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Environmental Claims Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/becj20

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ENVIRONMENTAL CLAIMS JOURNAL
https://doi.org/10.1080/10406026.2020.1847873

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Taking Stock of Climate Change Induced Sea Level Rise across the West African Coast

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ABSTRACT

The impact of climate induced sea level rise (SLR) is a major threat, likely to continue even if greenhouse gas concentrations were stabilized. SLR will not be geographically uniform. Developing countries are most impacted because of their low adaptive capacity. This study reviewed the most recent scientific evidence of the impact, vulnerability and adaptation of coastal areas in West Africa to climate induced SLR. The results show an increasing rate in SLR for the near and further future. Coastal communities in West Africa are vulnerable to erosion, flooding and inundation resulting in the loss of many coastal lands and ensuing socio-economic consequences. Therefore adaptation is a matter of urgency. Given that relatively little and unbalanced information exists on this subject for those areas, we call for the need to invest resources into studying and protecting coastal communities in West Africa against current and future impacts of climate change and SLR.

KEYWORDS

Climate change; sea level rise; Modelling; Impact; Vulnerability; Adaptation; West Africa

1. Introduction

Global sea level rise (SLR) is accelerating due to global warming (Cazenave, Palanisamy, and Ablain 2018; Dangendorf et al. 2019). From 2006 – 2015, the average global sea level rose by 3.6 mm/year, more than 2.5 times the mean rate of 1.4 mm/year which was sustained throughout the 20th century. SLR is further projected to increase by 0.3 m above 2000 levels (in more than about 95% of the ocean area) at the end of the 21st century, even with a relatively low greenhouse gas emissions pathway in the coming decades (IPCC 2014; Lindsey 2019). There is unanimous agreement among scientists studying the problem that the rate of SLR will increase, and its impact will be geographically non-uniform, particularly threatening the sustainable

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management of coastal zones across the globe (IPCC 2013; Nerem et al. 2018; Nicholls and Cazenave 2010; Palanisamy et al. 2014).

The impacts of SLR could be catastrophic, nevertheless, studies on the impacts of SLR have focused more on developed than in developing countries so far (Hinkel et al. 2012). In Africa, SLR is not viewed by many as an important threat, although its impacts can be far reaching (Dasgupta et al. 2009; McGranahan, Balk, and Anderson 2007). It is estimated that even a 1 m rise in sea level in coastal countries of the developing world would submerge 194,000 km^2 of land area, and displace at least 56 million people. The actual impacts will, however, depend on each country's ability to adapt to the potential impacts of SLR (Dasgupta et al. 2009).

Thus, managing coastal zones in African countries, and West Africa in particular, has become very relevant, especially since many livelihoods will be affected. Africa's coastal zones are very low-lying, vulnerable, and expected to be the worst hit by the impact of climate induced SLR. Moreover, impact will be exacerbated due to the West African populations' low capacity to respond to such challenge (Boko et al. 2007). Most of the capital cities in West Africa are situated in the coastal zone and are directly exposed to the threat of the climate induced SLR. At present, the West African coastline is increasingly devastated by erosion and flood, causing loss of livelihood and environmental problems (Nicholls et al. 2008). The rapid population growth, coastward migration, urbanization, and uncontrolled and unregulated socio-economic growth is increasing the exposure of people and assets to SLR, and further exacerbating the forthcoming devastation (Nicholls et al. 2008; Syvitski et al. 2009).

Despite the above challenges only a few studies have looked at the impact of climate change and SLR in West Africa. No study up to date has provided an overview and compared the issues resulting from SLR across countries along the West African coastline. Therefore, this article aims at synthesizing the most recent works on Climate Change (CC) and SLR in West Africa through a systematic review of the most recent literature to answer the following research questions;

1. In what ways do CC & SLR impact West African coast (WAC)?
2. How vulnerable is the WAC to CC and SLR?
3. How are communities in WAC adapting to the impact of CC and SLR?
4. Which modeling approaches have been used to assess CC and SLR in WAC?

Further, we discuss the implications of the review results, laying emphasis on existing knowledge gaps, to inform the direction of future research and practice. In the subsequent sections of this article, we elaborate on the methodology adopted for the review in section 2. The results of the study are presented in section 3. Further reflection and the main conclusion of the study are shown in section 4.

