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Sea Level Rise and Coastal Erosion Adaptation: A Bibliometric Analysis

Loso Judijanto [1], Olivia Marie Caesaria Kesauliya [2], Novaldi Laudi Angrianto [3]
[1] IPOSS Jakarta losojudijantobumn@gmail.com
[2] Prodi Teknik Sipil, Fakultas Teknik, Universitas Papua, Monokwari-Papua Barat omc.kesauliya@unipa.ac.id
[3] Prodi Teknik Sipil, Fakultas Teknik, Universitas Papua, Monokwari-Papua Barat n.angrianto@unipa.ac.id
Corresponding Author: losojudijantobumn@gmail.com

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ABSTRACT

Sea level rise is speeding up shoreline retreat on many coasts, and research on how societies should adapt to coastal erosion has grown quickly across several disciplines. This study maps that body of work through a bibliometric analysis of 1,756 Scopus-indexed documents published between 1983 and 2026. VOSviewer was used to build keyword co-occurrence, overlay and density maps, together with co-authorship networks at the author, institution and country levels, while the most cited documents were examined through citation analysis. Five thematic clusters were found: coastal geomorphology and sediment dynamics, coastal zone management and risk assessment, climate-driven shoreline response, remote sensing and shoreline monitoring, and coastal ecosystems such as mangroves and wetlands. Coastal erosion and sea level rise form the densest core of the field, while recent studies have moved toward remote sensing, machine learning, hazard assessment, decision making and ecosystem-based adaptation. The United States, the United Kingdom, France, China and Germany lead international collaboration, and author groups around Ranasinghe, Nicholls and Le Cozannet connect several research communities. Collaboration between institutions remains thin and is concentrated in Arctic coastal research. The most cited works deal with global shoreline dynamics, deltas and the limits of the Bruun Rule. The results call for research that ties physical projections to planning, financing and community-level adaptation, particularly in the Global South and in small island states.

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Corresponding Author:
Name: Loso Judijanto
Institution: IPOSS Jakarta
Email: losojudijantobumn@gmail.com

INTRODUCTION

Coastal zones hold a large share of the world's population, cities, ports and agricultural land, which makes them highly exposed to changes in sea level. As the climate warms, rising seas shift the

balance between erosion and accretion, increase the reach of storm waves and push shorelines landward on many sandy, muddy and deltaic coasts (FitzGerald et al., 2008; Zhang et al., 2004). Satellite records covering more than three decades show that the loss of land to erosion is widespread, although some coasts continue to gain land through accretion (Mentaschi et al., 2018). Tidal flats, which act as natural buffers, have also declined in many regions (Murray et al., 2019).

Erosion along the coast is rarely driven by sea level rise alone. In large deltas, sediment trapping by dams, sand mining, groundwater extraction and land subsidence add to the effects of rising water, creating what has been described as effective sea level rise (Anthony et al., 2015; Ericson et al., 2006). Coastal infrastructure built to protect assets can also change sediment pathways and marine habitats (Bulleri & Chapman, 2010). These combined pressures are most visible in densely populated lowlands, such as the coasts of Bangladesh and Southeast Asia, where erosion threatens settlements, farmland and livelihoods (Brammer, 2014; Dong et al., 2024).

Predicting how shorelines will respond is still difficult. The Bruun Rule, long used to estimate shoreline retreat from sea level rise, has been criticised for its simplified assumptions (Cooper & Pilkey, 2004), and recent work shows that projections of sandy shoreline change carry large uncertainties (Le Cozannet et al., 2019). Short-term events can also outweigh long-term trends; a single sequence of extreme storms may cause retreat equal to decades of projected change (Harley et al., 2022), and climate modes such as El Niño shape erosion patterns across entire ocean basins (Barnard et al., 2015).

Adaptation to coastal erosion covers a wide range of options. Hard defences such as seawalls and groynes remain common, though their costs and side effects are increasingly questioned (André et al., 2016; Rashidi et al., 2021). Sand nourishment offers a softer form of protection (Stronkhorst et al., 2018), while ecosystem-based measures, including mangrove and wetland restoration, are promoted for their ability to keep pace with rising seas (Chow, 2018; Salgado & Martinez, 2017). In some places, planned relocation of communities has already taken place (Albert et al., 2018). Choosing among these options depends on long-term planning, economic assessment and the capacity of coastal institutions (Gopalakrishnan et al., 2016; Nicholls, 2011; Nicholls et al., 2013).

Research on this topic now draws on geomorphology, oceanography, engineering, ecology, economics and policy studies. New monitoring tools, especially remote sensing combined with machine learning, have expanded the volume and detail of shoreline data (Tsiakos & Chalkias, 2023). As the literature grows in size and scope, it becomes harder to see how its themes connect, which groups lead the field and where attention is shifting. Bibliometric analysis helps answer these questions by mapping keyword patterns, collaboration networks and citation impact across a large set of publications, as earlier mapping of sea level rise science has shown (Khojasteh et al., 2023).

Existing reviews on sea level rise and coastal erosion tend to focus on single regions, single methods or single adaptation measures. A broader view of how physical research on shoreline change relates to adaptation planning, and how this relationship has changed over time, is still limited. This study therefore conducts a bibliometric analysis of global research on sea level rise and coastal erosion adaptation, aiming to identify the main thematic clusters, trace the shift in research focus over time, map collaboration among authors, institutions and countries, and highlight the most influential publications in the field.

METHODS

This study uses a quantitative bibliometric approach that combines performance analysis and science mapping. Performance analysis was applied to describe the size, composition and

citation impact of the literature, while science mapping was used to examine the intellectual and social structure of research on sea level rise and coastal erosion adaptation. A similar mapping logic has been applied to the wider field of sea level rise science (Khojasteh et al., 2023). All maps were produced with VOSviewer version 1.6.20, which is widely used to visualise bibliometric networks.

Data were collected from the Scopus database and exported in RIS format on 2 October 2026. The search combined terms related to sea level rise, coastal erosion, shoreline change and adaptation in the titles, abstracts and keywords of indexed documents, without restricting the publication year. The final dataset contained 1,756 documents published from 1983 to 2026, consisting of 1,282 journal articles, 213 conference papers, 143 book chapters, 85 reviews and a small number of other document types. Most records (1,694 documents) were written in English, and the dataset had received 50,008 citations at the time of retrieval. Records were checked for duplicates and incomplete metadata before analysis.

