Science of the Total Environment 838 (2022) 156234

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Adaptive management of environmental challenges in West African coastal lagoons

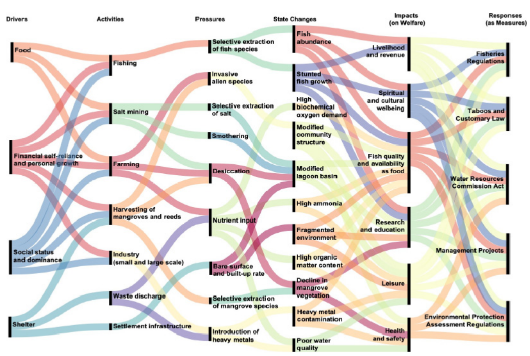
Richard Takyi [a,*], Badr El Mahrad [b,c,d], Francis Kofi Ewusie Nunoo [e], Richard Adade [f], Mohamed ElHadary [d], John Essandoh [g]

[a] Blue Resources Research and Policy Institute, L534, Mallam, Greater Accra, Ghana
[b] Murray Foundation, Brabners LLP, Horton House, Exchange Street, Liverpool L2 3YL, UK
[c] Laboratory of Geoscience, Water and Environment, (LG2E-CERNE2D), Department of Earth Sciences, Faculty of Sciences, Mohammed V University of Rabat, Rabat 10000, Morocco
[d] CIMA, FCT-Gambelas Campus, University of Algarve, 8005-139 Faro, Portugal
[e] Department of Marine and Fisheries Sciences, University of Ghana, Legon, Ghana
[f] Centre for Coastal Management, University of Cape Coast, Ghana
[g] Department of Conservation Biology and Entomology, University of Cape Coast, Ghana

HIGHLIGHTS

- Coastal lagoons provide several essential ecosystem services.
- Biological, physiological, and self-actualization drive activities in lagoons.
- The state of lagoons has been negatively impacted by human activities.
- Several management measures have been implemented with little success.

GRAPHICAL ABSTRACT



ARTICLE INFO

Guest Editor: Irene Laiz

Keywords:
Africa
Integrated management
DAPSI(*W*)R(M)
Environment
Lagoon
Ghana

ABSTRACT

Human activities in coastal lagoons over several decades have had a significant impact on their ecology and the valuable ecosystem services they provide. Although there are several management approaches to mitigate the problem, they are unable to link human needs and activities with changes in the state of the environment. This research provides this link via assessment of eleven lagoons in Ghana with a socio-ecological framework (Drivers (D), Activities (A), Pressure (P), State (S), Impact (I) on welfare (W), and Response (R) as a Measure (M); DAPSI(*W*)R(M)). Data were systematically obtained from relevant publications, previously conducted research, and national reports on the subject and were analyzed using this socio-ecological framework. Results show that basic biological and physiological needs such as food and shelter, social status and dominance, financial self-reliance, and self-actualization are the drivers of fishing, farming, settlements, salt mining, mangrove harvesting, industries, among others. These activities have contributed to pressures of selective extraction of fish and mangroves species, the introduction of heavy metals, organic materials, and smothering of substrates, consequently altering the environment by decreasing the oxygen rate and increasing the biochemical oxygen demand, organic matter, nutrients and pathogens, and reduction in lagoon areas and biodiversity. Thus, ultimately impacting human welfare, such as loss of revenue, employment, and seafood provision. Management options, including addressing the building and fuelwood material sources, afforestation and community ownership of lagoons, the prohibition of construction activities, and research-led management that can

* Corresponding author.
E-mail address: richardktakyi@gmail.com (R. Takyi).

http://dx.doi.org/10.1016/j.scitotenv.2022.156234
Received 21 December 2021; Received in revised form 19 May 2022; Accepted 22 May 2022
Available online 26 May 2022
0048-9697/

support decision-makers to improve the sustainability of these ecosystems, are highlighted. The findings have global implications for guiding local planners and state regulators in the applications of such integrated environmental management.

1. Introduction

Coastal lagoons are vulnerable and dynamic ecosystems with rich biodiversity that, among others, support essential ecosystem services (e.g., nutrition, climate regulation, resource extraction, culture, etc.) for several populations worldwide (Agbekpornu et al., 2016; Mahapatro et al., 2013). The vulnerability of coastal lagoons stems from the value and benefits they provide and their proximity to local communities, industries, and increasing populations leading to excessive dependence (Brinks, 2017; Finlayson et al., 2000).

Coastal lagoons are typically shallow, and their typology can be subdivided as 'restricted,' 'close,' 'leaky,' and 'open'(Kjerfve, 1994). They are fed by rivers or streams and the sea (seasonally or continuously), brackish, and are fringed by intertidal mud or sandflats or mangroves swamps (Entsua-Mensah et al., 2000; Kjerfve, 1994; Kwei, 1977; Lassere, 1979). These socio-ecological ecosystems are dominant features along the West African coast, with Ghana having over ninety of them (Balogun et al., 2011; Gnandi et al., 2011; Madiop et al., 2020).

The Sustainable Development Goals (SDGs) identify human-induced environmental degradation and natural resources (including coastal lagoons) depletion as some of the major challenges in recent times (UNESCO, 2020). Globally, including Ghana, anthropogenic activities (e.g., salt mining, settlements, pollution, agriculture, etc.) in-situ and in the catchment areas of coastal lagoons continue to threaten the existence of this ecosystem especially the flora and fauna with dire consequences for human welfare (Balogun et al., 2011; Botello et al., 2016). As a result, several management measures have been suggested and or implemented by scientists, managers and policymakers at the national and local levels to reduce the effect of human activities on Ghanaian lagoons to ensure sustainable and responsible use in line with conservation measures, such as the international conservation agreements and conventions (e.g., the Ramsar Convention on Wetlands) and the SDGs (Finlayson et al., 2000; Ramsar Convention Secretariat, 2014; UN, 2019).

However, the management measures in Ghana have failed largely due to the challenge of linking human needs and activities with state changes in the lagoon ecosystem in policy formulation and decision making. Hence, a tool that supports policy formulation and decision-making by ending the siloed sector-thinking in the management of coastal lagoons that integrates the social, environmental and economic wellbeing to ensure sustainability, and ecological health for a sustainable solution in a changing climate cannot be overemphasized (Gari et al., 2015; Patrício et al., 2016; Takyi et al., 2021; UNESCO, 2020). Prudent environmental management improves the socio-economic and ecological services from natural resources that could help enhance the adaptive capacity of local communities in Ghana to climate change (Antwi-Agyei, 2018). Adaptive management systems for socio-ecological such as the Drivers (D), Activities (A), Pressures (P), State changes (S), Impacts (I) on human welfare (W), and Response (R) as Measures (M) (DAPSI(*W*)R(M)) provide this framework for managers to ensure the facilitation of management and assessment of issues of ecosystems in Ghana (El Mahrad et al., 2020; Smith et al., 2016; Takyi et al., 2021).

Therefore, the objective of this study is to analyze the Drivers (D), Activities (A), Pressures (P), State changes (S), Impacts (I) on human welfare (W) and to provide the Response (R) as Measures (M) (DAPSI(*W*)R(M)) for eleven of the over 90 coastal lagoons in Ghana (El Mahrad et al., 2020; Elliott et al., 2017). These lagoons are in three of the four coastal administrative regions of Ghana, namely the Central, Greater and Volta Regions. Although DAPSI(*W*)R(M) has definition discrepancy limitations, its adoption for this study stems from its capacity to highlight all aspects of the anthropogenic activities and their effect on both the ecosystem and society (Gari et al., 2015).

2. Materials and methods

2.1. Study area

Ghana (Fig. 1), a lower-middle-income country, located in tropical Western Africa, on the Gulf of Guinea of the Atlantic Ocean was selected for this study because it has over 90 coastal lagoons which are in four out of the 16 administrative regions, namely, the Western, Central, Greater Accra, and Volta, along the coast. The country has a coastline that stretches 550 km from Aflao in the Volta Region to New Town in the Western Region, with over 70% being sandy and the rest being rocky (Afoakwah et al., 2018). A total of eleven coastal lagoons (i.e., 5 each from the Central and Greater Accra regions, and 1 from the Volta Region of Ghana) were studied based on factors including data availability, the extent of research on them, their location, population density in their catchment area, ecological, socio-cultural, and economic importance (Fig. 1, Table 1).

2.1.1. Central Region

The ***Benya*** lagoon is in the western end of Elmina township of the Central Region, a peri-urban area where fishing and tourism are the mainstays of inhabitants. The ***Fosu*** lagoon is in the Cape Coast metropolis, the administrative capital of the Central Region. The ***Muni-Pomadze*** and ***Oyibi*** lagoons are, in and near Winneba township (a peri-urban area), respectively, and ***Narkwa*** lagoon is in ***Narkwa***, a small fishing village, about 50 km east of Cape Coast (Asare et al., 2019).

2.1.2. Greater Accra Region

The ***Korle*** lagoon is in Accra, the capital of Ghana, and serves as the principal outlet to the sea for major drains (Boadi and Kuitunen, 2002; Obodai et al., 2010). The ***Sakumo II*** lagoon lies between Accra and Tema (a port city) and downstream of residential and industrial areas (Tay et al., 2010). Also, the ***Kpeshie*** and ***Mukwe*** lagoons are in La and on the southern part of Nungua, on the outskirts of the city of Accra, respectively (Asmah et al., 2008; Attuquayefio and Gbogbo, 2001). ***Songhor*** is a low lying coastal lagoon located in the Dangme East District of the Greater Accra Region (Sackey, 2014).

2.1.3. Volta Region

The ***Keta*** lagoon is alongside the delta of the Volta River on the eastern coast of Ghana. It is the largest lagoon in the country (Addo et al., 2014; Ahmed and Isaac, 2016).

The majority of these lagoons **(**Table 1**)** are opened to the sea either naturally or by anthropogenic means. Few of them are separated from the sea by sandbars but are occasionally open (e.g., by rain, tide, etc.) to the sea during some periods of the year (Apau et al., 2012; Dankwa et al., 2016).

The studied lagoons have mean surface areas, depth, salinity, and temperatures between 0.04 and 300 km^2, 0.4 to 1.3 m, 1.1 to 43.8 PSU, and 28 to 31.4 °C, respectively (Table 1) (Asare et al., 2019; Davies-Vollum et al., 2019; Finlayson et al., 2000; Gordon, 1987; Van Stiphout, 2002) with catchment areas ranging between 22 km^2 (Kpeshie lagoon) to 2900 km^2 (Keta lagoon) (Fianko et al., 2013; Tufour, 1999).

Four (Keta, Muni-Pomadze, Songhor, and Sakumo II lagoons) out of the over 90 coastal lagoons studied have the Ramsar site's designation under the Ramsar Convention (Entsua-Mensah, 2002; Ntiamoa-Baidu and Gordon, 1991). The majority of these lagoons have direct freshwater drains from rivers, streams, and other sources (Avornyo, 2017; Boateng et al., 2012; Finlayson et al., 2000; Karikari et al., 2009). The lagoons and their fringes of wetlands are sanctuaries for local and migratory birds (e.g., black-wing stilt, spotted red shank, etc.) (Ntiamoa-Baidu and Gordon,

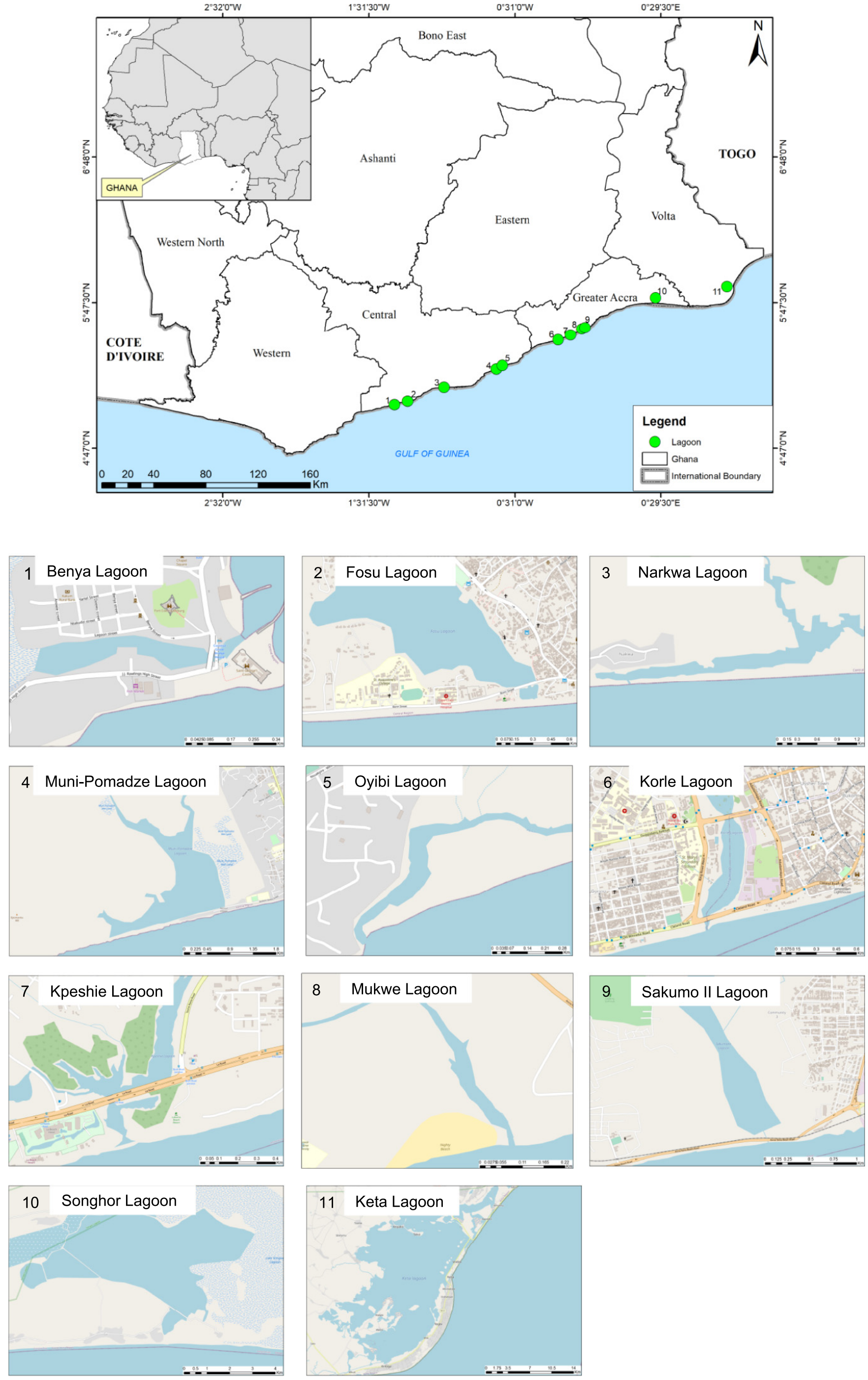


Fig. 1. Geographical distribution of the studied coastal lagoons in Ghana.

