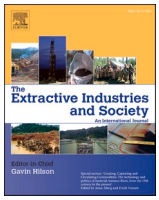
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Review article

Decomposing sand mining complexities to chart ocean sustainability narratives and pathways in the coastal zones of Africa

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ABSTRACT

Coastal zones/states of Africa are some of the leading sand-mining and exporting spots globally, a conduit for lucrative socioeconomic transformation. Unfortunately, in Africa, as with most emerging economies, sand mining benefits have not yielded comprehensive socioecological benefits. Rather, sand mining and trade have spiraled into negative externalities that cataclysmically scupper socioecological systems and ocean sustainability targets. The lack of coherent sand mining governance mechanisms and increasing natural resource contestations, proliferated by bumper global sand demand, have further created dire sustainability indicators/ramifications. The externalities have explosive negative effects on coastal and marine ecosystems that sustain livelihoods. These have spilled into unsustainable socioecological outcomes,cremating the avenues for realizing Agenda 2063 of Africa's Ocean Decade and sustainable actions, necessitating urgent redress. This study digs deeper into the literature on sand mining in Africa to kickstart new epochs for sustainable sand mining in Africa that are replicable. A systematic literature review of 2514 peer-reviewed articles and 15 grey literature, including policy documents and reports on sand mining, were explored and analyzed using a bibliometric analysis technique. A bibliometric analysis entailed the uncovering of three key issues (i) sand mining research and policy trends/directions in Africa, including their complexity in tandem with the sustainability trilogy (ii) ramifications of the current sand mining landscape to/on ocean sustainability pillars (social, economic, institutional, scientific &environmental) and (iii) thematic mapping/analysis to highlight the current governance mechanisms (including sustainability issues/gaps therein). Findings revealed that Africa's coastal states are some of the leading sand exporters but lose most of their revenue by reimporting sand from middle or high-income states. Research on sand mining has receded. If it exists, it is led by a few countries and western (developed/richer) institutions/scholars. Increasing sand mining is associated with increase in socioecological vulnerabilities. Africa's coastal regions experiencing unsustainable sand mining are losing critical natural and social livelihood capitals. Governance mechanisms are unsustainable. Few powerful actors (including an emerging network of African oligarchs and foreign companies/individuals), operate or manage the sand-mining value chains. There is limited understanding of the environmental, social, and governance nexus and its relationship to local and global development targets. To chart/regurgitate sustainable narratives for sustainable sand mining, a new pathway called the SSMAP (Sustainable Sand Mining Action Pathway) that has five key interrelated steps has been developed. Localizing the SSMAP and incorporating emerging co-governance pathways in micro-settings could help identify leverage points for collaborative and voluntary engagements/governance on sand mining. Scaling up the SSMAP (micro to macro levels) could help build evidence-based inventories and transformative options to co-design coherent transnational governance mechanisms. Such mechanisms could bolster the monitoring of sand mining, legitimize sustainable sand mining operations and value chains, and lay the foundations for better coastal socioecological livelihood and development indicators.

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1. Introduction

The development of sustainable mechanisms that reduce externalities emanating from sand mining is an urgent requirement (Asare et al., 2023; Matovu et al., 2024a; 2024c; Johnstone and Genc, 2025; Blackwell, 2025). This is relevant in vulnerable coastal zones of the global south, which are experiencing unprecedented sand mining trends never seen before (Torres et al., 2017; Bendixen et al., 2021; 2023; Jouffray et al., 2023). Charting sustainable safety nets would further promote the attainment of sustainable ocean development pillars that align with a typology of tenets embedded under the Decade of Sustainable Action (global, local, people actions) (UNCTAD, 2022; UN, 2023; NRGI, 2021; WOA II, 2021; IRP, 2020). This can help link sustainable development goals (SDGs) with the environmental, social, and governance targets that are knit to promote sustainable actions, including in complex sand mining value chains and activities (Hübler and Pothen, 2021; Baninla et al., 2025; Hilson et al., 2025; Matovu et al., 2025).

Over the last 25 years, coastal zones have exponentially become the leading global sources of sand (including unique black sands) (OECD, 2024; OEC, 2024; Atlas of Economic Complexity, 2024). The exponential rise/demand would not have been a concern per se, as sand has led to transitions e.g., in infrastructural developments (including urban/-housing development) that serve the increasing population demands, such as in India, China, and the Gulf countries (Filho et al., 2021; Hubler et al., 2021). In Africa's case, however, most of the extracted sand is being traded to developed countries (See Fig. 2). Additionally, sand mining activities, allocations, and benefits have not been proactively utilized to spur sustainable livelihoods, and infrastructure developments to serve the increasing population, as reported in coastal regions of Mozambique, and sub-Saharan Africa (Marshke & Rousseau, 2022; Grant and Wilhelm, 2022; Blackwell, 2025; Hilson et al., 2025). This is worsened by Africa's commodified sand trade being one of the least regulated (increasing revenue outflows) globally (Matovu et al., 2024a). Still, sand mining/trade value chains are governed by a cobweb of well-connected foreign private companies/individuals who disregard sustainable extraction practices (Wiegink and Garcia, 2022; Shitima & Suyken, 2023; Bachmann et al., 2024). The ramifications have been dire, as myriad negative externalities to livelihoods, inland, and marine ecosystems are well documented in global and regional studies (Filho et al., 2021; Jouffray et al., 2023; Amann et al., 2024; Matovu et al., 2024c; 2024d; Hamid et al., 2024).

Amidst the unsustainable trends in sand mining extraction (2nd most used commodity after water) (Matovu et al., 2024c; UNEP, 2024), one may wonder what needs to be done to save the highly fragile marine ecosystems and vulnerable communities sedentary in sand extraction zones both globally and in Africa (Baninla et al., 2025; Hilson et al., 2025). Even though bright spots are emerging, documented by the emergence of sustainability pathways, such as the United Nations Environment Programme (UNEP) proposal for a global sand observatory "marine sand watch", the African Union (AU) Agenda 2063, and the *Blue Wall Initiative*, the salient features that glue sustainability pathways for sand mining have remained generalistic. Most often, policy, strategic plans, and assessment mechanisms hardly enable progress towards responsible sand mining and possibilities for resilience or (un/re) learning, especially in less sedentary, but sand-rich zones-'wildernesses' (Mensha & Mattah, 2023; Matovu et al., 2024a; UNEP, 2024; Ganie and Bhat, 2024; Blackwell, 2025). This is partly because relevant actors hold or run concessions and possess conflicts of interest in sand-mining dealings and source zones- a sandwich for contested extractivism and exploitative capitalistic tendencies (Engels and Dietz, 2017; Arbeloda, 2020; Wiegink, 2020). Regional and national governance mechanisms in most African states are either fragmented or circumvented by illicit sand mining dealers, thus ruining avenues for ensuring sustainable sand extraction, sharing of benefits, and sustainable value chains (Bachmann et al., 2024; Asare et al., 2024; Hamed et al., 2024). This is worsened by the lack of a global and continental coherent and comprehensive framework for sustainable sand mining (e.g., on trade and governance) (Matovu et al., 2024a; Blackwell, 2025). Proposed global frameworks, such as the social development license to operate (SDLO) and the sand extraction allowances trading scheme (SEATS), are yet to be ratified. Natural resource reporting platforms, such as those under the NRGI, do not explicitly work on understanding the specific complexities of sand but focus on other dominant mineral resources, such as gold and natural oil (NRGI, 2021; IRP, 2020; Matovu et al., 2024a).

Fortunately, a sigh of relief cascading towards sustainable sand-mining practices is maturating and evolving. At global and regional levels, an exponential appetite to create inventories and a knowledge base for sustainable sand mining is emphasized and recommended, such as in the IRP (2020) report. The rejuvenated focus for initiating sustainable sand mining practices creates an opportunity to critically explore mechanisms to address the current sand mining paradox in vulnerable and resource-rich regions, such as Africa, as it can ameriolate further harm to marine ecosystems and coastal communities in the 38 coastal states of Africa (Grant and Wilhelm, 2022; Jouffray et al., 2023). Affirmative research and policy directions on sustainable sand mining could further cement the potential of Africa's coastal states to reap blue economy (BE) benefits (UNCTAD, 2022). Recent estimates postulate that as Africa's BE is projected to be worth $405 billion by 2030, sustainability transitions in extractivist and non-extractivist BE sectors could aid exorbitant national development shifts and Africa's renaissance (UNCTAD, 2022; Laubchenco & Haugan, 2023; OECD, 2024).

