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Systematic Review

Contemporary Global Coastal Management Strategies and Coastal Infrastructure and Their Application in Ghana: A Systematic Literature Review

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Abstract: Systematic literature reviews provide the foundation for evidence-based research in a particular field of study. In this regard, the systematic review of the relationship between coastal management strategies and coastal infrastructure typologies provides an opportunity to benchmark local coastal adaptation policies against contemporary global practices, technologies, and sustainability. However, systematic reviews of coastal infrastructure in Ghana and West Africa at large are limited. To close this research gap, we conducted a systematic literature review of the global implementation of coastal management strategies and coastal infrastructure and provided a synopsis of coastal management in Ghana. To achieve this, we searched the Scopus Database for literature on coastal management approaches and infrastructure typologies. Forty-eight peer-reviewed publications met the inclusion criteria for full-text analysis. The results indicate a significant global shift from purely grey infrastructure toward integrating green and grey infrastructure. However, despite contemporary global advances, coastal infrastructure in developing contexts—particularly in Ghana—remains mostly static, using reactive, hold the line strategies, and grey infrastructure. As sea-level rise continues to intensify coastal hazards globally, increasing the demand for coastal protection, researching coastal management policies and coastal infrastructure is essential to support the hybridization of grey and green infrastructure and encourage transitions to adaptive coastal management instead of continuous coastal hardening using grey infrastructure.

Keywords: coastal management strategies; coastal infrastructure; coastal adaptation; green and grey infrastructure; hybrid infrastructure; systematic literature review

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1. Introduction

One of the greatest global challenges facing coastal management in the 21 st century is the adaption to climate-induced sea-level rise (SLR) and the associated coastal hazards such as coastal erosion and flooding. Tol et al. [1] define adaptation as "the planned or unplanned, reactive or anticipatory, successful or unsuccessful response of a system to a change in its environment." In this regard, reactive (responsive) and proactive (anticipatory) approaches are often used in complementary ways [1]. Proactive adaptation approaches are based on the prediction of how ongoing processes may eventually unfold [1,2], with the aim of responding to both current and perceived future hazards. As a result, coastal managers are challenged to establish the appropriate coastal management policy or adaptation approach and the suitable coastal protection infrastructure to apply under different sea-level rise scenarios to protect the coastlines [3,4].

1.1. Current Body of Knowledge on Coastal Management Strategies

Coastal management has evolved substantially over time in response to climate-induced sea-level rise scenarios, coastal changes [3,4], and technological advancements in coastal infrastructure [1,2,5]. In the literature, coastal management policies are generally classified into two categories, namely: (1) "Protect", "Accommodate", and "Retreat" approaches coined by the Intergovernmental Panel on Climate Change (IPCC) [1,2,5], and (2) United Kingdom (UK) Shoreline Management Plans (SMPs), coined in the United Kingdom by the Department of Environment, Food, and Rural Affairs [6,7]. SMPs (strategies or policies) comprise four major coastal management strategies for aligning the shoreline in response to coastal erosion, categorised into (1) hold the line (HTL); (2) advance the line (ATL); (3) managed realignment (MR); and (4) no active intervention (NAI) policies [6–8]. SMPs involve not only identifying policy options (HTL, ATL, MR, and NAI) for each section of the coast [6,7], but also developing and testing policy scenarios [7,9].

1.1.1. Hold-the-Line Policy

The HTL strategy entails building defences or maintaining the existing coastal defences in their current positions to maintain the current shoreline [6]. Due to increasing SLR and associated hazards (storms, erosion, and flooding), the HTL approach is projected to grow by at least 5.4% in four decades [10]. HTL also implies actions to improve or maintain the standard or performance of existing coastal protection, which also include operations to build secondary protection on top of existing defences to maintain the current level of protection. Consequently, the hold the line strategy is often the stakeholder preference across studies [11]. This is because communities are content with the preservation of current conditions and also trust grey infrastructure to provide not only immediate but guaranteed protection to cushion the perception of risk. However, many researchers [11,12] associate grey infrastructure and HTL strategies with community complacency, overreliance on hard structures, and a reluctance to use other adaptive coastal adaptation options.

1.1.2. Advance the Line Policy

The ATL strategy involves building new defences seaward of existing structures to increase protection and reduce stress on current infrastructure [6], and by doing so, claim new land [9]. The seaward movement of defences should be appraised in terms of environmental impacts, especially impacts on ecosystems and biodiversity [6,7]. ATL is an extremely expensive approach that is rarely practised, but it has been increasingly used in 21st century mega-coastal land reclamation [13–15]. It requires expensive and specialized equipment, technology, and skilled human capital. Above all, ATL is most likely to be affected by future SLR. This requires both continuous improvements and plans to adapt to future SLRs. Recent examples of ATL cited in the literature include the tree-shaped Palm Jumeirah Island in Dubai, international airports in Hong Kong, Macau, and Singapore, and mega smart city projects such as 'Eko Atlantic' in Lagos, Nigeria, and Songdo smart city, South Korea [13,15]. In recent global analysis of mega land reclamations, ATL is attributed to the rising demand for suitable land for agricultural, residential, commercial, or industrial developments in countries such as China, which led to the conversion of many tidal flats and coastal wetlands [13].

1.1.3. Managed Realignment Policy

MR involves management decisions to allow the shoreline to move backward but with options to direct its movement in certain areas [6,9]. This entails options to remove structures in threatened built areas, move people and infrastructure away from danger zones (or harm's way) [16,17], and surrender to natural processes. Instances of MR include land buyouts and coastal setback zones [9,18], among other methods that may provide benefits to communities, e.g., from an ecosystem services perspective [19]. In many cases, MR demands making difficult strategic decisions (e.g., relocation), and if undertaken without a strategic vision, guiding frameworks, and capacity to manage the retreat, it may put communities at risk [20]. MR may not always be successful, with underlying issues of governance, justice, and compensation [20,21].

1.1.4. No Active Intervention

NAI (or do nothing) does not require investments in coastal defences; hence, no action is taken to prevent threats or intrusion by natural coastal hazards [9]. As a result, NAI is considered ideal in low-value coastal land such as farmland, places with no people or occupied by few properties, or areas where coastal erosion rates are very rapid, posing engineering challenges to defend the coasts [6]. NAI is associated with the culture of "wait and see" or simply "no action" approach [11]. However, in the face of increasing sea-level rise and threatening coastal hazards (storms, flooding, and erosion), the NAI approach is not preferable, as people and property need to be protected. Overall, NAI is not a preferable approach in areas where there are people and property.

1.1.5. Protect, Accommodate, and Retreat

The IPCC's "Protect", "Accommodate", and "Retreat" approaches are universally acclaimed. These policies, together with the options for their implementation, have been thoroughly discussed in the literature [2,5]. In this regard: (1) The "protect" strategy entails reducing the risk of an event by decreasing the probability of its occurrence, e.g., using seawalls and levees; (2) the accommodate approach entails increasing society's ability to cope with the effects of the event, e.g., through insurance or raising properties above the ground; and (3) "retreat" entails reducing the risk of the event by limiting its potential effects, e.g., relocation [2,5].

Overall, coastal adaptation policies can either be reactive or proactive, with consideration given to which proactive adaptation must take precedence [1]. Proactive adaptation comprises five generic objectives aimed at reducing a system's vulnerability, either by minimising risk or maximizing adaptive capacity, hence: (1) increasing robustness of infrastructural designs and long-term investment; (2) increasing flexibility of vulnerable managed systems; (3) enhancing adaptability of vulnerable natural systems; (4) reversing maladaptive trends; and (5) improving societal awareness and preparedness [1,5]. In developing countries, proactive coastal adaptation approaches that help reduce threats from coastal hazards are often lacking.

1.2. Current Body of Knowledge on Coastal Infrastructure

To implement coastal adaptation approaches, three fundamental types of coastal infrastructure can be identified in the literature [12,22,23] and categorised as: (1) Green (soft-engineered), (2) grey (hard-engineered), and (3) hybrid (integrated green and grey) infrastructure. Grey infrastructure is less natural and mostly associated with the modification of coastlines or ecosystems, while green and nature-based approaches are more natural and less intrusive on the coast and its ecosystems [8]. Hill [22] further describes four categories of coastal infrastructure designs (structural or static walls, dynamic or non-structural walls, static landforms, and dynamic landforms) whose application can be context-specific, thus providing a range of alternative implementation options. Categorising coastal infrastructure is essential to supporting coastal management decision-making when selecting coastal infrastructure by highlighting the strengths and weaknesses, impacts on coastal ecosystems, and long-term response to future sea-level rise of the different coastal infrastructure typologies [22].

1.2.1. Grey Infrastructure

Grey infrastructure is identified throughout the literature as the "traditional" form of coastal protection that has unarguably dominated coastal protection for centuries [12,22,23]. Grey infrastructure includes seawalls, revetments, groynes (or groyne fields), breakwaters, jetties, and roads. In recent decades, grey infrastructure has gradually lost its supremacy to green and hybrid infrastructure due to their support of ecosystem services. Consequently, there has been tremendous assessment and comparison of grey and green infrastructure, weighing the advantages and disadvantages of both stocks [1,2,5,12,24], and investigating options for their integration to maximise benefits [23,25].

Grey infrastructure boasts standardised, tried-and-tested designs and models trusted by investors. Importantly, grey infrastructure provides immediate and effective protection against the impacts of SLR such as flooding and coastal erosion [5,12,22,25]. On the negative side, grey infrastructure does not deal with the causes of erosion [2]. They lack dynamic protection and ecosystem benefits [12], contribute to coastal squeeze by limiting the natural landward migration of the shoreline [25,26], and contribute to coastal scenery deterioration [12,27]. Moreover, grey infrastructure promotes sediment starvation and erosion migration to downdrift areas, generating new erosion hot spots [28,29]. The ecological impacts include genetic alteration of marine species and disruption of biodiversity [12,25], non-colonisation by marine species such as fish, epibenthic organisms, and epibiota, and potential invasion by alien species [30]. In the absence of maintenance, grey stocks become vulnerable to climate change, and substantial extra investment will be required to sustain coastal defences in highly eroding areas [31].

1.2.2. Green Infrastructure

Green infrastructures are low-technology and low-cost approaches that utilise natural or nature-based solutions (NbS) to reduce the impacts of coastal hazards such as erosion and flooding [12,24,32,33]. Bridges et al. [8] define green infrastructure as the application of nature and nature-based features (NNBF) and bioengineering techniques to manage coastal flooding and erosion [8]. Green infrastructure includes but is not limited to coastal habitats such as sandy beaches, dunes, mangroves, salt marshes, natural and artificial coral and oyster reefs, seagrass beds (seagrass meadows), and other marine habitats that provide both coastal protection and ecosystem services [8,12,24,32,34,35]. The classification of green infrastructure may be variable in the literature, depending on the perspective given. Schoonees et al. [23] subclassified green infrastructure into: (1) soft infrastructure (e.g., nourishment); (2) environmentally-friendly infrastructure (e.g., vegetated revetments); and (3) hybrid infrastructure such as a constellation of seawalls and saltmarshes [23]. However, in most articles, hybrid infrastructure is described as distinct from green infrastructure.