2. Methodology

This study focused on the coastline of West Africa (Figure 1). The conditions of the coastal systems in West Africa are described elsewhere (Allersma and Tilmans 1993; Goussard and Ducrocq 2014). Following the components of systematic review for climate change adaptation research proposed by Berrang-Ford et al. (Berrang-Ford, Pearce, and Ford 2015), this article adopted a stepwise approach of selecting the most recent literature that answer our research questions. Our search for literature started in 2007, the year in which the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC AR4) was published. Even though IPCC AR5 (published in 2014) remains the latest publication, the limited information available on climate change and SLR in West Africa necessitated the need to start from IPCC AR4. Articles included in the study were sourced from the Scopus database following a set inclusion and exclusion criteria. According to Mongeon and Paul-Hus (2016), Scopus database covers a wide range of disciplines in its journal article sorting for systematic reviews. The first search included key terms "climate change" and "sea level rise" or "impact" "vulnerability" or "adaptation" and/or "policy," and yielded a total of 5102 records. A subsequent search of the key terms "West Africa" and/or "Ghana", and/or "Nigeria" and/or "Cameron", and/or "Benin", and/or "Togo", and/or "Cote d'Ivoire", and/or "Liberia", and/or "Serra Leone", and/or "Guinea Bissau", and/or "The Gambia", and/or "Senegal", and/or "Mauritania" reduced the records to 65 peer-reviewed articles. The

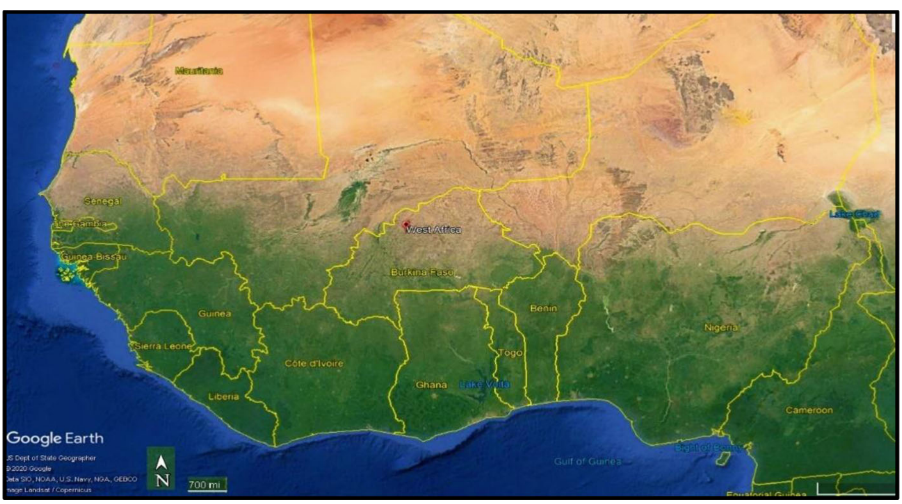

Figure 1. West African coastline (Google Earth).

exclusion criteria include all years before 2006 and duplicated articles. A total of 30 articles were used for the final evaluation after excluding non-relevant publications which used CC and SLR as buzz words.

Thirty selected articles comprised the following studies: (1) assessments of the impact of climate change and/or sea level rise in combination or as standalone, (2) modeling of climate change impact on sea level rise, (3) evaluations or proposed tools or methods for assessing CC and SLR, and (4) studies of the West African Region or coastline of individual countries in the region. Based on the selection criteria, the articles were grouped into four categories: 3 articles (10.0%) presented overviews and reviews of climate change and SLR impact on mangrove ecosystem and in coastal cities, 4 articles (13.3%) focused on qualitative analysis, which comprised policy and stakeholder surveys and assessments, 20 articles (66.7%) were quantitative assessments of climate change and/or sea level rise, and 3 articles (10.0%) employed both qualitative and quantitative analysis. The scope of CC and SLR studies were global (10.0%), West African Region (6.7%), sub-national studies within more than one continent (6.7%), and the rest were all national studies in countries along WAC. Countries that had more than one study ($n = 30$) were Ghana (40.0%), Nigeria (10.0%), Cape Verde (6.7%) and Benin Republic (6.7%). The year 2014, 2016, 2017 and 2018 recorded the highest number of publications (13.0%) and journals with more than one publication were Journal of Coastal Conservation (10.0%), Journal of Coast Research (10.0%), and Marine Geodesy (6.7%).