1991) and nursery grounds for fishes (e.g., Clupeidae, Carangidae, etc.) (Koranteng et al., 2000; Van Leeuwen et al., 2018).

2.2. Methodology

2.2.1. Data collection

We developed suitable keywords and search phrases based on the eleven identified coastal lagoons to serve as a guide. The predefined keywords and phrases include the *lagoon name* (e.g., *Keta lagoon), the importance of coastal lagoons, characteristic of named lagoon, anthropogenic activities within the catchment area of named lagoon, physicochemical properties of named lagoon, sources of pollution in named lagoon, state of named lagoon,* and *lagoon management systems in Ghana* (El Mahrad et al., 2020; Khamis et al., 2017; Van Cauwenberghe et al., 2015). Based on the search guides, abstract, and full-text reading, a total of 94 publications significant to the study consisting of 58 peer-reviewed papers, 11 reports (i.e., National Compendium of Environmental of Ghana, Ghana State of the Environment 2016, FAO Fisheries on Ghana, Tourism Sector Development Project, Republic of Ghana Coastal Wetlands Management Project, etc.), 13 masters and PhD thesis, and 12 other kinds of literature (i.e., a book, book chapters, conference proceedings, master plans, working paper and online news sources), spanning periods between 1982 and 2021, were retrieved. The publications were sorted according to the eleven coastal lagoons, keywords, and search phrases for easy analysis. Field observation (Plate A1 to A4) to assess anthropogenic activities was also undertaken at Sakumo II, Korle, and Kpeshie lagoons.

Table 1
Characteristics of the studied coastal lagoons.

Properties	Benya	Fosu	Narkwa	Muni-Pomadze	Oyibi	Korle	Kpeshie	Mukwe	Sakumo II	Songhor	Keta
Location	Central Region	Central Region	Central Region	Central Region	Central Region	Greater Accra	Greater Accra	Greater Accra	Greater Accra	Greater Accra	Volta Region
Mean surface area (km^2)	1.6	0.6	1.2	3	0.7	0.6	1.8	0.04	3.5	115	300
Mean depth (m)	1.3	0.6	0.6	0.6	0.5	0.5	0.4	0.7	0.6	0.4	0.8
Mean Salinity (psu)	33.7	2.1	31.5	39.3	1.1	32.4	22.7	11.6	1.9	43.8	18.2
Mean temperature (°C)	28	31.4	29.5	28	27	29.5	29	31.3	29.6	30	30.6
Freshwater inflow	Anwim River		Okyi Narkwa River	Pratu and Aboaku Rivers	Ayensu River	Odaw River and two other channels			Dzorwulu and Mamahuma	Sege River, Zano stream	Todzie and Volta Rivers, Aka, and Belikpa Streams
Ramsar				x					x	x	x
Status of lagoon inlet	Permanently opened to the sea	Separated from the sea by sandbar but occasionally breached	Opened to the sea most of the year	Separated from the sea by sand dune, opens when the water level becomes high	Permanently opened to the sea	Permanently opened to the sea by a culvert	Separated from the sea by sandbar but intermittently spills into the sea at high water levels	Closed but opened to sea during the rainy season	Permanently open to the sea by culverts	Separated from the sea by a sandbar	Considered open but mostly closed throughout the year

x – documented.

2.2.2. Data analysis

Relevant information in the publications gathered was collated, analyzed, and tabulated into *Drivers* **(D)**, *Activities* **(A)**, *Pressure* **(P)**, *State* **(S)** changes, *Impact* **(I)** *on Welfare* **(W),** and *Response* **(R)** *as a Measure* **(M)** (DAPSI(*W*)R(M)) to explain the issues and problems relating to the use and management of coastal lagoons (Elliott et al., 2017; Fiandra, 2019). The DAPSI(*W*)R(M) is a socio-ecological framework that evolved from Drivers-Pressure-State-Impact Responses (DPSIR), which was an initiative of Rapport and Friend (1979). The DAPSI(*W*)R(M) provides a more accurate and comprehensive indication (Patrício et al., 2016) as follows:

Drivers (D) are the biological, physiological, psychological, and self-fulfilment needs that an individual within a lagoon's catchment area requires for their survival. For example, food, security, friendship, status, respect from others, realizing personal potential, etc.

Activities (A) include the actions of an individual due to the desire to meet their drivers. For example, fishing, mining, farming, etc.

Plate A1 to A4. Human activities in the catchment area of Sakumo II, Korle and Kpeshie lagoons.

Pressure (P) refers to the direct, measurable effect and reflects the mechanism of change in the ecosystem due to the activities. E.g., removal of targeted and non-targeted species, the input of nutrients and organic matter, etc.

State changes (S) refer to the changes in the natural environment system of the lagoon due to pressures. For example, changes in biodiversity, food web dynamics, physicochemical properties, etc.

Impact on welfare (I(W)) relates to the consequences of the state change on ecosystem services provided by a coastal lagoon, especially for societal good concerning the myriads of ecosystem benefits. For example, food, health benefits, educational and research benefits, spiritual and cultural benefits, etc.

Response as a measure (R(M)) relates to minimizing or mitigating intervention in response to changes in the studied lagoon resulting from Drivers, Activities, and Pressures. For instance, the response must be ecologically or biologically sustainable, socially, and legally permissible, culturally inclusive, among others.

The activities and their effects were illustrated with symbols for diagrams, courtesy of the Integration and Application Network (ian.umces.edu/ symbols) (Fig. 2). A conceptual diagram was used to illustrate the linkages that exist between the drivers, activities, pressures, state, impact, and responses in the lagoon ecosystem (Fig. 3).

3. Results and discussion

3.1. Drivers

The drivers (Fig. 3) include the desire of the individual who lives within the catchment area of a lagoon to meet their basic biological and physiological requirements (food and shelter) to ensure survival. The lagoons provide fish (a cheap source of protein), salt (an essential component of food preparation and preservation for many Ghanaians), vegetables and crops, land and thatch for making shelter (Third World Network-Africa, 2017; Tufour, 1999; Vowotor et al., 2019).

The need for self-actualization through financial self-reliance and personal growth is an essential driver in a country where about 23% of the population (Ghana Statistical Service, 2018) live below the poverty line, the majority being rural dwellers. For instance, coastal lagoons enable fishers, salt miners, basket weavers, nets, and landowners to attain wealth for the purchase of properties.

The wealth generated through the exploitation of natural resources from lagoons can change the societal status and dominance of an individual with the potential of improving their capacity to influence decision making in families and community gatherings.

There are similarities in human behavior irrespective of their location and the essence of their effect on lagoon ecosystems. For instance, the majority of the drivers, including "*basic biological and physiological, and self-actualization needs*" identified in this study, were similar to findings made by Fiandra (2019) and El Mahrad et al. (2020) as essential drivers of anthropogenic activities in the Venice and North African lagoons, respectively.

3.2. Activities

The anthropogenic activities (Fig. 3) in coastal lagoons include the fishing of *Sarotherodon melanotheron*, *Tilapia guineensis*, *Callinectes spp,* etc. with dragnet, traps, mosquito net, monofilament gillnet, and cast net with mesh-size below the recommended 25 mm diagonal stretch mesh (Addo et al., 2014; Dankwa et al., 2016; Kraan, 2009; Owusu et al., 2014). The fishing activity also involves the use of bottles, chemicals, handpicking, and 'Acadja' (a fish aggregation device) (Table 2, Fig. 2) (Entsua-Mensah, 2002; Gbogbo et al., 2008; Lamptey and Ofori-Danson, 2014).

The hunting (e.g., Muni-Pomadze and Keta lagoon) for waterbirds and other animals in the forest cover of mangroves, and the harvesting of mangroves and reeds (e.g., Keta, Songhor, Fosu, Muni, Narkwa, Oyibi, and Mukwe lagoons) for fuelwood, fishing, fish smoking, the distilling of local

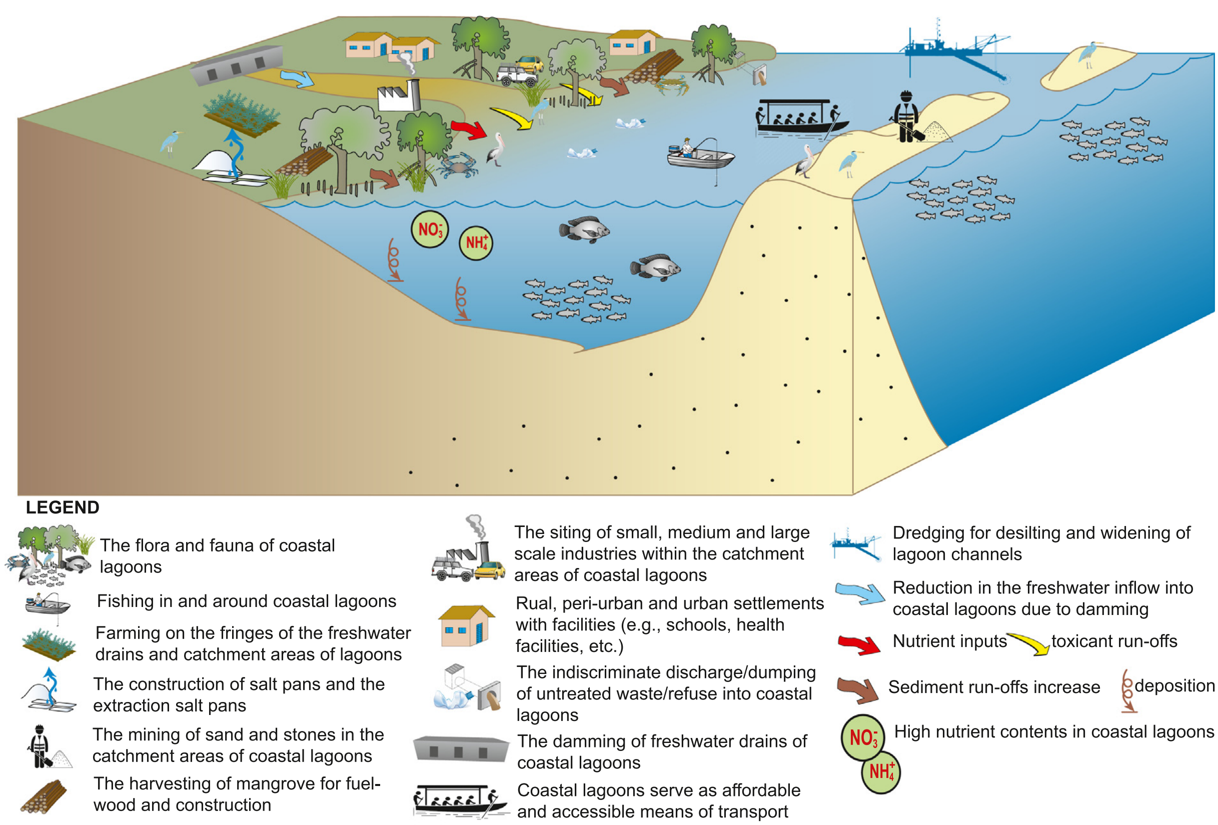


Fig. 2. Conceptual framework of human activities and their effect on studied coastal lagoons in Ghana.