Although green infrastructure is not as effective as hard-engineered approaches to provide immediate protection, it is acclaimed to be more sustainable and resilient to climate change impacts because: (1) it is less intrusive on the coast, helps to restore and maintain natural landscapes, and (2) it minimises environmental impacts while creating environmental opportunities [12,29]. For instance, salt marshes and mangroves protect coasts by attenuating wave energy, regulating water and sediment flow, reducing coastal erosion, and providing ecosystem services [35]. However, despite their increasing popularity, soft-engineered solutions such as mega beach nourishment are also associated with ecological disruption, the high cost of beach recharge, the need for specialised equipment, expert engineering, and highly technical skills, which are still lacking in developing countries [32,36]. The major current setback for natural and nature-based infrastructure is the lack of knowledge, standardisation, and effective governance for NbS [36]. Other challenges include difficulty quantifying marine ecosystems' protective capacity against coastal hazards such as coastal erosion, storm surges, and coastal flooding [12]. This makes it difficult to establish a common metric and put a value on both protective capacity and ecosystem services from green assets in different environments. Overall, green infrastructure is not anticipated to merely substitute grey infrastructure but to complement it.

1.2.3. Hybrid Infrastructure

In hybrid systems, grey infrastructure such as seawalls is created or restored alongside green infrastructure such as salt marshes [12,22,25]. Hybrid infrastructure is analogous with terms such as building with nature (BwN) [32,33], nature and nature-based features (NNBF) or engineering with nature (EwN) [8], and living shorelines [37,38] that contribute to both coastal resilience and climate (and coastal) change adaptation and mitigation, supporting societal objectives, and providing many opportunities for innovation [24]. In recent times, the integration of both green and grey assets, or hybrid infrastructure, has gained popularity and support for biodiversity restoration, contributing to the attainment of sustainable development goals (SDGs) and climate change adaptation. Notably, at the recently concluded Climate Change Convention (CCC) Conference of Parties (COP27), NbS was accorded recognition and pledges for global project financing towards climate change adaptation [39]. Therefore, it is anticipated that future coastal protection will be a mix of green and grey assets.

Altogether, different adaptation technologies play different roles in reducing coastal vulnerability to climate-induced coastal hazards [5]. While there is a broad suite of coastal adaptation options for decision-makers, some regions have limited experience with newer coastal adaptation technologies such as living shorelines and living breakwaters [22]. In recent times, hybrid infrastructure approaches have become increasingly popular [23–25], indicating a global transition from static, hold the line strategies using grey infrastructure toward a dynamic, proactive adaptation approach integrating green and grey assets into hybrid infrastructure. This is evidenced, among other things, by the emergence of buzzwords such as NbS, BwN, and EwN [8,12,24,32,37,38,40] in the past decade.

1.3. Limitations of Existing Coastal Management Approaches and Regional Gaps

Despite contemporary advances in coastal management research toward hybrid infrastructure, most of the technologies have been tested in developed countries. Therefore, there has been a slow implementation of green and hybrid technologies in developing countries. Consequently, most developing countries have continued with grey infrastructure due to several factors. First, grey infrastructure requires less maintenance. Second, it is appropriate for the build-and-forget approach, which is favoured in many developing contexts due to their shrinking capital budgets. Third, the regional and development state of the country (developed or developing context) and policy differences affect the implementation of integrated infrastructure [5,22]. For instance, some technologies (such as floodgates) are not suited to developing countries [5]. In Ghana, for example, coastal management is predominantly reactive, using hold the line strategies and grey infrastructure without a properly instituted SMP [41]. In addition, the "build and forget" strategy is often favoured, as evidenced by the uniform application of rock revetment, seawalls, and groynes.

1.4. Research Objective

The fundamental objective that arises is to establish the relative application of coastal management policies and different types of coastal infrastructure in the last two decades (2000–2023) to establish trends in the transition from hard-engineered (static adaptation) toward hybrid infrastructure (dynamic management). Different stakeholders have different opinions on what works best, and regional, cultural, and political barriers are certain. In this study, we analysed the global literature on contemporary coastal management approaches and the types of coastal infrastructure and narrowed our focus to the application of coastal management policy in Ghana with a view to benchmarking local adaptation to global practices.

2. Methodology

Systematic literature reviews provide a basis for evidence-based research and the acquisition of thematic knowledge in a particular field of study [11]. Empirical knowledge of the state of global coastal adaptation strategies is important to improve not only coastal adaptation but also sustainability. In recent years, systematic reviews have become standard and are increasingly recommended for climate change adaptation research [42]. This study employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol [43], (Figure 1). The PRISMA methodology is used to perform and report systematic reviews and meta-analyses. PRISMA comprises a checklist that helps researchers adhere to standard protocol in all areas, including data search strategy, analysis, and reporting systematic reviews and meta-analysis. These guidelines help to establish how the research was conducted to ensure high-quality research, transparency, and evidence-based reporting [43].

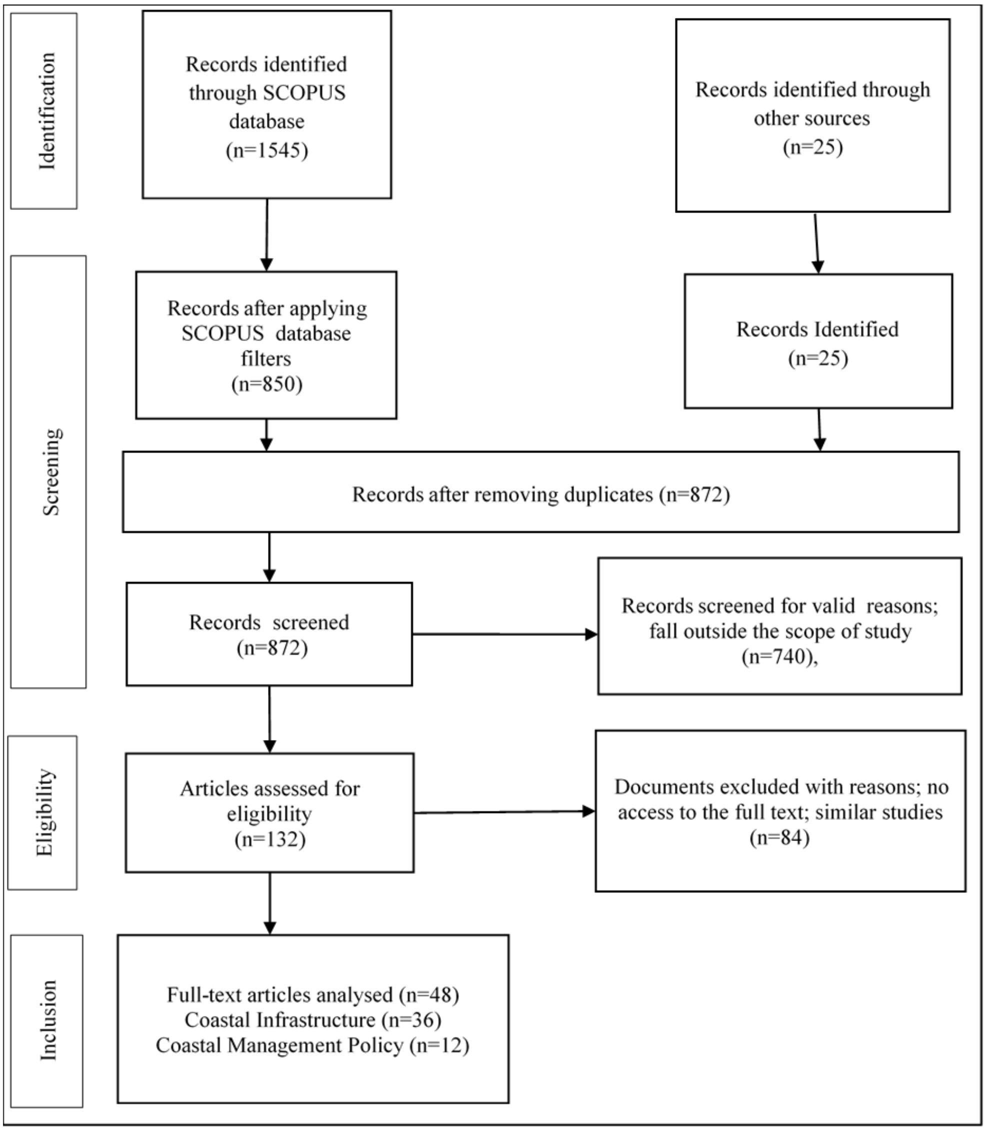

Figure 1. Flow of information during a systematic review based on the PRISMA protocol illustrating information flow through different stages of the systematic literature review [42,43]. The PRISMA framework is designed to improve quality and transparency in conducting systematic reviews and meta-analyses. In the figure, n = number of documents.

2.1. Database Search Strategy and Data Extraction

We searched the Scopus databases for research articles and review papers spanning the years 2000–2023 using the following search criteria: Title Abs Key (“Coastal management” AND (“coastal infrastructure” OR “green infrastructure” OR “grey infrastructure” OR “hybrid infrastructure” OR “coastal adaptation” OR “nature-based solutions” OR “coastal protection” OR “coastal engineering”) AND PUBYEAR > 1999 AND PUBYEAR < 2024 AND LIMIT-TO (DOCTYPE = “ar” AND LIMIT-TO (DOCTYPE = “re”)) consistent with the PRISMA standard [42,43]. In total, 1545 articles were established in the SCOPUS database from January 2000 to March 2023. After applying database filters and removing duplicates, only 850 articles remained. We also established records from important international guidelines on coastal management policy, natural and nature-based solutions for erosion, and flood risk management that were included in the study. In total, 25 records were identified from other sources. After combining the two datasets, three duplicate documents that focussed on coastal management in West Africa were removed, leaving a total of 872 documents. We then applied the inclusion/exclusion criteria to screen documents based on the relevance of the articles.

2.2. Data Quality Assessment

To guarantee the quality, we exhaustively synthesised abstracts for relevance to the topic, following the identification, screening, eligibility, and inclusion phases consistent with the PRISMA framework (Figure 1). Furthermore, inclusion criteria meant papers were written in the English language and published from 2000 to 2023.

2.3. Screening, Eligibility, Data Inclusion, and Exclusion Criteria

To be included in this study, documents had to: (1) specifically focus on categorising coastal management or adaptation approaches or policies; and (2) focus on the coastal infrastructure typologies (green, grey, or hybrid) and their subtypes (e.g., seawalls, revetments, groynes, seagrasses, saltmarshes, or mangroves). Articles that fell outside the scope of the study (Figure 2) were excluded.

