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River Sand Mining and Groundwater Systems: Mechanisms, Impacts, and Pathways to Sustainable Management

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ABSTRACT

Sand mining is a common practice that provides vital resources for economic development and infrastructure development, but it also has adverse effects on the environment and social activities worldwide. However, its unregulated practices pose significant threats to the groundwater system. This review examines the impact of river sand mining on groundwater recharge, quality, and availability. Excessive sand mining alters riverbed morphology, reducing infiltration capacity and lowering the water table in adjacent aquifers. The sand acts as a natural filter; removing it can degrade groundwater quality by causing turbid water and contamination from surface pollutants. The over-extraction of sand disrupts hydraulic connectivity between rivers and aquifers, exacerbating groundwater depletion and threatening water scarcity for agricultural, industrial, and domestic use. This review paper consolidates the findings of the impact of sand mining on groundwater recharge, storage capacity, and sustainable water management practices. Strategies to mitigate adverse effects, including implementing a regulatory framework, adopting sustainable mining practices, and using alternative materials such as M-sand, quarry stone dust, and crushed rock, were suggested. This review highlights the need to balance developmental demands with the preservation of groundwater resources to ensure long-term environmental sustainability.

Key words:
Groundwater recharge
Groundwater quality degradation
Hydrogeological impacts
River sand mining
Sustainable groundwater management

1 | INTRODUCTION

Sand mining, which involves removing sand and gravel, is becoming an environmental problem due to the growing demand for sand in construction and industry. The establishment of flora in abandoned mines depends on the presence of topsoil, which must be maintained for post-mining land restoration. In almost every mineral-bearing region, land degradation and sand mining are closely linked (Barman *et al.*, 2019). The unscientific mining process causes land degradation and is followed by mine fires, subsidence, and disruption of the water table, which destroy land-use patterns in and around mining districts and cause topographical disorder and severe ecological imbalance (Ghose, 2000). Heavy metal concentrations and physico-chemical parameters of Pb^{2+}, Zn^{2+}, Ni^{2+}, Co^{2+}, As^{3+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, and Sn^{2+} were examined in mined soil regions. The results showed that the majority of the parameters and metal concentrations were higher than allowed and that the ex-mining catchment had a high potential for contamination (Saviour & Stalin, 2012). It has been shown that sand mining has detrimental, irreversible effects on the ecology. (Kondolf, 1994; Rovira *et.al.*,2005; Nabegu, 2012). With 36 lakh hectares (0.11%) of the country's total land area (329 million hectares), mining is a significant contributor (2nd) to the GDP and creates jobs for 1.1 million people. (Saviour, 2016). In India, Anthropogenic problems harm the sustainable drainage system. It includes illegal sand mining (of alluvial channels) and gravel mining (of perennial channels) (Saviour & Stalin, 2012).

In India, sand mining increased after rapid urbanization driven by economic liberalization in 1990. According to the UN Environment Programme, sand is the most mined commodity worldwide and the second most exploited resource after water (Rajesh *et al.*, 2019). It is often removed from riverbeds without considering the negative effects on the river's natural ecosystem. Although the country has sand mining laws, poor enforcement and monitoring leave riverbeds constantly threatened. Locals have complained about the impact of sand extraction on migratory birds and fish visiting the River Yamuna. Sand mining expanded into a large and often illegal industry after the rapid urbanization brought on by economic liberalization in the 1990s. Even with regulations in place, riverbeds remain in danger due to inadequate enforcement. In the Hamirpur district of Uttar Pradesh, natural and disturbed flows can be distinguished from one another, caused by man-made bunds that extend over seven kilometers. Active sand mining operations are indicated by earthmovers and sand trucks near these bunds. This severe disturbance to the river's normal flow causes ecological effects such as changes in aquatic species migration and shifts in the food chain. In Ken in Banda district, UP, which originates in MP and passes through UP to merge with the Yamuna in Banda, a roughly 5-kilometer stretch of sand mining is evident. This is marked by trucks, earthmovers, and bunds that impede the river's natural flow. Under state law, mining licenses can be revoked early due to ecological imbalance and environmental contamination, including pollutant discharge from the damaged riverbed. The hydrogeological impacts at these sites—including disruption of natural river flow, riverbed disturbance, and threats to downstream water supply—are direct manifestations of groundwater recharge disruption, infiltration loss, and breakdown of river–aquifer connectivity, as systematically examined in Section 4 of this review.

