severe, and it threatens human settlements, economic, health and ecosystem.

3.2 Coastline change between 1963 to 2002

A sign of coastal erosion in Cotonou started to be shown in 1963 (Codjia et al., 1997). After 24 years, the shoreline in east of Cotonou lagoon has been retreated by 400 m at a maximum rate of 16 m per year. This equals approximately 1,120,000 m^2 of area. Even after 1987, the coastal erosion did not stop but kept recessing land. As a result, about 370 m additionally retreated between 1985 and 2002 (Fig. 6).

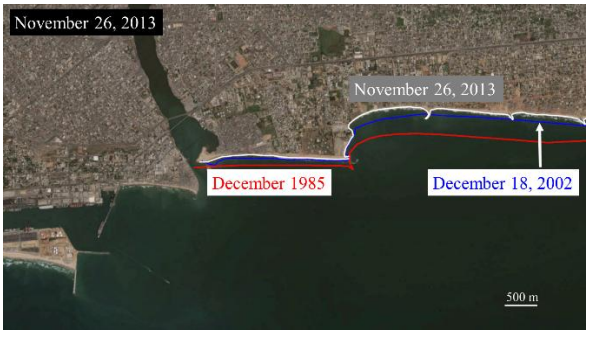

Fig. 6. Change of coastlines in east of Cotonou lagoon (red line: December 1985, blue: December 18, 2002, white/background image: November 26, 2013). Modified from Longueville et al. (2020).

3.3 Coastline change between 2002 to 2013

By using high-resolution satellite images, Longueville et al. (2020) found out that coastline retreated approximately 115 m between 2002 and 2013 as see in Fig. 7. The result value has local variations from 28 to 145m and considers 5 m as a margin of error that may be caused by natural influences, imprecisions of images, and measurement uncertainties. Estimated average of erosion rate is 10.5 m per year, which is less than rate of 16m between 1963 and 1987. The loss of land area is nearly 930,000 m^2, and about 60 standing houses and 750 makeshift houses (informal settlements) disappeared due to coastal erosion. With a simple calculation using average household size, at least 3100 individuals were needed to leave their homes to avoid threaten from the sea. Thus, total coastline retreated between 1963 and 2013 is 885 m.

Fig. 7. Coastline change between December 18, 2002 and November 26, 2013 for the blue boxed area in Fig. 5. Redrawn from Longueville et al. (2020).

In March 2009, the authorities in Benin implemented a measure to reduce erosion by closing all marine sand quarries at the Groyne zone. The measure showed positive result but was not enough to keep the coastline from retreating. Finally, Beninese government decided to build seven groynes, 8.3 km along the sea (Gulf of Benin) to the east of Siafato groyne, so that coastline can be stabilized (Fig. 8).

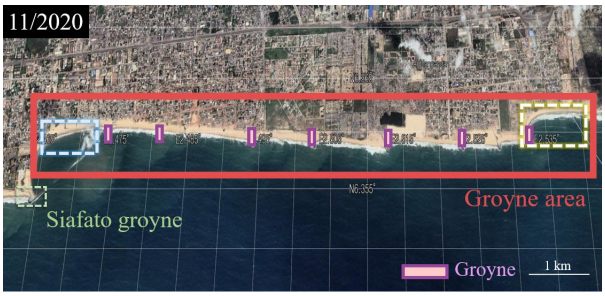

Fig. 8. Locations of Siafato groyne and 7 groynes in a groyne area on Google Map (November 2020)

Fig. 9. Progress of destruction of coastline between 1985 to November 26, 2013 on Google Map (March 2020).

Fig. 10. Severe erosion at yellow boxed area in Fig. 5 due to littoral drift between February 21, 2013 and May 5, 2018.

3.4 Coastline change between 2013 to 2018

After implementing of seven groynes in 2013, notable local variations in groyne scale observed. The west side of groyne showed accretion while the east side of groyne showed fast erosion. However, still general stabilization was observed in Groyne zone (Fig. 9). In contrast, the next kilometers east of the Groyne zone where protective structures were not installed showed significantly severe erosion. As see in Fig. 10, coastline retreated rapidly with rate of 49m per year (2013-2018). This is likely caused by littoral drift that often brings unwanted effects to the neighboring beaches due to protective measures such as groynes (Choi et al., 2016).