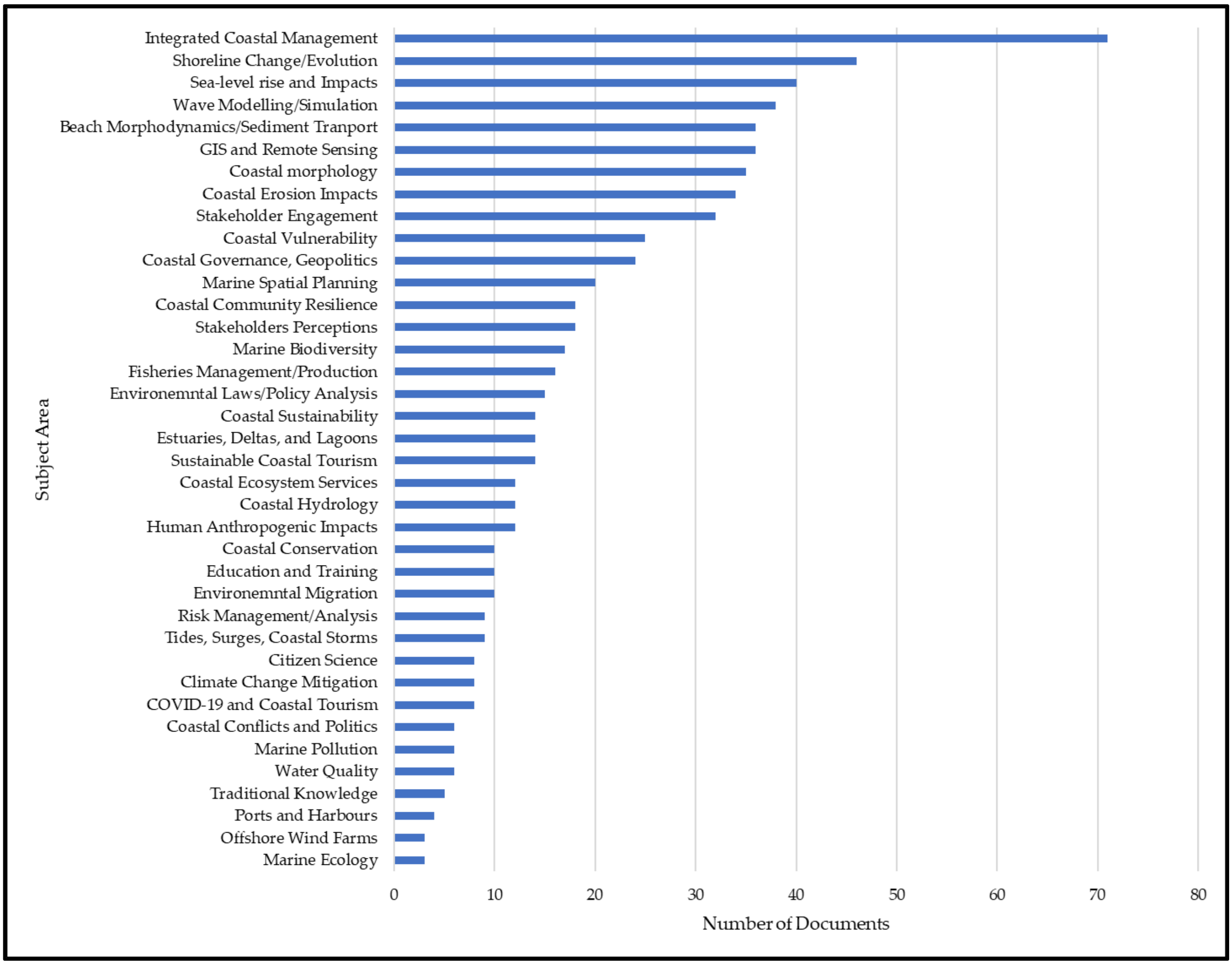

Figure 2. Document exclusion from the study, classified by subject area.

3. Results

In this section, we provide an interpretation of the results of the study.

3.1. Screening, Eligibility, Data Inclusion and Exclusion Criteria

About 872 documents were screened in an Excel environment. By analysing the topic, keywords, and reading the abstracts, approximately 740 documents were disqualified due to falling outside the context of classifying coastal management/adaptation approaches or categorising coastal infrastructure, even though they focussed on general ICM. For instance, some papers on ICM focussed on successes or failures in different contexts. This exclusion also included articles that focussed on, among others, sediment transport, beach morphology, general marine spatial planning, and other blue economy sectors, coastal ecosystems, climate change stressors (ocean acidification and global warming), stakeholder engagement, and coastal vulnerability assessments (Figure 2).

After exclusion, precisely 132 documents, comprising 100 documents on coastal infrastructure and 32 documents on coastal management or adaptation policies, were eligible for inclusion in the study (Figure 3). However, 84 documents were excluded with valid reasons, and only 48 full-text documents were read in full.

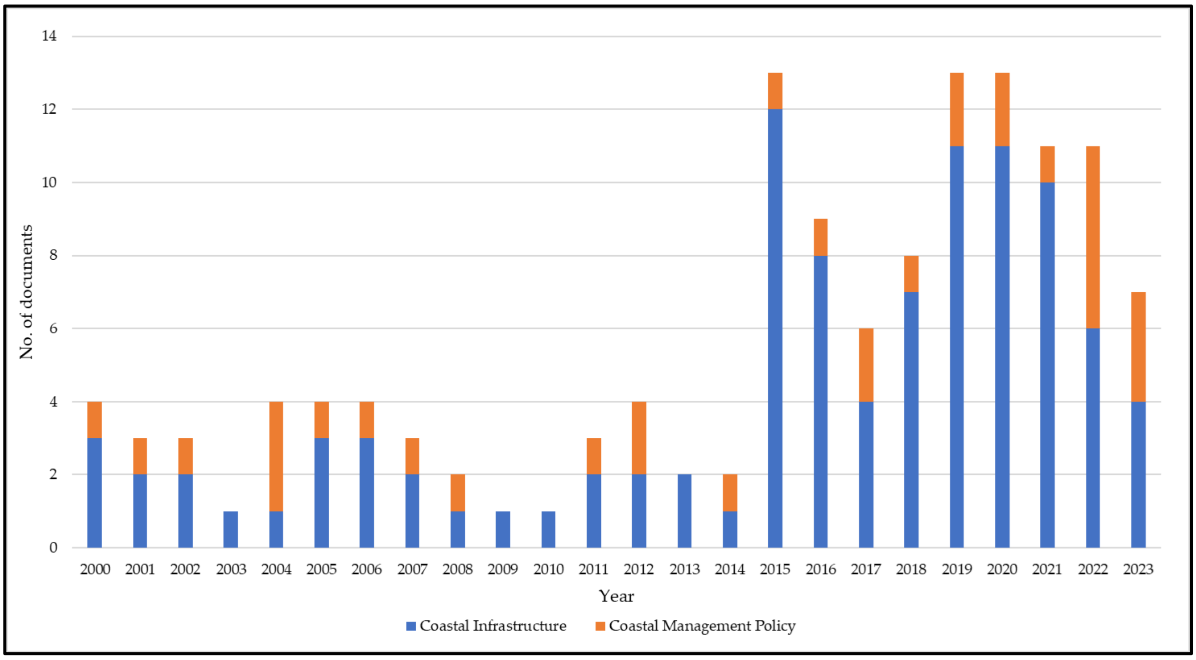

Figure 3. Categories of documents assessed for eligibility comprised 100 documents on coastal infrastructure and 32 documents on coastal management policy.

These results indicate that during the past decade, at least the majority of the literature was more focussed on coastal infrastructure and technological options to improve coastal adaptation and the implementation of coastal management policies.

3.2. Document Publication by Year

A quick overview of documents screened for eligibility during the study shows an incremental trend in the number of documents published per year on coastal management and coastal infrastructure between 2000 and 2023 (Figure 4).

This trend indicates growing research on coastal adaptation and the assessment of coastal adaptation technologies.

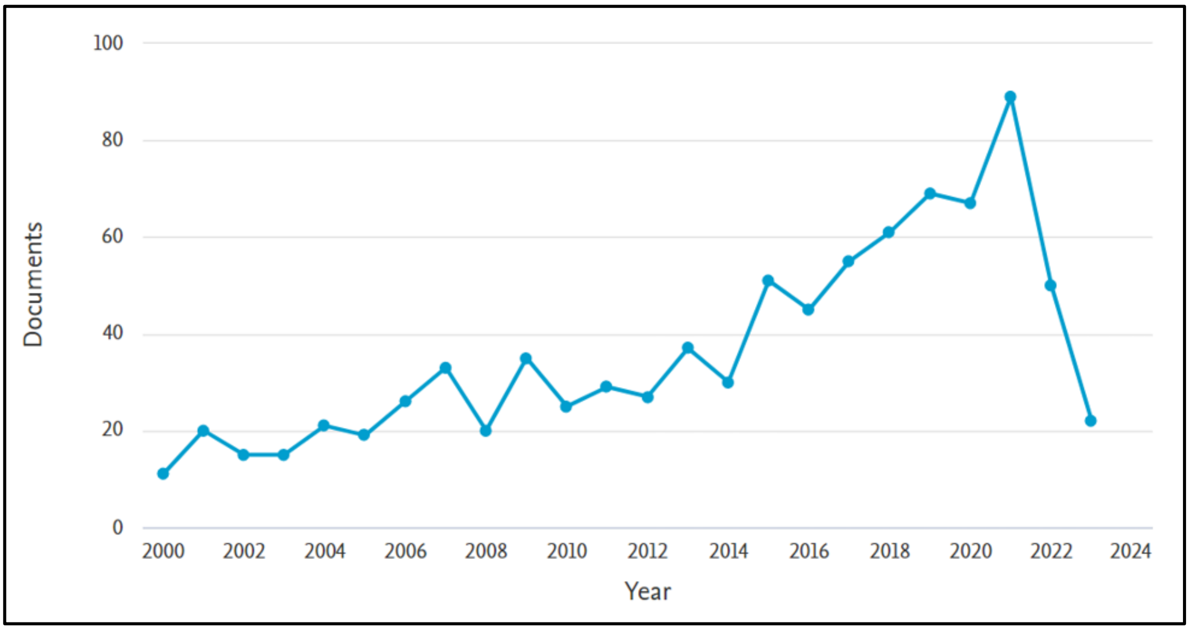

Figure 4. Analysis of documents published per year between 2000 and 2023.

3.3. Classification of Results by Type of Documents

Our database search revealed that the majority of the literature was research articles (Figure 5), probably a signal for the need for more reviews on coastal adaptation.