2 | METHODOLOGY

This review study was conducted following a structured and systematic literature review framework to critically synthesize scientific evidence on the impacts of river sand mining on groundwater systems. Relevant peer-reviewed publications, review articles, conference papers, and authoritative institutional reports published by internationally recognized databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar (Fig.1). A comprehensive keyword search strategy was employed using combinations of terms such as “river sand mining,” “groundwater recharge,” “aquifer dynamics,” “hydrogeological impacts,” “groundwater quality,” and “surface water–groundwater interaction,” refined using Boolean operators to ensure relevance and coverage. Retrieved studies were screened through title, abstract, and full-text evaluation based on predefined inclusion criteria emphasizing hydrogeological processes, groundwater quantity and quality assessment, and environmental impacts associated with sand extraction, while non-scientific, duplicate, or unrelated studies were excluded. Relevant information was systematically extracted and categorized into major thematic domains: physical hydrogeological alterations; groundwater recharge and flow modifications; contaminant transport and water quality degradation; and ecological and anthropogenic impacts. A qualitative thematic synthesis and comparative analysis were performed to identify recurring mechanisms, regional patterns, and research gaps related to sand mining–induced groundwater disturbances. Cross-verification among multiple studies ensured reliability and minimized bias. The synthesized findings were further integrated to develop a conceptual understanding of the interactions between riverbed mining activities and groundwater systems, forming the basis for evaluating sustainable groundwater management strategies and policy implications presented in this review.

HIGHLIGHTS

- Excessive river sand mining reduces infiltration capacity and disrupts river–aquifer connectivity, causing significant groundwater table decline in adjacent aquifers.
- Removal of sand layers — nature's primary filtration media — elevates turbidity, mobilizes heavy metals, and triggers acid mine drainage, collectively degrading groundwater quality.
- Sand mining impacts cascade across ecological, hydrological, and social systems, threatening biodiversity, riparian habitats, and community water security simultaneously.
- Sustainable groundwater protection requires integrated regulatory frameworks, adoption of alternative materials such as M-sand, and scientifically monitored extraction practices aligned with SDG 6, 13, 14, and 15.