3. Results

3.1. Impacts of CC & SLR in WA

Rising sea level under a changing climate is expected to cause flooding and inundation of coastal areas affecting water resources, vegetation, transportation, and agriculture. It is estimated that SLR relative to 2000 baseline at the Gulf of Guinea will increase from +0.21 to +0.36 m and +0.55 to +1.1 m during the mid and end of the 21st century, respectively (Kebede et al. 2018). This is expected to hit hard the coastal areas in West Africa. Along the coast of Côte d'Ivoire, Ghana, Togo and Benin, an overall area loss due to SLR will be at a rate of about 0.25 m/yr to 0.8 m/year, with an assumed relative SLR of 0.3 m and 1.0 m, respectively, by 2100 (Kebede et al. 2018). For example, in Ghana and by 2050, SLR will pose risk to between 2.66 km^2 − 3.24 km^2 of the area, with an expected increase of up to 10.70 km^2 by 2100 (Evadzi et al. 2018). Projected future recession rates of Ghana's coast are between 1.47 − 2.25 m/year with about 30 m − 140 m width of coastal land lost within the next 250 years (Addo, Walkden, and Mills 2008). Analysis of satellite imagery of Lagos in Nigeria shows a loss

Figure 2. Right: Disappearing buildings in Aneho, Togo (Addeh 2015). Left: Marine Erosion of the coastal highway in Limbe, Cameroon (Kometa et al. 2016).

of 0.75 km^2 of beach land for a period of 10 years (1999–2009), representing an annual inundation rate of about 0.075 km^2 along the area. Based on this, the authors projected a complete disappearance of the beach and a consistent loss of built-up areas into the ocean before 2029 (Fashae and Onafeso 2011). Boateng (2012) posit that the presence of lagoons bordered by settled barrier beaches worsens the impact of SLR on surrounding coastal communities.

An increase in SLR will affect the ecosystems, species loss and human habitations, infrastructure, as well as the local economies of WA coastal cities. About 33.4% – 43.0% of the nesting area of green turtle in Bijagós island of Guinea Bissau will be lost by 2100 due to coastal flooding (Patrício et al. 2019). Sea level rise is expected to significantly affect green turtle in Boa Vista of Cape Verde (Abella Perez et al. 2016). A number of highly populated communities will be destroyed by 2065 and river beach resorts eroded in 2035. It is estimated that, in Ghana, natural fish landing sites in Osu will be inundated by 2045 and certain highly populated communities will be destroyed by 2065 in addition to beach resorts being eroded by 2035 (Appeaning Addo 2014). Also, about 381 buildings are likely to be affected by the year 2050, while by the year 2100 a total of about 926 houses could be destroyed at the Dansoman coastal area (Appeaning Addo et al. 2011). Using IPCC AR5 RCPs 2.6, 4.5, and 8.5 scenarios, Evadzi, Zorita, and Hünicke (2017) estimated SLR at the coast of Ghana by 2025 to be 26.4 mm, 18.7 mm, and 23.1 mm respectively. This, according to the authors, is expected to rise up to 79.2 mm, 82.8 mm, and 97.2 mm by 2050 and 146.2 mm, 206.4 mm, and 335.4 mm by 2100. Based on future emission pathways of the corrected IPCC AR5, a rate of about 2 m/y in SLR is sufficient to inundate approximately 20 m of coastal areas within the lowest slope range (0.0–0.4%) by the year 2050 (Fashae and Onafeso 2011). Figure 2 shows an example of physical damage caused by SLR in Togo and Cameroon.

An important impact of climate induced SLR is the socio-economic one, based on the population at risk and their economic activities value. For example, Niang et al. (2010) studied the socio-economic impact of climate change and SLR in Cap Vertpeninsula and Saloum estuary in the coastal zone of Senegal and found that a 1 m inundation level over the two cities by 2050 represents about 14.1% of the actual Gross Domestic Product, due to destruction of houses and agricultural losses.