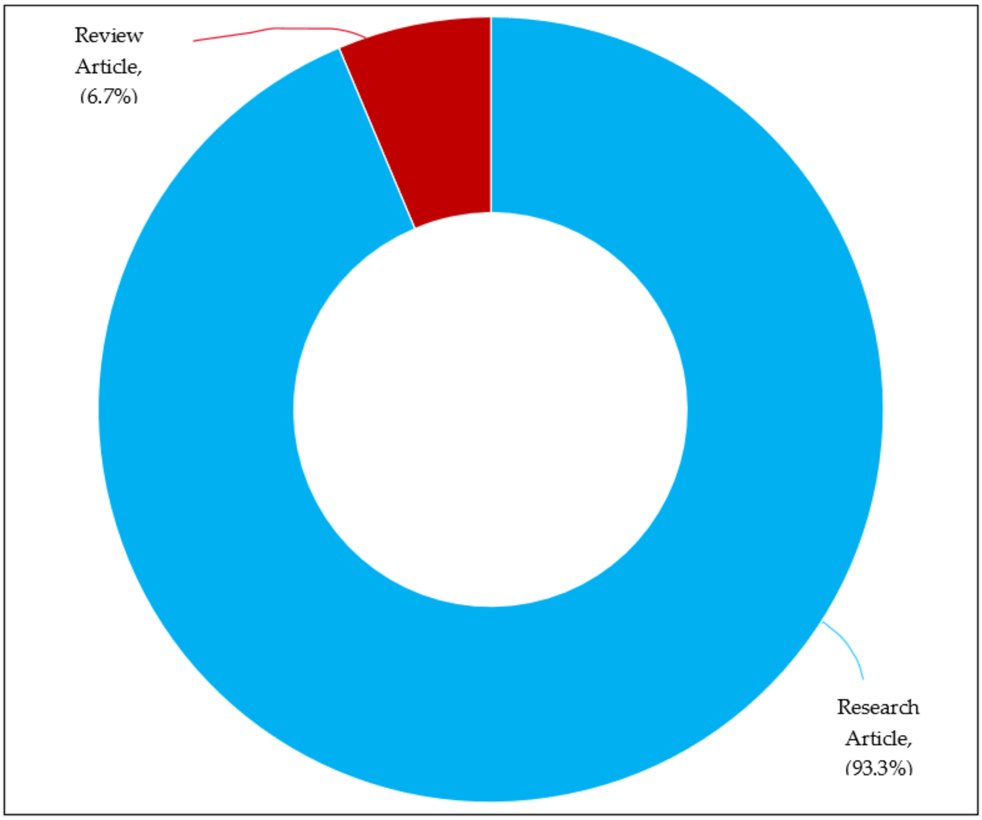

Figure 5. Classification of results based on the type of document.

3.4. Journal-Wise Comparison of Publications Per Year

In this study, the top five journals in terms of publication per year were the Journal of Ocean and Coastal Management, the Coastal Management journal, the Journal of Coastal Engineering, the Journal of Coastal Conservation, and the Journal of Coastal Research (Figure 6).

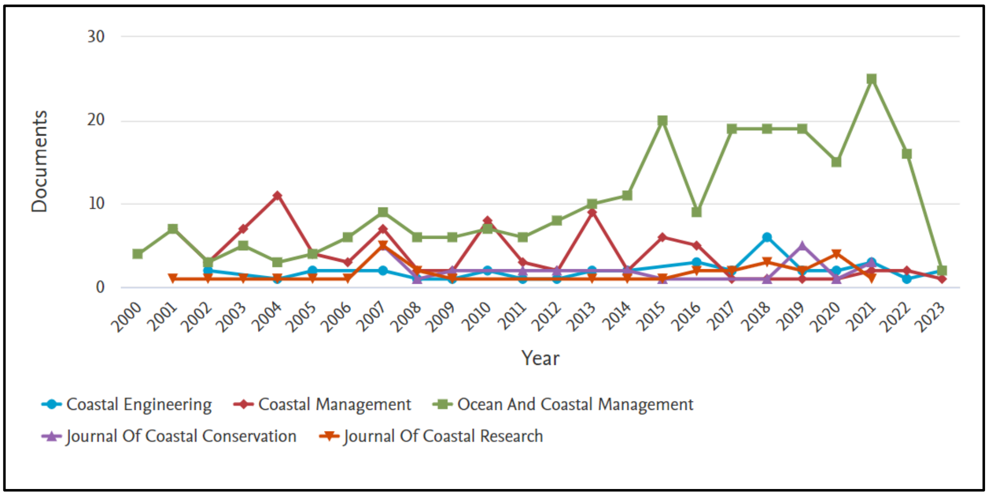

Figure 6. Journal-wise comparison of documents published per year.

The study reveals that the journal Ocean and Coastal Management dominated other journals in terms of the number of documents published per year.

3.5. Classification of Documents by Subject Area

The synthesis of the results indicated that the top five subject areas of research are Environmental Science (36.5%), Earth and Planetary Science (25.6%), Agricultural and Biological Science (19.7%), Engineering (7.0%), and Social Sciences (5.6%), (Figure 7).

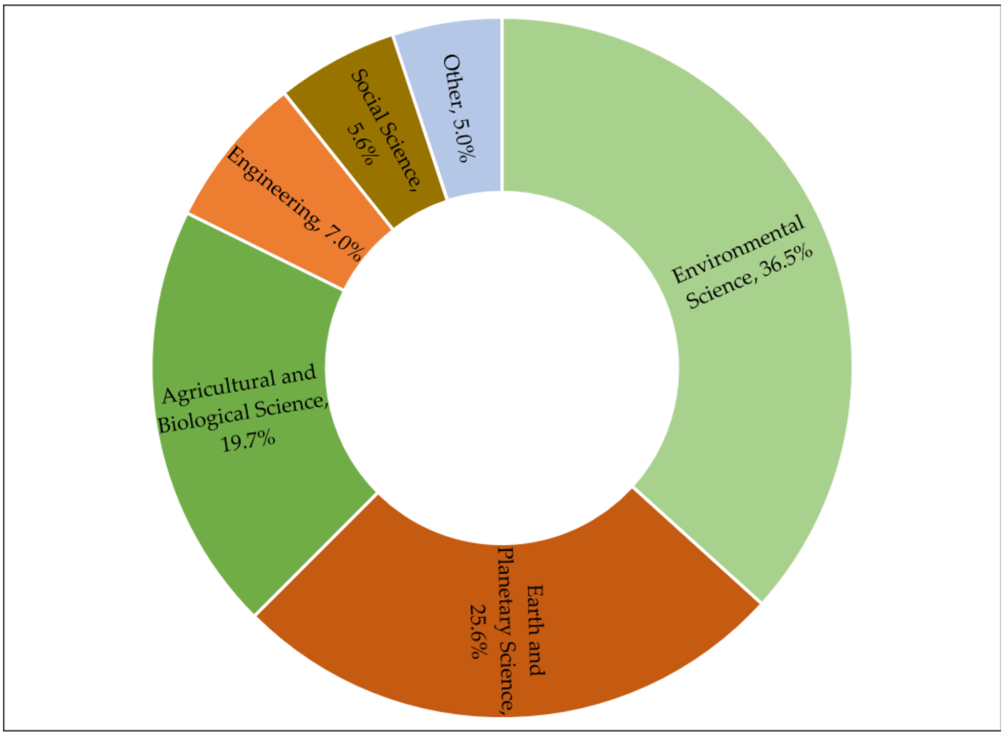

Figure 7. Classification of documents by subject area.

Other subject areas combined, including Energy, Decision Science, and Biochemistry, represented only 5% of the study literature.

3.6. Countrywise Distribution of Documents

The country-wise assessment of the literature (Figure 8) indicates the combined global outlook of the coastal management literature. From this analysis, we can see that 75% of the literature on coastal management policies and coastal infrastructure typologies that passed the inclusion criteria was conducted in developed countries, mainly the USA, Europe, and Australia. Developing countries constitute only 25%, with Africa representing less than 5% of this production. There are no records of the implementation of nature-based infrastructure for coastal protection in Africa.

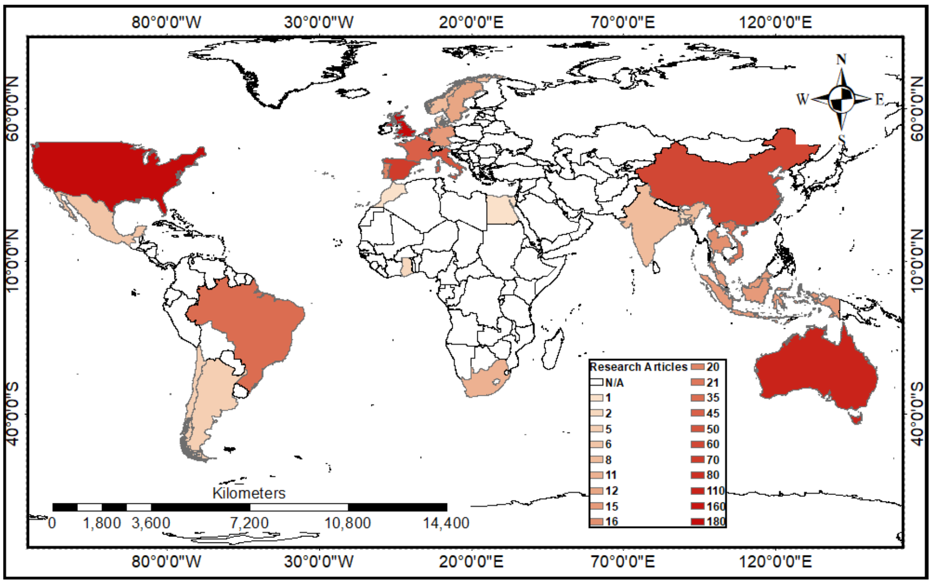

Figure 8. Global overview of the literature on coastal infrastructure and coastal management policy.

Based on these findings, we conclude that although there have been significant advances in coastal management research around the world, research and projects on coastal management policy, including building with nature (hybrid solution), are still underdeveloped in developing countries. The top ten countries (Figure 9) are the United States, the United Kingdom, Australia, and China.

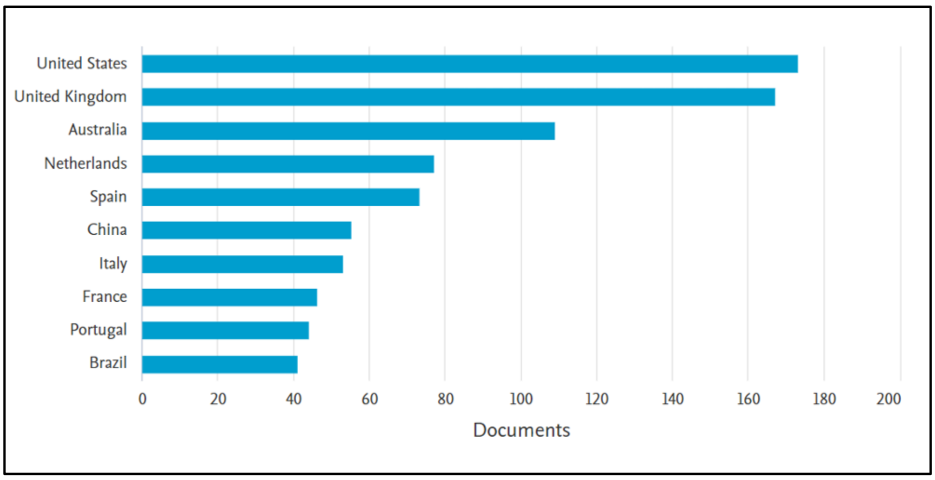

Figure 9. Top 10 countries or territories creating literature on coastal management and coastal infrastructure.