An attempt to contribute towards decomposing the complex sand mining ecologies and the associated socioecological ramifications towards sustainability transformations forms the main gist for this study. Putting it into simple policy terms and scholarly perspectives, this paper aims at exploring literature to gain an in-depth understanding of the complex intricacies of coastal sand mining in Africa by identifying (i) sand mining trends (ii) ramifications of current trends on ocean sustainability pillars and targets, and (iii) current gaps and strategies towards creating better and sustainable sand mining governance mechanisms. To contribute to scholarship, critical and logical reflections of the findings obtained from the literature are made to create a novel pathway. The developed pathway could be utilized to (re)energize and augment enthusiasm towards sustainable actions/roadmaps for sustainable sand mining at micro, meso, and macro scales in Africa, the tropics, and globally. To this end, this paper has been conducted based on three main questions:

(i) What are the current sand mining trends in Africa, and what do they reveal regarding the sustainability of the sand mining trade flows and marine/coastal socioecological systems?
(ii) What are the ramifications of the current trends/trade flows on coastal communities' livelihoods and marine/ocean resources and ecosystems?
(iii) Are current mechanisms fit enough to address emerging marine/ocean (un)sustainability concerns? What specific gaps and barriers exist? How can research contribute to the development of novel pathways/narratives for sustainable sand mining in coastal zones of Africa?

2. Method used

The study utilized a systematic literature review (SLR) of documents sourced from Scopus (published and peer-reviewed articles) and Google Scholar (gray literature) online databases, following steps recommended in previous studies (Matovu et al., 2024b).

2.1. Data sourcing for bibliometric analysis

Initially, the Scopus database was utilized, using a structured search query targeting article titles, abstracts, and keywords related to coastal and sand-based studies in various African countries. The search was

conducted on 22nd April 2024. Since the method of literature analysis to be utilized was bibliometric analysis, five steps were followed to source and extract data (See Fig. 1). A unique customized query was applied in Scopus to obtain published articles (See Fig. 1). In the query, an effort was made to include all the coastal African countries, and this yielded 2514 documents without any filters applied. Secondly, Google Scholar was utilized to source gray literature. This was done by utilizing the search term '*sand mining reports in Africa*' to access reports and policy papers that revealed strategies/governance mechanisms and pathways for sand mining in Africa. 15 targeted reports on sand mining were obtained through this search query.

2.2. Bibliometric analysis of sourced data

The Biblioshiny software in R Studio was utilized to conduct bibliometric analysis. The extracted data were exported to a CSV file [link to CSV-https://shorturl.at/jDJX6] and loaded as a *Scopus.ris* file into the Biblioshiny cloud application. The analysis revealed a total of 6907 authors, 6039 author keywords, 1026 sources, and 428 single-authored authors. The average number of co-authors per document was 3.64, with 33.53 % of the publications involving international co-authorship. The annual growth rate was 2.69 %, and the average number of citations per document was 17.6. The bibliometric analysis conducted encompassed several components, including an overview of production over time, a three-field plot encompassing authors' countries, authors, and corresponding author affiliations, and a focus on five key areas: authors (most relevant authors), affiliations (most relevant affiliations and affiliations production over time), countries (corresponding authors' countries, countries production over time, most cited countries), document citation/co-citation (most frequent words, word cloud, words frequency over time), and network analysis (co-occurrence network based on author keywords, thematic evolution).

3. Results

3.1. Sand mining trends in Africa

Globally, it is estimated that about 50 billion tonnes of aggregates (mainly sand, gravel, and stones) are extracted annually. Sand extraction and demand are projected to increase to about 60 billion tons by 2030, and sand has become scarcer than initially thought (Katz-Lavigne et al., 2022; Matovu et al., 2023c). Unfortunately, reports from the leading sand extraction zones e.g., Africa, reveal that gaps are prevalent regarding the uncovering of the situational sand mining data, evaluation of sand availability, risks, impacts, consumption patterns, and alternatives; and yet, indicators of unsustainable sand mining patterns have become more evident (Friot, and Gallagher., 2021; Katz-Lavigne et al., 2022). As indicated in Table 1, the leading sand-mining coastal states in Africa are mainly exporting their sand. (un)Surprisingly, African states

Table 1
Share of global natural sand mining trade by African coastal states by 2021. (Authors' development based on data sourced from The Atlas of Economic Complexity; www.atlas.cid.harvard.edu) (*n.d implies no data available).

Country	Gross Exports (in millions USD)	Global Share (%)	Gross Imports (in millions USD)	Global Share (%)
Mozambique	**49.8**	**2.30**	0.488	0.02
Egypt	41.6	1.98	1.31	0.08
Tunisia	19.5	0.90	0.887	0.04
South Africa	8.13	0.38	1.79	0.11
Morocco	2.43	0.11	**3.19**	**0.15**
Senegal	0.503	0.02	0.885	0.04
Democratic Republic of Congo	0.376	0.02	0.523	0.02
Kenya	0.210	0.01	0.743	0.03
Angola	0.118	0.01	1.64	0.09
Nigeria	0.105	0.001	1.74	0.10
Tanzania	0.015	0.001	0.483	0.02
Madagascar	n.d	n.d	0.984	0.04

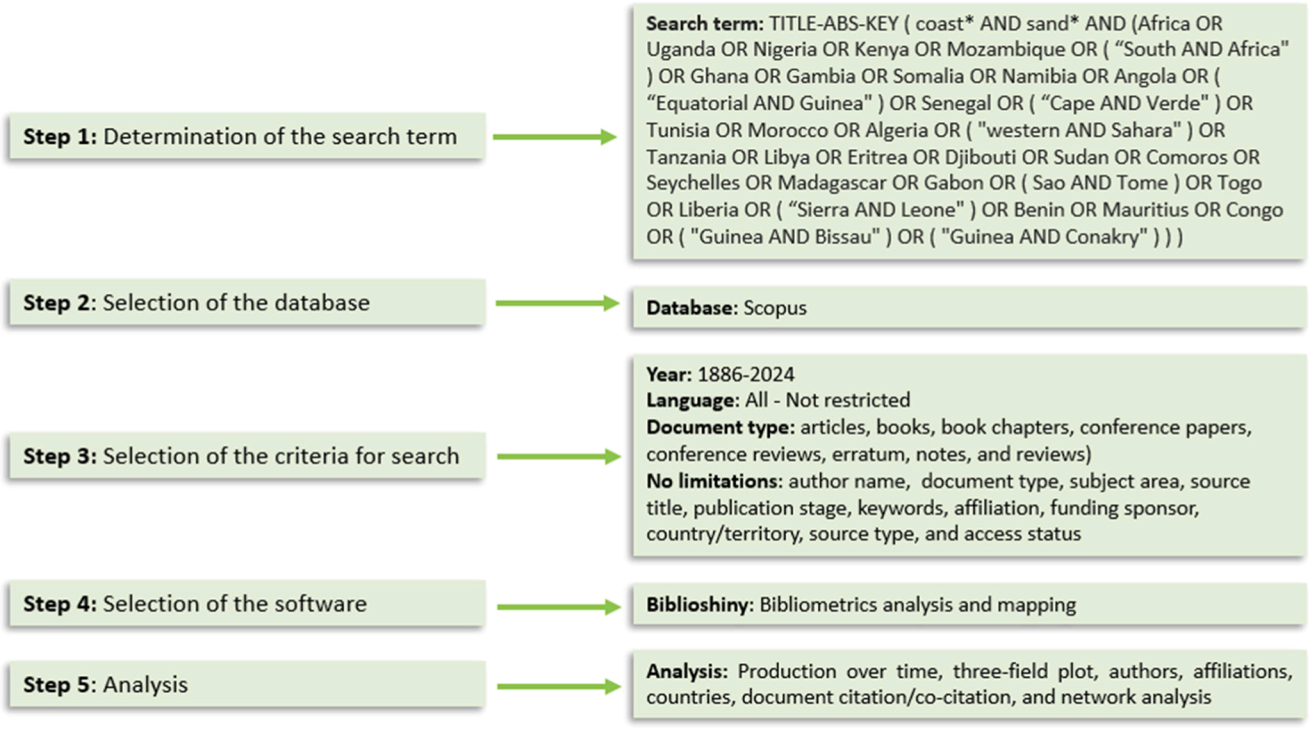


Fig. 1. Research flow and methodology for bibliometrics analysis (Authors' creation).

spend more revenue on importing sand, especially from countries where they export sand, such as the European Union (EU) and China (especially Mozambique). This creates unfavorable terms of trade, a risk of unfair net import reliance, and speculative demand scenarios (See Fig. 2). The worst socioeconomic trade indicators are predominant in countries endowed with abundant natural resources, such as Madagascar and the Democratic Republic of Congo (OEC, 2024). Data on sand mining exports is also lacking or unreported in some coastal states, such as Madagascar, Somalia, Seychelles, Mauritius, and Gambia, among others. Further, African exporting countries are paid less compared to other countries, as none of the African countries rank among the top five with the highest receipts (See Appendix I).