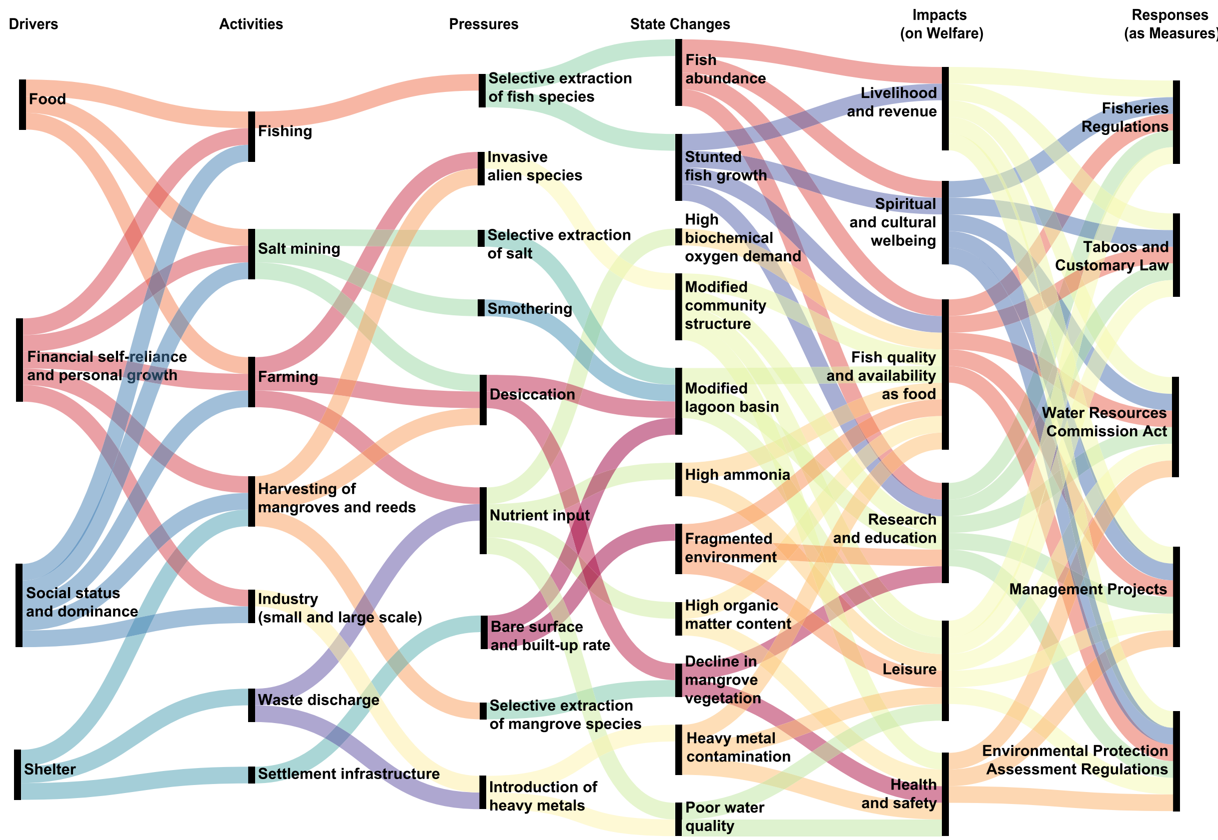


Fig. 3. The link between DAPSI(*W*)R(M) elements.

gin, basket weaving, construction of homes, bark for tanning of fishing nets and treatment of diseases, and to make way for saltpan construction are rife (Table 2, Fig. 2) (Atta-Quayson, 2018; Attuquayefio and Ryan, 2006; Badu, 2012; Brinks, 2017; Entsua-Mensah, 2002; Finlayson et al., 2000; Gordon, 2012; Tufour, 1999).

Farming of vegetables (e.g., shallots, pepper, and okra), crops, and animals along fringes and the freshwater drains of the Keta, Fosu, Songhor, Muni-Pomadze, Benya, Mukwe, Fosu, Sakumo II, Kpeshie and Oyibi lagoons are common phenomena as the lagoons provide the readily available fertile soil and water (Table 2, Fig. 2) (Kondra, 2018; Ntiamoa-Baidu and Gordon, 1991; Porter et al., 1997; Sackey, 2014).

Salt mining, either artisanal or large scale with solar drying techniques, directly and or conversion of land within the wetlands into saltpans are rife (Table 2, Fig. 2) (Affum et al., 2016; Finlayson et al., 2000; Ghana Statistical Service, 2014). The mining of sand and stone on a small-scale level for moulding of blocks and construction is also present (e.g., Muni-Pomadze, Sakumo II, Oyibi, and Kpeshie lagoons) (Ametefe, 2016; Fianko et al., 2013; Kraan, 2009; Nixon et al., 2007; Van Stiphout, 2002).

The accessibility and affordability of coastal lagoons for transportation, coupled with the inadequate motorable roads, the Songhor, Benya, and Keta lagoons, for instance, serve as means of transport of people and goods between communities (Kraan, 2009; Lamptey and Ofori-Danson, 2014; Ntiamoa-Baidu and Gordon, 1991). Although it has been reported by some authors, the number of daily traffic on the lagoons has not been documented.

There are also small and large scale industries (e.g., palm kernel industry, automobile garages, batik on the fringes of Benya, Fosu, and Kpeshie lagoons, electronic scrap processing on the fringes of Korle lagoon (Plate A1))

Table 2
Human activities in situ and within the catchment area of the studied coastal lagoons.

Anthropogenic activities	Benya	Fosu	Narkwa	Muni-Pomadze	Oyibi	Korle	Kpeshie	Mukwe	Sakumo II	Songhor	Keta
Fishing (finfish and shellfish)	x	x	x	x	x	x	x	x	x	x	x
Hunting				x			x				x
Mangrove and reed harvesting	x	x	x	x	x			x	x	x	x
Farming (crops/ animal)	x	x	x	x	x			x	x	x	x
Salt mining	x		x	x	x		x	x	x	x	x
Sand and stone mining		x		x	x		x				
Transportation	x							x	x	x	x
Industry (small and large scale)	x	x		x		x	x	x	x		
Settlement (homes, hospitals, schools, etc.)	x	x	x	x	x	x	x		x	x	x
Domestic waste discharge	x	x	x	x	x	x	x	x	x	x	x
Industrial waste discharge	x	x				x	x		x		
Damming of drains									x	x	x
Construction (harbor/bridges/roads, etc.)	x	x				x	x		x		
Dredging	x					x					x
Tourism/recreation	x	x		x					x		x

x - present; List of activities adapted from Smith et al. (2016).

(Abalansa et al., 2021; Adjei et al., 2017; Agbemehia, 2014), settlement (e.g., Anloga and Woe towns (Keta lagoon); Old Fadama; Sakumono Estate and Village (Sakumo II lagoon); Akosua Village (Muni-Pomadze lagoon)), waste discharge of both industrial and domestic wastes (e.g., medical, breweries, schools, settlement waste (Plate A2), etc.) (Ahmed and Isaac, 2016; Biney, 1982; Boadi and Kuitunen, 2002; Nortsu, 2018).

Damming of freshwater drains for electricity, domestic, and agriculture purposes. For instance, the damming of the Volta River at Akosombo and Kpong, and Dzorwulu and Mamahuma streams that feed the Keta and Sakumo II lagoons, respectively (Ametefe, 2016; Kondra, 2018; Tufour, 1999; Van Leeuwen et al., 2018). There is also the construction of fishing harbors, roads, railway (e.g., Sakumo II lagoon) (Plate A3) and bridges (Plate A4) over coastal lagoons and dredging (e.g., Benya, Narkwa, and Korle lagoons) for the widening of channels for commerce and ease of movement (Baffour-Awuah, 2014; Bentum et al., 2011; Sackey, 2014). Activities including ecotourism (e.g., birdwatching) and recreation are also rife in coastal lagoons (Kraan, 2009; Ntiamoa-Baidu and Gordon, 1991).

Similar studies in Europe, Asia, and North Africa, also identified mostly the same types of human activities associated with coastal lagoons (Dolbeth et al., 2016; El Mahrad et al., 2020; Fiandra, 2019; Khamis et al., 2017; Lin et al., 2007; Newton et al., 2014; Scheren et al., 2004). However, concerning fishing activities, the types of fishing gears (e.g., trammel nets, fyke nets, etc.) used differed in the lagoons studied in Ghana (El Mahrad et al., 2020; Fiandra, 2019).

3.3. Pressures

Each human activity in the studied coastal lagoons generates either single or multiple pressures (Fig. 3, Table 3), which can affect several environmental characteristics. The pressure from fishing involves an almost year-round (Nunoo et al., 2014) selective extraction of *S. melanotheron, T. guineensis, Mugil cephalus, Callinectes amnicola, Penaeus notialis, Crasostrea tulipa, Tympanotonus fuscatus,* etc. For instance, the exploitation rate of *Sarotherodon melanotheron* in Muni, Sakumo II, Songhor and Keta Lagoon is 0.55 to 0.66, 0.61, 0.59 and 0.56, respectively (Entsua-Mensah et al., 2000; Koranteng et al., 2000). This is higher than the optimal exploitation rate of 0.5 (Gulland, 1971). Data on the exploitation rate of the other species in the coastal lagoons is not easy to find. Similarly, there is also pressure from the selective harvesting of targeted (e.g., *Typha domingensis*, mangrove species (an essential substrate for *Crassostrea tulipa*) such as *Rhizophora mangle, Avicennia germinans*) and non-targeted (e.g., *Sesuvium portulacastrum*) plant species for fuelwood, shelter, etc. (Cohen et al., 2020; Environmental Protection Agency of Ghana, 2020; UN, 2019).

There is pressure from the selective extraction of non-living resources such as salt, sand, and stones due to salt, sand, and stone mining activities. For instance, the extraction of salt at a rate of 750 kg bag $person^{-1}$ day^{-1} in the Songhor lagoon and 1600 ton yr^{-1} ha^{-1} in coastal lagoons through direct harvest or pumping into saltpans (e.g., Ada, Benya) or diversion of lagoon water (e.g., Songhor) (Affam and Asamoah, 2011; Atta-Quayson, 2018; Ntiamoa-Baidu and Gordon, 1991; Vowotor et al., 2019). Additionally, the mining of sand and stones along the borders of Oyibi and Muni-Pomadze lagoons by individuals or small-scale operators for construction purposes (e.g., moulding of blocks). The rate of sand and stone mining is unknown due to their small-scale and illegal nature.

The introduction of heavy metals (arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), zinc (Zn)), hydrocarbons, pesticides, pathogens, plastic, and organic materials due to discharge from domestic and industrial activities (small and large scale), transportation, agriculture and settlements (approximately between 83 and 3300 individual km^{-2}) constitutes pressure to the lagoon ecosystem (Adjei et al., 2017; Ametefe, 2016; Bentum et al., 2011; Nixon et al., 2007; Van Stiphout, 2002; Vowotor et al., 2012). For instance, the introduction of manganese (Mn) and copper (Cu) of 22.54 mg/day and 59.22 mg/day into *S. Melanotheron,* respectively. The organic matter input at rates of 11 tons day^{-1} and 121 tons yr^{-1} into Korle lagoon and Sakumo II lagoon, respectively (Nixon et al., 2007; Van Stiphout, 2002). The Korle lagoon also receives about 60% of Accra's waste (Nixon et al., 2007; Van Stiphout, 2002).

There is pressure from sediment runoff due to the destruction of vegetation, industrialization, and settlement. For instance, sediment runoff of about 8000 tons yr^{-1} into the Sakumo II lagoon, and sedimentation at 1.3 mm yr^{-1} in the Keta lagoon (Van Stiphout, 2002). Nutrient input, including nitrogen (76.2 to 361.7 kg day^{-1}) and phosphorous (19.1 to 90.4 kg day^{-1}), nitrogen-enriched fertilizers (e.g., about 50 kg bags of NPK fertilizer per 11 m^2 of farmland), manure (e.g., cattle dung, bat and fowl droppings, etc.) from runoff of nearby farms and settlements also represents pressure to the ecosystem (Ansa-Asare et al., 2008; Finlayson et al., 2000; Porter et al., 1997). Scheren et al. (2004) and Hernández-López et al. (2020) also reported pressure from nutrient input into the Ebrié lagoon in Cote d'Ivoire and the Juluapan lagoon in Mexico, respectively, due to similar human activities.

Smothering pressure from the construction of harbors (e.g., the Elmina fishing harbor in the Benya lagoon), homes (e.g., Sakumono estates and village, Old Fadama, etc.), educational institutions (e.g., Zenith College), leisure centers (e.g., La Palm Hotel), roads, bridges, railway tracks, and culverts within the catchment areas of lagoons (Fianko et al., 2013; Van Leeuwen et al., 2018; Wiegleb, 2016).

The conversion of the wetlands and vegetation cover into settlements, farmlands, saltpans, etc., contributes to the built-up pressure on the lagoon ecosystem (Atampugre, 2010; Duku et al., 2021; Ekumah et al., 2020).

There are loss of substratum and abrasion pressures on epi-benthic substrates, fauna, and flora due to the use of dragnet, trampling, land clearance, and construction activities in these shallow ecosystems (Asmah et al., 2008; Lamptey and Ofori-Danson, 2014; Nixon et al., 2007).