Notably, there is growing literature on coastal management from Australia, Brazil, and Portugal, mostly with regards to integrated coastal management (ICM), pitfalls of shoreline stabilisation [43,44], negative impacts of hard structures in Brazil [27,45,46], and different cases along the Portuguese coast [47,48].

3.7. Summary of Coastal Management Approaches

Table 1 summarises the coastal management approaches established in the literature. Determining the appropriate coastal management strategy to apply for a section of the coast depends on factors such as the rate of erosion or shoreline change, the economic value of threatened land, the value of houses and businesses, the presence of road infrastructure, the value of habitats under threat, and the cost of intervention [6,7].

Table 1. Summary of coastal management strategies [5–7].

Category of Management Strategy	Coastal Management Strategy or Adaptation Policy	Implementing Technologies
IPCC/Coastal Adaptation Approaches	Protect	1. Hard structural options: bulkheads, groynes, seawalls, revetments, levees, floodgates, and dikes [5]. 2. Soft options: Periodic beach nourishments, saltwater intrusion barriers, dune creation and recreation, wetland recreation, and restoration. 3. Indigenous methods: Afforestation, coconut leaf walls, Coconut fibre, stone units, wooden walls, and stone walls [2,5].
	Accommodation	1. Management preparedness for disasters. Involves creating and increasing society's ability to cope with and live with disasters. 2. Emergency planning through early warning systems. 3. Modification of land use through aquaculture and salinity-resilient crops [5]. 4. Modifying building styles using various technologies such as raising houses above ground, increasing the diameter of drainage pipes, improving drainage, and using desalination plants [2,5].
	(Managed) Retreat	1. Establish coastal setbacks. 2. Relocate threatened buildings. 3. Phased-out or no development in vulnerable areas, creating buffers, managed realignment [2,5].
United KingdomShoreline Management Plans	Hold-the-line	Building and maintaining the existing coastal defences in their current positions [6,7].
	Advance the line	Building new defences on the seaward side of existing structures to claim land, and reduce stress on current infrastructure [6,7].
	Managed Realignment	Removing structures in built areas under threat, relocating people away from danger zones, and surrendering to natural processes. Approaches include open space preservation, land buyouts, and land-use planning [5–7].
	No Active Intervention	This entails that no action is taken to prevent intrusion by natural coastal hazards, hence no investments are made in coastal defences [6,7]
Proactive Coastal Adaptation Considerations	Increasing the robustness of infrastructural designs and long-term investments	Changing the tolerance of loss or failure of investments (e.g., by increasing economic reserves or insurance) [1].
	Increasing flexibility of vulnerable managed systems	Setting up midterm adjustments and/or reducing economic lifetimes (including increasing depreciation) [1].
	Enhancing the adaptability of vulnerable natural systems	Managed retreat and Managed realignment [1].
	Reversing maladaptive trends	Introducing setbacks, enforcing development prohibition in vulnerable areas such as coastal floodplains, and eroding cliffs [1].
	Improving societal awareness and preparedness	Setting up early warning systems for coastal floods due to storm surges [1] and beach monitoring. Beach monitoring promotes a shift from reactive to proactive coastal adaptation [1,5].

Coastal adaptation technologies have varying rewards and shortcomings, and the implementation of coastal adaptation is not "one size fits all" [2]. Globally, the success of coastal adaptation is variable due to differences in geography, level of development, and policy [2,5]. Therefore, local factors largely dictate the choice and success of the appropriate coastal adaptation technology. Contemporary research shows that there is a major transition from reactive to proactive coastal management and a shift from hard engineering towards hybrid engineering by incorporating nature and nature-based infrastructure.

3.8. Distribution by Type of Coastal Infrastructure: Strengths and Weaknesses

An analysis of the literature shows more research on green and hybrid infrastructure than grey assets (Figure 10).

Figure 10. Analysis of coastal management policies, coastal infrastructure, and their subtypes.

Of the documents analysed, 12 were MR (relocation, coastal setbacks, land buyouts, and managed retreat), and 16 focussed on hybrid infrastructure, including living shorelines, groynes with beach nourishment, and multiple lines of defence (MLD) approaches [49]. Twenty documents focussed on hard structures alone; six documents analysed ATL strategy, pros, and cons. Green infrastructure had the most documents that included studies on wetland restoration, mangroves, seagrasses, and saltmarshes.

3.9. Summary of Coastal Infrastructure Typologies: Strengths and Weaknesses

Categorising coastal infrastructure (Table 2) is essential to understanding their strengths and weaknesses, impacts on coastal ecosystems, and long-term response to future sea-level rise, which is necessary to support coastal management decision-making [22]. As discussed, the categories of coastal infrastructure used for coastal protection are three-fold: green (natural/soft), grey (hard-engineered), and hybrid (combined green and grey) infrastructure [22].

Table 2. Summary of the strengths and weaknesses of green, grey, and hybrid infrastructure.

Category of Coastal Infrastructure	Typical Examples	Advantages	Disadvantages
Green Infrastructure or soft engineering	Mangroves, Salt marshes, Coral reefs, Oyster reefs, Seagrass beds, Beach recharge, Sand dunes, Dune creation, and recreation. Wetland restoration.	They are acclaimed to be more resilient to climate change impacts [12] and have the potential to self-recover after storm events [22]. Green infrastructure supports ecosystem biodiversity and, hence, ecosystem health. Ecosystems such as mangroves and saltmarshes provide fisheries habitats [36], and improve primary productivity, water quality, and climate change mitigation through carbon sequestration and storage [12,22,30]. It minimises environmental impacts while creating environmental opportunities [29]. Ecosystems such as sandy beaches and dunes provide various functions such as storm protection, nutrient cycling, biological filtration and detoxification of coastal waters, acting as nesting and breeding sites, food stores, and nursery for marine organisms such as turtles, birds, and fish, and providing home and food to human beings, plants, and animals [12,25,26,38]. Green infrastructure is less intrusive on the coast and helps restore and maintain natural landscapes [29].	They are not as effective as hard-engineered approaches and are associated with the nonlinearity of coastal protection and associated co-benefits, and success is variable depending on factors such as the type of ecosystem, geography, and severity of storms [12,22,25]. Due to the relative newness of green approaches, there is limited coastal planning expertise in the field [12]. Green infrastructure projects, such as ecosystem restoration, require a substantial amount of space to implement, and such spatial requirements may not be feasible [22]. It is difficult to quantify the coastal protection provided by natural systems [12,24,25]. Green infrastructure takes a long time to be fully established to provide the necessary level of coastal protection [22]. There is limited expertise in coastal planning and engineering with nature [8,22].
Grey Infrastructure or hard engineering	Seawalls, Revetments, Groynes, Breakwaters, Storm surge barriers, Closure dams, Levees, Jetties.	They are fairly easy to construct using diverse materials such as rocks or granite boulders. They hold the line against coastal erosion [29] and provide immediate and effective storm protection [22]. They provide maximum protection against coastal erosion and flooding if well-designed [2]. They have a global implementation, known engineering standards, level of protection, and lifespan [12,22]. They already have trusted experts in their design and implementation. Moreover, there is a clear understanding of their functionality and level of protection at different levels of protection [22].	They lack dynamic protection from changing conditions such as sea-level rise, offer no co-benefits under normal conditions, and their protective capacity weakens with time [22]. They have high initial capital costs. They hinder the natural sand deposition on the coast [26]. They cause sediment starvation and erosion migration to adjacent sites [29]. They damage habitats during construction, leading to the loss, migration, and extinction of species [12,25,27]. Defences such as seawalls interfere with natural processes such as habitat migration [2] and contribute to coastal squeeze by obstructing the natural landward migration of coastal systems [2,29,50,51]. They affect water colour, genera of organisms living in sediments, and are susceptible to invasion by alien species [12,25].

Table 2. *Cont.*

Category of Coastal Infrastructure	Typical Examples	Advantages	Disadvantages
Hybrid infrastructure	Living shorelines Groynes and beach nourishment Buried revetments [52]. Headland-controlled pocket beaches [52].	Hybrid infrastructure is trusted to leverage the advantages of both green and grey infrastructure with a focus on sustainable protection and coastal resilience [12,22,24]. Compared to hard-engineered structures, living shorelines have fairly minimum annual maintenance costs after major storm events due to the self-repair capabilities of natural stock. [25]. Compared to natural infrastructure, they have a greater level of confidence and trust among investors and stakeholders [22] They can also be used in areas where there are space limitations.	Since hybrid approaches are still growing, there are limited data and expertise in coastal planning and engineering with nature [22]. Hybrid infrastructure requires more research and innovation [22]. There is success variability in geography and coastal management policy [12,25]. The costs vary with geographic location and are largely dependent on the frequency of maintenance [25]. There are limited data on the cost-benefit ratios for hybrid infrastructure projects [22]. This undermines investor confidence and risk appetite.

Analysis of the setbacks of different coastal infrastructure typologies shows the need to balance the triple bottom line of sustainability—the environmental, social, and economic parameters. Therefore, to guarantee sustainability, the implementation of coastal protection infrastructure should be performed in consideration of the impacts on adjacent landscapes, coastal livelihoods, and ecosystems.

3.10. Implementation of Coastal Management Policy and Infrastructure in Ghana

In this study, six documents [28,41,53–56] described coastal management in Ghana. Although there are no instituted SMPs along the coast of Ghana, evidence from literature reviews [53] and handbooks of coastal management in Ghana [41,54] and West Africa [56] and empirical research findings [28,55] on coastal infrastructure in Ghana. We highlighted the key gaps in coastal management policy in Ghana, reviewed the reactive versus proactive application of strategies, historic implementation of coastal protection, key gaps in coastal management, ad hoc implementation of coastal protection, and discussed the opportunities for green and hybrid infrastructure in Ghana, benchmarking local coastal adaptation to global practices.

3.10.1. Major Gaps in Coastal Management Policy in Ghana

Many researchers [41,53,57,58] identify the key coastal management policy gaps in Ghana to include: (1) the absence of shoreline management plans (SMPs) to regulate which coastal management policy (HTL, ATL, MR, and NAI) to apply for a particular coast or region; (2) the multiplicity of coastal management regulations; (3) the multiplicity of disjointed coastal management institutions; (4) the non-implementation of coastal management decisions and environmental laws, a culture that has worsened problems of brisk real estate developments, encroachment into wetlands and land degradation [54], and coastal sediment mining [59], altogether contributing to severe coastal erosion and unsustainable coastal changes. Traditionally, exploitation of coastal sediment is considered an endowment that coastal communities have a right to [54,59]; (5) the exclusion of key stakeholders, including coastal communities and research institutions, from coastal management decision-making, from planning to implementation [53]. Consequently, in most cases, coastal communities do not have a voice in coastal adaptation approaches; (6) political implementation of defences by the government or political interference in coastal management matters [41,54]. Political interference in coastal management has also led to the dominant use of a single approach—the hold the line strategy—and a single type of material, which is granite rocks (Table 3). Consequently, all forms of grey infrastructure along the coast—revetments, seawalls, jetties, and groynes—are most often constructed using granite rock. This is primarily because: (1) granite rocks require less maintenance and support the build-and-forget strategy; (2) granite rocks are less affected by ocean processes (e.g., salination, corrosion); and (3) compared to concrete structures, they are locally sourced and fairly cheap. However, this does not exonerate the policymakers from the deliberate choice of one method over other options that could have been better, more effective, and more sustainable.