Inconsistent indicators are reported concerning interest in research and reporting on sand mining. Bar South Africa, scientific research/interest in publishing findings on sand mining has declined, especially since 2018 (See Fig. 3 & *Appendix VII*). There is relative interest in research by non-coastal African countries and small island developing states (SIDS) whose data is not reported or readily available by/in global sand mining databases, e.g. (www.atlas.cid.harvard.edu) (See *Table 2*). But, most of this research is led by non-African authors, countries, or institutions from developed countries (*Appendices II & III (a & b)* respectively).

In Africa, research/collaborations are mainly done/led either by South African researchers (See Fig. 4) or South African institutions (with more resources devoted to sustainability research in environmental, social, and governance nexuses) (See *Appendix IV: a & b*). This could limit the comprehensive/critical understanding of sand mining socio-ecological resilience typologies and livelihood dynamics in countries such as Mozambique and coalesce partial reporting of sand mining effects in highly vulnerable regions.

3.2. Human-Environmental impacts of sand mining in Africa

Findings revealed a nexus of mainly environmental ramifications across spatial-temporal landscapes. As indicated in Fig. 5, most impacts are negative (and have regenerated into organized transnational crime for contested sand resource-rich zones, notably among leading coastal sand mining states). The cobwebbed components of sand mining networks represent a perpetually concerning trend that is comparably and consistently reported in global reports and regional studies (Jouffrey et al., 2023; OEC, 2024; Matovu et al., 2024a; 2024c). The negative ramifications have affected sediment fluxes (a threat to a sustainable resource nexus), biodiversity, and geological structures of either coastal regions or source points (including lacustrine wetlands, freshwater lakes, and rivers) (IRP, 2021; Brouwer et al., 2024; Matovu et al., 2024d). Most of the ramifications have ballooned along vulnerable small and artisanal mining zones sedentary along tropical oceans and seas that swash along Africa's coastal zones (Indian, Atlantic Ocean(s), and the Mediterranean Sea) (Hilson et al., 2025).

Regionally, the negative impacts have been prevalent in the south, north, and west African coastal states. The negative impacts on socio-ecological settings are cascading into inland sand mining zones, especially in sub-Saharan Africa, such as in Uganda, where data/knowledge on the dangers of exploitative sand mining are underreported or lacking (Katz-Lavigne et al., 2022; Matovu et al., 2024d; Hilson et al., 2025). The increasing externalities have a negative correlation on sustainable livelihood welfare. This is because the negative impacts of sand mining are leading to increased coastal/shoreline changes, biotic resources decline, climate change, sea-level rise, changes in coastal depositional/sedimentology and hydrological components that are crucial to sustaining livelihoods of sedentary coastal populations (especially in coastal plains and deltas e.g., Nile Delta and Okavango) (Aziz et al., 2020; Bendixen et al., 2021; Cole & Broadhurst, 2022; Hamed et al., 2024; Matovu et al., 2024d).

3.3. Governance mechanisms for/on sand mining in Africa

From the literature, most governance mechanisms either revolve around conventional top-down approaches (indicative of hard laws/regulations on sand mining). Additionally, sand mining governance mechanisms are designed or led by national or regional-level MDAs (Ministries, Departments, Agencies) with low local community-driven governance mechanisms (IRP, 2020; Katz-Lavigne et al., 2021). Private actors/sand mining companies' influence in governance/policy decisions is increasing. This compromises compliance (e.g., in conducting Strategic Environmental and Social Impact Assessments (ESIA)) and future quantitative assessments on evaluating sand availability in strategic sand mining areas (Friot and Gallagher, 2021) (Fig. 6).

A concurrent network analysis revealed that even in cases where governance mechanisms are collaborative, their level of implementation

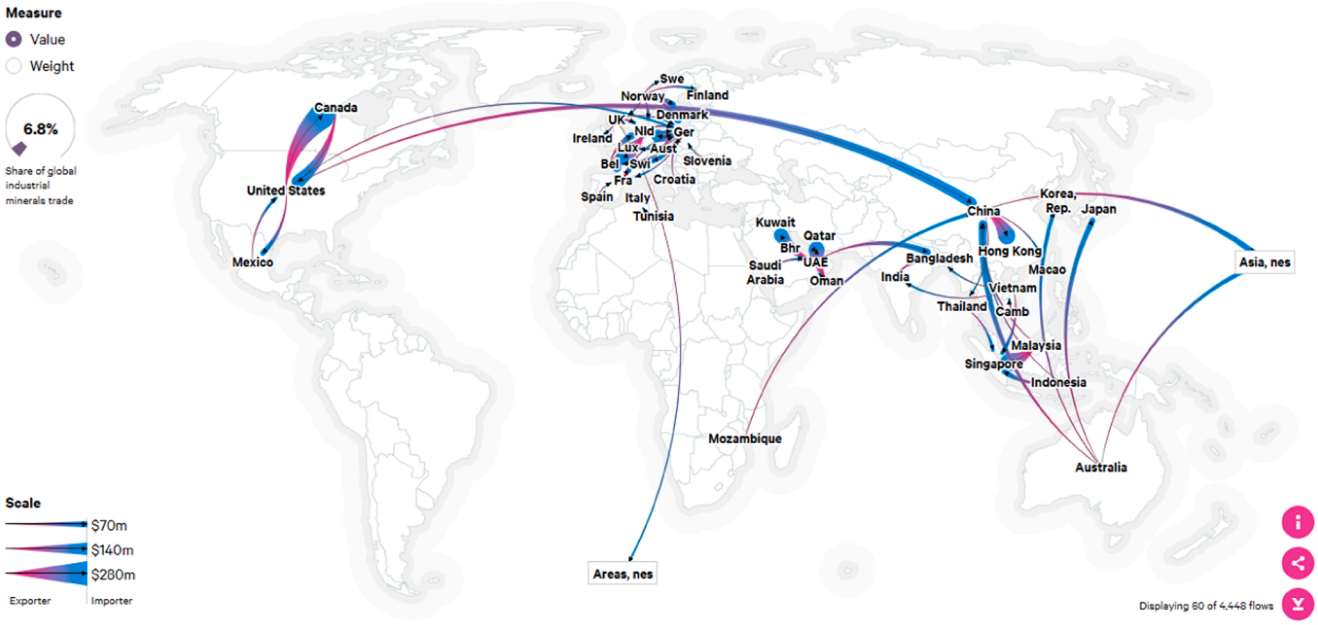


Fig. 2. Global Sand trade flows in 2022 (Source: Authors' development based on data sourced from The Observatory Economic Complexity; https://oec.world/en).