Three types of analysis were carried out. Keyword co-occurrence analysis used both author keywords and indexed keywords to produce network, overlay and density visualisations, with similar terms reviewed for consistency. Co-authorship analysis was performed at the author, institution and country levels to show patterns of collaboration. Citation analysis ranked the documents by the number of citations recorded in Scopus to identify the ten most influential works. In each map, node size reflects the frequency of occurrence or the number of documents, link thickness reflects the strength of the relationship, and colours indicate clusters formed by the VOSviewer clustering algorithm or, in the overlay map, the average publication year.

RESULTS

Keyword Co-Occurrence Network Visualization

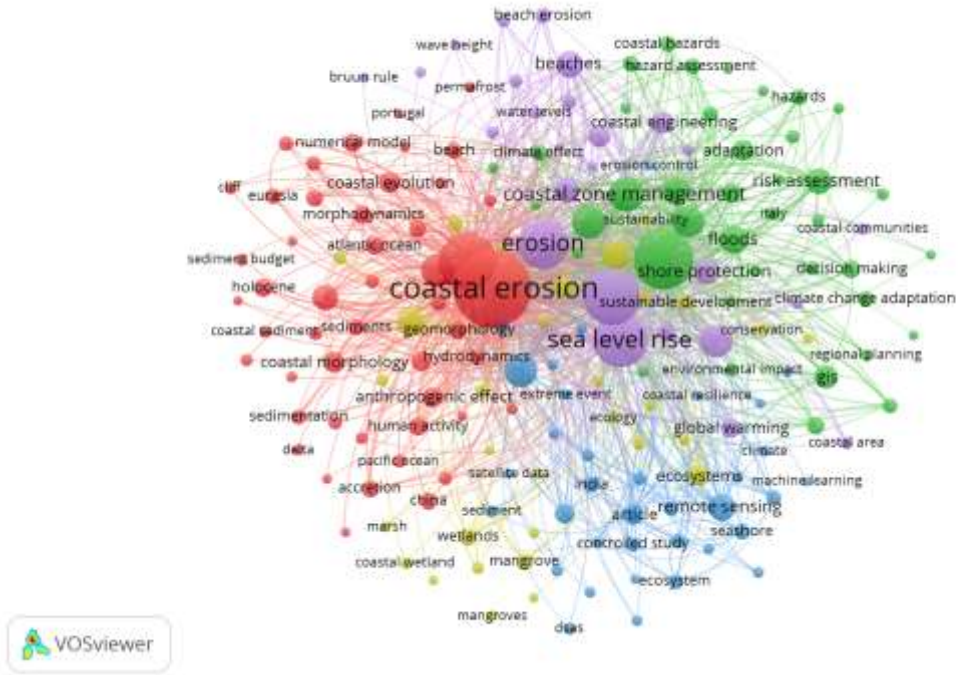
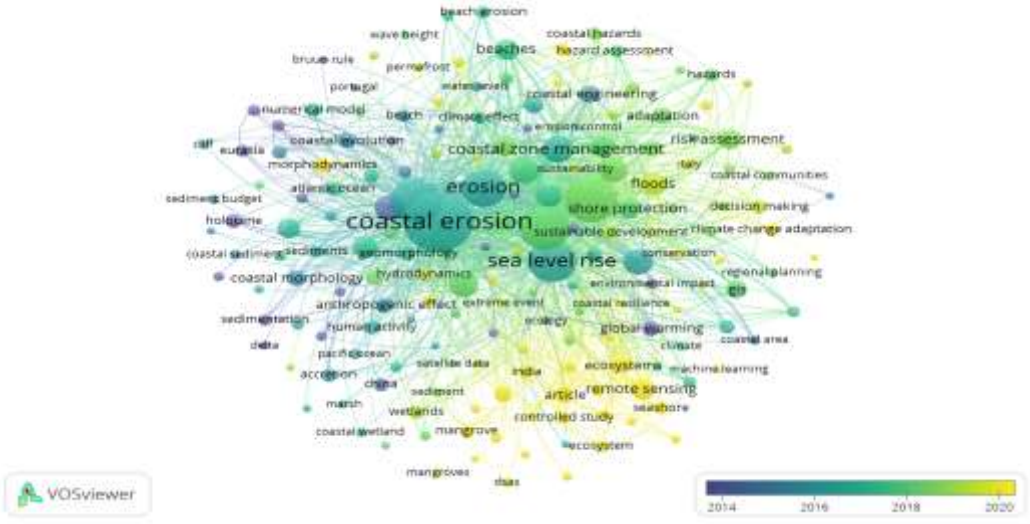


Figure 1. Network Visualization
Source: Data Analysis

Figure 1 shows the keyword co-occurrence network for research on sea level rise and coastal erosion adaptation. Coastal erosion is the largest node and sits at the centre of the map, followed by sea level rise, erosion, shore protection, coastal zone management and sustainable development. The short distance and dense links between coastal erosion and sea level rise confirm that most studies treat the two as one linked problem, in line with the view that rising seas are a major long-term driver of shoreline retreat (FitzGerald et al., 2008; Zhang et al., 2004). The map also shows that this shared problem is approached from three directions at once: how coasts change physically, how they are managed, and how ecosystems respond. Five clusters can be distinguished, marked in red, green, purple, blue and yellow, each representing a distinct line of research within the field.

The red cluster brings together the physical science of coastal change, with terms such as coastal evolution, morphodynamics, numerical model, sediment budget, sedimentation, coastal morphology, hydrodynamics, delta, accretion and Holocene. Its links to anthropogenic effect, human activity, China, Eurasia and the Atlantic and Pacific oceans reflect a large body of work on deltas whose erosion is driven by reduced sediment supply and human interference as much as by rising water, as seen in the Yellow River, Mekong and Po deltas (Anthony et al., 2015; Liu et al., 2004; Simeoni & Corbau, 2009). The green cluster represents the management side of the field, including coastal zone management, risk assessment, adaptation, floods, hazards, hazard assessment, decision making, climate change adaptation, regional planning and GIS. The position of this cluster on the right of the map, close to shore protection and sustainable development, shows that scientific findings on erosion are increasingly used to guide planning choices, cost assessments and protection strategies (André et al., 2016; Nicholls, 2011).