Table 3. Coastal management strategies and coastal infrastructure implemented in Ghana, based on previous studies [55].

Coastal District	Name of Place	Coastal Management Policy	Coastal Infrastructure Typology						Total Length
			Groynes			Seawalls/ Revetments	Jetties	Material	
			No. of Groyne Fields	No. of Groynes in the Field	Alongshore Distance (m)	Length	Length	Rock	
Ketu South	Blekusu	HTL	2	18	4000	0	0	Rock	4000
Keta Municipal	Keta	HTL	1	7	2600	760	1	Rock	3360
Keta Municipal	Atorkor, Agbledom	HTL	1	13	3500	2735	1	Rock	6235
Ada East	Ada Foa	HTL	1	22	16,000	0	0	Rock	16,000
Ningo Prampram	New Ningo	HTL	1	14	3915	186	10	Rock	4915
Ningo Prampram	Old Ningo	HTL	1	8	1457	114	20	Rock	1471
Tema Metropolis	Sakumono	HTL	0	0	0	4932	0	Rock	4932
Kpone Katamanso	Kpone Katamanso	HTL	0	0	0	225	0	Rock	225
Ledzokuku	Ledzokuku	HTL	0	0	0	264	0	Rock	264
Ladade Kotopon	Labad	HTL	0	0	0	296	0	Rock	296
Accra Metro	Glefe	HTL	1	2	300	1, 662	0	Rock	1962
Gomoa Central	Gomoa	HTL	0	0	0	3, 538	0	Rock	3538
Mfantisman	Anomabo	HTL	1	7	1200	2371	90	Rock	3571
Mfantisman	Agyei	HTL	0	0	0	1256	0	Rock	1256
Cape Coast	Oasis Beach	HTL	1	4	600	900	1	Rock	1500
Cape Coast	Lemom Beach	HTL	1	5	600	900	1	Rock	1500
Cape Coast	Variable places	HTL	0	0	0	5000	1	Rock	3364
Komenda	Elmina	HTL	1	4	600	6343	1	Rock	6943
Edna Agufo	Komenda	HTL	2	12	600	2856	2	Rock	2856
Shama	Aboadze	HTL	1	1	30	5365	6	Rock	5365
Takoradi	Takoradi	HTL	0	0	0	3641	2	Rock	3641
	New Takoradi	HTL	0	0	0	5947	2	Rock	5947
New Amanful	Funko	HTL	2	3	360	4110	2	Rock	4470
Multiple districts	Multiple areas	NAI	Many areas are naturally not protected along the coast of Ghana, not as a shoreline management plan but mostly due to the absence of officially designated SMPs.						

3.10.2. Reactive versus Proactive Adaptation

In this review, we take a panorama of coastal management responses to benchmark local implementation to global practices. In these lenses, we establish that even though some coastal protection projects along the coast of Ghana involved planned or proactive responses, e.g., Keta Sea Defence Project (2000–2004), Cape Coast Coastal Protection (2019–2021), Axim Sea Defence Project (2015–ongoing), and Ada (2013–2015) [60]. However, following the construction of the KSDP in 2004, coastal adaptation became more reactive than proactive, mostly due to coastal erosion migration and impacts on downdrift coasts [28]. Therefore, between 2000 and 2022, there were more ad hoc and reactive responses, which led to the construction of more than 15 coastal protection projects. The inexhaustive list includes Ada SDP, Atorkor groyne system and revetment, Sakumono, Dansoman, Glefe, Mumford, Anomabo, Cape Coast (Oasis Beach), Elmina (Coconut Groove and Lemon Beach), Komenda, Adwoa, Discove, Axim, and Ningo-Prampram [55], and

15 fishing harbours, which include Axim, Dixcove, Winneba, Senya Beraku, Elmina, James Town, Gomoa Fetteh, Moree, Mumford, Teshie, Keta, Osu, Mfantseman, and Otuam [61]. Presently, coastal management in Ghana has been broadly static and reactive. To correct this trend, many researchers [41,53,58] recommended, among other suggestions, the development of SMPs for sustainable coastal management in Ghana. While the development of SMPs could apparently improve coastal management, questions arise about whether the district authorities that are mandated to manage coastal erosion have the capacity to deliver their functions [41]. Reactive adaptation in Ghana is evident through "quick fixes" or "piece meal approaches" that are linked to the culture to provide temporary protection, cutting spending budgets in the short term, but also to capitalize on the long-term effectiveness of hard-engineered structures. In addition, due to the politicization of the implementation of defences, there is often a lack of moral responsibility to plan for long-term adaptation or dynamic management of the coast.

3.10.3. A History of Hard Engineering: Grey versus Green and Hybrid Infrastructure

Throughout the history of coastal management in Ghana, hard engineering has been at the centre of coastal management discussions. Many factors, including high costs of engineering, a lack of engineering capacity, a lack of equipment (dredgers, caterpillars, etc.), and a shortage of skilled human capital, thwarted historic coastal protection endeavours [62]. Evidently, these issues are still recurrent today, not only in Ghana but in the West African region [53]. In addition, hard engineering is also attached to the political implementation of coastal defences, often characterised by standoffs between the government and coastal communities [62]. The summary of the major implemented coastal infrastructure typologies in Ghana is detailed in Table 3, categorised under the respective coastal management strategy, based on a previous study mapping the implemented defences and their spatial distribution along the coast of Ghana [55]. This information points to the general conclusion that the "hold the line" strategy and grey infrastructure are the primary approaches used for coastal adaptation in Ghana.

In this study, we observe that most coastal defences in Ghana are implemented using the hold the line policy and grey infrastructure. Figure 11 shows some of the coastal projects. Since virtually all coastal protection in Ghana was implemented using grey infrastructure, it can be concluded that, in the absence of instituted SMPs, the HTL strategy is, unofficially, the coastal management policy used along the coast of Ghana. Currently, it is estimated that nearly 20% of the coast of Ghana is protected by hard defences [55]. This may seem small in terms of global comparison; e.g., 45.6% of England's coastline is protected by coastal defences [9]. However, given the severity of coastal hazards and demands for more protection, the continuous armouring of the coast may significantly affect the future coastal management and sustainability aspects of the coastal area.

3.10.4. Hybrid Coastal Infrastructure: Challenges and Opportunities

In Ghana, although hybrid infrastructure has been applied, e.g., groyne and beach nourishment at Keta, Ada [60], and Blekusu, this approach is not widespread due to its high cost [53,56]. For instance, beach nourishment was discontinued at Ada due to high costs. However, the cessation of beach refill coupled with the lack of maintenance plans caused the deterioration of the groyne system, compromising permeability and groyne function. In addition, many opportunities exist for green infrastructure projects. However, only a few green infrastructure projects have been piloted, mainly mangrove restoration and afforestation. Because the coast has favourable deltaic and estuarine ecosystems [41], there are many opportunities for pilot projects with living shorelines, dune reclamation, and rehabilitation.

Figure 11. Coastal infrastructure along the coast of Ghana showing (**a**) Axim sea defence; (**b**) Blekusu groyne field; (**c**) Atokor revetment; and (**d**) Cape Coast (Oasis Beach) groyne field and seawall, all implemented using the HTL and grey infrastructure [55].

4. Discussion

Coastal management policies and coastal infrastructure have evolved rapidly over the past two decades to adapt to increasing threats from climate-induced coastal hazards [63]. In this study, we highlighted research on contemporary coastal management strategies and positioned their application along the coast of Ghana. Despite contemporary transitions from grey to green and hybrid coastal infrastructure [12,24,25,32,33], coastal management research in developing countries, such as Ghana, remains underexplored [11]. In Ghana, coastal adaptation remains static, dominated by hold the line strategies using coastal grey infrastructure [41]. Our examination of the wide array of coastal adaptation technologies (green, grey, and hybrid) shows varying rewards and shortcomings. Mostly, it was established that the success of coastal adaptation is variable from place to place, and local factors largely dictate the choice and appropriateness of coastal adaptation technology [2].

4.1. No Single Panacea for Coastal Adaptation

Coastal areas are dynamic areas that evolve rapidly in response to many factors, such as an increase in climate-induced SLR [63]. Moreover, coastal adaptation is not "one size fits all", and not a single solution can address all problems [2,5]. Therefore, coastal adaptation will continue to have a mix of green and grey infrastructure. To achieve efficiency, enabling shoreline management policy frameworks and institutional reforms are necessary to overcome barriers and address gaps in coastal management. In developing contexts, most implemented projects may have lapsed their design time frames due to the inherent "build and forget" culture, hence the need for revision of coastal adaptation policies towards dynamic management, also considering future sea-level rise projections. Here, we acknowledge and emphasise the global philosophy that coastal areas are dynamic ecosystems, and as such, dynamic coastal management should prevail as the first option before any attempt to consider hard engineering options [25]. The objective is to maximise hybrid (nature-based) adaptation solutions where appropriate [22], instead of hold the line policies using static, hard engineering. Since the goal of coastal protection is to reduce coastal vulnerability, we also acknowledge that no active intervention approaches (do nothing) may not be preferable as communities need protection and relocation may be impossible due to high costs, the attachment of communities to their traditional lands, and the lack of government support.

4.2. Hybrid Infrastructure, Scalability, and the Future of Coastal Adaptation

The integration of green and grey infrastructure is essential to enhancing coastal resilience [8,12,24,25,64,65]. Contemporary research on coastal infrastructure is increasingly hybrid-infrastructure-centric, e.g., living shorelines [37,38], BwN [32], EwN [8,37], and NbS [12,24,33,66,67]. Notably, NbS has taken centre stage during the past decade in both research and policymaking (2012–2022), [35]. During the 2022 Climate Change Convention (CCC), Conference of Parties (COP) 27, an initiative was accorded to coordinate global efforts to address climate change, land and ecosystem degradation, and biodiversity loss through NbS [39]. Moreover, the United Nations Decade of Ocean Science for Sustainable Development (UN Ocean Decade) supports NbS through the UN Decade on Ecosystem Restoration (UNESCO–IOC, 2022). Therefore, NbS has been positioned as the future nature-based coastal defence strategy. Morris et al. [36] established that improved scientific knowledge, effective governance, and social acceptance are key to upscaling NbS [36]. It is therefore likely that the next decade will see a boom in innovation and engineering with nature-based infrastructure.