3.2. Vulnerability of the West African coast to climate induced sea level rise

About 33.33% (n = 30) of the analyzed articles indicates that the West African coast is vulnerable to climate change and SLR. Ellison and Zouh (2012) reported that the current SLR on central Cameroon coastline was due to climate change affecting mangrove prograding. Ellison (2015) later reported that the mangrove areas in the Douala estuary (Cameroon) have the highest vulnerability, due to low tidal range and certain non-climate stressors. The author provided evidence of moderate seaward edge retreat in Douala compared to Tikina Wai (Fiji) and Rufiji Delta (Tanzania). According to Ward et al. (2016), there was limited empirical data to determine the vulnerability of Africa's mangroves in addition to the geomorphological setting of the continent's coastline. The West African coast and its mangrove were vulnerable to future changes in precipitation and temperature due to climate change. According to Patrício et al. (2019) marine turtles along the WAC are vulnerable to climate change and SLR and about 86.2% of current nesting habitat could be lost by 2100.

Gomez et al. (2020) found that areas about 250 m distant from the shoreline in The Gambia are highly exposed to SLR and that the human system within this range is also highly vulnerable. According to (Dossou and Gléhouenou-Dossou 2007) the coast of Benin is vulnerable to climate change and SLR, especially the first and fourth arrondissements of Cotonou. In the Cap Vert Peninsula and Saloum estuary along the Senegalese coast, between 1.2 – 12.4% of the total population of the country is vulnerable to climate change and SLR which could cause 7.3% loss of actual GDP from 1 m inundation level by 2050 (Niang et al. 2010). The coastal vulnerability index (CVI) of the whole of Accra in Ghana showed a moderate risk ranging from 4.5 – 12.0. However, sectional analysis shows that the western part of the coast of Accra is highly at risk to SLR (Addo 2013). Furthermore, Boateng, Wiafe, and Jayson-Quashigah (2017) determined the CVI along the total coastline of Ghana to be in the range of 15.49 – 86.60, 50% of the coastline were found to be highly vulnerable. Also, the coastal zone of Cote d'Ivoire is found to be vulnerable to climate induced SLR with an estimated CVI rising from 1.63 (in 1972) to 18.25 (in

2004), falling within a moderate risk category of vulnerability (Tano et al. 2016).

3.3. Adaptation to sea level rise among coastal communities in West Africa

Analysis of the implemented measures in the sub-region shows that adaptation can be passive and active (Dossou and Gléhouenou-Dossou 2007). The passive measures comprise minimum interventions involving decisions or behavioral changes that help address the negative effects of SLR. Kebede et al. (2018) suggested the need for practices that restructure the social-ecological systems, encourage the best use of ecosystem services, increase the financial capacity of coastal areas and reduce costs while protecting vulnerable citizens. In Benin, Dossou and Gléhouenou-Dossou (2007) identified passive adaptation practices such as moving sandy sediments and beach rocks to more deficient and vulnerable areas in order to protect infrastructure located near the seashore of Cotonou (Figure 3 left). In Nigeria, vulnerable fisher folks in Ogun coastal area have expressed the need to access credit from cooperative societies or banks to increase labor and acquire assets that will improve their capacity to deal with the increasing incidence of floods (Adelekan and Fregene 2015). Active adaptation measures, involve building structures at the coast or into the sea to alleviate the impact of SLR. Dossou and Gléhouenou-Dossou (2007) mentioned two main types of active measures; (i) lengthways structures like seafront walls, beach defenses, breakwaters, and (ii) transverse structures such as groins built from concrete or wood and run perpendicular to the coastline (see Figure 3 right).