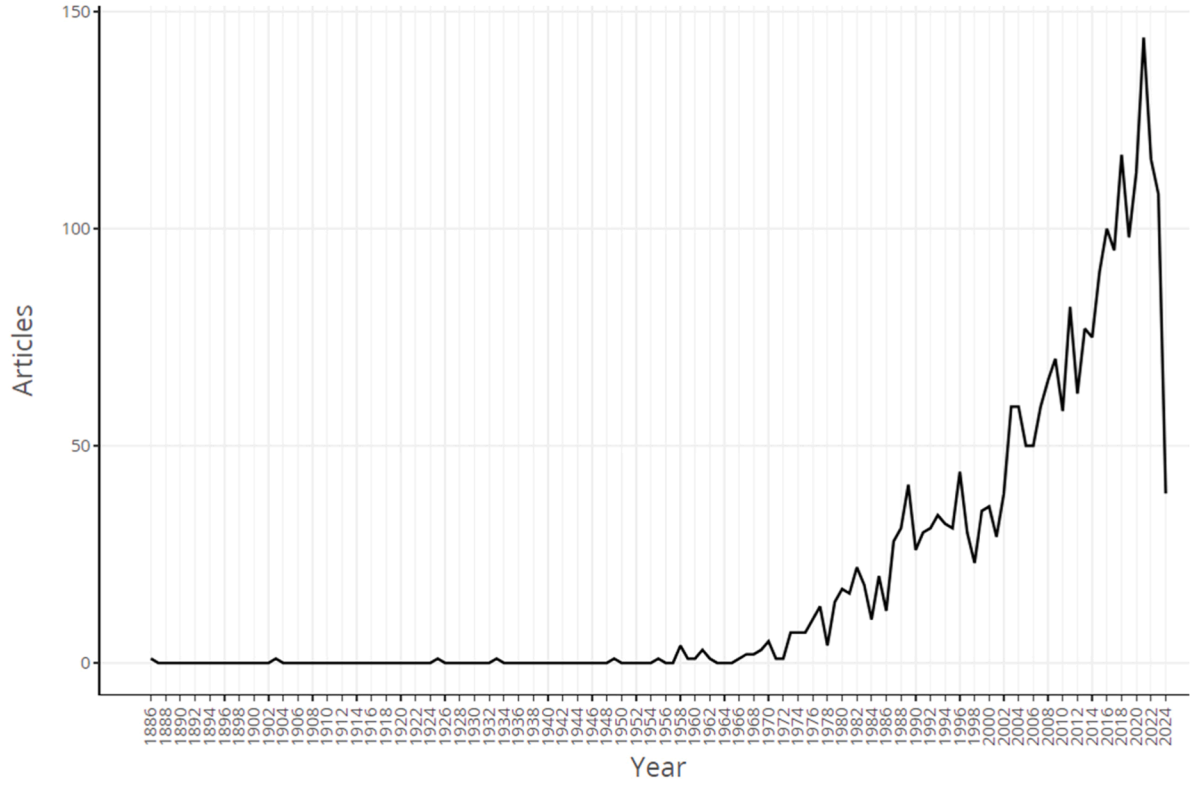


Fig. 3. Scientific production on sand mining in Africa (1886–2024) (Source: Scopus/Biblioshiny).

Table 2
Leading African countries researching sand mining (Authors' creation, based on the synthesis of sourced literature) **C: Coastal, SIDS: Small Island Developing State, LLC: Land-Locked Country.

Country	Country Category	Frequency of Publication
South Africa	C	1572
Morocco	C	574
Nigeria	C	566
Tunisia	C	504
Algeria	C	194
Senegal	C	130
Ghana	C	120
Egypt	C	118
Kenya	C	98
Tanzania	C	82
Mozambique	C	60
Mauritius	SIDS	24
Togo	C	12
Angola	C	9
Sudan	C	8
Seychelles	SIDS	5
Somalia	C	4
Uganda	LLC	1
Sierra Leone	C	1

varies. For instance, promising inclusive governance mechanisms are reported in South Africa, especially along the Indian Ocean region (Kwazulu Natal) (Fig. 7) (Also See *Appendix* V *&* *VI* on thematic evolution and mapping). However, most of these mechanisms mainly focus on environmental governance components, such as hydrogeology, and are mainly restricted to coastal plains/selected areas. In North Africa, emerging governance narratives are evidenced in Egypt, Tunisia, and Morocco (Mediterranean Sea area) but still focus on environmental monitoring aspects and lithological/coastal geoengineering mechanisms (thus missing out on best co-governance mechanisms for sand mining). According to Baninla et al. (2025), a blind focus on specific sustainability pillars dimensions cripples the ability to correlate or localize SDGs with integrated environmental, social, economic, and institutional governance mechanisms for sustainable sand mining.

4. Discussion

Findings on Africa's sand mining landscape reveal sickening indicators that warrant an in-depth surgical explanation, especially if Africa is to progressively attain sustainable sand mining mechanisms, the ocean decade targets, and, more crucially, the five sustainable ocean development pillars (UNCTAD, 2022; UN, 2023; Lubchenco and Haugan, 2023).

First, exploitative sand mining trade flows have been revealed (indicative of an unfavorable balance of payments and terms of trade) (OEC, 2024; Atlas of Economic Complexity, 2024; OECD, 2024). In most of these regions, tracing sand material flows from the source to user and post-consumption stages is challenging (due to unregulated mining and data gaps). Opaque sand mining trade flows and value chains are impediments to the generation and dissemination of knowledge on how to account for the scale of sand mining damage on livelihoods and ecosystems/environment (Katz-Lavigne et al., 2021; Friot and Gallagher, 2021). The exploitative transboundary sand trade flows and networks reported in literature are unsurprising per se, as they are symbolic of the nature of unjust historical global economic systems/models, especially in the global south (including in Asia and South America), where poor countries are used as 'finite' natural raw material sources (Torres et al., 2017; Bleischwitz, 2020; Hübler and Pothen, 2021; Partelow et al., 2023). In Africa's case, however, the extractivist and resource consumerism models/practices are more exploitative, economically derogatory, and socioecologically complex (Jouffray et al., 2023). For instance, all African countries (including landlocked ones) import sand and (un)surprisingly, from countries that own or run sand mining concessions in Africa e.g., China, the United States, Australia, and Brazil (Wiegink, 2020; Friot and Gallagher, 2021; Filho et al., 2021; Marschke and Rousseau, 2022; Katz-Lavigne et al., 2022; OEC, 2024). This has not

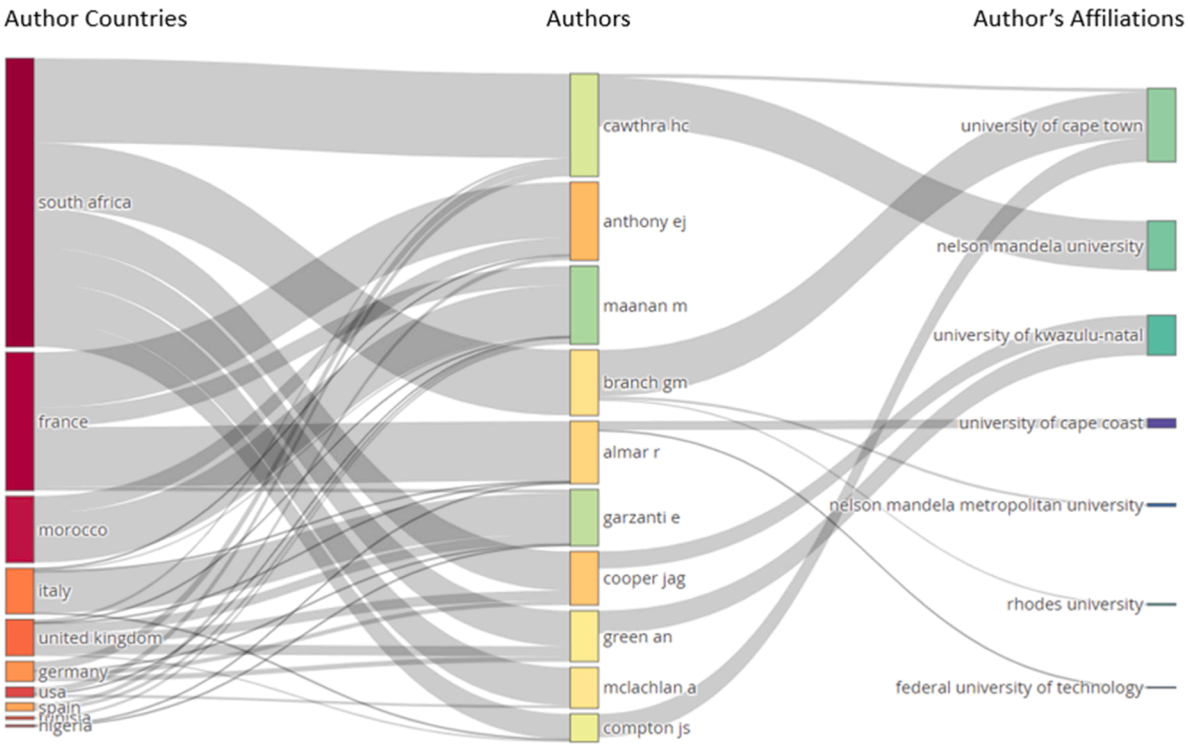


Fig. 4. Research production by countries, authors & affiliations (Source: Scopus/Biblioshiny).