4.3. Knowledge Gaps and Opportunities for Engineering with Nature

Developing countries cannot afford to be left out in the race for hybridisation of coastal adaptation. Although there are regional implementation knowledge gaps, opportunities exist to leverage decision-support tools for developing countries [8,33,38]. Working with nature requires careful adaptation planning, with no shortcuts. In West Africa, adaptation technologies such as beach nourishments previously applied in Ada, Ghana [60], Gambia, and Nigeria [53] were discontinued due to high costs. This provides evidence that beach nourishment is usually problematic in developing countries because it requires expensive periodic top-ups [2,5]. There is increasing need to understand stakeholders' preferences for different coastal infrastructure options [11]. In addition, the lack of both technology and knowledge on EwN or BwN contributes to the minimum implementation. Linham and Nicholls [2] rated that developing countries have a low degree of experience across different coastal infrastructures, ranging from artificial dunes creation and rehabilitation to storm surge barriers, wetland restoration, and managed realignment [2]. To guarantee success, governments can leverage finance, technology, and know-how from development partners [8,37,38,64] and engage stakeholders and policymakers in planning and execution to accelerate success.

4.4. Stakeholder Engagement and Good Governance Structures

Adaptation is, by and large, a social, political, and economic process [1]. The key factors for successful coastal adaptation are stakeholder engagement, public education, and awareness [2,5,8,33]. Contemporary research indicates that bottom-up approaches are favourable, successful [2,5], and most top-down solutions fail due to the non-inclusion of communities to improve adaptive capacities. Therefore, stakeholders must be continually engaged to understand their perception of risks and their perception of dynamic responses such as relocation, which could be affected by community attachment to the coast, financial (and insurance) considerations, knowledge gaps, preferences, and motivations regarding protective versus ecosystem service benefits [11]. Overall, the success of any coastal management policy depends on governance and the engagement of policymakers, public and private stakeholders, and civil society in the short, medium, and long-term planning for coastal adaptation.

5. Conclusions

In the past two decades, there have been considerable advances in coastal management and coastal infrastructure. In this study, we identified, categorised, and discussed the major classifications of coastal management approaches and different coastal infrastructure typologies used for coastal protection and their subtypes. We observe two general schools of thought regarding coastal management approaches or policies: (1) protect, accommodate, and retreat; and (2) UK SMP classification (HTL, ATL, MR, and NAI). Similarly, coastal infrastructure was broadly classified into three categories: grey (hard-engineered), green (natural and nature-based), and hybrid (integrated green and grey). However, we observe that different authors use different terminologies regarding green and hybrid infrastructure. For instance, the terms nature-based solutions (NbS), nature and nature-based infrastructure (NNBI), and nature-based feature (NBF) were used in different research contexts to refer to the hybridization of green and grey infrastructure. The results indicate that there is a significant global advance towards hybrid engineering using nature and nature-based solutions.

Despite the global advances towards dynamic management and hybrid coastal infrastructure, there is still a huge research gap on coastal infrastructure in developing countries, especially research on engineering with nature. In this regard, coastal management in Ghana remains mostly static, using hold the line strategies and grey infrastructure for coastal protection. In addition, the absence of properly instituted shoreline management plans creates a culture of reactive, build and forget, ad hoc implementation of coastal protection using hard-engineered infrastructure. As a result of the ad hoc implementation of coastal projects, it can be argued that the hold the line strategy is prevailing. Unfortunately, the spontaneous use of grey infrastructure is linked to unsustainable impacts, mainly coastal erosion migration to downdrift communities, turning natural, stable shorelines into new erosion hotspots and thus complicating the entire coastal management function.

Lastly, the implementation of coastal adaptation technologies cannot be generalised, variable on differences in geography, policy, and level of development. Different coastal adaptation technologies also have varying advantages and disadvantages. We observed two trends in contemporary coastal management research: (1) there is a global emphasis on proactive approaches, such as dynamic or adaptive management, instead of the traditional static or reactive approaches; and (2) there is more and more drive towards integrated approaches through the engagement of stakeholders to guarantee the success of projects. Therefore, we acknowledge that stakeholder engagement is increasingly important to establish perspectives regarding coastal management policy, e.g., managed realignment, and to establish knowledge gaps or mainstream the uptake of nature and nature-based infrastructure for climate change adaptation.

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References

1. Tol, R.S.J.; Klein, R.J.T.; Nicholls, R.J. Towards Successful Adaptation to Sea-Level Rise along Europe's Coasts. *J. Coast. Res.* **2008**, *242*, 432–442. [CrossRef]
2. Linham, M.M.; Nicholls, R.J. *Technologies for Climate Change Adaptation. Coastal Erosion and Flooding*; United Nations Environment Programme (UNEP): Nairobi, Kenya, 2010. Available online: https://www.osti.gov/etdeweb/biblio/1010716 (accessed on 13 May 2021).
3. IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; The Intergovernmental Panel on Climate Change (IPCC): Geneva, Switzerland, 2021. Available online: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf (accessed on 25 March 2022).
4. IPCC. *The Ocean and Cryosphere in a Changing Climate: Special Report of the Intergovernmental Panel on Climate Change*, 1st ed.; Cambridge University Press: Cambridge, UK, 2022. [CrossRef]
5. Klein, R.J.; Nicholls, R.J.; Ragoonaden, S.; Capobianco, M.; Aston, J.; Buckley, E.N. Technological Options for Adaptation to Climate Change in Coastal Zones. *J. Coast. Res.* **2001**, *17*, 531–543.
6. DEFRA. *Shoreline Management Plan Guidance Volume 1: Aims and Requirements*; Department for Environment, Food and Rural Affairs: London, UK, 2006. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69206/pb11726-smpg-vol1-060308.pdf (accessed on 8 August 2021).
7. DEFRA. *Shoreline Management Plan Guidance Volume 2: Procedures*; Department for Environment, Food and Rural Affairs: London, UK, 2006. Available online: www.defra.gov.uk/environ/fcd/ (accessed on 19 January 2021).
8. Bridges, T.; King, J.; Simm, J.; Beck, M.; Collins, G.; Lodder, Q.; Mohan, R. *International Guidelines on Natural and Nature-Based Features for Flood Risk Management*; Engineer Research and Development Center (U.S.): Vicksburg, MS, USA, 2021. [CrossRef]
9. Kirby, J.A.; Masselink, G.; Essex, S.; Poate, T.; Scott, T. Coastal adaptation to climate change through zonation: A review of coastal change management areas (CCMAs) in England. *Ocean Coast. Manag.* **2021**, *215*, 105950. [CrossRef]
10. Beasley, W.J.; Dundas, S.J. Hold the line: Modeling private coastal adaptation through shoreline armoring decisions. *J. Environ. Econ. Manag.* **2021**, *105*, 102397. [CrossRef]
11. Mallette, A.; Smith, T.F.; Elrick-Barr, C.; Blythe, J.; Plummer, R. Understanding Preferences for Coastal Climate Change Adaptation: A Systematic Literature Review. *Sustainability* **2021**, *13*, 8594. [CrossRef]
12. Sutton-Grier, A.E.; Wowk, K.; Bamford, H. Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environ. Sci. Policy* **2015**, *51*, 137–148. [CrossRef]
13. Sengupta, D.; Chen, R.; Meadows, M.E.; Choi, Y.R.; Banerjee, A.; Zilong, X. Mapping Trajectories of Coastal Land Reclamation in Nine Deltaic Megacities using Google Earth Engine. *Remote Sens.* **2019**, *11*, 2621. [CrossRef]
14. Sengupta, D.; Chen, R.; Meadows, M.E. Building beyond land: An overview of coastal land reclamation in 16 global megacities. *Appl. Geogr.* **2018**, *90*, 229–238. [CrossRef]
15. Sengupta, D.; Choi, Y.R.; Tian, B.; Brown, S.; Meadows, M.; Hackney, C.R.; Banerjee, A.; Li, Y.; Chen, R.; Zhou, Y. Mapping 21st Century Global Coastal Land Reclamation. *Earth's Future* **2023**, *11*, e2022EF002927. [CrossRef]
16. Dundon, L.A.; Abkowitz, M. Climate-induced managed retreat in the U.S.: A review of current research. *Clim. Risk Manag.* **2021**, *33*, 100337. [CrossRef]
17. Dyckman, C.S.; St. John, C.; London, J.B. Realizing managed retreat and innovation in state-level coastal management planning. *Ocean Coast. Manag.* **2014**, *102*, 212–223. [CrossRef]
18. Sylaios, G.K.; Lalenis, K.; Anastasiou, S.; Papatheocharis, I.; Kokkos, N. A Tool for Coastal Setbacks Demarcation over Rough, Impermeable Shores: The Test Case of Kavala Coastline (Northern Greece). *Coast. Manag.* **2015**, *43*, 519–538. [CrossRef]
19. MacDonald, M.A.; de Ruyck, C.; Field, R.H.; Bedford, A.; Bradbury, R.B. Benefits of coastal managed realignment for society: Evidence from ecosystem service assessments in two UK regions. *Estuar. Coast. Shelf Sci.* **2020**, *244*, 105609. [CrossRef]
20. Hanna, C.; White, I.; Glavovic, B.C. Managed retreats by whom and how? Identifying and delineating governance modalities. *Clim. Risk Manag.* **2021**, *31*, 100278. [CrossRef]
21. Ajibade, I.; Sullivan, M.; Lower, C.; Yarina, L.; Reilly, A. Are managed retreat programs successful and just? A global mapping of success typologies, justice dimensions, and trade-offs. *Glob. Environ. Chang.* **2022**, *76*, 102576. [CrossRef]
22. Hill, K. Coastal infrastructure: A typology for the next century of adaptation to sea-level rise. *Front. Ecol. Environ.* **2015**, *13*, 468–476. [CrossRef]
23. Schoonees, T.; Gijón Mancheño, A.; Scheres, B.; Bouma, T.J.; Silva, R.; Schlurmann, T.; Schüttrumpf, H. Hard Structures for Coastal Protection, towards Greener Designs. *Estuaries Coasts* **2019**, *42*, 1709–1729. [CrossRef]