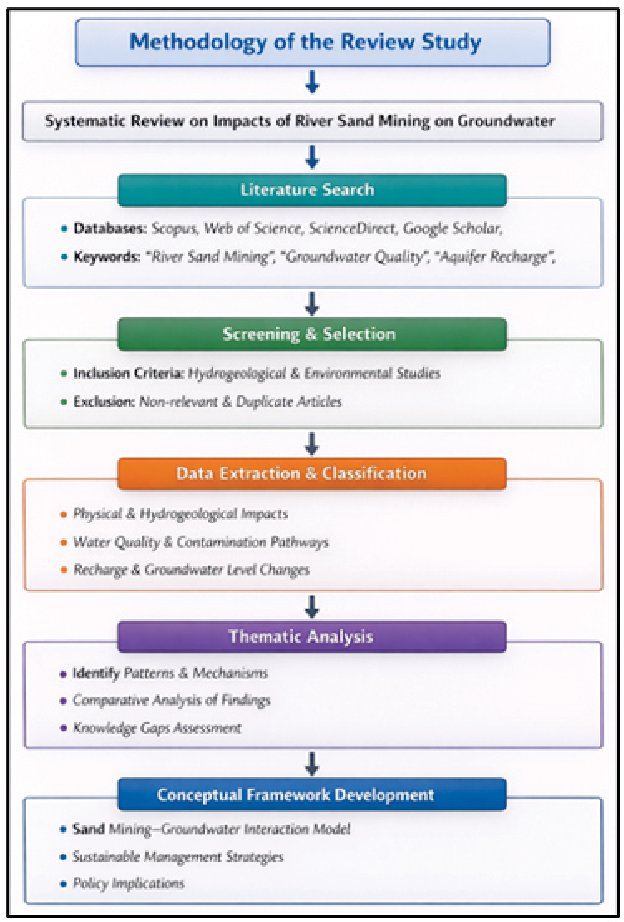

FIGURE 1 Overview of the study's methodology

3 | RESULTS AND DISCUSSION

3.1 | Mechanistic Impact of Sand Mining on Ground Water Recharge

The conceptual mechanisms illustrating the influence of river sand mining on groundwater recharge are presented in Fig. 2. Under natural conditions, permeable sand layers in riverbeds act as effective filtration media that facilitate infiltration and maintain strong hydraulic connectivity between the river channel and adjacent alluvial aquifers. These permeable sediments allow efficient exchange between surface water and groundwater, sustaining groundwater recharge, regional flow systems, and river baseflow.

However, excessive sand extraction disrupts these natural recharge processes. Removal of the permeable sand layer reduces infiltration capacity and weakens river–aquifer connectivity. In addition, mining activities often cause riverbed incision and channel deepening, which alter hydraulic gradients and promote groundwater drainage toward the river channel. These changes can result in the formation of localized cones of depression and reduced groundwater storage in surrounding aquifers. Consequently, sand mining significantly decreases groundwater recharge efficiency and may contribute to long-term groundwater depletion in riverine environments

3.2 | Environmental Impacts of Sand Mining

Environmental impacts of sand mining are broadly classified into physical, chemical, biological, and anthropogenic components based on findings from existing literature (Fig. 3). These interconnected impacts influence river morphology, groundwater systems, water quality, ecosystem health, and human activities (Barton N. and Mini G., 2013). This classification provides a structured framework for synthesizing previous studies and evaluating sustainable management approaches in this review paper..

