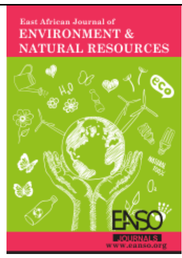

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Original Article

Impacts of Sand Mining on Fish Breeding: A Review

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ABSTRACT

Sand mining, the process of extracting sand aggregate from the land surface and underneath the water surface, such as rivers, lakes, and wetlands, is a growing environmental concern. In the quest for economic development, unsustainable sand mining practices threaten the integrity and functioning of an aquatic ecosystem, specifically the fish breeding behaviour and ecology. The changes associated with sand mining alter the aquatic environment hydrologically, geomorphically, and ecologically and these impact fish reproductive behaviour. Despite more research on sand mining, including the environmental and socio-economic effects of sand mining, there is a knowledge gap on its impacts on fish breeding and general reproductive behaviour. In a narrative review, this review article explores the impact of sand mining on fish breeding ecology. Sand mining activities, including excavation, heavy machinery, transportation, ground clearance, alter sediment composition, food web dynamics, and increase noise and vibration pollution. This degrades the fish breeding habitat quality through altering sediment composition, reducing dissolved oxygen, increasing turbidity, and reducing macroinvertebrate populations, hence food shortages. Furthermore, this is associated with the reduced fish production in areas with high sand mining activities. To reduce the trend and mitigate these impacts, there is a need for an integrated approach. This includes implementing clear regulatory frameworks, adoption of sustainable mining practices, habitat protection and restoration programs. Further, there is a need for comprehensive research on the long-term impacts of sand mining on aquatic ecosystems.

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INTRODUCTION

Sand mining is the process of extracting sand aggregate from the land surface and underneath the water surface, such as rivers, lakes, and wetlands (NwalI, 2023). Sand is the second most consumed natural resource due to increased human population, urbanisation and the need for improved infrastructure development (Gavriletea, 2017). It is economically important for job creation, revenue collection, and infrastructure development. However, it comes at a cost of complex geomorphic, ecological, societal and health complexities through effects and implications on the environment and society (Bendixen *et al*., 2021). Its benefits need to be weighed against its negative impacts on the environment, as a basis for a strategic management approach to promote sustainable development (Sanni, 2020).

Sand mining disrupts the aquatic environment quality through: underwater noise and pollution, increased water turbidity, changes in water colour, and local habitat destruction, degradation, and food web changes, these impact the fish breeding success (Todd *et al.*, 2015; Kunc *et al.*, 2016; Pirotta *et al.*, 2017). Sand mining clears off the riparian vegetation structure due to developments like access roads, storage facilities, leading to fragmentation. It also degraded the critical spawning areas, affecting species that are habitat characteristic species. These include species that rely on specific sediment flow, texture and water depth for reproduction. This calls for integrated approaches for sustainability of sand mining and environmental conservation through a clear and implementable regulatory framework (Koehnken *et al.*,2020; Damseth *et al.*, 2024).

Ecologically, it impacts the aquatic ecostem species directly and indirectly through habitat disturbance, downstream sediment transport changes, fish movement restriction and community structure changes, species abundance, and food web dynamics alteration of riparian zones (Koehnken *et al.*, 2020). Sand mining disrupts the sedimentary flow, creating an imbalance in the sedimentation process and deposition accumulating from years of erosion (Pandey *et al.,*2023). It disrupts sedimentary structure and flow through reduced sedimentary load, selective removal of some sediments, and disrupting the bed to sediment load ratio (Sadeghi & Kheirfam, 2015).

Although research has been done on the environmental and socio-economic impacts of sand mining on the environment, there is limited knowledge on its impacts on fish breeding behaviour (Zou *et al.*, 2019; Ali, 2020). The aim of this review article is to understand and examine how sand mining-related changes, such as sediment composition, water quality, food web-changes, noise and vibration, impact fish breeding behaviour.