24. Sutton-Grier, A.E.; Gittman, R.K.; Arkema, K.K.; Bennett, R.O.; Benoit, J.; Blitch, S.; Burks-Copes, K.A.; Colden, A.; Dausman, A.; DeAngelis, B.M.; et al. Investing in Natural and Nature-Based Infrastructure: Building Better Along Our Coasts. *Sustainability* **2018**, *10*, 523. [CrossRef]
25. Powell, E.J.; Tyrrell, M.C.; Milliken, A.; Tirpak, J.M.; Staudinger, M.D. A review of coastal management approaches to support the integration of ecological and human community planning for climate change. *J. Coast. Conserv.* **2019**, *23*, 1–18. [CrossRef]
26. Pilkey, O.H.; Cooper, J.A.G. *The Last Beach*; Duke University Press: Durham, NC, USA, 2014. [CrossRef]
27. Rangel-Buitrago, N.; Williams, A.T.; Anfuso, G. Hard protection structures as a principal coastal erosion management strategy along the Caribbean coast of Colombia. A chronicle of pitfalls. *Ocean Coast. Manag.* **2018**, *156*, 58–75. [CrossRef]
28. Angnuureng, D.B.; Appeaning Addo, K.; Wiafe, G. Impact of sea defense structures on downdrift coasts: The case of Keta in Ghana. *Cademia J. Environ. Sci.* **2013**, *1*, 104–121.
29. Mycoo, M.; Chadwick, A. Adaptation to climate change: The coastal zone of Barbados. *Proc. Inst. Civ. Eng.-Marit. Eng.* **2012**, *165*, 159–168. [CrossRef]
30. Bulleri, F.; Chapman, M.G. The introduction of coastal infrastructure as a driver of change in marine environments. *J. Appl. Ecol.* **2010**, *47*, 26–35. [CrossRef]
31. Kantamaneni, K.; Rice, L.; Du, X.; Allali, B.; Yenneti, K. Are Current UK Coastal Defences Good Enough for Tomorrow? An Assessment of Vulnerability to Coastal Erosion. *Coast. Manag.* **2022**, *50*, 142–159. [CrossRef]
32. Bouw, M.; Eekelen, E. *Building with Nature: Creating, Implementing and Upscaling Nature-Based Solutions*; nai010: Rotterdam, The Netherlands, 2020.
33. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. *Nature-Based Solutions to Address Global Societal Challenges*; IUCN International Union for Conservation of Nature: Gland, Switzerland, 2016.
34. CGIES Task Force. *Ecosystem-Service Assessment: Research Needs for Coastal Green Infrastructure*; The National Science and Technology Council (NSTC): Washington, DC, USA, 2015. Available online: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/cgies_research_agenda_final_082515.pdf (accessed on 25 February 2021).
35. Spalding, M.D.; Ruffo, S.; Lacambra, C.; Meliane, I.; Hale, L.Z.; Shepard, C.C.; Beck, M.W. The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean Coast. Manag.* **2014**, *90*, 50–57. [CrossRef]
36. Morris, R.; Strain, E.M.A.; Konlechner, T.M.; Fest, B.J.; Kennedy, D.M.; Arndt, S.K.; Swearer, S.E. Developing a nature-based coastal defence strategy for Australia. *Aust. J. Civ. Eng.* **2019**, *17*, 167–176. [CrossRef]
37. Currin, C.A. Living Shorelines for Coastal Resilience. In *Coastal Wetlands*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 1023–1053. [CrossRef]
38. NOAA. *Guidance for Considering the Use of Living Shorelines*; National Oceanic and Atmospheric Administration (NOAA): Seattle, WA, USA, 2015. Available online: https://www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf (accessed on 30 October 2021).
39. IUCN. *Egyptian COP27 Presidency, Germany and IUCN Announce ENACT Initiative for Nature-Based Solutions*; IUCN: Gland, Switzerland, 2022. Available online: https://www.iucn.org/press-release/202211/egyptian-cop27-presidency-germany-and-iucn-announce-enact-initiative-nature (accessed on 8 April 2023).
40. Rosenzweig, C.; Solecki, W.D.; Blake, R.; Bowman, M.; Faris, C.; Gornitz, V.; Horton, R.; Jacob, K.; LeBlanc, A.; Leichenko, R.; et al. Developing coastal adaptation to climate change in the New York City infrastructure-shed: Process, approach, tools, and strategies. *Clim. Chang.* **2011**, *106*, 93–127. [CrossRef]
41. Wiafe, G.; Boateng, I.; Appeaning-Addo, K. *Handbook for Coastal Processes and Management in Ghana*; Choir Press: Gloucester, UK, 2013. Available online: https://researchportal.port.ac.uk/en/publications/handbook-for-coastal-processes-and-management-in-ghana (accessed on 19 March 2022).
42. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ* **2009**, *339*, b2535. [CrossRef]
43. Brayshaw, S.; Lemckert, C. Pitfalls of Shoreline Stabilisation–Tweed River Mouth, Gold Coast, Australia. In *Pitfalls of Shoreline Stabilization*; Cooper, J.A.G., Pilkey, O.H., Eds.; Coastal Research Library; Springer: Dordrecht, The Netherlands, 2012; Volume 3, pp. 1–13. [CrossRef]
44. Cooper, J.A.G.; Pilkey, O.H. (Eds.) *Pitfalls of Shoreline Stabilization: Selected Case Studies*; Coastal Research Library; Springer: Dordrecht, The Netherlands, 2012; Volume 3. [CrossRef]
45. Da Veiga Lima, F.A.; de Souza, D.C. Climate change, seaports, and coastal management in Brazil: An overview of the policy framework. *Reg. Stud. Mar. Sci.* **2022**, *52*, 102365. [CrossRef]
46. Frohlich, M.; Smith, T.F.; Fidelman, P.; Baldwin, C.; Jacobson, C.; Carter, R.W. Towards adaptive coastal management law: Lessons from Australia and Brazil. *Ocean Coast. Manag.* **2022**, *219*, 106057. [CrossRef]
47. Antunes do Carmo, J.S. The changing paradigm of coastal management: The Portuguese case. *Sci. Total Environ.* **2019**, *695*, 133807. [CrossRef] [PubMed]
48. Schmidt, L.; Prista, P.; Saraiva, T.; O'Riordan, T.; Gomes, C. Adapting governance for coastal change in Portugal. *Land Use Policy* **2013**, *31*, 314–325. [CrossRef]
49. Le Xuan, T.; Ba, H.T.; Thanh, V.Q.; Wright, D.P.; Hasan Tanim, A.; Tran Anh, D. Evaluation of coastal protection strategies and proposing multiple lines of defense under climate change in the Mekong Delta for sustainable shoreline protection. *Ocean Coast. Manag.* **2022**, *228*, 106301. [CrossRef]

50. Pilkey, O.H.; Cooper, J.A.G. Are natural beaches facing extinction? *J. Coast. Res.* **2014**, *70*, 431–436. [CrossRef]
51. Zhi, L.; Li, X.; Bai, J.; Shao, D.; Cui, B.; Mu, Y.; Ma, T.; Xie, X.; Bilal, H.; Abdullahi, U. Seawall-induced impacts on large river delta wetlands and blue carbon storage under sea level rise. *Sci. Total Environ.* **2023**, *859*, 159891. [CrossRef]
52. Hughes, S.A. *Coastal Engineering Considerations in Coastal Zone Management (Coastlines of the World)*; American Society of Civil Engineers: New York, NY, USA, 1993.
53. Alves, B.; Angnuureng, D.B.; Morand, P.; Almar, R. A review on coastal erosion and flooding risks and best management practices in West Africa: What has been done and should be done. *J. Coast. Conserv.* **2020**, *24*, 38. [CrossRef]
54. Adams, O.D.; Donkor, P.O.; Kankam, S.; Mensah, J.C. *A Planner's Guide to Integrated Coastal Management in the Central Region of Ghana*; University of Rhodes Island: Kingston, RI, USA, 2017.
55. Charuka, B.; Angnuureng, D.B.; Agblorti, S.K.M. Mapping and assessment of coastal infrastructure for adaptation to coastal erosion along the coast of Ghana. *Anthr. Coasts* **2023**, *6*, 11. [CrossRef]
56. Alves, B.; Angnuureng, D.B.; Almar, R.; Louarn, A.; Rossi, P.L.; Corsini, L.; Morand, P. *Compendium: Coastal Management Practices in West Africa*; West Africa Coastal Management Area (WACA): Benin, Ghana, 2022. Available online: https://www.wacaprogram.org/knowledge/compendium-coastal-management-practices-west-africa (accessed on 19 March 2022).
57. Appeaning Addo, K.; Appeaning Addo, I. Coastal erosion management in Accra: Combining local knowledge and empirical research. *Jàmbá J. Disaster Risk Stud.* **2016**, *8*, 10. [CrossRef]
58. Boateng, I.; Wiafe, G.; Jayson-Quashigah, P.-N. Mapping Vulnerability and Risk of Ghana's Coastline to Sea Level Rise. *Mar. Geod.* **2016**, *40*, 23–39. [CrossRef]
59. Jonah, F.E.; Adams, O.; Aheto, D.W.; Jonah, R.E.; Mensah, E.A. Coastal zone management challenges in Ghana: Issues associated with coastal sediment mining. *J. Coast. Conserv.* **2017**, *21*, 343–353. [CrossRef]
60. Bolle, A.; das Neves, L.; Rooseleer, J. Coastal protection for Ada, Ghana: A case study. *Proc. Inst. Civ. Eng.-Marit. Eng.* **2015**, *168*, 125–133. [CrossRef]
61. Ghanaports. *Fish Landing Sites to Be Constructed in Osu, Mfantseman and Otuam–Minister of Transport*; Ghana Ports and Harbours Authority: Tema, Ghana, 2021. Available online: https://www.ghanaports.gov.gh/media/news-details/289/9SKTD83NUS4/FISH-LANDING-SITES-TO-BE-CONSTRUCTED-IN-OSU,-MFANTSEMAN-AND-OTUAM-%E2%80%93-MINISTER-OF-TRANSPORT (accessed on 19 March 2022).
62. Akyeampong, E.K. *Between the Sea & the Lagoon: An Eco-Social History of the Anlo of Southeastern GHANA: C. 1850 to Recent Times*; Western African Studies; Ohio University Press: Athens, OH, USA, 2001.
63. Bongarts Lebbe, T.; Rey-Valette, H.; Chaumillon, É.; Camus, G.; Almar, R.; Cazenave, A.; Claudet, J.; Rocle, N.; Meur-Férec, C.; Viard, F.; et al. Designing Coastal Adaptation Strategies to Tackle Sea Level Rise. *Front. Mar. Sci.* **2021**, *8*, 740602. [CrossRef]
64. Browder, G.; Ozment, S.; Bescos, I.R.; Gartner, T.; Lange, G.-M. *Integrating Green and Grey: Creating Next Generation Infrastructure*; World Bank: Washington, DC, USA, 2019.
65. Waryszak, P.; Gavoille, A.; Whitt, A.A.; Kelvin, J.; Macreadie, P.I. Combining gray and green infrastructure to improve coastal resilience: Lessons learnt from hybrid flood defenses. *Coast. Eng. J.* **2021**, *63*, 335–350. [CrossRef]
66. Chee, S.Y.; Firth, L.B.; Then, A.Y.-H.; Yee, J.C.; Mujahid, A.; Affendi, Y.A.; Amir, A.A.; Lau, C.M.; Ooi, J.L.S.; Quek, Y.A.; et al. Enhancing Uptake of Nature-Based Solutions for Informing Coastal Sustainable Development Policy and Planning: A Malaysia Case Study. *Front. Ecol. Evol.* **2021**, *9*, 708507. [CrossRef]
67. Narayan, S.; Beck, M.W.; Reguero, B.G.; Losada, I.J.; van Wesenbeeck, B.; Pontee, N.; Sanchirico, J.N.; Ingram, J.C.; Lange, G.-M.; Burks-Copes, K.A. The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. *PLoS ONE* **2016**, *11*, e0154735. [CrossRef]