The purple cluster focuses on how beaches respond to rising water, with sea level rise, beaches, beach erosion, wave height, water levels, Bruun Rule, global warming, erosion control and coastal engineering. Its content follows the long debate on shoreline projection, from the Bruun Rule to newer models suggesting that many sandy beaches may retreat sharply by the end of the century (Cooper & Pilkey, 2004; Vitousek et al., 2017). The blue cluster gathers monitoring and data-driven work, such as remote sensing, satellite data, DSAS, machine learning, seashore, extreme event and coastal resilience, with India as a frequent study area for vulnerability mapping (Sudha Rani et al., 2015; Tsiakos & Chalkias, 2023). The yellow cluster covers coastal ecosystems, including mangrove, mangroves, wetlands, coastal wetland, marsh, ecosystems and ecology. Its placement between the physical and monitoring clusters suggests that mangroves and wetlands are studied both as habitats



at risk from rising seas and as natural defences that reduce erosion (Chow, 2018; Saintilan et al., 2023).

Figure 2. Overlay Visualization
Source: Data Analysis

Figure 2 presents the overlay visualisation, where colours show the average publication year of each keyword, ranging from dark blue (around 2014) to yellow (2020 and later). The oldest themes, shown in purple and dark blue, include numerical model, Holocene, Bruun Rule, sedimentation, delta, coastal sediment, global warming, erosion control, China and Eurasia. These terms belong to a phase in which research sought to explain long-term coastal evolution from geological records and sediment budgets, and to estimate shoreline retreat with simple equilibrium models (Cooper & Pilkey, 2004; Liu et al., 2004). Most of these older keywords sit on the left side of the map, inside the red and purple clusters, which shows that the physical foundation of the field was built first.

Core terms such as coastal erosion, sea level rise, erosion, beaches, coastal evolution and coastal zone management appear in teal, with an average year around 2016 to 2017. Their steady presence across the whole period shows that the central problem has not changed, even as methods and questions have. Terms in green, such as shore protection, sustainable development, adaptation, risk assessment and GIS, mark a middle phase in which studies moved from describing erosion to assessing exposure and comparing protection options, including sand nourishment and large-scale schemes such as the Dutch sand engine (Stive et al., 2013; Stronkhorst et al., 2018).

The newest themes, shown in yellow, include remote sensing, machine learning, DSAS, seashore, controlled study, ecosystems, mangrove, hazard assessment, floods, decision making, climate change adaptation and extreme event. Most of them lie in the lower and right parts of the map, within the blue, yellow and green clusters. This pattern points to three recent directions: the use of satellite imagery and deep learning to detect shoreline change at large scales (Dang et al., 2022; Tsiakos & Chalkias, 2023), greater attention to the role of extreme storms in short-term erosion (Harley et al., 2022), and a stronger focus on ecosystem-based adaptation and the future of coastal habitats under warming (Saintilan et al., 2023; Salgado & Martinez, 2017).

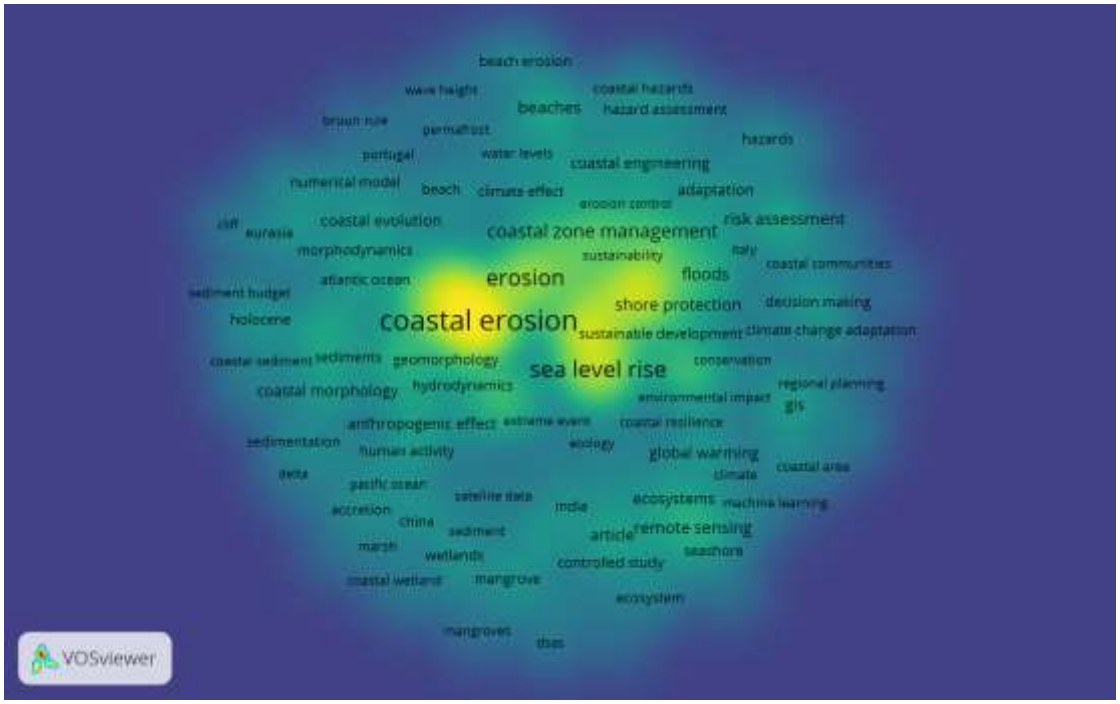


Figure 3. Density Visualization
Source: Data Analysis

Figure 3 displays the density visualisation, where yellow areas indicate the highest concentration of keywords and blue areas indicate lower concentration. The brightest zone surrounds coastal erosion, which confirms it as the anchor term of the whole dataset. A second dense area joins sea level rise, shore protection, sustainable development and erosion, forming a bright band that links the physical problem with the search for protection and sustainability. This shape suggests that much of the literature studies sea level rise mainly through its effect on erosion and on the need to protect the shore.