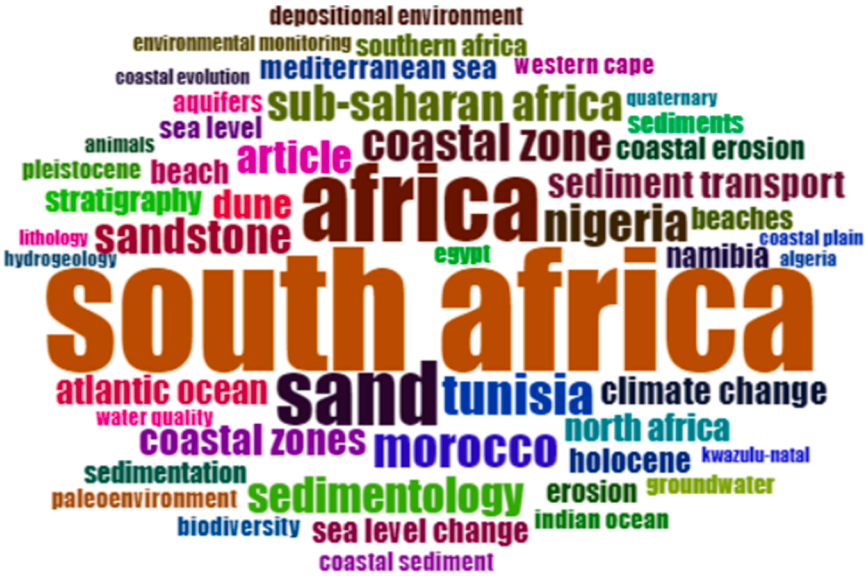


Fig. 5. Word cloud analysis showing sand mining ramifications on diverse socioecological aspects and regions or countries in Africa on a spatial scale in Africa (Source: Scopus/Biblioshiny).

only propagated new waves for contested extractivism of/for African resources, e.g., in the Democratic Republic of Congo (a precursor for perpetual underdevelopment, but also led to neocolonialism, political mayhem [civil wars], and increased debt burdens (Engels and Dietz, 2017; Arbeloda, 2020). This is worsened by the low levels of collaboration among African countries on sustainable sand mining chains (See Fig. 8). For instance, Madagascar lost about 1 million USD from the importation of sand (OEC, 2024; Atlas of Economic Complexity, 2024). To sustain the insatiable appetite for unique African sands (black and white) that are highly demanded in the making of glass, mining companies/concessions have scaled up their operations to inland freshwater bodies, such as Lake Victoria (Arbeloda, 2020; Matovu et al., 2024d). The ramifications of this emerging trend have been dire, spreading to regional countries, such as Egypt, that rely on freshwater from the River Nile for livelihood security, resource provision, regional security, and environmental balance (Aziz et al., 2020; Matovu et al., 2024d; Hamed et al., 2024). The avalanche gushed by the entry of private foreign companies into sand-mining zones has proliferated sand-mining politics, such as in Kenya. This has ploughed despicable livelihood challenges, such as displacement of coastal communities e.g., in Kenya, increased illegal sand mining e.g., around Lake Volta region in Ghana, and unwarranted low levels of compliance to environmental safety and

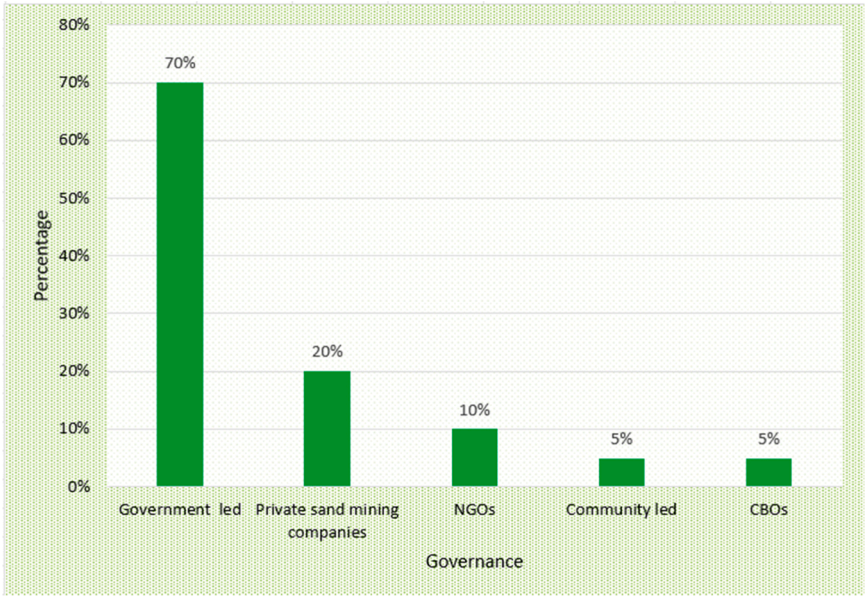


Fig. 6. Distribution of responsibility in developing/implementing governance practices (Authors' creation based on the synthesis of literature on ocean governance mechanisms and stakeholders in Africa).

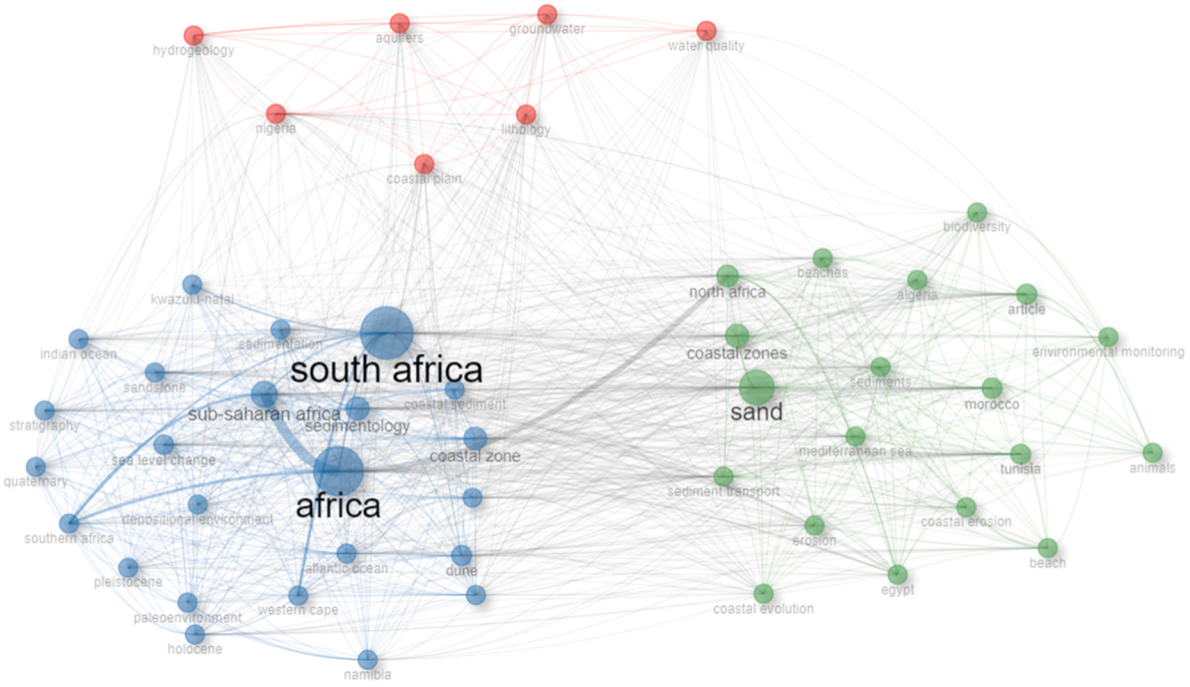


Fig. 7. Concurrent network analysis of sand mining governance mechanisms (Source: Scopus/Biblioshiny).

safeguards, such as in Mozambique (Wiegink, 2020; Wiegink and Garcia, 2022; Nasare et al., 2023; Asare et al., 2024; Bachmann et al., 2024).

Amidst these complex sand-mining trends, the losers have been coastal communities and marine environments in Africa (Grant and Wilhelm,2022; Hilson et al., 2025). In most cases, the mechanization of sand mining operations has increased the carbon footprint in coastal regions of Africa, thus worsening climate change vulnerabilities (OEC, 2024). Still, marginal benefits are injected into socioeconomic and environmentally sustainable actions for sustainable futures, especially in remote sand mining zones (Bendixen et al., 2023; Mensha & Mattah, 2023; Blackwell, 2025; Johnstone and Genc, 205). Worst-case impacts have been meted out to vulnerable coastal women, especially those engaged in coastal activities, such as small-scale fishing and farming (Marschke and Rousseau, 2022; Paschal and Kauangal, 2023; Matovu et al., 2024e; 2025). In most cases, leading sand mining actors (though aware of the negative impacts) seek quick monetary benefits rather than sustainability (Bleischwitz, 2020). These concerns have been reported in most regions of West Africa, such as among three coastal communities of Akwanda, Mbofra Akyinim, and Elmina in Ghana (Mensah and Mattah, 2023). In Mozambique, sand mining has not only affected sediment fluxes along alluvial and coastal plains and altered land morphology but also perpetuated negative large-scale sand mining-induced social livelihood resilience or welfare safeguards failures (Bendixen, 2021, OEC, 2024; Hilson et al., 2025). For instance, over 10,000 people (including