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METHODOLOGY

A narrative literature review approach was used following a modified method used by Dennis *et al.* (2024) to obtain information from original peer-reviewed articles published in scientific journals. The search focused on the impact of sand mining on fish breeding. The review process involved critically searching electronic literature databases from trusted courses such as PubMed, Google Scholar, Web of Science and Research Gate for all available topical related peer-reviewed data. The following key search terms were used: "Sand mining impacts", "environment impacts of sand mining on fish", OR "Sand mining and fish breeding ecology". The accuracy of the information was peer-verified by a third party who reviewed the draft write-up, and any differences were settled through discussion with the authors. This review considered English peer-reviewed publications between 2005 and 2024 at a global level.

FINDINGS

Impacts of Sand Mining

Impacts of Sediment Composition Changes on Fish Breeding

Sandy bottom habitats are preferred breeding grounds for a variety of fish species, such as the Nile tilapia. The male fish constructs the nest, attracts the ripe female to lay eggs in the nest, where they are fertilised externally (Walugembe et al., 2023). Sand mining activities such as dredging operations (Figure 1) clear all the fish eggs and nests, disrupting the nesting/ breeding activity (Aminu *et al.*, 2023).

Studies have shown that sand mining affects macroinvertebrate drifts and benthic fish population richness, abundance and structure, and has the potential for invasive species introduction in the ecosystem, such as exotic fish populations (Paukert *et al*., 2008; Béjar *et al.,* 2017). Invasive species such as *Pistia spp* and *Salvinia spp* (Karib) affect the water quality, reducing the suitability of breeding grounds for species like the Nile tilapia (Aura *et al.,* 2018).

The invasive species covers the water surface, reducing light penetration and oxygen circulation, and provides hideouts for predators of the fish eggs or the fish fry (Obubu *et al.,* 2021).

Figure 1: Sand Mining at Lwera Wetland. A: Sand Mining Activities. B: Sand Pile

(Photo Credit: NEMA, 2024)

Sand mining is associated with sediment accumulation within the mining areas that inhibit the egg incubation process. This is through impacting the gravel permeability, the oxygenated water flow rate, and reduced intragraval oxygen concentrations. Furthermore, sediment

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accumulation disrupts the oxygen exchange in the egg membrane, thus reducing reproductive success (Greig *et al.*, 2005; Pedersen, 2024). Fine suspended sediment increases mortality in benthic spawning fish by affecting newly partially immobile hatched larvae, which are highly sensitive to high total suspended solids concentrations in sandy sediments (Suedel et al., 2017).

Sand mining interferes with fish migratory corridors and spawning grounds, which reduces hydraulic conductivity, affecting the embryo incubation process and the fish survival rate (Kondolf, 2022; Seguerra, 2024). Sand dredging selectively removes sediments of a specific size that are used to construct spawning redds or nests and also destabilises the sediment deposits and hence affecting embryos sheltering within (Koehnken *et al.*, 2020). Change in water colour limits the penetration of sun rays, which reduces photosynthesis rate and increases eutrophication, hence reducing dissolved oxygen levels. Some fish species, such as the Nile tilapia, are very sensitive to areas of low dissolved oxygen (DO) concentration. The low DO levels in water increase stress, reduce appetite and slow growth, increase disease susceptibility and mortality rates (Abd El-Hack, 2022; Solomon, 2023). In Ethiopia, sand mining has been associated with low fish catches and production in the fishing villages, which is linked to the fish breeding ecology (Mingist & Gebremedhin, 2016).

Change in Food Webs and Impacts on Fish Breeding

Sand mining alters the aquatic-terrestrial systems, disrupting the food web structure through energy changes in the energy flow. Fish supplement their nutrition by feeding on terrestrial insects that fall into the water (Scharnweber *et al.,* 2023). However, habitat loss and degradation caused by sand mining reduce the macroinvertebrate population in the aquatic ecosystems, which reduces the food (prey) availability of the fish species. The physical impacts, such as channel incision and widening, impact the population structure of prey, including the beetles, by reducing shelter and habitat for riverine species (Skalski *et al*., 2016; Koehnken et al., 2020). Decline in prey populations compromises the available energy reserves necessary for fish spawning and larval development success (Arevalo *et al.,* 2023).