In Ghana, construction of coastal defence wall is the main adaptation strategy adopted by the government. Most inhabitants along the coast resort to temporary relocation due to coastal flooding or inundation (Evadzi et al. 2018). Coastal protection measures for adaptation in Senegal

Figure 3. Passive adaptation (left): using rocks in human settlements on the Benin coast (Dossou and Gléhouenou-Dossou 2007). Active adaptation (right): groins along Keta in Ghana (Angnuureng, Appeaing Addo, and Wiafe 2013).

include littoral dune reforestation in addition to sea walls, groins and rock protection (Niang et al. 2010). Special management actions are implemented for adaptation to SLR in Cameroon. For example, rehabilitation of degraded mangroves, designing shore structures to allow longshore sediment drift, design dams to allow sediments to pass through and control boat wakes to reduce erosion (Ellison 2015).

3.4. Modeling approaches to climate change and sea level rise in West African coast

The literature examining the impacts of CC and SLR in the coast of West Africa and the associated adaptations has been dominated by the use of mathematical models and Geographical Information Systems (GIS) approaches. The models focused on cases ranging from global, regional, national and sub-national scale, but with particular interest in the coastal areas. Most of the models utilized in the region focused on estimating and predicting changes in shorelines using scenarios and reflecting on the exposure and vulnerability analyses and at best include adaptation measures (Addo, Walkden, and Mills 2008; Addo 2011; Evadzi, Zorita, and Hünicke 2017; Niang et al. 2010). Others predicted future sea-level rise under different climate change scenarios (Melet, Almar, and Meyssignac 2016; Schleussner et al. 2016). Some specific studies analyzed the future trends of wave from offshore to nearshore in addition to sediment transportation (Giardino et al. 2018).

A number of different models and tools have been used for different purposes to provide better insight into climate change and SLR. The Soft Cliff and Platform Erosion (SCAPE) numerical model was used to project future geomorphology of the shoreline on cliff shores in Ghana. It was operationalized with the assumption of offshore equilibrium profile where materials eroded onshore are directly deposited offshore with no gain or loss in sediment volume (Addo, Walkden, and Mills 2008; Appeaning Addo 2014). The Bruun model was used to quantify changes in shoreline caused by rising sea level in Senegal and Ghana (Appeaning Addo et al. 2011; Niang et al. 2010). The modified version of Bruun model was later used to predict future shoreline recession on beach shores under plausible sea level rise scenarios in Ghana (Appeaning Addo et al. 2011). The impact of inundation on coastal communities in Ghana was estimated with CoastCLIM component of the SimCLIM model system (Appeaning Addo et al. 2011). Different studies utilized the Digital Shoreline Analysis System (DSAS) as an extension in ArcGIS to digitize the direction and shape of the outer shoreline and to make future projections on the basis of the corrected SLR projections of IPCC AR5. The objective was to compute changes in shoreline and evaluate the trends in coastal erosion (Addo, Walkden, and Mills 2008; Appeaing Addo 2014; Evadzi, Zorita, and Hünicke 2017). Parameterized representation of the SCAPE model called the equation of Walkden and Dickson was used in addition to Shore platform model to calculate future shoreline recession in Ghana (Addo, Walkden, and Mills 2008). In the work of Giardino et al. (2018) across the coast of Côte d'Ivoire, Ghana, Togo and Benin, the Delft3D-WAVE (SWAN) model was used to estimate wave from offshore to nearshore. In addition, the authors used UNIBEST-CL + modeling package to model longshore sediment transport generated by local wave and flow conditions. Other studies have used simple mathematical algorithms. For example, in the work of Melet, Almar, and Meyssignac (2016) in Cotonou, Benin, the authors modeled SLR with summation mathematical algorithm of altimetry-derived sea level, wind-wave set-up, swell-wave set-up, wind-wave run-up, swell-wave run-up, wind set-up, astronomical tide and inverted barometer effect.

4. Reflections

This review shows that sea levels in coastal areas of West Africa are rising and climate change is likely to accelerate the rate of rising both in the near and more distant future. The major impacts of SLR in the studied areas included erosion of beaches, flooding and inundation, resulting in the loss of many coastal lands and socio-economic consequences. Our analysis reveals that coastal communities in West Africa are vulnerable to the impact of SLR. Given that most of the coastal cities in West Africa serve as commercial hubs and home to a large and rapidly growing population, there is an urgent need to improve the adaptive capacities of their inhabitants.