Moderately dense green areas cover coastal zone management, beaches, floods, coastal engineering, geomorphology and hydrodynamics. These topics are well established but are spread across more specific subjects, such as beach response, flood risk and engineering design. The density around beaches and coastal engineering, for example, reflects the many studies that test hard and soft protection on sandy coasts (Rashidi et al., 2021; Stronkhorst et al., 2018), while the green area near floods and risk assessment reflects the growing link between erosion and coastal flooding in hazard studies (Anderson et al., 2015).

The low-density blue zones at the edge of the map hold terms such as DSAS, machine learning, mangroves, Bruun Rule, permafrost, wave height, coastal communities and regional planning. Some of these, such as the Bruun Rule, are older and less used today, while others, such as machine learning, mangroves and coastal communities, are newer topics that have not yet built a large literature. Permafrost, also in a low-density area, points to the small but distinct body of work on Arctic coasts, where thawing ground speeds up erosion (Radosavljevic et al., 2016). These outer zones mark the areas where future growth of the field is most likely.

Co-Authorship Network

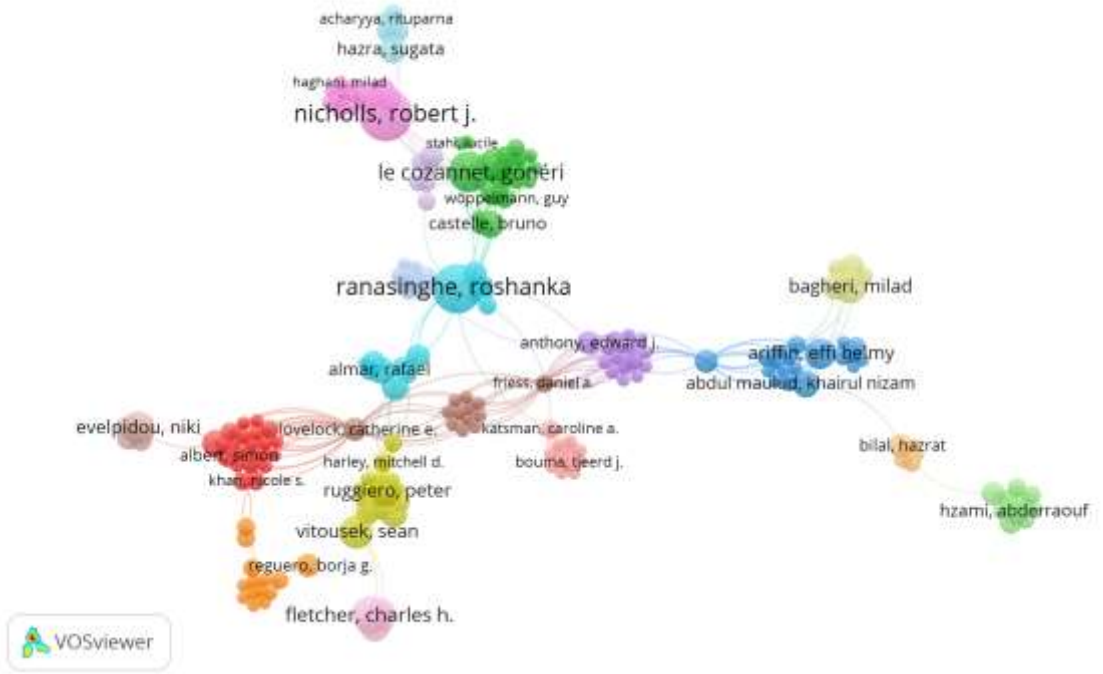


Figure 4. Author Visualization

Source: Data Analysis

Figure 4 shows the co-authorship network among authors. The map consists of nearly twenty small clusters joined through a few central researchers, rather than one large connected group. Ranasinghe, Roshanka is the largest and most connected node. His work on shoreline projection under rising seas and on soft protection such as the sand engine links the French group around Le Cozannet, Gonéri, Castelle, Bruno, Wöppelmann, Guy and Stahl, Lucile with the West African research of Almar, Rafael and with the planning research of Nicholls, Robert J. (Le Cozannet et al., 2019; Stive et al., 2013). Nicholls also connects to Haghani, Milad, co-author of a bibliometric study of sea level rise science, and further to Hazra, Sugata and Acharyya, Rituparna, who study the deltas and estuarine islands of South Asia (Khojasteh et al., 2023).

On the right side of the map, Anthony, Edward J., known for his work on delta and mud coast erosion, links to a Malaysian cluster led by Ariffin, Effi Helmy and Abdul Maulud, Khairul Nizam, which focuses on climate-driven erosion in Southeast Asia (Dong et al., 2024; Winterwerp et al., 2020). This group connects to Bagheri, Milad, who studies shoreline change on the Malaysian coast, and through Bilal, Hazrat to the group of Hzami, Abderraouf, which works on the southern Mediterranean. In the lower part, the clusters of Lovelock, Catherine E., Albert, Simon, Khan, Nicole S., Evelpidou, Niki and Reguero, Borja G. are joined through Friess, Daniel A. and Katsman, Caroline A. These authors share an interest in coastal habitats, reef islands and nature-based protection, as shown by work on the retreat of coastal habitats under warming and on coral reefs as coastal defence (Albert et al., 2016; Reguero et al., 2018; Saintilan et al., 2023).

Ruggiero, Peter, Vitousek, Sean, Harley, Mitchell D. and Fletcher, Charles H. form a further group focused on beach and shoreline modelling around the Pacific, including studies on storm impacts and on erosion projections for Hawaii and California (Anderson et al., 2015; Barnard et al., 2015; Vitousek et al., 2017). Overall, the structure shows that the field depends on a few bridging researchers to connect otherwise separate communities. Groups that work on physical projection, nature-based protection and regional erosion in Asia and Africa are linked, but mostly through single authors, which suggests room for more direct collaboration between them.