Desiccation pressure exacerbates through the destruction of vegetation for farming, construction, settlements, pollution (e.g., Kpeshie lagoon), and saltpan construction (e.g., Songhor lagoon, Muni-Pomadze lagoon) (Apau et al., 2012; Attuquayefio and Gbogbo, 2001; Dankwa et al., 2016; Ekumah et al., 2020; Finlayson et al., 2000). For instance, Sakumo II and Muni lagoons, losing water areas of 0.21 km^2 yr^{-1} and 0.03 km^2 yr^{-1}, respectively (Environmental Protection Agency of Ghana, 2020).

The harvesting of endemic flora and fauna, farming activities, and waste discharge have contributed to the pressure of invasion by non-native

Table 3
Pressures from activities in the studied coastal lagoons.

Pressures	Benya	Fosu	Narkwa	Muni-Pomadze	Oyibi	Korle	Kpeshie	Mukwe	Sakumo II	Songhor	Keta
Selective extraction of living resource (species)	x	x	x	x	x		x	x	x	x	x
Selective extraction of non-living resource	x		x	x	x		x	x	x	x	x
Introduction of heavy metals and hydrocarbons	x	x				x	x				
Plastics	x	x				x	x		x		
Bare surface and built-up rate		x		x		x			x	x	x
Sedimentation		x				x	x		x		x
Nutrient and organic matter input	x	x	x	x	x	x			x	x	x
Smothering	x	x				x	x		x	x	
Desiccation and water body reduction		x		x					x	x	
Introduction of non-native species		x				x		x	x		

x – documented List of pressures from activities adopted from El Mahrad et al. (2020) and Elliott et al. (2017).

species. For instance, the invasion of herbaceous vegetation, grass, acacia, and weeds in the Fosu lagoon, water hyacinth in the Korle lagoon, strong reed and Pistia (Ekumah et al., 2020) in the Sakumo II lagoon from the native water lettuce, and *Pistia stratiotes* and *Typha domingensis* into the Mukwe lagoon (Attuquayefio and Gbogbo, 2001; Boadi and Kuitunen, 2002; Dankwa et al., 2016; Essel et al., 2019; Van Leeuwen et al., 2018).

There is pressure from climate change (i.e., rainfall has become erratic) and increasing temperature with an average of 0.21 °C per decade exacerbated by the continual destruction of mangroves and other vegetations in studied coastal lagoons (Porter et al., 1997; USAID, 2017). Climate change predictions project adverse effects (e.g., flooding, etc.) on coastal lagoons in Ghana (Environmental Protection Agency of Ghana, 2017).

The pressure of selective extraction of fish and plant species, the introduction of invasive species, exacerbation of heavy metals, nitrogen, organic matter, and pesticide inputs in lagoons due to human activities are similar to those identified in some lagoons in Europe and North Africa (Dolbeth et al., 2016; El Mahrad et al., 2020; Fiandra, 2019; Newton et al., 2014).

3.4. State changes

Single or multiple pressure from human activities can affect the state changes (Fig. 3) in the abiotic and biotic factors of an environment and reduce their suitability for individuals or several species (Smith et al., 2016). Because lagoon conditions shape the population of resident species, regular migrants and occasional colonizers (Pérez-Ruzafa et al., 2019).

3.4.1. Fauna, flora, and species growth

The biodiversity of a coastal lagoon is essential to the survival of humans on earth (Anthony et al., 2009; De Wit, 2011). Hence, their utilization must be at a level that ensures the sustainability of the resource. However, this is not the situation for the studied coastal lagoons.

In years past, the Korle lagoon (Table 4) had a vibrant fishery and biodiversity but due to excessive fishing pressure and pollutions, this lagoon has lost almost all its fish species (Nixon et al., 2007). Similarly, the Fosu lagoon has lost fish species such as *Porogobius schlegellii, Elops lacerta, Lutjanus goreensis,* rock sole, shrimps, grey mullet, and crabs due to excessive fishing pressure and pollution (Dankwa et al., 2016). The *Sardinella maderensis, Liza* spp. *and Illisha Africana in* Keta lagoon, and *M. cephalus* and *C. amnicola* in Mukwe lagoon have also become rare due to excessive fishing (Attuquayefio and Gbogbo, 2001; Lamptey and Ofori-Danson, 2014). The distribution of *Tympanotonus fuscatus* has become sparse in Muni and Sakumo II lagoons due to overexploitation (Kraan, 2009). The *S. melanotheron* in all the lagoons is maturing at a small size (stunted growth) due to intense fishing pressure and pollution (Blay and Asabere-Ameyaw, 1993; Dankwa et al., 2016; Entsua-Mensah, 1998). The mean width of the carapace of *C. amnicola* in the Sakumo II lagoon, for instance, has become shorter (5.8 cm) than the maximum adult carapace width of 30 cm due to pressure from fishing (Babatunde, 2008; Gbogbo et al., 2008).

Crocodylus niloticus, which used to inhabit the Mukwe lagoon, has been lost due to hunting activities and continuous pollution (Attuquayefio and Gbogbo, 2001). The population of important international bird species, including Blacktail Godwit, Waders, and Avocet, has reduced by their thousands to under a hundred individuals (Environmental Protection Agency of Ghana, 2017). Only one out of six bird species remains at the Sakumo II lagoon, while Korle, Muni-Pomadze, and Benya lagoons have lost all their internationally important waders (Environmental Protection Agency of Ghana, 2017).

About 24% (44 km^2) of mangrove vegetations along the 550 km coastline have been degraded at a rate of 0.003 and 0.3 $km^2\ yr^{-1}$ contributing to an increase in atmospheric carbon dioxide levels (Armah et al., 2009; Environmental Protection Agency of Ghana, 2017, 2020; UN, 2019). For instance, about 85% (0.2 km^2) of the mangrove forest cover of the Fosu lagoon is degraded, with one-third of the lagoon taken over by aquatic weeds (Bentum et al., 2011; Essel et al., 2019; Owusu et al., 2014). Songhor and Muni-Pomadze lagoons have lost approximately 1.67 km^2 and 7.97 km^2 of their healthy vegetation due to increasing harvesting, respectively (Adda, 2016; Environmental Protection Agency of Ghana, 2020; Essel et al., 2019; Kraan, 2009). Their natural habitats have become fragmented due to the increasing built-up rate (Ametefe, 2016; Ekumah et al., 2020).

Similarly, the mangrove forests in Songhor and Keta lagoons have become patchy (Environmental Protection Agency of Ghana, 2017). Mangroves in Sakumo II, Benya, and Korle lagoon have also been heavily degraded, Songhor, Kpeshie and Narkwa being moderately degraded (Boadi and Kuitunen, 2002; Entsua-Mensah, 2002). The *Avecenia* sp. and *Rhizophora* sp. population has declined rapidly, with *Laguncularia* sp. being the most threatened mangrove species (Environmental Protection Agency of Ghana, 2017).

Other aquatic weeds (e.g., water hyacinth), plastics, and metals have taken over the degraded portions that once were covered by mangroves and native aquatic plants (Armah et al., 2009; Bentum et al., 2011; Boadi and Kuitunen, 2002; Mensah and Enu-Kwesi, 2019). The Venice lagoon and some lagoons in Europe for instance have also seen a decline in species diversity, and alien species invasion due to the exogenic pressure (Fiandra, 2019; Newton et al., 2014).

3.4.2. Dissolved oxygen (DO)

The dissolved oxygen content of the Benya, Mukwe, Sakumo II, and Korle lagoons (Table 4) is below 2 mg/l due to the anthropogenic activities within their catchment areas, hence they are classified as being oxygen stressed, and this has an adverse impact on the survival of aquatic organisms (Armah et al., 2012; Avornyo, 2017; Van Leeuwen et al., 2018). Although the level of dissolved oxygen in Keta, Muni-Pomadze, Narkwa, Oyibi, Fosu, and Kpeshie lagoons are within favorable limits, they were generally low except for the Fosu lagoon, which was very high (Armah et al., 2012; Avornyo, 2017; FAO, 1986; Fosu-Amankwah, 2012). This is due to the discharge of domestic and industrial wastes and runoff from agriculture (Armah et al., 2012; Avornyo, 2017; Fosu-Amankwah, 2012). A similar study by Hernández-López et al. (2020) also observed that pressure from human activities within the Juluapan lagoon's (Mexico) catchment area contributed to low DO in the lagoon.

3.4.3. Biochemical oxygen demand (BOD)

The biochemical oxygen demands (BODs) of the Benya, Songhor, Sakumo II, and Kpeshie lagoons have become high (>3 mg/l), with that of Fosu and Korle lagoons being very high (an indication for DO utilization by microbes) due to the pollution from discharge of effluent and runoff from agriculture activities (Amuzu, 1997; Avornyo, 2017; Badu, 2012; Biney, 1982). Newton et al. (2014) also identified increased BOD levels due to pressure associated with human activities in some lagoons in Europe. Although the BODs of Keta, Muni-Pomadze, Oyibi, and Mukwe lagoons are low, there is evidence of anthropogenic impact (Amuzu, 1997; Avornyo, 2017; Badu, 2012; Biney, 1982).

3.4.4. Organic matter and nutrients

The majority of the lagoons (Table 4), including Fosu, Muni-Pomadze, Benya, Mukwe, Sakumo II, and Kpeshie lagoons, have attained high organic content, with Korle lagoon being very high due to the discharge of domestic waste, industrial waste (e.g., breweries) and farming activities on their fringes and freshwater drains (Apau et al., 2012; Armah et al., 2012; Avornyo, 2017; Fianko et al., 2013; Nixon et al., 2007).

Ammonia levels in the majority of the lagoons are above the natural level limit of 0.2 mg/l (World Health Organization, 2011) for surface water system due to domestic and industrial discharge (Amuzu, 1997; Ansa-Asare et al., 2008; Avornyo, 2017; Eshun, 2011; Van Leeuwen et al., 2018). Similarly, due to domestic and industrial discharge, the Fosu lagoon has nitrate levels higher than WHO's guidelines of 50 mg/l (Eshun, 2011; World Health Organization, 2011)

3.4.5. Heavy metal

The heavy metal concentrations in studied coastal lagoon waters are above the standards required to support aquatic organisms proposed by the United States Environmental Protection Agency (US EPA) for saline

Table 4
State of studied coastal lagoons in Ghana.

State Changes	Benya	Fosu	Narkwa	Muni-Pomadze	Oyibi	Korle	Kpeshie	Mukwe	Sakumo II	Songhor	Keta
Dissolved oxygen	Stressed (1.24 mg/l)	Favorable and high	Favorable (7.3 mg/l)	Favorable but low (5.7 mg/l)	Favorable but low (4.8 mg/l)	Stressed (0–1.7 mg/l)	Favorable (4.6 mg/l)	Stressed (1.2 mg/l)	Stressed (0.4 mg/l)	Favorable but low (3.8 mg/l)	Favorable but low (5.8 mg/l)
Biochemical oxygen demand	High	Very high		Low	Low	Very High	High	Low	High	High	Low
Organic matter content	High	High		High		Very high	High	High	High		
Nutrient	High ammonia	High ammonia and nitrate	High ammonia	High ammonia	High ammonia	Extremely high ammonia,	High ammonia	Very high ammonia	Very high ammonia,	within normal range	High ammonia
Heavy metal content *Water*	High Cd, Pb and Hg	High Cu, Cd, Pb, Hg and Ni	High Cd, Pb and Hg				High Cd, Pb, Zn and Ni		High Pb, Cu, Zn and Ni	High Cd, Pb and Ni	
Sediment		High Cu and Cd	High Cd and Hg	High Cd and Cu			High Cd, Pb and Cr	High Cr	High Cd and Pb	High Cd, Pb and Ni	
Fish		*S. melanotheron* polluted with Cd, As, Zn, Mn, and Cu	*S. melanotheron and C. tulipa* polluted with Cd, Pb, As, Hg			*T. ovatus* polluted with As and Hg *T. ovatus, M. cephalus, M. curema* polluted with Pb and Co	Polluted with Al, Mg, Mn, V, (*S. melanotheron)*		*S. melanotheron* polluted with Cd	Fish tissue polluted with Pb	
Area and depth		Area reduced by 0.2 to 0.4 km^2 and depth by 0.9 m		Area reduced by 0.4 km^2		Area reduced by 2.1 km^2; depth reduced	Reduce		Area reduced; 3.13 km^2 depth reduced by 0.5 m	The natural shape of basin has been modified	
Flora and fauna community structure/	The mangrove habitat is degraded	Mangrove declined by 85% (0.2 km^2); *E. lacerta*, flounders, *Lutjanus goreensis*, grey mullet, shrimp, and crab loss; Disappearance of *H. picarti*	The mangrove habitat is moderately degraded; *Typha domingensis* becoming dominant species	Fragmentation of habitats; Mangrove and other vegetation habitat degraded by 2.7 km^2; shellfish species reduced *T. fuscatus* is sparsely distributed		Mangrove habitat in degraded; Near extinction of resident and visiting organisms (e.g., hawks)	Mangrove habitat moderately degraded	*M. cephalus* and *C. amnicola* scarce; Extinction of *Crocodylus niloticus*	Increased fragmentation of habitats; Mangrove habitat in degraded; Pelicans moved away Low abundance of *T. fuscatus*	Mangrove habitat in moderately degraded	Changed, *T. guineensis*, *S. melanotheron, Porogobius schlegeli*, *Callinectes amnicola, Mugil spp*, *Ethmalosa spp* have become rare*;* Loss of fish some species
Species growth		*S. melanotheron* is stunted and mature at small size						*S. melanotheron* is stunted and mature at small size	*S. melanotheron* is stunted and mature at small size The small size of crabs (*C. amnicola*)		*S. melanotheron* is stunted and mature at small size
Pathogens/ Water quality (WQ)	High fecal coliforms	High fecal coliforms (*Escherichia coli*) and *Vibrio spp* in fish	Doubtful quality	High microbial activity		Very high fecal coliforms	High fecal coliforms	Poor	High microbe, fecal coliforms, very poor water quality		Poor and unsuitable for drinking

systems due to waste disposal, settlements, transportation, and construction activities within their catchment areas (Table 4) (US EPA, 2019). For instance, the copper (Cu), cadmium (Cd), lead (Pb), mercury (Hg), and nickel concentrations in the Fosu lagoon are above the recommended values of 0.005, 0.033, 0.1, 0.0008, and 0.07 mg/l (Adokoh et al., 2011; Eshun, 2011; Fosu-Amankwah, 2012; US EPA, 2019). Similarly, the cadmium and copper levels in Muni-Pomadze lagoon (Tay et al., 2010), the cadmium, lead and mercury in Benya and Narkwa lagoons (Adokoh et al., 2011; Ansa-Asare et al., 2008; Obodai et al., 2011), the cadmium, lead and nickel in Songhor lagoon (Finlayson et al., 2000; Sackey, 2014), and the lead, copper, zinc (Zn) and nickel in Sakumo II and Kpeshie lagoons are high (Amuzu, 1997; Avornyo, 2017; Doamekpor et al., 2018; Tay et al., 2010).