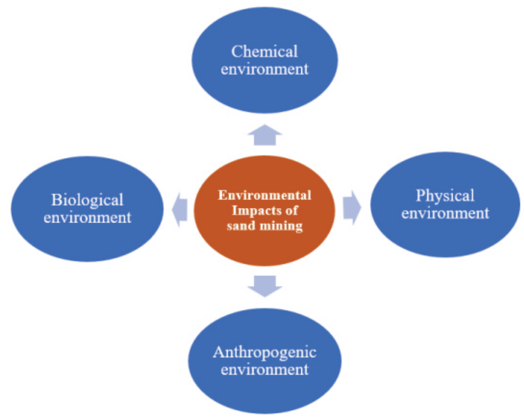

FIGURE 3 Environmental impacts of sand mining

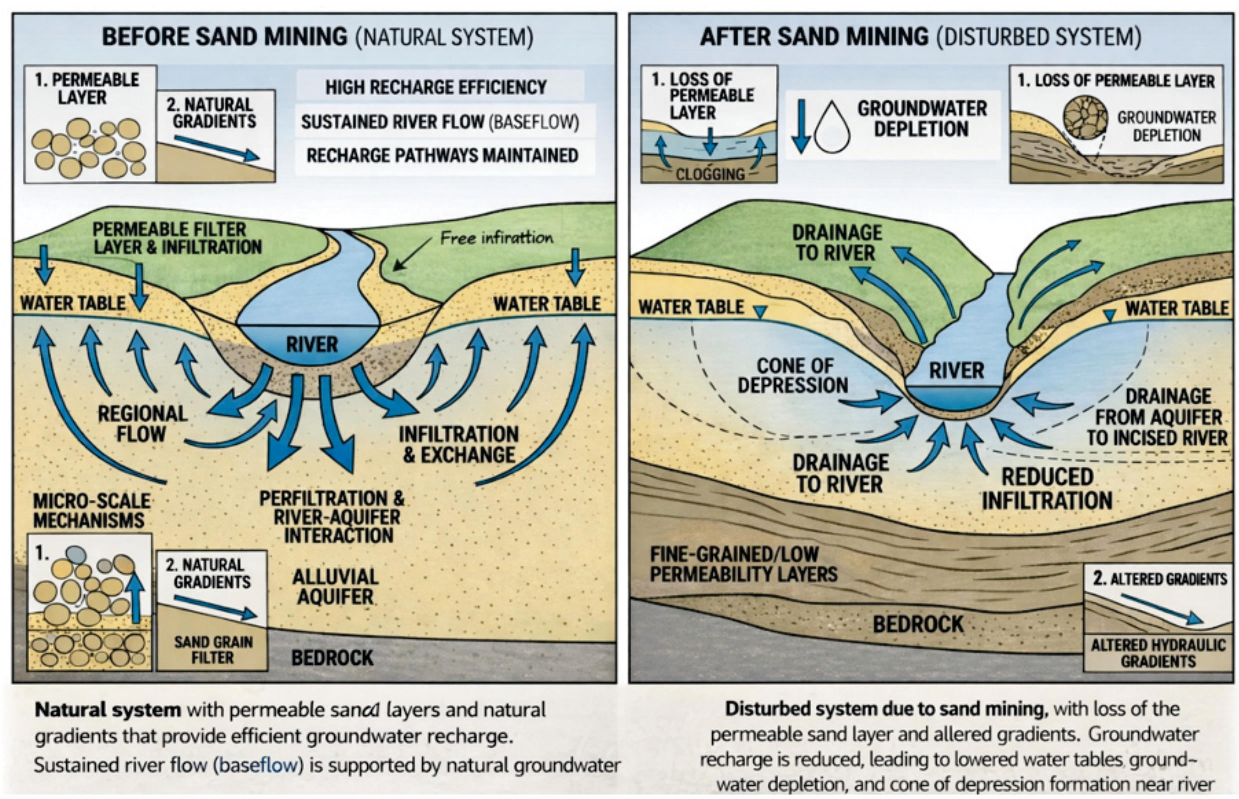

FIGURE 2 Mechanistic impact of river sand mining on groundwater recharge

3.2.1 | Turbidity

Turbidity is a key environmental impact associated with sand mining, especially in aquatic ecosystems. When sand is extracted from riverbeds, coastal areas and lakes, it disturbs the sediments, causing them to become suspended in the water. This suspension increases the water turbidity, leading to several environmental concerns.

Increased turbidity reduces light penetration leads to blocks sunlight from penetrating the water column, impacting photosynthesis in aquatic plants and phytoplankton. These organisms are from the base of the food web, so they are reduced photosynthesis can ripple through the entire ecosystem, affecting fish and other wildlife dependent on these resources. The oxygen depletion in aquatic systems leads to higher sedimentation rate, covering the organisms living in the bottom and reducing oxygen levels in the substrate. When the oxygen levels drop, it can lead to hypoxic conditions, stressing or even killing fish and other aquatic species. Fine sediments can settle over gravel beds used by fish, particularly species like salmon and trout, which lay their eggs in these areas. Increased turbidity and sedimentation can smother eggs and larvae, severely affecting the fish population. Turbid water is often associated with higher concentrations of pollutants, as partials suspended in water can bind with metals, pesticides and other toxins. These substances can travel towards downstream, spreading pollution and affecting water quality for communities and ecosystems.

3.2.2 | Bird Habitat

The negative environmental impacts of sand mining, particularly on fish, crocodiles, turtles, otters, birds and river dolphins. Many bird species, including the Indian skimmer, black-bellied tern, river tern, great thick-knee and river lapwing, find that rivers transitory sand islands, which provide an abundance of food for birds, are perfect places for them to nest. These sandbar nesting birds' breeding sites are being deteriorated by extensive sand mining, which may ultimately cause a reduction in their number. (Grbes *et al*., 2024 and Kajtoch *et al.*, 2024).