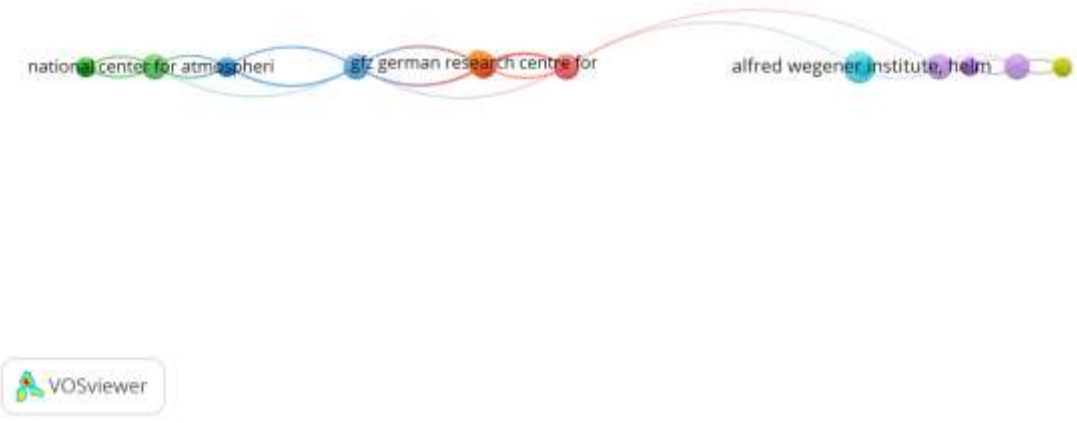


Figure 5. Institution Visualization
Source: Data Analysis

Figure 5 presents the co-authorship network among institutions. Only a small number of institutions meet the threshold, and they form a thin chain rather than a dense network. The National Center for Atmospheric Research sits at the left end and is linked through a few intermediate institutions to the GFZ German Research Centre for Geosciences in the middle. GFZ then connects to the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research and to a small group of partner institutions on the right. The Alfred Wegener Institute is the largest node in the chain.

The institutions in this chain share a strong focus on Arctic and permafrost coasts. Joint studies from this group document how thawing permafrost, sea ice loss and rising water speed up coastal erosion and threaten infrastructure in places such as Herschel Island in Canada and the Alaskan coast (Jones et al., 2018; Radosavljevic et al., 2016). This explains why permafrost appears as a separate term in the keyword maps. The same network also extends into studies on the economic loss of coastal ecosystem services due to erosion in Europe (Paprotny et al., 2021).

The weak and scattered institutional links suggest that most collaboration in this field takes place between individual researchers rather than through stable partnerships between organisations. Major centres that are visible at the author and country level, such as those in the United States, the Netherlands, France and Malaysia, do not form strong institutional ties in this dataset. Building such ties could help share long-term monitoring data and modelling tools, which are essential for adaptation planning on rapidly changing coasts.

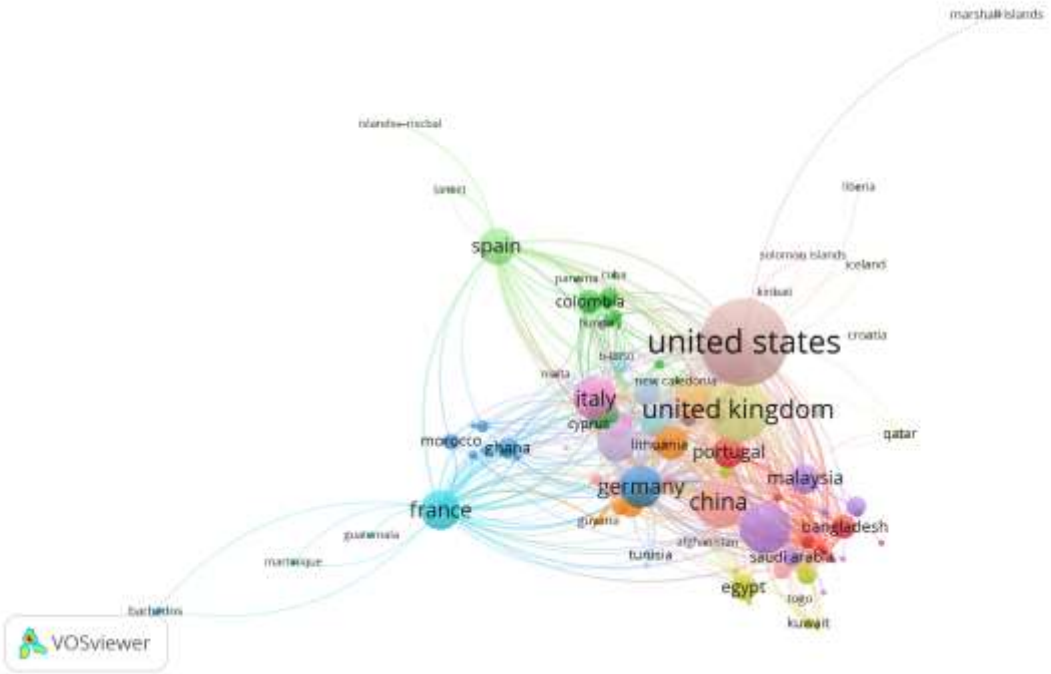


Figure 6. Country Visualization
Source: Data Analysis

Figure 6 shows the co-authorship network among countries. The United States is the largest and most connected node, followed by the United Kingdom, China, France, Germany, Italy, Spain and Portugal. These countries form the core of international collaboration. Their position reflects strong national research funding, long monitoring records and a large number of studies on their own coasts, from the Pacific coast of the United States to the deltas of China and the eroding shores of Europe (Barnard et al., 2015; Liu et al., 2004; Nicholls et al., 2013).

Several regional groups are visible around this core. France links with Caribbean and Central American partners such as Martinique, Barbados and Guatemala, and Spain connects closely with Colombia, Cuba and Panama, which reflects language and historical ties. A cluster of Asian and Middle Eastern countries, including Malaysia, Bangladesh, Saudi Arabia, Egypt and Kuwait, is active in studies on delta erosion, low-lying coasts and vulnerability assessment (Brammer, 2014; Dong et al., 2024). African countries such as Morocco, Ghana, Tunisia and Togo are linked mainly with France and Germany, in line with research on the eroding coasts of West and North Africa.

Small island states, including the Marshall Islands, Kiribati and the Solomon Islands, appear at the edges of the map with only a few links, mostly to the United States and the United Kingdom. This is notable, since these islands are among the places most exposed to sea level rise and have been the focus of important studies on atoll shoreline change and community relocation (Albert et al., 2016, 2018; Ford & Kench, 2015). The pattern shows that research capacity is concentrated in high-income countries, while many vulnerable coastal nations take part mainly as study sites or minor partners rather than as leading authors.