4. Impacts of the coastal erosion

4.1 Projected effects of coastal erosion on human settlement, and population dynamics

Coastal erosion due to sea level rise has been appearing in Cotonou where the bulk of Benin's population lives. Thus, it is inevitable that coastal erosion threatens human living.

As evidence, several types of infrastructure or urban structures such as housing, roads, fishing ports, presidential building, etc. have been lost by the coastal erosion. From 2002 to 2018, approximately 800 houses disappeared. Victims who lost their house can be divided into 5 groups: Wealthy people, people in danger, precarious people, fisherman, and poor newcomers. When the houses of wealthy group are threatened, the wealthy group could easily move to inland areas from the risk zone because their financial conditions are affordable to buy new houses.

In contrast, people in danger (poor population) are forced to stay in the risk area due to their lack of financial conditions. They cannot even make a small movement. Likely, precarious people represent a group who wants to leave the risk area, but all they can do is making small movements that barely can avoid the danger for a short time. What they need is the necessary resources to re-establish livelihoods. Surprisingly, the fishermen group was willing to stay in the risk area so that they can continue their economic activities at the close. However, most fishermen also have a high potential to become a poor population because erosion impacts the ecosystem negatively. Lastly, poor newcomers are people who recently migrated to risk zone from rural areas or other countries because they cannot afford safe settlements in the city. As result, they are also trapped in the risk area. Thus, the rate of poor population in the risk area increased. We organized the financial status and responses of each group in Table 2.

Table 2. Responds of each resident types to the coastal erosion

Type	Financial status	How responded
Wealthy people	Wealthy	They easily moved to the new houses that locates inland.
People in danger	Poor	Can't take any action due to their lacking financial status.
Precarious people	Neither wealthy nor poor, however having high chance to become the poor	Slightly move or take coping strategies that lasts only temporarily time.
Fishermen	Neither wealthy nor poor, however having high chance to become the poor	Wanted to stay near the risk area even though they can leave the place.
Poor newcomers	Poor	Slightly move when the sea threatens them.

4.2 Effects on human system such as economy and human health

The industrial and the tourism sector of Benin are under the risk as well. The great parts of the industries of Benin located in the fourth district where coastal erosion gradually progresses. If coastal erosion keeps exacerbating, then over 1500 people who are working in over 30 state or private enterprises would lose their jobs (Dossou and Glehouenou-Dossou, 2007). Hotel infrastructure in Benin is also damaged and destroyed by the sea (Fig. 11). Since those two sectors considerably contribute to the national economy, the disappearance of these facilities would possibly lead Benin towards great economical danger.

Fig. 11. Damaged hotel infrastructures by coastal erosion (Ocean Climate Alliance).

In addition, inundation by sea level rise can harm human health. Flooding in the inter-dune area would also resurgent endemic tropical diseases like malaria (Bokonon-Ganta, 1999). This could be deadly especially for elderly people, pregnant women, and infants (MEHU, 2003).

4.3 Effects on coastal and lagoon ecosystem

Damaging human settlement is not the only downside of coastal erosion and sea level rise. They also cause biophysical disruption and salt intrusion.

Shore of Benin has a great variety of ecological area that is colonized by diverse plant and animal species. Therefore, if sea level rises by 50 cm, it will disrupt plant formations and animal species such as crabs, marine turtles, and especially mangroves (Dossou and Glehouenou-Dossou, 2007). The fishermen in the area declared that some fish species were already experiencing disruption in their ecological niche.

Moreover, sea level rise would lead to saltwater intrusion to freshwater in Cotonou. Saltwater intrusion would harm not only freshwater ichthyological fauna, but also masonry structure on the ground. The soil becomes salinized, and it would likely attack the foundation of structures resulting in building collapse.

5. Adaptation applied to reduce vulnerability

Vulnerability can be lessened when the individuals can adapt to the changes. Therefore, applying proper measures is one of the keystones to overcome the crises (Kang and Hong, 2016). Since coastal erosion is not a problem that is only confined to Cotonou, adaptive measures, introduced here, can be applied throughout the Gulf of Guinea. The implement of measures mainly takes in three forms, which are passive, active, and technical.

In particular, the difference between the passive and active way of measures is determined by how much influence the environment changes. The active way of measures has as little impact on the natural environment, and the active way of measures does not take into account the impact of the natural environment.