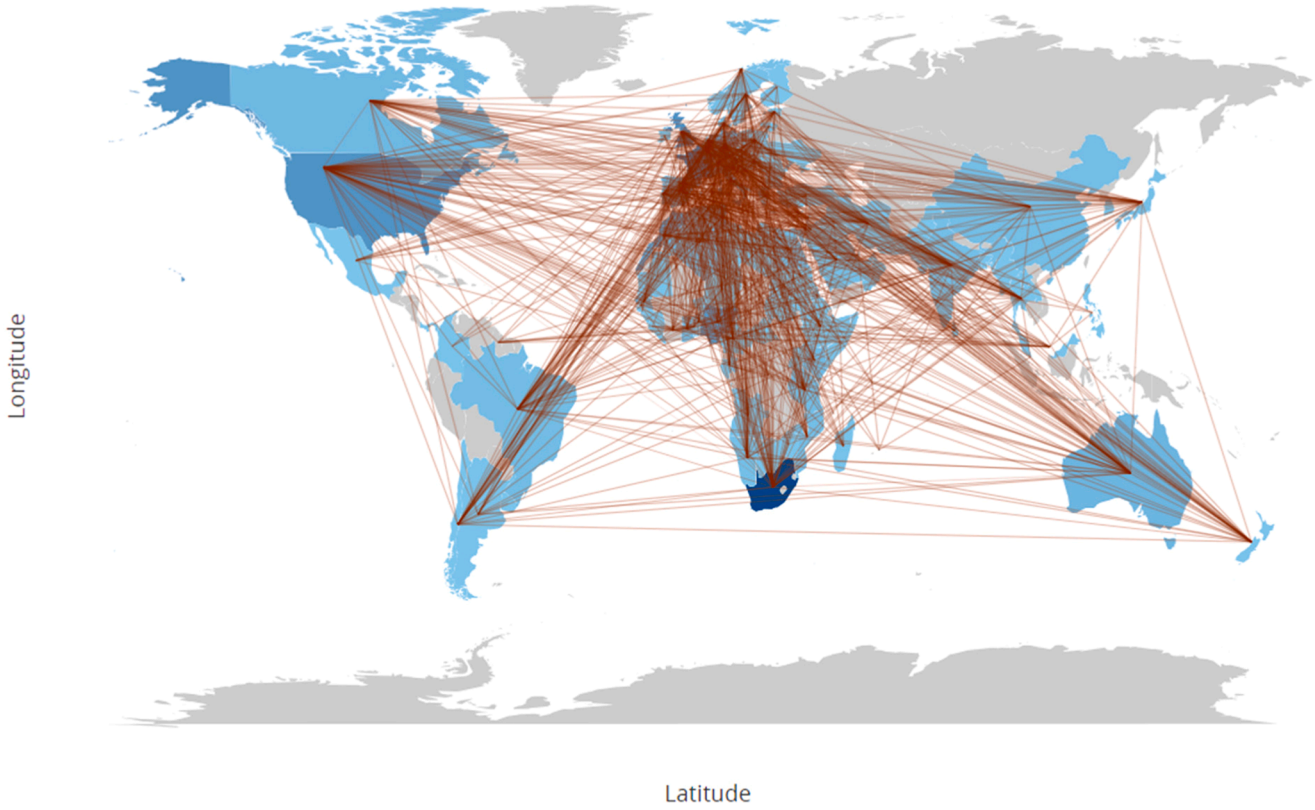


Fig. 8. Cross-country collaborations on sand mining practices (Source: Scopus/Biblioshiny).

indigenous communities) in Mozambique have lost their critical social assets (including land tenure/ownership) and goods. This has been due to resettlement failures of 'surplus populations', such as around the Tete province, to pave the way for foreign companies. such as Vale from Brazil, Riversdale from Australia, and Rio Tinto of the Indian consortium-ICVL (Wiegink, 2020; Wiegink and Garcia, 2022). This has sprawled natural-resource user conflicts and loss of property and lives (Arbeloda, 2020; Jouffray et al., 2023). These human-environmental ramifications reinforce findings from previous studies that reveal innumerable (mainly negative) ramifications of unsustainable sand mining activities; especially in sand-rich coastal regions of developing countries (Lukambagire et al., 2023; Bendixen et al., 2023; Shitima & Sykens, 2023; Matovu et al., 2024c; Ganie and Bhat, 2024). Unsustainable ramifications/risks have increased the urgency for governance mechanisms that promote sustainable sand mining and production alternatives, such as M-sand (IRP, 2020; NRGI, 2021; ORRAA, 2022).

As indicated in Fig. 6 and from the literature, current governance policies and pathways are unsustainable. This is because they emphasize and equalize neoMalthusian economic models, use diffused governance with hard laws, and are designed to suit monopolies/actors with huge capital investments (Arbeloda, 2020; Wiegink and Garcia, 2022; Jouffrey et al., 2023). In countries such as Kenya and Tanzania, private companies have created a 'mafia-like' *modus operandi* (dominated by exploitative actors/actions) to the detriment of coastal resources and communities (Shitima and Suykens, 2023; Bachmann et al., 2024). Similar governance deficits have been reported in most coastal sand mining zones (Wiegink, 2020; Matovu et al., 2024a; 2024c; 2024d; Hamed et al., 2024; Ganie and Bhat, 2024). In most cases, private foreign companies or concessions are the benefactors as they operate without licenses, are given land acquisition waivers, use connections with government officials, and kickbacks to influential officials to circumvent regulations for ESIA compliance (Nasare et al., 2023; Jouffray et al., 2023). Where relatively strong regulations and regulatory bodies exist (mostly under environmental management or protection MDAs), funding gaps to (a) monitor sand mining activities, (b) bring to book culprits, and (c) support collaborative actor engagements, are persistent (Bendixen et al., 2023; Matovu et al., 2024d; Asare et al., 2024). The works of International non-government organizations (INGOs) have also been incapacitated by bureaucratic practices and threats (Engels and Dietz, 2017; Filho et al., 2021). Local community-based organizations (CBOs), advocacy groups, and actors (e.g., traditional leaders & micro-level citizens' committees & landowners) are largely powerless to develop actions or by-laws for sand mining governance (some local environment managers are part of intricate sand mining cobwebbed networks) (Bendixen et al., 2021; Cole & Broadhurst, 2022; Mensha & Mattah, 2023; Jouffray et al., 2023; Matovu et al., 2024c).

Amidst this complex and unsustainable sand mining landscape, one may wonder how much damage to human and environmental safeguards in coastal zones will occur in the future and what the predicament of the unique marine resources, goods, and services that oceans/coastal zones in Africa offer will be in the next few decades. Urgently answering this question/equation is more relevant now as coastal sedentary populations (including coastal urban developments) have stratospherically increased since the 2000s (IRP, 2020; 2021; WOA II, 2021; IORA, 2023; Matovu et al., 2025). Most studies have recommended leveraging of novel approaches, such as the system thinking approach in sand mining practices, the System of Environmental-Economic Accounting (SEEA), United Nations Framework Classification for Resources (UNFC), due diligence for 'development minerals' e.g., sand, circular models in the Blue Economy, and extended Ecosystem-Based Management (EBA) among others (Friot and Gallagher, 2021; Katz-Lavigne et al., 2021; Bleischwitz et al., 2023; Matovu et al., 2024a; 2024b; 2024e; Amann et al., 2024;). Unfortunately, the complexity of sand mining nexuses and social/institutional dynamics in coastal zones of Africa might render these less replicable unless they are strategically aligned with the crisp understanding of sustainability perspectives/micro-level dynamics. One way of

positioning global sand mining sustainability perspectives and initiatives to micro-level contexts is the reimagining of sustainability by developing simplistic and evidence-based pathways that could guide bottom-up governance and voluntary management. As a way of advancing this perspective, this study contributes by leveraging Afro-centric scholarly perspectives and synthesizing literature to develop a novel pathway called the *Sustainable Sand Mining Action Pathway (SSMAP)*. The next section expounds on the sustainability prospects of sand mining that the SSMAP brings to the fore.