The sediments of the studied coastal lagoons have also acquired high heavy metal concentrations above US EPA benchmarks due to human activities. For instance, Fosu and Muni-Pomadze lagoons have high copper and cadmium, and cadmium and mercury sediment concentrations, respectively (Table 2) (Adjei et al., 2017; Eshun, 2011; Obodai et al., 2011). Mukwe, Sakumo II, and Kpeshie lagoons have high chromium (Cr), cadmium, and lead, and cadmium, lead, and chromium sediments concentrations, respectively (Addo et al., 2012; Doamekpor et al., 2018).

Additionally, the levels of cadmium, lead, copper, arsenic, mercury, and zinc are above FAO, WHO, and other international guidelines for fish (finfish and shellfish) of 2, 0.3, 0.05, 1.4, 0.5, and 30 mg/kg, respectively, in some of the lagoons have been reported due to the continuous pollution from industrial and domestic wastes (FAO and WHO, 2015; Steinhausen et al., 2021). For instance, *S. melanotheron, C. tulipa,* and *C. amnicola* in Fosu, Benya, Narkwa, and Kpeshie lagoons have high zinc, copper, arsenic, lead, mercury, and manganese (Mn) beyond the international guidelines (Akoto et al., 2014; Clottey, 2018; Doyi et al., 2012; Eshun, 2011; Fosu-Amankwah, 2012; Obodai et al., 2011). Fish from the Songhor and Korle lagoons have lead levels higher than the recommended value of 0.05 mg/kg (Klubi et al., 2021; Steinhausen et al., 2021). The *Trachinotus ovatus, M. cephalus,* and *M. curema* in the Korle lagoon have high Cobalt (Co) concentrations in their tissues due to industrial and e-waste activities (Steinhausen et al., 2021). Due to indiscriminate waste disposal, salts from the Benya lagoon have been polluted with aluminum (Al), magnesium (Mg), and manganese (Vowotor et al., 2019).

3.4.6. Water quality and pathogen

Pollutants including sewage and nutrient runoff degrade water quality and impair coastal ecosystems (UN, 2019). The Benya, Fosu, and Korle lagoons are classified as the most polluted lagoons in Ghana due to human activities which is reflected in their current physicochemical state (Adinortey, 2014; Mitchell et al., 2017). Sakumo II, Fosu, Korle, Kpeshie, and Benya lagoons are high in fecal coliform (227–4650 CFU/100 ml) concentrations due to the continuous disposal of untreated sewage (Adinortey, 2014; Karikari et al., 2009; Mitchell et al., 2017; Owusu et al., 2014).

3.4.7. Area, depth, and water inflow

The depth, areas, and freshwater inflow into some of the lagoons have reduced (Fig. 3, Table 4). For instance, the sizes of the Sakumo II, Korle, Muni, and Fosu lagoons have reduced by 3.1 km^2, 2.1 km^2, 0.4 km^2, and 0.2 to 0.4 km^2, respectively due to siltation, high decomposition of organic materials settlement, damming, and pollution (Akpabey and Amole, 2015; Essel et al., 2019; Gordon, 1987; Porter et al., 1997). Similarly, pressures from anthropogenic activities in the Yuandang lagoon in China (Lin et al., 2007) and the Venice lagoon in Italy (Fiandra, 2019), have contributed to a reduction in their surface areas. The depths of Sakumo II and Fosu lagoons have also reduced by 0.5 m (from 1.5 m to 1 m) and 0.9 m, respectively due to changes in the water in-flow (Asmah et al., 2008; Nixon et al., 2007). The natural shape of the Songhor lagoon basin has been modified due to salt production (Finlayson et al., 2000).

The construction of the Akosombo and the Kpong dams on the Volta River for hydropower, water supply, and irrigation has reduced the freshwater inflow to the Keta (by 60 m^3/s) and Songhor lagoons, contributing to their siltation. Other dams on the Dzorwulu and Mamahuma streams for irrigation have reduced the water inflow into the Sakumo II lagoon and contributed to its siltation (Kondra, 2018; Lamptey and Ofori-Danson, 2014; Tufour, 1999; Van Leeuwen et al., 2018). The freshwater inflow to the Mukwe lagoon has reduced considerably due to the introduction of aquatic weed at the inlet of the lagoon's freshwater drain (Attuquayefio and Gbogbo, 2001). These have affected the seasonal pattern of the water ecosystem which serves as a cue for species that depend on changes in the inflows and inundation for food, migration and breeding (Kondra, 2018; Lamptey and Ofori-Danson, 2014; Tufour, 1999; Van Leeuwen et al., 2018).

3.5. Impact (on welfare)

The ecosystem services, including provision services (e.g., food), regulating services (the control of diseases and natural disasters), and cultural services (e.g., aesthetics, spiritual, educational, and recreational) provided by the coastal lagoons for the well-being of humans have been affected (Table 5) (Millennium Ecosystem Assessment, 2005).

3.5.1. Food availability

The availability of fish, an important protein source in Ghana, for food has been affected as the current quantity and sizes of fish from coastal lagoons have reduced as a result of the pressure and state of the natural environment influenced by human activities (Agbekpornu et al., 2016; Gbogbo et al., 2008; Lamptey and Ofori-Danson, 2014). The situation has implications for the global effort of reducing undernourishment especially, in sub-Saharan Africa (UN, 2019).

3.5.2. Health and safety

For a healthy life, the concentration of heavy metals must be low in foods. However, heavy metals that pollute *C. tulipa* from Narkwa lagoon magnify with cooking (Obodai et al., 2011). For instance, cadmium magnifies from 1.1 to 1.6 mg/kg, arsenic from 0.3 to 3.2 mg/kg, and mercury from 0.3 to 0.4 mg/kg. Consumption of fish species, including *S. melanotheron,* from the majority of the studied lagoons, poses a sublethal effect due to the enrichment of heavy metals in their tissues.

Residents within the catchment areas of lagoons such as Korle, Sakumo II, and Keta have been experiencing severe flooding during the rainy season because the lagoons have become shallow due to siltation and pollution, defeating the strategy of disaster risk reduction in line with the Sandai Framework (Boadi and Kuitunen, 2002; UN, 2019; Van Leeuwen et al., 2018). The unsanitary conditions, the invasive vegetations in the studied coastal lagoons and their freshwater inlets resulting from anthropogenic activities have created habitats for disease-carrying vectors including, *Biophalaria* sp., *Bulinus* sp., houseflies, and mosquitos, leading to the outbreak of diseases such as urinary schistosomiasis, malaria, cholera, etc., among residents, in communities such as Old Fadama (Greater Accra), Keta (Volta Region), and Elmina (Central Region) (Ahmed and Isaac, 2016; Akpabey and Amole, 2015). The high coliforms in almost all the studied lagoons make their water unsafe for drinking because they are not within WHO standards (World Health Organization, 2011).

Table 5
Impact of state change on ecosystem service.

Ecosystem services	Well-being impacted
Provisioning - Food	Food availability Health and safety
Regulating - Flood, disease, and erosion regulation	Health and safety
Cultural - Aesthetics, spiritual, educational, and recreational	Leisure Livelihood and revenue Education and research Spiritual and cultural wellbeing

The risk to human safety due to the discovery of a high concentration of heavy metal in fish, and flooding have also been identified in North African lagoons (El Mahrad et al., 2020).

3.5.3. Leisure

Pungent smell and reduction in aesthetics due to heavy pollution of Fosu, Korle, Kpeshie, and Benya lagoons in Ghana have reduced their appeal as leisure centers (Boadi and Kuitunen, 2002; Owusu et al., 2014). Also, due to the reduction in the population of some aquatic birds as a result of the hunting, deprivation of food and shelter for birds from fishing pressure, pollution, and settlement in the Sakumo II, Korle, Muni-Pomadze, and Benya lagoons, bird watching activities have been hampered (Battley et al., 2003; Environmental Protection Agency of Ghana, 2017, 2020).

3.5.4. Livelihood and revenue

Data on the impact on livelihood and revenue loss over the years due to the state change in lagoon ecosystems are very scanty. This is due to the minimal attention and value given to the ecosystem. However, in recent times fewer fishers are engaged in fishing activities in Sakumo II (used to record about 30–310 fishers at any time) and Fosu lagoons due to their state contributing to the income inequality in Ghana (Baffour-Awuah, 2014; Ntiamoa-Baidu, 1991). Revenues from lagoon fishery (e.g., Keta lagoon) have been affected due to a decline in the quantity of catch and size (Agbekpornu et al., 2016).

3.5.5. Education and research

The coastal ecosystems provide grounds for research and knowledge for universities and other research centers within and outside Ghana due to available genetic resources and biodiversity (UN, 2019). For instance, students, lecturers, and researchers from the University of Ghana, University of Cape Coast, University of Energy and Natural Resources, Water Research Institute of Centre for Scientific and Industrial Research, etc., rely on lagoons in Table 1 and many others for educational and research purposes. Therefore, their continuous destruction presents a loss of research and knowledge service due to limited access to them.

3.5.6. Spiritual and cultural wellbeing

Coastal lagoons have both cultural and spiritual significance to the individual or communities where they are located. For instance, it is the belief that fishes in the Muni-Pomadze lagoon are the children of the gods, and that on non-fishing days, the gods bring them out to play freely in the water. The lagoon is believed to have saved the people of Winneba (Central Region) from enemies during wars (Kraan, 2009). Similarly, the Fosu lagoon is associated with a god worshipped by the people of Cape Coast (*Oguaa*) of the Central Region and plays a significant role in the *Fetu Afahye* festival of the *Oguaa* people (Apter, 2017; Entsua-Mensah, 1998; Korsah and Kuwornu-Adjaottor, 2019). The Sakumo II and Korle also serve as courts of adjudication for spiritual malfeasance for the *Ga* people (British Library, 2013). Therefore, their destruction or modification will negatively affect these beliefs.

3.6. Responses

In response to human activities and their effect (Fig. 3) in the coastal lagoons, the Government of Ghana, and other stakeholders (e.g., USAID, and Hen Mpoano (local non-governmental organization)) have implemented several management measures and legal regimes (Table 6) to curb and reduce their effect. These include:

3.6.1. Rules and regulations

The Fisheries Act 625 of 2002 and Fisheries Regulation L.I. 1968 of 2010 for the restriction of some gear types (e.g., dragnets, mosquito nets, poisons, etc.), mesh sizes, and fish sizes to ensure the conservation of fish species, have been enacted to regulate and protect these ecosystems (Kraan, 2009). Similarly, the Wetland Management (Ramsar) Regulations L.I. 1965 of 1999 has been enacted. This legal instrument designates the Keta, Songhor, Sakumo, and Muni-Pomadze lagoons as Ramsar sites, and they are subject to closed seasons (e.g., 2–3 weeks annually for Muni-Pomadze). There is also the Wildlife Laws and Regulations Act 43 of 1961 with subsequent amendments, the Water Resources Commission Act 552 of 1996, and the Environmental Protection Assessment Regulation of 1999 to protect the flora, fauna, and the aquatic ecosystem. Similarly, countries including Morocco, Algeria, Libya, and Tunisia have enacted legislation to protect their coastal lagoons in response to human activities and pressures (El Mahrad et al., 2020). However, except for the four lagoons with the Ramsar designation, lagoon management in Ghana is generally part of legislation for wetlands and other aquatic systems with enforcement generally being weak or non-existent. Similar studies also show that management measures for coastal lagoons are part of the general wetland legislation in China, Morocco and Egypt (El Mahrad et al., 2020; Lin et al., 2007). In Mexico, the applicable regulation in response to human activities is in the constitution, federal laws, and municipal ordinance of environmental regulations, and enforcement is usually weak or non-existent (Hernández-López et al., 2020).