Finding effective ways for the people and ecosystems in WAC to adapt is a matter of urgency. In view of the scale of impact of SLR in some coastal areas in West Africa, passive adaptive measures such as the use of sandbags and beach rocks are no longer effective means to salvage affected communities. Nonetheless, inhabitants of these areas continue to use them because of inadequate finances to develop active measures, such as sea defence walls. In some areas, like Cotonou, certain active adaptation measures like beach defenses are no longer suitable, and breakwaters and groins would appear more appropriate (Dossou and Gléhouenou-Dossou 2007). Furthermore, in countries where governments have intervened by providing active adaptation measures, not all communities benefit from such adaptation facilities and have therefore resorted to relocation from their homes. Also, the development of an integrated coastal adaptation plan backed with scientific knowledge on how to respond to SLR under climate change is vital for the region. While this working plan has been applauded by relevant stakeholders, national governments for example, Ghana is yet to formulate one (Evadzi et al. 2018).

With regard to inadequate adaptation measures implemented in WAC, one cannot help but wonder why governments and civil society remain inactive in their approach to protect these places. The coastal areas receive numerous tourists and have expensive recreational facilities in addition to a vibrant fishing industry that contributes to the growth of both the micro and macro economy. Perhaps it can be argued that proper cost-benefit analysis of improving coastal resilience to SLR will be an eye-opener for investment into adaptation measures. Nonetheless, economic viability should not be the only basis for developing infrastructure for adaptation. Protecting the cultural heritage of inhabitants is an essential factor. In the adaptation literature, no-regret actions offer the best alternative in situations where there is a conflict between economic and social benefits. These actions are win-win and contribute to adaptation, whilst having socio-economic and environmental benefits (Klein et al. 2014; Prutsch et al. 2013). Unfortunately, it seems that for many parts of the WAC, adaptation projects are not planned to include all components that might make it a win-win. For example, Tsikata (2016) argued that the Keta Sea Defense Project in Ghana was politically motivated rather than economically needed. The author explained that even though the project has been able to halt the speedy erosion of the landmass in the area, it has failed to yield economic benefits, suggesting that inclusion of a fishing harbor as a component of the project could improve the livelihood of the fishing folks, and at the same time contribute in the form of taxable activities to the government revenue.

This study has shown that coastal areas of West Africa are already at risk and likely to be more at risk if sea level rise continues to increase. Yet it is important to emphasize that the literature on climate change and SLR in WAC is inadequate and unbalanced, with several of the countries having little to no recent information on the subject. To enrich the understanding of the scientific community on prevailing challenges posed by SLR in WAC, intense research efforts are required. A critical task ahead is gathering quality data for analysis to guide the development of adaptation responses relevant for policy formulation and practice. Fashae and Onafeso (2011) mentioned the inability to perform rigorous predictive analysis for climate change and SLR research in Nigeria, due to lack of data. Another important observation is that none of the studies accounted for the local processes and driving factors of climate induced SLR in WAC, such as thermal expansion and changes in land water storage, a gap that needs further studies.

5. Conclusion

This study draws on recent literature to offer insight into the impact, vulnerability and adaptation of coastal communities in West Africa to climate change and SLR, including the methods and approaches utilized for study. It acknowledges that the WAC is vulnerable to the many challenges posed by SLR and outlines promising directions for further research and the practice of adaptation which our review suggests. While discussed in most of the studies reviewed, adaptations are rarely the focus of the studies. In SLR they are addressed more in a qualitative manner, compared to assessing impacts and vulnerability which were more quantitatively addressed. Given that adaptation is relevant for building a more resilient coastline in West Africa, we advocate for greater involvement of all relevant stakeholders in the provision of site specific adaptation facilities. We also expect that explicit evaluation of adaptation projects will improve understanding of the design based on local characteristics of the SLR and implementation supported by impact mechanisms for a better outcome. There is also a window of opportunity to explore the processes of climate induced sea level rise in WAC and to evaluate the cost-benefit analysis of adapting and selecting a particular adaptation measure. Finally, our conclusions are based on a relatively small empirical knowledge base and therefore call for a broader discussion on the need for governments and institutions to invest resources into studying and protecting coastal communities against current and future impacts of climate change and SLR.

Notes on contributors

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