5. SSMAP as a novel pathway towards decomposing unsustainable sand mining chains in Africa

At the global level, several pathways for sustainable sand and material resources governance are emphasized. However, most of these pathways have only been applied in a few (developed) countries, as they require huge input-output data and financial outlays that are lacking in most developing regions (Katz-Lavigne et al., 2021). In addition, most pathways do not focus on social/institutional dynamics that determine sand extraction, especially among artisanal miners (Friot and Gallagher, 2021). The developed SSMAP breaks this jinx and comprehensively integrates all the sustainability dimensions that have been coalesced based on five steps. The five steps situate in key sustainability perspectives and dimensions in complex coastal zones that if well augmented, curated, and implemented, could kickstart or create novel perspectives for sustainable sand mining in Africa (See Fig. 9). The SSMAP is grounded on a critical synthesis of system interactions, drivers of vulnerability, and possibilities for transformation in vulnerable sand mining and complex coastal natural resource zones; as emphasized in global and regional policy reports, such as the UNEP IRP (2020) report on mineral and coastal governance(e.g., resource nexus & circular economy perspectives in the ocean activities) (WOA II, 2021; UNCTAD, 2022; Partelow et al., 2023; Curran et al., 2023; Laubchenco & Haugan, 2023; Bleischwitz et al., 2023; Matovu et al., 2024b; 2024e; Brouwer et al., 2024).

Subsequent paragraphs superimpose the relevance of the developed SSMAP towards charting new narratives for ocean sustainability (especially those aligned to the Ocean Decade actions).

First, under *step 1*, developing micro-level evidence indicators and inventories is emphasized. Micro-level indicators and inventories are projected as a benchmark in driving transformative actions that could benefit coastal communities and marine biodiversity health (such as through ocean accounting and sand material flow trend analysis, i.e., revenue, concessions, permissions, and financial disclosure (Katz-Lavigne et al., 2021). This is more relevant in coastal zones experiencing complex natural resource user contestations that holistically compromise marine ecosystem health and coastal livelihoods (Grant and Wilhelm, 2022; Cole & Broadhurst, 2020). The creation of situational inventories that show critical assets, goods, and services crucial for a given community thus becomes paramount (NRGI, 2021). As most coastal states lack evidence-based data to identify micro and macro-level material flows, value chains, and their ramifications (IRP, 2020; OEC, 2024), co-developing baseline inventories can help create novel benchmarks and tools (including locally developed) that can be used to kickstart sustainability narratives or assess existing trends in sand mining. Tools, such as resource mapping of sand mining zones, can help identify risk zones and evaluate micro-level risks, threats, livelihood asset gaps, and collaborative stakeholder management (Katz-Lavigne et al., 2021). The benefits of micro and macro-level data inventories (including visual mapping) have been reported in studies in South Africa and Asia (Grant and Wilhelm, 2022; Cole & Broadhurst, 2020; Marshke & Rousseau, 2022). In Africa, baseline and end-line data, co-designed tools, and strategies could be incorporated into the African Union's Mining Vision of just and fair benefit by both artisanal and commercial miners and communities (Katz-Lavigne et al., 2021). This perspective has been emphasized and complimented in studies conducted in contested extractivist zones, such as under the UNEP GRID and Mette Bendixen's project at McGill. Here, progressive indicators are being realized by utilizing hi-tech mapping techniques and technologies to assess the social, economic, and environmental impacts arising from (sand) mining (Arbeloda, 2020; Filho et al., 2021; Friot and Gallagher, 2021; Matovu et al., 2024a; 2024c). Resounding benefits of leveraging mapping tools, such as rule mapping tools to simulate future and imaginative thinking on sustainable sand mining transitions, have been

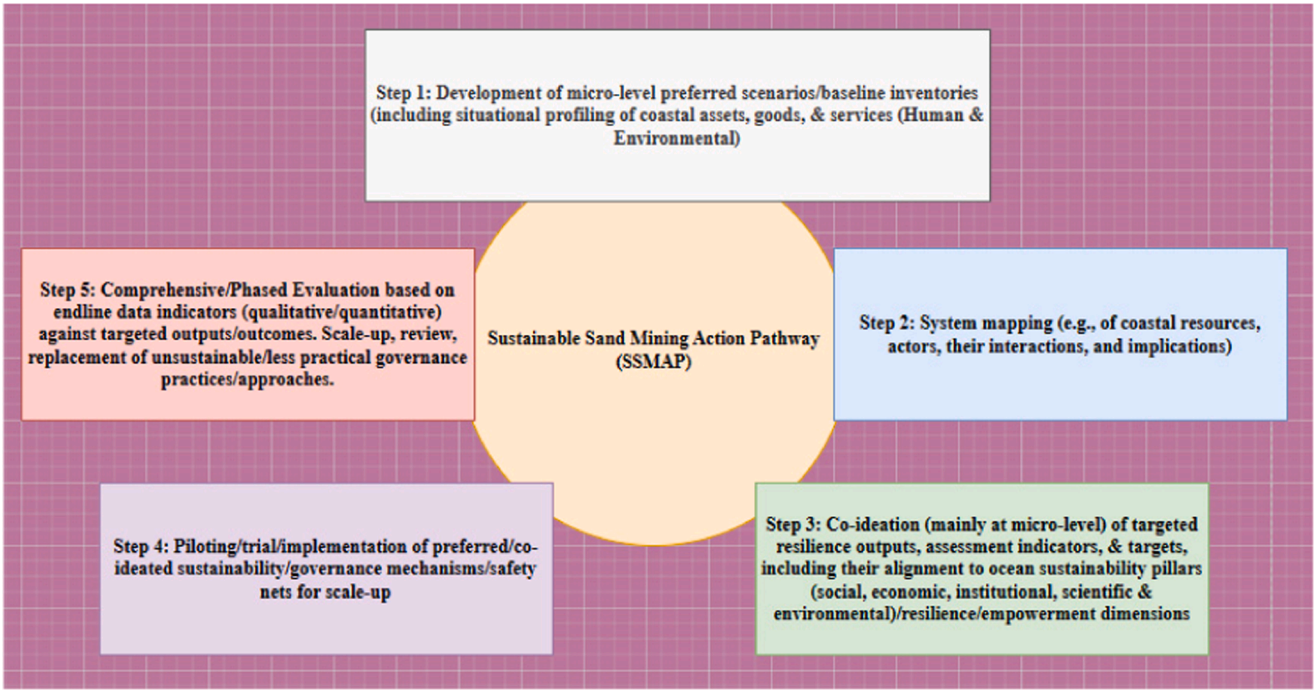


Fig. 9. The developed SSMAP, including a description of the five steps that could promote sustainable sand mining and governance transformations in ocean/coastal zones (Authors' creation based on the synthesis of literature).

reported in a recent study by Johnstone & Genc (2025). Most often, such socio-technological innovations in inventory development help in the spatial zoning of natural assets and sociocultural capitals, including unique cultural sites/heritage and strategic planning for sand mining quotas/zones (Blackwell, 2025). Achieving this success further requires collaborative mechanisms for stakeholder engagement and inclusion of all users (women, traditional leaders, media, indigenous communities) and also the consideration of their interests (Jouffrey et al., 2023; Paschal and Kauangal, 2023; Hamed et al., 2024). Sustaining micro-level interests can be done through affirmative practices, such as targeted advocacy/resilience funding and nature impact tokens for micro-level community-based organizations (CBOs) (Matovu et al., 2024b).

Under *step 2*, an argument for the leveraging of system thinking approach(es) in natural resource and socioecological dimensions is presented. The system thinking perspectives in vulnerable sand mining/resource-endowed zones avail new perspectives on the holistic understanding of resource nexuses and value chain fluxes and their ramifications on rural/resource-dependent livelihoods (Hilson et al., 2025). This approach is increasingly gaining traction; especially in ocean sustainability studies as it helps in the holistic understanding of how different actors (stakeholders), natural and anthropogenic activities interact, and the nature/effect of their interaction (feedback mechanisms) (Partelow et al., 2023; Bleischwitz et al., 2023; Jouffray et al., 2023). This helps to identify synergies and externalities that must be considered in creating a preferred future for marine resource sustainability (UNCTAD, 2022). The benefits of this approach have been reported in coastal zones in India experiencing human-induced vulnerabilities to environmental and sand-mining-induced shocks (Matovu et al., 2024e). Since there are many approaches/theories on system thinking, critical emphasis on identifying the most feasible approach is necessary (Matovu et al., 2024e; 2024b). For instance, prominent models or pathways that can mingle well with vulnerable coastal zones of Africa include those on global ocean accounts, the 3 Horizon model (using specific area-based indicators), material flow accounting, and the Iceberg model (UNCTAD, 2022; Matovu et al., 2024e). The iceberg model is key in unearthing complex overt and covert social, economic, and institutional dynamics that impede collaborative governance engagements or reaping benefits emanating from sand mining (Engels and Dietz, 2017; Matovu et al., 2024e). This can help in localizing key requirements embedded into the Convention on Biological Diversity (CBD) criteria for marine biodiversity/ecosystem identification and threat drivers (Wiegink, 2020; Bendixen et al., 2021; 2023; Curran et al., 2023).