Table 6
Previous response and suggestions to the problem.

Earlier response	Suggestions
Rules and regulations	Address building and fuelwood material sources
Management through projects	Encourage afforestation and community ownership
Taboos and customary laws	Introduce sustainable farming methods
	Eliminate or reduce construction activities
	Improve sanitation management
	Protect coastal lagoons
	Undertake research-led management

3.6.2. Management through projects

Agencies of the Government of Ghana, including the Ministry of Land and Natural Resources, Ghana Wildlife Division, with other stakeholders and donors, have initiated various management projects to protect coastal lagoons (Cape Coast Metropolitan Assembly, 2015; Essel, 2018; Mohan, 2002; Snorek, 2017; The World Bank, 1992; Tufour, 1999). These include and are not limited to:

The Ghana Environmental Resource Management Project which aimed at ensuring community involvement in environmental resource decision making and providing for the demarcation of coastal wetlands (e.g., Muni-Pomadze, Sakumo, Songhor, and Keta lagoons) that are important for migratory bird species (Entsua-Mensah et al., 2000; Mohan, 2002);

The Biodiversity Project of the Fosu lagoon by the Cape Coast Metropolitan Assembly- which aims to conserve and protect the lagoon and wading birds through a community-based approach and the development of a GIS database (Cape Coast Metropolitan Assembly, 2015; Essel, 2018); and Keta Lagoon Complex Ramsar site project: this was to regenerate, ensure sustainable use and management of mangroves in the Keta lagoon (Armah et al., 2009).

3.6.3. Taboos and customary laws

To manage the behavior of people and their activities in the coastal lagoons, the traditional leaders in the communities enacted taboos (e.g., taboo species such *Egretta ardesiaca*) and customary laws (e.g., non-fishing days and entry requirements) with fines for offenders to regulate entry and catch. For instance, the annual closure of the Fosu lagoon is from August to September, the Sakumo II lagoon is from November to March, and the Narkwa and Benya lagoons are for six to ten months. In Keta, one needed permission from the lagoon landowners before setting their traps (Dankwa et al., 2016; Entsua-Mensah et al., 2000; Kraan, 2009; Nixon et al., 2007; Van Stiphout, 2002; Weigel, 1985). However, their effectiveness has reduced over time due to the advent of foreign religious beliefs and urbanization (Kraan, 2009; Ntiamoa-Baidu, 1991).

Enforcement of these laws and successful implementation of management measures have always been lacking due to logistic constraints and unresolved stakeholder issues. The stakeholder issues include the nature of the land tenure systems, which gives owners the right to lease their land (with mangroves) for a specified period without formal governmental approval. Others are the conflict between salt miners (artisanal and large-scale miners) and the government over the release of portions of lagoons in areas such as Songhor and Keta over the right to mine (e.g., 81 km^2 to private companies) (Atta-Quayson, 2018). The gap between research and policy implementation due to political expediency is hampering efforts at managing these ecosystems. The responses have been mostly unsuccessful in Ghana due to the difficulty in balancing socio-economic activities, safeguarding the environment, and tackling stakeholder issues (El Mahrad et al., 2020; Newton et al., 2014).

3.7. Suggestions

Considering the above challenges, the following the recommendations are suggested (Table 6):

Address building and fuelwood material sources – The use of alternative building materials that reduces the use of mangroves, reeds, sand, and stones from coastal lagoons should be encouraged. Similarly, the use of environmentally sustainable fuel sources (e.g., biogas) as an alternative to mangroves for fuelwood at an affordable cost should be intensified. These will contribute to meeting the drivers and at the same time ensure sustainable consumption and production patterns, combat climate change, and promote sustainable use of terrestrial ecosystem in fulfilment of goals 12, 13, and 15 of the SDGs.

Encourage afforestation and community ownership – This can be achieved through intensified re-afforestation of coastal lagoons and the establishment of community lagoon and mangrove watch groups to ensure community ownership. This measure would help in the protection of terrestrial biodiversity, combat, and reduce the effect of climate change by reducing greenhouse gases in fulfilment of SDGs 13 and 15, and the Paris Agreement on climate change.

Introduce sustainable farming methods – The concept of green farming should be encouraged in these communities to reduce their impact on the lagoons for sustainable production pattern and protection of aquatic and terrestrial organisms in fulfilment of goals 12, 14, and 15 of the SDGs. This method of farming would enable individuals and communities to fulfil the driver need for food, which is in fulfilment with goal 2 of the SDGs.

Eliminate or reduce construction activities – Discourage the establishment of settlements and siting of saltpans in-situ of coastal lagoons and their fringes, since it is important to ensure sustainable production patterns that contribute to combating climate change and reverse land degradation in line with SDGs 12, 13, and 15. Where possible, communities sited close to coastal lagoons should be relocated.

Improve sanitation management – Improve community toileting facilities and encourage community-based waste separation and recycling in lagoon catchment communities. Enforce bylaws governing polluter pays policy devoid of partisan consideration and social status of offenders. Establish and enforce the treatment of waste via treatment plants for the cleaning of domestic and industrial wastes before they are released. These would contribute to enhancing access to basic sanitation and the protection of aquatic and terrestrial organisms in fulfilment of goals 11, 14, and 15 of the SDGs.

Protect coastal lagoons – According to the Sustainable Development Goal report of 2019 (UN, 2019), protected areas are essential in sustainable development when they are efficiently managed. Coastal lagoons with or without Ramsar designation should be placed under national key biodiversity areas with the appropriate policy, legislative and institutional framework to ensure effective management.

Undertake research-led management – Conduct an extensive study on the effect of anthropogenic activities, the state and loss of livelihood and revenue on the various ecosystem serves of the over 90 lagoons for effective management with DAPSI(*W*)R(M). Deploy monitoring programs to monitor sand change with remote sensing analysis and direct field accounting of activities.

4. Conclusion

This research demonstrates that an application of the DAPSI(*W*)R(M) as a decision support tool can synthesize complex information to assist policymakers, environmental managers, and scientists in the decision-making process, such as in the case of the management measures for coastal lagoons by tackling issues from different aspects.

This framework highlighted the predominant human need (Drivers) regarding the use of 11 of the over 90 coastal lagoons in Ghana, including the need for food, shelter, social status and dominance, and self-reliance. Consequently, the major Activities were in different sectors, such as fishing, farming, salt mining, mangrove harvesting, hunting, and settlement. These lead to Pressures, including the introduction and exacerbation of physical pressure from selective extraction of fish and mangrove species, salt, runoffs of heavy metals and hydrocarbons, sediments, nutrients, and organic matter in the studied coastal lagoons.

Due to single or multiple pressures associated with human activities, the environmental state of dissolved oxygen in Benya, Mukwe, and Sakumo II lagoons is below 2 mg/l. The Benya Songhor, Sakumo II, and Kpeshie lagoons have acquired high levels of biochemical oxygen demand, the sediments, water, and fish tissue have been contaminated with high heavy metal concentrations.

The research showed the change in the state of community structure in the Korle, Fosu, Muni, Sakumo II, Mukwe and Songhor lagoons due to the loss of one or more species of plants and animals. The water quality in lagoons, including Benya, Fosu, Korle, Sakumo II, and Kpeshie, has degraded due to pollution from untreated domestic and industrial discharge. These state changes have affected the ecosystem services provided by the lagoons, which include the availability and quality of lagoon fish (fin and shellfishes), birdwatching, and clean and fresh air from the lagoon environment for leisure, among others.

In response to these, there have been several management measures that have been instituted to protect and restore these ecosystems, which include fisheries laws and regulations, wetland regulations, wildlife laws and regulations, environmental resources management projects, and customary laws and taboos.

However, these measures have not yielded the needed results. Therefore, laws protecting coastal lagoons should be enforced, community-owned reafforestation projects should be established, and bio-gas usage should be encouraged as an alternative to mangroves for fuel. Further studies were recommended to focus on quantifying the value of ecosystem services provided by these lagoons and the losses associated with their destruction for effective decision making.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.156234.

CRediT authorship contribution statement

Richard Takyi: Conceptualization, Methodology, Writing-Original Draft, Visualization **Badr El Mahrad:** Methodology, Writing, Reviewing and Editing **Francis Kofi Ewusie Nunoo:** Reviewing and Editing **Richard Adade:** Visualization and Reviewing **Mohamed ElHadary**: Visualization **John Essandoh**: Reviewing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

Richard Takyi acknowledges the Center for Marine and Environmental Research (CIMA) of the University of Algarve, Portugal and the Water and Coastal Management (WACOMA) programme. Badr El Mahrad acknowledges the Murray Foundation and Sustainable Blue Growth program. Mohamed ElHadary acknowledges the University of Bologna in Italy and the University of Cadiz in Spain and the Water and Coastal Management (WACOMA).

References

Abalansa, S., El Mahrad, B., Icely, J., Newton, A., 2021. Electronic waste, an environmental problem exported to developing countries: the good, the bad and the ugly. Sustainability 13, 1–24. https://doi.org/10.3390/su13095302.

Adda, A.J., 2016. The Influence of Land Tenure and Ownership Regimes on Sustainable Conservation of Mangroves in the Songhor and Keta Lagoon Complex Ramsar Sites in Ghana. Kwame Nkrumah University of Science and Technology.

Addo, C., Ofori-Danson, P.K., Mensah, A., Takyi, R., 2014. The fisheries and primary productivity of the Keta lagoon. World J. Biol. Res. 6, 15–27.

Addo, M.A., Affum, H.A., Botwe, B.O., Gbadago, J.K., Acquah, S.A., Senu, J.K., Adom, T., Coleman, A., Adu, P.S., Mumuni, I.I., 2012. Assessment of water quality and heavy metal levels in water and bottom sediment samples from Mokwé lagoon, Accra, Ghana. Res. J. Environ. Earth Sci. 4, 119–130.

Adinortey, C.A., 2014. Antibiotic Resistance, Phylogenetic Grouping and Virulence Potential of "Escherichia coli" Isolated From Clinical and Environmental Samples From the Cape Coast Metropolis of the Central Region of Ghana. University of Cape Coast.

Adjei, G., Adokoh, C., Bentum, J., Hadzi, G., Ameho, E., 2017. The impact of anthropogenic activities on the fosu lagoon in the central district of Cape Coast: integrated assessment of heavy metal contamination. Br. J. Appl. Sci. Technol. 21, 1–11. https://doi.org/10.9734/bjast/2017/31275.

Adokoh, C.K., Obodai, E.A., Essumang, D.K., Serfor-Armah, Y., Nyarko, B.J.B., Asabere-Ameyaw, A., 2011. Statistical evaluation of environmental contamination, distribution and source assessment of heavy metals (Aluminum, arsenic, cadmium, and Mercury) in some lagoons and an estuary along the coastal belt of Ghana. Arch. Environ. Contam. Toxicol. 61, 389–400. https://doi.org/10.1007/s00244-011-9643-5.

Affam, M., Asamoah, D.N., 2011. Economic potential of salt mining in Ghana towards the oil find. Res. J. Environ. Earth Sci. 3, 448–456.

Affum, A.O., Dede, S.O., Nyarko, B.J.B., Acquaah, S.O., Kwaansa-Ansah, E.E., Darko, G., Adomako, D., Affum, E.A., Fianko, J.R., 2016. Influence of small-scale gold mining and toxic element concentrations in Bonsa river, Ghana: a potential risk to water quality and public health. Environ. Earth Sci. 75, 1–17. https://doi.org/10.1007/s12665- 015-5000-8.

Afoakwah, R., Osei, M.B.D., Effah, E., 2018. A Guide on Illegal Fishing Activities in Ghana. Cape Coast.

Agbekpornu, H., Yeboah, D., Quaatey, S., Pappoe, A., Ennin, J., 2016. Value chain analysis of captured shrimp and tilapia from Keta lagoon in Ghana. Asian J. Agric. Extension, Econ. Sociol. 14, 1–11. https://doi.org/10.9734/ajaees/2016/30829.

Agbemehia, K., 2014. Effect of Industrial Waste Effluents Discharge Into Sakumo II Lagoon in Accra Ghana. Kwame Nkrumah University of Science and Technology.

Ahmed, S., Isaac, S., 2016. Assessing the effects of indiscriminate disposal of waste: a case study of the Keta lagoon in the Volta region of Ghana. J. Biodivers. Endanger. Species 4, 1–5. https://doi.org/10.4172/2332-2543.1000170.

Akoto, O., Eshun, B.F., Darko, G., Adei, E., 2014. Concentrations and health risk assessments of heavy metals in fish from the Fosu lagoon. Int. J. Environ. Res. 8, 403–410.

Akpabey, F.J., Amole, R., 2015. Assessment of the aquatic macrophytes and algae of the Fosu lagoon, Cape Coast, Ghana. Acad. J. Life Sci. 1, 14–19.

Ametefe, R., 2016. Impacts of Socio-economic Activities of Communities on Water Resource Management in Songor bioshpere Reserve. Accra, Ghana.

Amuzu, A.T., 1997. The Impact of Urbanization and Development on Surface Waters in Ghana - Case Studies. 243. IAHS-AISH Publ., pp. 117–120.