Sand mining activities disrupt substrate composition and concentrations, as well as water level variations. These disruptions lead to lateral erosion, ground vegetation removal, and dumping of tailings, all of which alter the nutrient concentrations of the substrates. Water level variation greatly interferes with fish spawning, the incubation process, and hatching of eggs, and the development of the lifecycle (Koehnken *et al.*, 2020; Mangi, 2024). Furthermore, disrupts, replenishes nutrients in the wetland ecosystems, which are important for fish reproduction (Logez *et al.,* 2016).

Noise and Vibration Effects on Fish Reproductive Behaviour

The reproductive success of many fish species is sensitive to noise pollution from human activities, including sand mining from sailing, mining machines, and offshore developments (De Jong *et al.,* 2018). Sand mining activities increase noise levels in water bodies and disrupt acoustic signals that are biologically relevant sounds to fish (Rentier & Cammeraat, 2022). This noise interrupts the essential behaviours, including the ability of the fish to communicate between mates, the detection of predators and prey, navigation and habitat selection (Popper & Hawkins, 2019). Some fish species, such as Yangtze finless porpoise, rely on echolocation systems to guide navigation in the water, prey and predator detection (Mei *et al.*, 2021). The noise and vibrations reduce the survival and fitness of such individuals and populations. Furthermore, they cause changes in behaviour such as impairment of spawning, interference with foraging and feeding and physiological changes such as stress effects (Filiciotto *et al.,* 2016). Fish tend to avoid areas with more noise and vibrations, leading to low reproduction and stock recruitment rates. This highlights the need for protection and safeguarding of spawning areas (Sivle *et al.*, 2021).

Adaptive Mechanisms in Fish Breeding to Sand Mining Stress

The intensive sand mining within fish breeding ranges amplifies the stress levels. This often happens during low water table levels, altering fish spatial distribution, diversity (Han *et al.*, 2023). Sand mining further increases the vulnerability of fish during sensitive life-history stages such as egg laying and livebearing (Kunc *et al.,* 2016). In response, fish have adapted to the changing environments through behavioural responses, which include altered habitat choice or foraging activity. These influence the breeding, growth, and survival of individual fish populations (Candolin & Rahman, 2023). Species change their movement patterns and avoid the deterioration of habitats such as mining sites. However, this is limited by anthropogenic structures such as physical barriers (like levees in wetlands) that restrict movement and increase the predation rate through channels in given directions (Hoch *et al.*, 2022). Some species, such as red snapper fish, have adapted by synchronising the environmental conditions and spawning at certain seasons, given temperature ranges and moonlight phase (Farmer *et al.,* 2017). With increasing anthropogenic disturbance to the ecological aquatic systems, some species have evolved and adapted by coping with changes in habitat use, feeding behaviour, and spawning patterns. However, these response adaptations are limited by anthropogenic barriers, habitat fragmentation and degradation, which limit fish movements, food availability, and increase predation risks.

CONCLUSION

Sand mining activities alter the sediment structure and composition, altering the aquatic food web structure and flow, reducing macroinvertebrate populations, which are key components of a diverse fish species' diets. The decline of prey populations and substrates also decreases the available energy resources needed for fish spawning, fry, and fingerling development. The natural challenges in the ecosystem are amplified and compounded by physical habitat changes, including channel incision and expansion, habitat loss and fragmentation, and substrate loss. These create a feedback loop disrupting fish population dynamics and aquatic biodiversity.

Noise and vibrations from mining equipment cause aquatic stress and affect communication between fish, the detection of prey, and mating behaviours. Reduced breeding success is more associated with species that depend on acoustic signals for reproduction. As a result, there is a decrease in reproductive success and recruitment rates due to avoidance of noisy areas.

Given these ecological impacts of sand mining on fish breeding, there is a need for sustainable mining systems and practices, supported by an integrated regulatory framework. Additionally, there is a need for intensive research on the long-term effects of sand mining on fish reproductive behaviour. Furthermore, implement an integrated sustainable sand mining practice that balances the economic demands and environmental conservation.

Author's Contribution

TD: Obtained and reviewed all the data and wrote the manuscript. **BE, TA, NA:** Reviewed all the data obtained and wrote the manuscript. **BA** and **FSO:** Reviewed and edited the manuscript. **KR:** Wrote the manuscript, and he is the corresponding author.

Conflict of Interest

The Authors declare no conflict of interest

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