Citation Analysis

Table 1. Most Cited Article

Citations	Author and Year	Title
1,039	(Murray et al., 2019)	The global distribution and trajectory of tidal flats
930	(Bulleri & Chapman, 2010)	The introduction of coastal infrastructure as a driver of change in marine environments
757	(FitzGerald et al., 2008)	Coastal impacts due to sea-level rise
757	(Ericson et al., 2006)	Effective sea-level rise and deltas: Causes of change and human dimension implications
691	(Mentaschi et al., 2018)	Global long-term observations of coastal erosion and accretion
666	(Liu et al., 2004)	Holocene development of the Yellow River's subaqueous delta, North Yellow Sea
658	(Zhang et al., 2004)	Global warming and coastal erosion
537	(Anthony et al., 2015)	Linking rapid erosion of the Mekong River delta to human activities
417	(Cooper & Pilkey, 2004)	Sea-level rise and shoreline retreat: Time to abandon the Bruun Rule
402	(Brammer, 2014)	Bangladesh's dynamic coastal regions and sea-level rise

DISCUSSION

The keyword maps show that research on sea level rise and coastal erosion adaptation rests on a strong physical science base. The red and purple clusters, covering sediment dynamics, coastal morphology, delta evolution and beach response, contain many of the most frequent terms and most

cited works. This base explains why coastal erosion and sea level rise dominate the density map. The green cluster, which carries terms such as coastal zone management, risk assessment, adaptation and decision making, shows that the field has developed a clear management stream, yet its links to the physical clusters are mostly indirect. Many studies describe how shorelines change, while fewer explain how that knowledge is translated into adaptation choices such as protection, nourishment or relocation (André et al., 2016; Stronkhorst et al., 2018).

The overlay map points to a clear change in research focus. Earlier work relied on Holocene records, sediment budgets and simple models such as the Bruun Rule, while newer studies use remote sensing, DSAS, machine learning and hazard assessment to measure and predict change at larger scales (Cooper & Pilkey, 2004; Tsiakos & Chalkias, 2023). This change has improved the quality of shoreline data, but it also raises new needs, since projections remain uncertain and extreme events can disrupt long-term trends (Harley et al., 2022; Le Cozannet et al., 2019). The recent growth of keywords related to mangroves, wetlands and ecosystems reflects increasing attention to nature-based options, which are seen as flexible and lower-cost ways of reducing erosion while supporting biodiversity (Chow, 2018; Salgado & Martinez, 2017).

The collaboration networks show a field that is international but uneven. A small number of researchers, especially Ranasinghe, Nicholls and Le Cozannet, connect separate groups and shape much of the research agenda on shoreline projection and coastal planning (Le Cozannet et al., 2019; Nicholls, 2011). Institutional collaboration is weak, and the country map is dominated by the United States and Western Europe. Countries such as Bangladesh, Malaysia and Egypt are active, but small island states and many African and Southeast Asian countries remain on the margins, even though they face some of the highest risks (Brammer, 2014; Dong et al., 2024; Ford & Kench, 2015). Stronger partnerships with researchers in these regions would help produce evidence that fits their coastal conditions and needs.

These findings carry several implications for research and policy. Adaptation planning requires more than accurate projections of shoreline change; it also needs economic assessment, clear governance arrangements and the involvement of affected communities (Berman et al., 2020; Gopalakrishnan et al., 2016). The limited presence of terms related to costs, finance and social outcomes in the keyword maps suggests that these dimensions deserve more attention. Experiences of community relocation and long-term coastal planning show that adaptation decisions often involve difficult trade-offs between protection, retreat and accommodation (Albert et al., 2018; Nicholls et al., 2013). Future research should therefore combine shoreline monitoring and modelling with social, economic and institutional analysis, so that the evidence produced can directly support coastal adaptation strategies.

CONCLUSION

This bibliometric analysis mapped 1,756 Scopus-indexed publications on sea level rise and coastal erosion adaptation published between 1983 and 2026. The keyword network revealed five thematic clusters: coastal geomorphology and sediment dynamics, coastal zone management and risk assessment, climate-driven beach response, remote sensing and shoreline monitoring, and coastal ecosystems. Coastal erosion and sea level rise form the core of the field, supported by shore protection, coastal zone management and sustainable development. Over time, research has moved from geological records and simple shoreline models toward satellite-based monitoring, machine learning, hazard assessment, decision making and ecosystem-based adaptation.

The collaboration analysis showed that the United States, the United Kingdom, France, China and Germany lead international research, while a few central authors connect separate research groups. Collaboration between institutions is sparse and centred on Arctic coastal research, and many highly vulnerable regions, including small island states and parts of Africa and Southeast Asia, remain at the edge of the network. The most cited works focus on the physical processes of coastal change, with relatively little attention to the social and economic sides of adaptation.

Future research should link shoreline projections with planning tools, cost assessment and community participation, and should give more room to studies led by researchers from the most exposed regions. Policymakers can use these findings to identify existing expertise, encourage cross-country partnerships and support adaptation strategies that combine engineering, ecosystem-based measures and managed relocation where needed. This study relied on a single database and on keyword-based mapping, so future work may add other databases, co-citation analysis or systematic review methods to deepen the picture of how coastal adaptation research develops.

REFERENCES

Albert, S., Bronen, R., Tooler, N., Leon, J., Yee, D., Ash, J., Boseto, D., & Grinham, A. (2018). Heading for the hills: climate-driven community relocations in the Solomon Islands and Alaska provide insight for a 1.5 °C future. *Regional Environmental Change*, *18*(8), 2261–2272. https://doi.org/10.1007/s10113-017-1256-8

Albert, S., Leon, J. X., Grinham, A. R., Church, J. A., Gibbes, B. R., & Woodroffe, C. D. (2016). Interactions between sea-level rise and wave exposure on reef island dynamics in the Solomon Islands. *Environmental Research Letters*, *11*(5), 054011. https://doi.org/10.1088/1748-9326/11/5/054011

Anderson, T. R., Fletcher, C. H., Barbee, M. M., Frazer, L. N., & Romine, B. M. (2015). Doubling of coastal erosion under rising sea level by mid-century in Hawaii. *Natural Hazards*, *78*(1), 75–103. https://doi.org/10.1007/s11069-015-1698-6