Ansa-Asare, O.D., Mensah, E., Entsua-Mensah, M., Biney, C.A., 2008. Impact of human activities on nutrient and trophic status of some selected lagoons in Ghana. West Afr. J. Appl. Ecol. 12, 1–10. https://doi.org/10.4314/wajae.v12i1.45761.

Anthony, A., Atwood, J., August, P., Byron, C., Cobb, S., Foster, C., Fry, C., Gold, A., Hagos, K., Heffner, L., Kellogg, D.Q., Lellis-Dibble, K., Opaluch, J.J., Oviatt, C., Pfeiffer-Herbert, A., Rohr, N., Smith, L., Smythe, T., Swift, J., Vinhateiro, N., 2009. Coastal lagoons and climate change: ecological and social ramifications in U.S. Atlantic and Gulf Coast ecosystems. Ecol. Soc. 14, 1–29.

Antwi-Agyei, P., 2018. Ghana's National Adaptation Plan. Accra, Ghana.

Apau, J., Appiah, S.K., Marmon-Halm, M., 2012. Assessment of water quality parameters of Kpeshie lagoon of Ghana. J. Sci. Technol. 32, 22–31. https://doi.org/10.4314/just.v32i1.4.

Apter, A., 2017. History in the dungeon: Atlantic slavery and the spirit of capitalism in Cape Coast Castle, Ghana. American Historical Review. Oxford University Press, pp. 23–54 https://doi.org/10.1093/ahr/122.1.23.

Armah, F.A., Ason, B., Luginaah, I., Essandoh, P.K., 2012. Characterization of macro-benthic fauna for ecological health status of the Fosu and Benya lagoons in coastal Ghana. J. Ecol. F. Biol. 35, 279–289. https://doi.org/10.5141/JEFB.2012.033.

Armah, K.A., Diame, A., Ajonina, G., Kairo, J., 2009. The role and work of African mangrove network (AMN) in conservation and sustainable use of mangroves in Africa. Nat. Faune 30–41.

Asare, B., Obodai, E., Acheampong, E., 2019. Mangrove oyster farming: prospects as supplementary livelihood for a Ghanaian fishing community. J. Fish. Coast. Manag. 1, 7. https://doi.org/10.5455/jfcom.20190311090846.

Asmah, R., Dankwa, H., Biney, C.A., Amankwah, C.C., 2008. Trends analysis relating to pollution in Sakumo lagoon, Ghana. Afr. J. Aquat. Sci. 33, 87–93. https://doi.org/10.2989/AJAS.2007.33.1.11.395.

Atampugre, G., 2010. Spatio-temporal Information and Analysis of Land Use/Land Cover Changes in the Muni-Pomadze Wetland. University of Cape Coast.

Atta-Quayson, A., 2018. Position Paper on Salt Sector in Ghana.

Attuquayefio, D., Ryan, J., 2006. Taxonomic report on small mammals from two coastal wetland (Ramsar) sites in Ghana. West African J. Appl. Ecol. 10. https://doi.org/10.4314/wajae.v10i1.45694.

Attuquayefio, D.K., Gbogbo, F., 2001. Prospects of conserving wetlands along the Mukwe lagoon at Nungua in the greater Accra region of Ghana. West African J. Appl. Ecol. https://doi.org/10.4314/wajae.v2i1.45564.

Avornyo, S.Y., 2017. Water Quality Assessment of Some Lagoons in Ghana. Lambert Academic Publishing, Beau Bassin.

Babatunde, 2008. The fisheries and bionomics of the swimming crab "Callinectes amnicola" (DeRocheburne 1883) from a tropical lagoon and its adjacent creek, south-west Nigeria. J. Fish. Aquat. Sci. 3, 113–125.

Badu, B.E., 2012. Fish as Bioindicators of Habitat Degradation in Coastal Lagoons. University of Ghana.

Baffour-Awuah, E., 2014. The state of a 'choked' lagoon: a two-decade overview of the Fosu lagoon in Cape Coast, Ghana. J. Econ. Sustain. Dev. 5, 77–90.

Balogun, K., Ladigbolu, I., Ariyo, A., 2011. Ecological assessment of a coastal shallow lagoon in Lagos, Nigeria: a bio-indicator approach. J. Appl. Sci. Environ. Manag. 15, 41–46. https://doi.org/10.4314/jasem.v15i1.65673.

Battley, P.F., Poot, M., Wiersma, P., Gordon, C., Ntiamoa-Baidu, Y., Piersma, T., 2003. Social foraging by waterbirds in shallow coastal lagoons in Ghana. Waterbirds 26, 26–34. https://doi.org/10.1675/1524-4695(2003)026[0026:sfbwis]2.0.co;2.

Bentum, J.K., Anang, M., Boadu, K.O., Koranteng-Addo, E.J., Owusu Antwi, E., 2011. Assessment of heavy metals pollution of sediments from fosu lagoon in Ghana. Bull. Chem. Soc. Ethiop. 25, 191–196. https://doi.org/10.4314/bcse.v25i2.65869.

Biney, C.A., 1982. Preliminary survey of the state of pollution of the coastal environment of Ghana. Proceedings International Symposium on Coastal Lagoons. SCOR/ IABO/ UNESCO, Bordeaux, pp. 39–43.

Blay, J.J., Asabere-Ameyaw, A., 1993. Assessment of the fishery of a stunted population of the cichlid, "Sarotherodon melanotheron" (Ruppell), in a "closed" lagoon in Ghana. J. Appl. Ichthyol. 9, 1–11. https://doi.org/10.1111/j.1439-0426.1993.tb00382.x.

Boadi, K.O., Kuitunen, M., 2002. Urban waste pollution in the Korle lagoon, Accra, Ghana. Environmentalist 22, 301–309.

Boateng, I., Bray, M., Hooke, J., 2012. Estimating the fluvial sediment input to the coastal sediment budget: a case study of Ghana. Geomorphology 138, 100–110. https://doi.org/10.1016/j.geomorph.2011.08.028.

Botello, A.V., Espino, G.L., Fragoso, S.V., Velez, G.P., 2016. Pollution issues in coastal lagoons in the gulf of Mexico. Lagoon Environment around the World - A Sientific Perspective. InTechOpen, p. 20.

Brinks, R.J., 2017. Sustainable Tourism Development in the Keta Lagoon Complex Ramsar Site, Ghana. Utrecht University.

British Library, 2013. Shrines of Accra: Witchcraft trial records at Nai, Korle and Sakumo We, Accra, Ghana| Endangered Archives Programme [WWW Document]. https://eap.bl.uk/project/EAP540 (accessed 8.20.21).

Cape Coast Metropolitan Assembly, 2015. The Composite Budget of the Cape Coast Metropolitan Assembly for the 2015 Fiscal Year.

Clottey, C.A., 2018. Assessment of Physicochemical Parameters and Heavy Metals Contamination in Korle and Kpeshie Lagoons. University of Ghana.

Cohen, J., Yankson, K., Acheampong, E., Wubah, D., 2020. Effects of tidal exposure on bivalve molluscs: First stab at the case of West African mangrove oyster "Crassostrea tulipa" in Benya lagoon, Elmina, Ghana. J. Fish. Coast. Manag. 2854, 35–42. https://doi.org/10.5455/jfcom.20200317105716.

Dankwa, H.R., Quarcoopome, T., Owiredu, S.A., Amedorme, E., 2016. State of fish and fisheries of Fosu lagoon, Ghana. Int. J. Fish. Aquat. Stud. 4, 259–264.

Davies-Vollum, K.S., Zhang, Z., Agyekumhene, A., 2019. Impacts of lagoon opening and implications for coastal management: case study from Muni-Pomadze lagoon, Ghana. J. Coast. Conserv. 23, 293–301. https://doi.org/10.1007/s11852-018-0658-1.

De Wit, R., 2011. Biodiversity of coastal lagoon ecosystems and their vulnerability to global change. Ecosyst. Biodivers., 29–40 https://doi.org/10.5772/24995.

Doamekpor, L.K., Abusa, Y., Ketemepi, H.K., Klake, R.K., Doamekpor, M.E.A.M., Anom, P.A., Obeng, J., 2018. Assessment of heavy metals in water and sediments of Sakumo II, Chemu and Kpeshie lagoons-Ghana. West African J. Appl. Ecol. 26, 56–71.

Dolbeth, M., Stålnacke, P., Alves, F.L., Sousa, L.P., Gooch, G.D., Khokhlov, V., Tuchkovenko, Y., Lloret, J., Bielecka, M., Różyński, G., Soares, J.A., Baggett, S., Margonski, P., Chubarenko, B.V., Lillebø, A.I., 2016. An integrated pan-european perspective on coastal lagoons management through a mosaic-DPSIR approach. Sci. Rep. 6, 1–12. https://doi.org/10.1038/srep19400.

Doyi, I.N., Darku, E., Egbi, C., Frimpong, S., Kokroko, W., Aryeequaye, F., Nyaba, L.A.K., Frimpong, E.O., Asamoah, C.O., 2012. Concentration of copper and zinc in black chin tilapia "Sarotherodon melenotheron" in Fosu lagoon, Cape Coast, Ghana. Elixir Pollut. 45, 7741–7745.

Duku, E., Mattah, P.A.D., Angnuureng, D.B., 2021. Assessment of land use/land cover change and morphometric parameters in Keta lagoon Ramsar site, Ghana. Water 13, 1–20.

Ekumah, B., Armah, F.A., Afrifa, E.K.A., Aheto, D.W., Odoi, J.O., Afitiri, A.R., 2020. Geospatial assessment of ecosystem health of coastal urban wetlands in Ghana. Ocean Coast. Manag. 193, 105226. https://doi.org/10.1016/j.ocecoaman.2020.105226.

El Mahrad, B., Abalansa, S., Newton, A., Icely, J.D., Snoussi, M., Kacimi, I., 2020. Social-environmental analysis for the management of coastal lagoons in North Africa. Front. Environ. Sci. 8, 1–17. https://doi.org/10.3389/fenvs.2020.00037.

Elliott, M., Burdon, D., Atkins, J.P., Borja, A., Cormier, R., de Jonge, V.N., Turner, R.K., 2017. "And DPSIR begat DAPSI(W)R(M)!" - a unifying framework for marine environmental management. Mar. Pollut. Bull. 118, 27–40. https://doi.org/10.1016/j.marpolbul.2017.03.049.

Entsua-Mensah, M., 2002. The contribution of coastal lagoons to the continental shelf ecosystem of Ghana. In: McGlade, J.M., Cury, P., Koranteng, K.A., Hardman-Mountfor, N.J. (Eds.), The Gulf of Guinea Large Marine Ecosystems. Elsevier Science B.V, pp. 161–169 https://doi.org/10.1016/S1570-0461(02)80035-0.

Entsua-Mensah, M., Ofori-Danson, P.K., Koranteng, K., 2000. Management issues for the sustainable use of lagoon fish resources. In: Abban, E.K., Casal, C.M.V., Falk, T.M., Pullin,