5.1 Passive way of measures

Passive measures require the adoption of decisions or attitudes to avoid or mitigate the negative effects of rising sea levels and coastal erosion (Dossou and Glehouenou-Dossou, 2007). These measures were implemented shortly after the construction of the Port of Cotonou. As see in Fig. 12, beach rocks used to protect the shoreline. In addition, sandy sediment was added to erosion risk

area, so that sandy sediments can be transferred from well-stocked area to poor-stocked area.

Fig. 12. An example of passive adaptation (reprinted from: The vulnerability to climate change of Cotonou (Benin): the rise in sea level).

5.2 Active way of measures

Active measures include building structures along the coast or by sea. There are two types: lengthways structures such as breakwater, shore walls, beach defenses, and transverse structures built from different materials, for instance, wood, concrete, etc.

Considering the obvious signs of erosion in Cotonou, breakwater and groynes would seem more appropriate rather than beach defenses. As an example of active measures, concrete barriers were constructed at the entrance to the Cotonou lagoon (Fig. 13). This structure was built to protect the first Cotonou Bridge, and reduce marine encroachment on lagoons and Lake Nokoué. In 1885, the lagoon was only a small canal because it just needed to drain rainwater from floods, but now it is over 200 m wide due to the power of water runoff (Colleuil, 1984). Recently, it has been reopened to allow sediment to flow that came from the banks of Seokho Lake and Nokoué Lake.

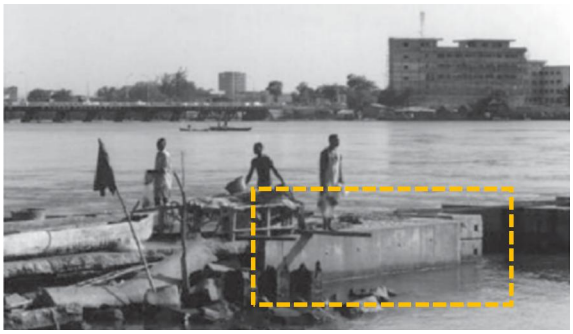

Fig. 13. The concrete barrier (Yellow box) built at the entrance to Cotonou Lagoon (reprinted from: The vulnerability to climate change of Cotonou (Benin): the rise in sea level).

5.3 Technical measures

Benin's government has also tried to introduce more technical measures to establish measures against sea erosion. The plan involves building groynes, moving communication network, transportation, and hotel infrastructure away from sea to stabilizing the coastline. As one of the examples, Benin authorities built Siafato groyne to protect the socioeconomic, administrative, and residential infrastructure established next to the sea. The establishment of the groyne was effective in alleviating local problems caused by erosion. However, the protection system transferred erosion to the Sèmé region and then further eastward to Nigeria.

Later in 2013, Benin authorities built another seven groynes at 8.3 km along the sea (Gulf of Benin) to the east of Siafato groyne (Fig. 14). It also successfully mitigated the coastal erosion in the area. 33 out of 37 risk residents who participated in the 2013 interview answered that they felt serenity accordingly (Longueville et al., 2020). However, erosion transferring to the east founded in 2018 as Siafato groyne case.

Fig. 14. One of seven groynes built in 2013 as a technical measure.

6. Summary and future plan

Cotonou has suffered from severe coastal erosion for several decades due to the complexity of climate changes and human infrastructures. Coastline retreat not only threatened human settlements, but also negatively affected Benin's economy, human health, and the coastal and lagoon ecosystem. As a result, population dynamics near the risk zone showed appealing changes. For instance, poor population density in the risk areas has increased because wealthy people could easily move to inland areas, while those who financially lacked were unable to move

their residencies. Those who could not move inland took their own measures, such as stacking stones, pouring sand, or building concrete protective structures where erosion occurred. However, those only lasted temporarily which means they are still in high vulnerability.

Finally, Benin's authorities built the Siafato groyne and the seven groynes as technical measures to prevent coastal erosion. As time passed, such measures showed stabilizing of the local coastline, however, at the same time, accelerated coastal erosion in the eastward region of groynes. Therefore, we expect to see future studies that examine the efficiency of existing groynes more in depth with broader perspective, and how to minimize the negative effects of groynes, such as erosion transferring to neighboring coasts.

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