Step 3 brings forward a new perspective concerning sustainable transitions on transdisciplinary research and policy-co-ideation/co-design. The collaborative creation of system interactions/networks work in tandem with mechanisms emphasizing the co-creation of phased approaches or strategies for attaining sustainability (Matovu et al., 2024b). Recent studies and developments, such as the Barcelona Ocean Declaration 2024, have revealed that collaborative engagements help in the identification of key resource management benefits based on micro-level perspectives of how sand mining is understood and needs to be governed in their locale (Partelow et al., 2023; UNEP, 2024). This could help break systemic barriers to sustainable sand mining and (i) chart a comprehensive understanding of micro or state-level dynamics on sand (including value chains), (ii) refine, sustain, or ensure the application of ocean sand monitoring tools or tactics (scientific domain), (iii) embrace of transdisciplinary ocean research (including social science perspectives e.g., of vulnerable coastal women) to inform policy and co-development of robust regulatory practice/mechanisms (institutional domain) and (iv) foster new waves of binding, collaborative and voluntary mechanism to regulate micro-level practices on illicit/licit sand mining and associated tradeoffs (socioeconomic) e.g., displacement (Wiegnik, 2020; Aziz et al., 2020; IRP, 2020; UNCTAD, 2022; Wiegink and Garcia, 2022).

To sustain or highlight missed points and gains, it is crucial to pilot targeted interventions or mechanisms, especially in specific zones (most vulnerable) or in demonstration sites using prototypes/simulations (Cole &Wilhelm, 2022) (*Step 4*). With the increasing emphasis on the Kunming-Montreal global biodiversity framework (GBF), this can help identify no-extraction coastal or marine zones. The identification of coastal or marine zones can be based on the in-depth understanding of geomorphological interactions, processes, and ramifications of site-specific sand mining activities on ocean-dependent communities (Hamed et al., 2024; Matovu et al., 2024a; 2025). This could help in the holistic understanding of sediment fluxes (e.g., in lacustrine sand mining zones), livelihood vulnerability or resilience indicators, resource nexus, and carbon footprints (Bleischwitz, 2020; Brouwer et al., 2024; Matovu et al., 2024d). Additional benefits include the easy identification of best-case scenarios (scenario building) and feasible human-environmental safeguards (Cole and Broadhurst, 2020; Bachmann et al., 2024). For instance, in Ghana, pilot projects done using geographic information systems (GIS) and remote sensing techniques in tandem with site-specific techniques helped reveal highly vulnerable and less vulnerable mining extraction sample sites along the Dallung-Kukuo catchment of the White Volta River Basin (Nasare et al., 2023). These emerging transformational pathways are key in creating databanks required under the marine sand watch initiative and coastal risk index formulations (ORRAA, 2022; Nasare et al., 2023; UNEP, 2024). Related benefits have been reported in South Africa, Kenya, and Tanzania that have involved the implementation of statements of intent and corporate social actions for sustainable sand mining (Cole & Broadhurst, 2020; Shitima and Suykens, 2023; Bachmann et al., 2024).

Finally, *step 5* epitomizes continuous evaluations. As most global sand mining governance actions and socioecological systems are shifting, continuous evaluation becomes critical. Continuous, systematic, and comprehensive marine or coastal-based evaluations are a conduit for the attainment of better ocean or global sustainability indicators, especially on complex or contested marine natural resources and extractive activities (UN, 2023). In ocean sustainability transformations, evaluation indicators need to be aligned with baseline data identified in a given location or site (UNCTAD, 2022; Matovu et al., 2025). This eases the linking of progress indicators to targets/outcomes co-ideated in a given area (Jouffray et al., 2023). Further benefits include assessing the viability/feasibility of a given tool/strategy envisioned to drive a given governance mechanism (including scalable matrices/scoring systems, e.g., Material Circularity Indicators (MCIs) to identify damage/loss), e.g., in coastal sand mining (IRP, 2020; Hübler and Pothen, 2021; NRGI, 2021; Matovu et al., 2024a). These can be spiced up by creating specific legal or regulatory sweeteners and safeguards at the national or regional levels. The safeguards could be amalgamated and romanticized into continental and global policy discourses, aimed at driving sustainable sand mining, e.g., the SDLO, corporate social responsibility (CSR), due diligence, and SEATS, among others (IRP, 2020; 2021; Hübler and Pothen, 2021; WOA II, 2021; UNCTAD, 2022; Joufrrey et al., 2023; Matovu et al., 2024a). The coherent, systematic, and transparent charting of this process/mechanism could present a novel opportunity for Africa's sand-mining states to become stewards in aligning their regulatory pathways and tools to the first globally developed terrestrial ecosystem condition method (TECM) (www.creditnature.com). This can further help align governance mechanisms/attract funding (e.g., on carbon offsetting and ocean risk insurance) to global matrices, databases (e.g., UNEP's Marine Sand Watch and recently inaugurated coastal risk index (CRI) by ORRAA to among others. An omlette of these comprehensive actions enhance (i) the assessments of coastal communities and ecosystem vulnerability and (ii) the building of collaborative and transformative responses by the blue finance and insurance stakeholders or sector actors. As coastal regions cascade towards blue futures and equity transformation, this can help reduce the exposure and vulnerability of coastal communities and ecosystems through targeted private and global capital or financing mechanisms for scaling down sand

mining risks. An additional benefit can be the creation of measurable percepts to monitor or evaluate community and state-level progress toward sustainable governance of diverse marine/coastal natural resources, including coastal sand (IRP, 2020; Cole and Broadhurst, 2020; NRGI, 2021; ORRAA, 2022; UNEP, 2024; Hilson et al., 2025).

6. Conclusion

This study reveals that sand mining presents a complex natural resource conundrum and trend in Africa (as it is globally). First, it is hard to brush aside the value of sand mining as it is a conduit for national and global development, e.g., infrastructural development (crucial to social service provision for the exponentially rising coastal developments and population in Africa) and a source of livelihood, especially to artisanal miners, including women. However, unsustainable trends have been reported, e.g., on who benefits and where the benefits of sand extracted in Africa trickle. This is further crippled by the absence of a globally or regionally binding regualtory or governance instrument that explicitly charts mechanisms for regulating sand mining activities, value chains, and transboundary flows. Similarly, complex, less effective, and fragmented top-down governance mechanisms are prevalent in Africa. This is worsened by the limited sharing of/transparency in sharing the limited data on sand mining activities, due diligence, and CSR, all of which affect coastal communities and resources. As sand increasingly becomes commodified and elite capture of sand-rich zones crystalizes, livelihood vulnerabilities might increase, and natural resource contestations might bubble. The worsening socioecological vulnerabilities in Africacan only be repulsed if proactive actions, pathways, win-win practices, and mechanisms that are testable, acceptable, and feasible are developed.

The developed SSMAP provides a critical launchpad in shifting towards sustainable practices, narratives, and the development of new lenses for creating win-win scenarios that benefit sand mining actors, sedentary coastal populations, and marine ecosystems and create sustainable sand trade flows/value chains. To explicitly replicate and advance the viability of the SSMAP and holistic governance, e.g., at micro-scales (including sustainability dimensions), transparency and accountability are key. This could naturally advance and soothe collaborative research and policy engagements for effective implementation or enforcement of developed fit-for-purpose tools, targets, and management actions. In this way, coastal communities, irrespective of their demographic status, can become leads and incumbents in co-building, mapping, and co-strengthening governance actions and impact pathways that cascade towards sustainable sand mining practices and complementary management of other ocean-based activities or BE sectors, e.g., small-scale coastal fishing. A critical limitation that is acknowledged is that the study entirely relied on existing literature, and this might side-step ground-truthed perspectives of coastal communities on how sustainability transitions coiled around sand mining could be attained. As Africa is a '*sleeping ocean resource giant*' with immense potential to reap from coastal resources, including sand mining, future studies could leverage participatory research techniques that engage coastal communities in exploring critical sand mining ecologies and what suits well where concerning sustainable ocean and resource transformations.

CRediT authorship contribution statement

Matovu Baker: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Raimund Bleischwitz:** Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Funding acquisition, Formal analysis. **Isaac Lukambagire:** Writing – review & editing, Writing – original draft, Visualization, Software. **Linda A Etta:** Writing – review & editing, Writing – original draft, Software, Resources, Project administration, Funding acquisition. **Bernard Lutalo:** Writing – review & editing, Writing – original draft, Validation, Resources, Funding acquisition.

Declaration of competing interest

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.exis.2025.101646.

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