R.S. (Eds.), Biodiversity and Sustainalbe Use of Fish in the Coastal Zone ICLARM Conf. Proc. 63, pp. 24–27.
Entsua-Mensah, R.E.M., 1998. Comparative Studies of the Dynamics and Management of Fish Populations in an Open and Closed Lagoon in Ghana. University of Ghana.
Environmental Protection Agency of Ghana, 2017. Ghana State of the Environment 2016 Report. Accra.
Environmental Protection Agency of Ghana, 2020. National Compedium of Environment Statistics, 2019. Accra.
Eshun, B.F., 2011. Distribution of Heavy Metals in the Fosu Lagoon (Cape Coast). Kwame Nkrumah University of Science ans Technology.
Essel, B., 2018. The Rufford Foundation: Final Report.
Essel, B., Gyesi, J.K., Addo, R.K., Galley, W., MacCarthy, G., 2019. The tale of a disappearing lagoon: a habitat mapping and ecological assessment of Fosu Lagoon, Ghana. Int. J. Ecol., 1–8 https://doi.org/10.1155/2019/6931329.
FAO, 1986. Environmental Quality Standards Regarding Water Pollution.
FAO, WHO, 2015. General Standard for Contaminants and Toxins in Food and Feed (Codex Stan 193-1995). https://doi.org/10.1017/CBO9781107415324.004.
Fiandra, M., 2019. The DAPSI(W)R(M) Problem-structuring Framework Applied to the Venice Lagoon. Unversita Ca'Foscari.
Fianko, J.R., Laar, C., Osei, J., Anim, A.K., Gibrilla, A., Adomako, D., 2013. Evaluation of some heavy metal loading in the Kpeshi lagoon, Ghana. Appl. Water Sci. 3, 311–319. https://doi.org/10.1007/s13201-013-0083-4.
Finlayson, C.M., Gordon, C., Ntiamoa-Baidu, Y., Tumbulto, J., Storrs, M., 2000. The Hydrobiology of Keta and Songor Lagoons: Implications for Coastal Wetland Management in Ghana, Supervising Scientist Report 152. NTUniprint, Darwin, Australia.
Fosu-Amankwah, K., 2012. Concentration Levels of Copper (Cu), Zinc (Zn), Cadium (Cd) and Lead (Pb) in Surface Water, Bottom Sediment, and Black Chin Tilapia "Sarotherdon melanotheron" of Fosu Lagoon, Cape Coast. Kwame Nkrumah University of Science and Technology.
Gari, S.R., Newton, A., Icely, J.D., 2015. A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. Ocean Coast. Manag. 103, 63–77. https://doi.org/10.1016/j.ocecoaman.2014.11.013.
Gbogbo, F., Oduro, W., Oppong, S.K., 2008. Nature and pattern of lagoon fisheries resource utilisation and their implications for waterbird management in coastal Ghana. Afr. J. Aquat. Sci. 33, 211–222. https://doi.org/10.2989/AJAS.2008.33.3.3.615.
Ghana Statistical Service, 2014. 2010 Population and Housing Census: District Report, Ekumfi District.
Ghana Statistical Service, 2018. Ghana Living Standards Survey (GLSS7): Poverty Trends in Ghana; 2005–2017. Accra.
Gnandi, K., Han, S., Rezaie-Boroon, M.H., Porrachia, M., Deheyn, D.D., 2011. Increased bioavailability of mercury in the lagoons of Lomé, Togo: the possible role of dredging. Ambio 40, 26–42. https://doi.org/10.1007/s13280-010-0094-4.
Gordon, C., 1987. Coastal lagoons of Ghana. In: Burgis, M.J., Symeons, J.J. (Eds.), Africa Wetlands and Shallow Water Bodies. Orstom, Paris, pp. 177–182.
Gordon, C., 2012. The Value of Mangroves to Ghana's Coasts.
Gulland, J.A., 1971. The Fish Resources of the Ocean. Fishing News Book, West Byfleet.
Hernández-López, J., Cervantes, O., Olivos-Ortiz, A., Guzmán-Reyna, R.R., 2020. DSPIR framework as planning and management tools for the la boquita coastal system, Manzanillo, Mexico. J. Mar. Sci. Eng. 8, 1–23. https://doi.org/10.3390/JMSE8080615.
Karikari, A.Y., Asante, K.A., Biney, C.A., 2009. Water quality characteristics at the estuary of Korle lagoon in Ghana. West Afr. J. Appl. Ecol. 10, 1–8. https://doi.org/10.4314/wajae.v10i1.45700.
Khamis, Z.A., Kalliola, R., Käyhkö, N., 2017. Geographical characterization of the Zanzibar coastal zone and its management perspectives. Ocean Coast. Manag. 149, 116–134. https://doi.org/10.1016/j.ocecoaman.2017.10.003.
Kjerfve, B., 1994. Coastal Lagoon Processes. 1st ed. Elsevier, Amsterdam.
Klubi, E., Adotey, D.K., Addo, S., Abril, J.M., 2021. Assessment of metal levels and pollution indices of the Songor wetland, Ghana. Reg. Stud. Mar. Sci. 46.
Kondra, M., 2018. The Status of the Wetlands in the Greater Accra Region (No. 9). Trier.
Koranteng, K.A., Ofori-Danson, P.K., Entsua-Mensah, M., 2000. Fish and fisheries of the Muni lagoon in Ghana, West Africa. Biodivers. Conserv. 9, 487–499. https://doi.org/10.1023/A:1008903813222.
Korsah, L.A., Kuwornu-Adjaottor, J.E.T., 2019. The Akan experience of god through the eyes of the Fante from Oguaa. Arts Humanit. Open Access J. Rev. 3, 280–283. https://doi.org/10.15406/ahoaj.2019.03.00142.
Kraan, M.L., 2009. Creating Space for Fishermen's Livelihoods: Anlo-Ewe Beach Seine Fishermen's Negotiations for Livelihood Space Within Multiple Governance Structures in Ghana.
Kwei, E.A., 1977. Biological, chemical and hydrological characters of coastal lagoons of Ghana, West Africa. Hydrobiologia 56, 157–174.
Lamptey, M.A., Ofori-Danson, P.K., 2014. The status of fish diversity and fisheries of the Keta lagoon, Ghana, West Africa. Ghana J. Sci. 54, 3–18.
Lassere, J., 1979. Rome et le sous-developpement 'de d'Afrique. REA 81, 67–104.
Lin, T., Xue, X.Z., Lu, C.Y., 2007. Analysis of coastal wetland changes using the DPSIR model: a case study in Xiamen, China. Coast. Manag. 35, 289–303. https://doi.org/10.1080/08920750601169592.
Madiop, G., Ngansoumana, B., Ablaye, N., Samba, M.M., Kandioura, N., 2020. Cyanophytes of the Joal-Fadiouth lagoon (Senegal). GSC Biol. Pharm. Sci. 12, 156–161. https://doi.org/10.30574/gscbps.2020.12.1.0211.
Mahapatro, D., Panigrahy, R.C., Panda, S., 2013. Coastal lagoon: present status and future challenges. Int. J. Mar. Sci. 3, 178–186. https://doi.org/10.5376/ijms.2013.03.0023.
Mensah, J., Enu-Kwesi, F., 2019. Implications of environmental sanitation management for sustainable livelihoods in the catchment area of benya lagoon in Ghana. J. Integr. Environ. Sci. 16, 23–43. https://doi.org/10.1080/1943815X.2018.1554591.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis, Zootaxa. Island Press, Washington, DC https://doi.org/10.11646/zootaxa.4892.1.1.
Mitchell, S., Boateng, I., Couceiro, F., 2017. Influence of flushing and other characteristics of coastal lagoons using dataan from Ghana. Ocean Coast. Manag. 143, 26–37. https://doi.org/10.1016/j.ocecoaman.2016.10.002.
Mohan, P.C., 2002. Ghana: Coastal Wetlands Management (Project). Washington, DC.
Newton, A., Icely, J., Cristina, S., Brito, A., Cardoso, A.C., Colijn, F., Riva, S.D., Gertz, F., Hansen, J.W., Holmer, M., Ivanova, K., Leppäkoski, E., Canu, D.M., Mocenni, C., Mudge, S., Murray, N., Pejrup, M., Razinkovas, A., Reizopoulou, S., Pérez-Ruzafa, A., Schernewski, G., Schubert, H., Carr, L., Solidoro, C., Viaroli, P., Zaldívar, J.M., 2014. An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters. Estuar. Coast. Shelf Sci. 140, 95–122. https://doi.org/10.1016/j.ecss.2013.05.023.
Nixon, S.W., Buckley, B.A., Granger, S.L., Entsua-Mensah, M., Ansa-Asare, O., White, M.J., McKinney, R.A., Mensah, E., 2007. Anthropogenic enrichment and nutrients in some tropical lagoons of Ghana, West Africa. Ecol. Appl. 17, S144–S164. https://doi.org/10.1890/05-0684.1.
Nortsu, O., 2018. Flooding Related Challenges of Lagoon Settlements: A Case Study of Keta. University of Cape Coast, Ghana.
Ntiamoa-Baidu, Y., 1991. Conservation of coastal lagoons in Ghana: the traditional approach. Landsc. Urban Plan. 20, 41–46.
Ntiamoa-Baidu, Y., Gordon, C., 1991. Coastal Wetlands Management Plans: Ghana. Accra, Ghana.
Nunoo, F.K.E., Asiedu, B., Amador, K., Belhabib, D., Pauly, D., 2014. Reconstruction of Marine Fisheries Catches for Ghana, 1950–2010, Working Paper Series. Vancouver.
Obodai, E., Nyarko, H., Amponsah, S., 2010. Effect of depuration on microbial content of mangrove oyster "Crassostrea tulipa" from Benya Llgoon Ghana. Ethiop. J. Environ. Stud. Manag. 3, 47–53. https://doi.org/10.4314/ejesm.v3i2.59832.
Obodai, E.A., Boamponsem, L.K., Adokoh, C.K., Essumang, D.K., Villawoe, B.O., Aheto, D.W., Debrah, J.S., 2011. Concentrations of heavy metals in two Ghanaian lagoons. Arch. Appl. Sci. Res. 3, 177–187.
Owusu, B.K., Jiagge, M.A., Adom, T.K.F., Amponsah, S., 2014. Sustainable Water Use for Development, Annual Report. Accra.
Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K.N., Smith, C.J., 2016. DPSIR-two decades of trying to develop a unifying framework for marine environmental management? Front. Mar. Sci. 3, 1–14. https://doi.org/10.3389/fmars.2016.00177.
Pérez-Ruzafa, A., Pérez-Ruzafa, I.M., Newton, A., Marcos, C., 2019. Coastal lagoons: environmental variability, ecosystem complexity, and goods and services uniformity. Coasts and Estuaries. Elsevier Inc., pp. 253–276 https://doi.org/10.1016/b978-0-12-814003-1.00015-0.
Porter, G., Young, E., Dzietror, A., 1997. Pressures on an intensive irrigated cash-crop system in coastal Ghana. Geoforum 28, 329–340. https://doi.org/10.1016/s0016-7185(97)00015-8.
Ramsar Convention Secretariat, 2014. Ghana. https://www.ramsar.org/search?search api views_fulltext=ghana.
Rapport, D., Friend, A., 1979. Towards a Comprehensive Framework for Environmental Statistics: A Stress-response Approach. Ottawa Catalogue 11-510.
Sackey, J., 2014. Impact of Anthropogenic Activities on the Water Quality of Songor lagoon, Ada, Greater Accra Region. University of Ghana.
Scheren, P.A.G.M., Kroeze, C., Janssen, F.J.J.G., Hordijk, L., Ptasinski, K.J., 2004. Integrated water pollution assessment of the Ebrié lagoon, Ivory Coast, West Africa. J. Mar. Syst. 44, 1–17. https://doi.org/10.1016/j.jmarsys.2003.08.002.
Smith, C.J., Papadopoulou, K.N., Barnard, S., Mazik, K., Elliott, M., Patrício, J., Solaun, O., Little, S., Bhatia, N., Borja, A., 2016. Managing the marine environment, conceptual models and assessment considerations for the European marine strategy framework directive. Front. Mar. Sci. 3, 1–19. https://doi.org/10.3389/fmars.2016.00144.
Snorek, J., 2017. Korle Lagoon restoration project and displacement from Accra's Old Fadama Slum, Ghana [WWW Document]. Environ. Justice Atlas. https://ejatlas.org/conflict/accras-agbogbloshie-electronic-waste-dump.
Steinhausen, S.L., Agyeman, N., Turrero, P., Ardura, A., Garcia-Vazquez, E., 2021. Heavy metals in fish nearby electronic waste may threaten consumer's health. Examples from Accra, Ghana. Mar. Pollut. Bull. https://doi.org/10.1016/j.marpolbul.2021.113162.
Takyi, R., Hassan, R., El Mahrad, B., Adade, R., 2021. Socio-ecological analysis of artisanal gold mining in West Africa: a case study of Ghana. J. Sustain. Min. 20, 206–219.
Tay, C., Asmah, R., Biney, C.A., 2010. A comparative study of the pollution status of sakumo II and muni lagoons in Ghana. Water Sci. Technol. 62, 1067–1075. https://doi.org/10.2166/wst.2010.359.
The World Bank, 1992. Republic of Ghana: Coastal Wetlands Management Project.
Third World Network-Africa, 2017. Towards Optimal Exploitation of Salt From the Keta Lagoon Basin in Ghana. Accra.
Tufour, K., 1999. Keta Lagoon Complex Ramsar Site Management Plan. Accra.
UN, 2019. The Sustainable Development Goals Report. New York.
UNESCO, 2020. International policy frameworks. World Water Development Report 2020.
US EPA, 2019. National recommended water quality criteria - Aquatic life criteria table. https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table (accessed 6.25.20).
USAID, 2017. Climate Change Risk Profile: Ghana.
Van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J., Janssen, C.R., 2015. Microplastics in sediments: a review of techniques, occurrence and effects. Mar. Environ. Res. 111, 5–17. https://doi.org/10.1016/j.marenvres.2015.06.007.
Van Leeuwen, N., Pije, L., Simons, A., Wauben, C., 2018. Analysis of Two Coastal Lagoons in Ghana: An Investigation for the Redesign of Two Lagoons Along the Ghanaian Coast.
Van Stiphout, M., 2002. What Are the Costs of Wetland Pollution? Integrating the Environmental Effect Chain and the Total Economic Value for a Coastal Wetland in Ghana. Eindhoven University of Technology.
Vowotor, M.K., Hood, C.O., Owusu, A., Akakpo, E.H., Mireku, K.K., 2012. Determination of mn, cu, and na in "Sarotherodon melanotheron" (Blackchin Tilapia) from the fosu lagoon,

Cape Coast - Ghana, using instrumental neutron activation analysis (INAA). Afr. Rev. Phys. 7, 367–375.
Vowotor, M.K., Sackey, S.S., Amuah, C.L.Y., Huzortey, A., Ahorlu, D.M., Kortey, G., Kuvedzi, D., 2019. Neutron activation analysis as a tool to determine concentration of selected metals in table salt mined from Benya lagoon, Ghana. Chem. Mater. Res. 11, 34–51. https://doi.org/10.7176/cmr/11-8-06.
Weigel, J.Y., 1985. Traditional Management of Some Lagoons of the Gulf of Guinea (Ivory Coast, Ghana, Togo, Benin). FAO Fisheries Circular, Lome.
Wiegleb, V., 2016. A Literature Review on Wetlands in Accra.
World Health Organization, 2011. Guidelines for Drinking-water Quality. 4th ed. Gutenberg.