André, C., Boulet, D., Rey-Valette, H., & Rulleau, B. (2016). Protection by hard defence structures or relocation of assets exposed to coastal risks: Contributions and drawbacks of cost-benefit analysis for long-term adaptation choices to climate change. *Ocean and Coastal Management*, *134*, 173–182. https://doi.org/10.1016/j.ocecoaman.2016.10.003

Anthony, E. J., Brunier, G., Besset, M., Goichot, M., Dussouillez, P., & Nguyen, V. L. (2015). Linking rapid erosion of the Mekong River delta to human activities. *Scientific Reports*, *5*, 14745. https://doi.org/10.1038/srep14745

Barnard, P. L., Short, A. D., Harley, M. D., Splinter, K. D., Vitousek, S., Turner, I. L., Allan, J., Banno, M., Bryan, K. R., Doria, A., Hansen, J. E., Kato, S., Kuriyama, Y., Randall-Goodwin, E., Ruggiero, P., Walker, I. J., & Heathfield, D. K. (2015). Coastal vulnerability across the Pacific dominated by El Niño/Southern Oscillation. *Nature Geoscience*, *8*(10), 801–807. https://doi.org/10.1038/ngeo2539

Berman, M., Baztan, J., Kofinas, G., Vanderlinden, J.-P., Chouinard, O., Huctin, J.-M., Kane, A., Mazé, C., Nikulkina, I., & Thomson, K. (2020). Adaptation to climate change in coastal communities: findings from seven sites on four continents. *Climatic Change*, *159*(1), 1–16. https://doi.org/10.1007/s10584-019-02571-x

Brammer, H. (2014). Bangladesh's dynamic coastal regions and sea-level rise. *Climate Risk Management*, *1*, 51–62. https://doi.org/10.1016/j.crm.2013.10.001

Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, *47*(1), 26–35. https://doi.org/10.1111/j.1365-2664.2009.01751.x

Chow, J. (2018). Mangrove management for climate change adaptation and sustainable development in coastal zones. *Journal of Sustainable Forestry*, *37*(2), 139–156. https://doi.org/10.1080/10549811.2017.1339615

Cooper, J. A. G., & Pilkey, O. H. (2004). Sea-level rise and shoreline retreat: Time to abandon the Bruun Rule. *Global and Planetary Change*, *43*(3–4), 157–171. https://doi.org/10.1016/j.gloplacha.2004.07.001

Dang, K. B., Dang, V. B., Ngo, V. L., Vu, K. C., Nguyen, H., Nguyen, D. A., Nguyen, T. D. L., Pham, T. P. N., Giang, T. L., Nguyen, H. D., & Hieu Do, T. (2022). Application of deep learning models to detect coastlines

and shorelines. *Journal of Environmental Management*, *320*, 115732. https://doi.org/10.1016/j.jenvman.2022.115732

Dong, W. S., Ismailluddin, A., Yun, L. S., Ariffin, E. H., Saengsupavanich, C., Abdul Maulud, K. N., Ramli, M. Z., Miskon, M. F., Jeofry, M. H., Mohamed, J., Mohd, F. A., Hamzah, S. B., & Yunus, K. (2024). The impact of climate change on coastal erosion in Southeast Asia and the compelling need to establish robust adaptation strategies. *Heliyon*, *10*(4), e25609. https://doi.org/10.1016/j.heliyon.2024.e25609

Ericson, J. P., Vörösmarty, C. J., Dingman, S. L., Ward, L. G., & Meybeck, M. (2006). Effective sea-level rise and deltas: Causes of change and human dimension implications. *Global and Planetary Change*, *50*(1–2), 63–82. https://doi.org/10.1016/j.gloplacha.2005.07.004

FitzGerald, D. M., Fenster, M. S., Argow, B. A., & Buynevich, I. V. (2008). Coastal impacts due to sea-level rise. *Annual Review of Earth and Planetary Sciences*, *36*, 601–647. https://doi.org/10.1146/annurev.earth.35.031306.140139

Ford, M. R., & Kench, P. S. (2015). Multi-decadal shoreline changes in response to sea level rise in the Marshall Islands. *Anthropocene*, *11*, 14–24. https://doi.org/10.1016/j.ancene.2015.11.002

Gopalakrishnan, S., Landry, C. E., Smith, M. D., & Whitehead, J. C. (2016). Economics of coastal erosion and adaptation to sea level rise. *Annual Review of Resource Economics*, *8*(1), 119–139. https://doi.org/10.1146/annurev-resource-100815-095416

Harley, M. D., Masselink, G., Ruiz de Alegría-Arzaburu, A., Valiente, N. G., & Scott, T. (2022). Single extreme storm sequence can offset decades of shoreline retreat projected to result from sea-level rise. *Communications Earth and Environment*, *3*(1), 112. https://doi.org/10.1038/s43247-022-00437-2

Jones, B. M., Farquharson, L. M., Baughman, C. A., Buzard, R. M., Arp, C. D., Grosse, G., Bull, D. L., Günther, F., Nitze, I., Urban, F., Kasper, J. L., Frederick, J. M., Thomas, M., Jones, C., Mota, A., Dallimore, S., Tweedie, C., Maio, C., Mann, D. H., … Romanovsky, V. E. (2018). A decade of remotely sensed observations highlight complex processes linked to coastal permafrost bluff erosion in the Arctic. *Environmental Research Letters*, *13*(11), 115001. https://doi.org/10.1088/1748-9326/aae471

Khojasteh, D., Haghani, M., Nicholls, R. J., Moftakhari, H., Sadat-Noori, M., Mach, K. J., Fagherazzi, S., Vafeidis, A. T., Barbier, E., Shamsipour, A., & Glamore, W. (2023). The evolving landscape of sea-level rise science from 1990 to 2021. *Communications Earth and Environment*, *4*(1), 257. https://doi.org/10.1038/s43247-023-00920-4

Le Cozannet, G., Bulteau, T., Castelle, B., Ranasinghe, R., Wöppelmann, G., Rohmer, J., Bernon, N., Idier, D., Louisor, J., & Salas-y-Mélia, D. (2019). Quantifying uncertainties of sandy shoreline change projections as sea level rises. *Scientific Reports*, *9*(1), 42. https://doi.org/10.1038/s41598-018-37017-4

Liu, J. P., Milliman, J. D., Gao, S., & Cheng, P. (2004). Holocene development of the Yellow River's subaqueous delta, North Yellow Sea. *Marine Geology*, *209*(1–4), 45–67. https://doi.org/10.1016/j.margeo.2004.06.009

Mentaschi, L., Vousdoukas, M. I., Pekel, J.-F., Voukouvalas, E., & Feyen, L. (2018). Global long-term observations of coastal erosion and accretion. *Scientific Reports*, *8*(1), 12876. https://doi.org/10.1038/s41598-018-30904-w

Murray, N. J., Phinn, S. R., DeWitt, M., Ferrari, R., Johnston, R., Lyons, M. B., Clinton, N., Thau, D., & Fuller, R. A. (2019). The global distribution and trajectory of tidal flats. *Nature*, *565*(7738), 222–225. https://doi.org/10.1038/s41586-018-0805-8

Nicholls, R. J. (2011). Planning for the impacts of sea level rise. *Oceanography*, *24*(2), 144–157. https://doi.org/10.5670/oceanog.2011.34

Nicholls, R. J., Townend, I. H., Bradbury, A. P., Ramsbottom, D., & Day, S. A. (2013). Planning for long-term coastal change: Experiences from England and Wales. *Ocean Engineering*, *71*, 3–16. https://doi.org/10.1016/j.oceaneng.2013.01.025

Paprotny, D., Terefenko, P., Giza, A., Czapliński, P., & Vousdoukas, M. I. (2021). Future losses of ecosystem services due to coastal erosion in Europe. *Science of the Total Environment*, *760*, 144310. https://doi.org/10.1016/j.scitotenv.2020.144310

Radosavljevic, B., Lantuit, H., Pollard, W., Overduin, P., Couture, N., Sachs, T., Helm, V., & Fritz, M. (2016). Erosion and Flooding—Threats to Coastal Infrastructure in the Arctic: A Case Study from Herschel Island,

Yukon Territory, Canada. *Estuaries and Coasts*, *39*(4), 900–915. https://doi.org/10.1007/s12237-015-0046-0

Rashidi, A. H. M., Jamal, M. H., Hassan, M. Z., Sendek, S. S. M., Sopie, S. L. M., & Hamid, M. R. A. (2021). Coastal structures as beach erosion control and sea level rise adaptation in Malaysia: A review. *Water*, *13*(13), 1741. https://doi.org/10.3390/w13131741

Reguero, B. G., Beck, M. W., Agostini, V. N., Kramer, P., & Hancock, B. (2018). Coral reefs for coastal protection: A new methodological approach and engineering case study in Grenada. *Journal of Environmental Management*, *210*, 146–161. https://doi.org/10.1016/j.jenvman.2018.01.024

Saintilan, N., Horton, B., Törnqvist, T. E., Ashe, E. L., Khan, N. S., Schuerch, M., Perry, C., Kopp, R. E., Garner, G. G., Murray, N., Rogers, K., Albert, S., Kelleway, J., Shaw, T. A., Woodroffe, C. D., Lovelock, C. E., Goddard, M. M., Hutley, L. B., Kovalenko, K., … Guntenspergen, G. (2023). Widespread retreat of coastal habitat is likely at warming levels above 1.5 °C. *Nature*, *621*(7977), 112–119. https://doi.org/10.1038/s41586-023-06448-z

Salgado, K., & Martinez, M. L. (2017). Is ecosystem-based coastal defense a realistic alternative? Exploring the evidence. *Journal of Coastal Conservation*, *21*(6), 837–848. https://doi.org/10.1007/s11852-017-0545-1

Simeoni, U., & Corbau, C. (2009). A review of the Delta Po evolution (Italy) related to climatic changes and human impacts. *Geomorphology*, *107*(1–2), 64–71. https://doi.org/10.1016/j.geomorph.2008.11.004

Stive, M. J. F., De Schipper, M. A., Luijendijk, A. P., Aarninkhof, S. G. J., Van Gelder-Maas, C., Van Thiel De Vries, J. S. M., De Vries, S., Henriquez, M., Marx, S., & Ranasinghe, R. (2013). A new alternative to saving our beaches from sea-level rise: The sand engine. *Journal of Coastal Research*, *29*(5), 1001–1008. https://doi.org/10.2112/JCOASTRES-D-13-00070.1

Stronkhorst, J., Huisman, B., Giardino, A., Santinelli, G., & Santos, F. D. (2018). Sand nourishment strategies to mitigate coastal erosion and sea level rise at the coasts of Holland (The Netherlands) and Aveiro (Portugal) in the 21st century. *Ocean and Coastal Management*, *156*, 266–276. https://doi.org/10.1016/j.ocecoaman.2017.11.017

Sudha Rani, N. N. V., Satyanarayana, A. N. V., & Bhaskaran, P. K. (2015). Coastal vulnerability assessment studies over India: a review. *Natural Hazards*, *77*(1), 405–428. https://doi.org/10.1007/s11069-015-1597-x

Tsiakos, C.-A. D., & Chalkias, C. (2023). Use of machine learning and remote sensing techniques for shoreline monitoring: A review of recent literature. *Applied Sciences*, *13*(5), 3268. https://doi.org/10.3390/app13053268

Vitousek, S., Barnard, P. L., & Limber, P. (2017). Can beaches survive climate change? *Journal of Geophysical Research: Earth Surface*, *122*(4), 1060–1067. https://doi.org/10.1002/2017JF004308

Winterwerp, J. C., Albers, T., Anthony, E. J., Friess, D. A., Mancheño, A. G., Moseley, K., Muhari, A., Naipal, S., Noordermeer, J., Oost, A., Saengsupavanich, C., Tas, S. A. J., Tonneijck, F. H., Wilms, T., Van Bijsterveldt, C., Van Eijk, P., Van Lavieren, E., & Van Wesenbeeck, B. K. (2020). Managing erosion of mangrove-mud coasts with permeable dams – lessons learned. *Ecological Engineering*, *158*, 106078. https://doi.org/10.1016/j.ecoleng.2020.106078

Zhang, K., Douglas, B. C., & Leatherman, S. P. (2004). Global warming and coastal erosion. *Climatic Change*, *64*(1–2), 41–58. https://doi.org/10.1023/B:CLIM.0000024690.32682.48