3.2.3 | Riparian Habitat, Flora and Fauna

The area along rivers and streams, is crucial for maintaining ecological health, supporting a diverse array of flora and fauna. These habitats provide essential resources like water, food and shelter for many species, including birds, fish, amphibians and mammals. The vegetation, such as willows, reeds and grasses, stabilizers riverbanks, strongly linked to the stability of channel bed and banks. Habitat degradation affects the natural nutrient cycle, impacting flora that rely on stable sediment layers (Kumar *et al.,* 2024). As riparian vegetation is cleared or degraded, local wildlife lose essential shelter and food sources, leading to biodiversity loss and altered ecosystem dynamics.

4 | Groundwater

4.1 | Impact on Aquifers-Confined, Unconfined

The complex hydrologic reactions can arise from the influence of sand mining, even if drainage to the mine is not involved. Dewatering from confined to unconfined conditions in bedrock aquifers is one reaction to water loss into new void space produced by bedding separations and fractures. (Bozeman, 2002). This dewatering process has been little studied but accounts for several hydraulic and geochemical effects of longwall mining (Booth, 2007). The increasing fracture permeability affects heads because upper aquifers in high relief areas lose water through fractured aquitards to lower aquifers and because the higher permeability lowers hydraulic gradients and up-gradient heads, and increases down-gradient discharge (Mace and Jones, 2023).

4.2 | Stability of Structures

The eroding of riverbanks**,** deteriorating coastal areas, lead to a reduced groundwater table and diminishing soil water quality, sand mining has a substantial negative influence on structural stability. This extraction eliminates the natural buffers that sustain coastal dunes, riverbanks and houses along the shore. Additionally, mining causes plant loss, subsidence and soil compaction, which weakens slope stability and increases the risk of landslides. In addition to endangering the surrounding infrastructure's foundations, this unreliability increases the risk of structural damage to the ecological system.

4.3 | Water Quality

Total suspended solids (TSS), magnesium (Mg), turbidity, and iron (Fe) levels in water samples taken downstream of the river near the mining site above WHO guidelines, which may be used to assess physiochemical analysis in sand mining sites (WHO) standards (Akankali *et al*., 2017, Candeias et al., 2018, Lekomo et al., 2021 and Bhattacharya *et al.*, 2019). The current condition of seawater quality has decreased due to increasing sedimentation, altering water flow and introducing pollutants (Doloksaribu *et al*., 2020, Hemalatha *et al*., 2025). Additionally, sand mining can cause erosion, increasing nutrient runoff and pollutant loads, including heavy metals and organic contaminants, which degrade water quality. The altered flow patterns can also lead to changes in water temperature, dissolved oxygen levels, and pH, further affecting aquatic life and potentially contaminating drinking water sources (Poonia *et al.,* 2024).

4.4 | Biological Environment

Biologically, SOC (Soil Organic Carbon) serves a food source for soil microorganisms, which are essential for nutrient cycling and maintaining soil fertility (Paustian *et al.*, 2019; Mirzaee *et al.*, 2020; Li *et al.*, 2018). Furthermore, the SOC content of agricultural and natural soil affected by mining activities can exert significant direct and indirect impacts on the environment (Ussiri *et al*., 2014). Mining activities have direct consequences such as the removal of vegetation, excavation resulting in loss of soil and overburden, permanent changes to the landscape and geological formations and disruptions to surface and subsurface hydrological systems (Shrestha and Lal, 2011).

Therefore, mining directly impacts SOC levels by removing or disturbing surface soils, which leads to the loss or degradation of soil organic matter (Zhu *et al.*, 2024).

4.4.1 | Health Hazards

Air quality is one of the most often mentioned environmental issues related to industrial sand mining, particularly in relation to crystalline silica particles that can be ingested. Inflammation of the lung and other respiratory tissues, known as silicosis, eventually results in fibrosis, a hardening of the lungs that impairs breathing efficiency (Orr and Krumenacher, 2015).

4.5 | Climate

Sand mining has significant effects on the climate and the environment, primarily due to its unregulated and often destructive practices. The extraction of sand from rivers and marine ecosystems leads to erosion, habitat destruction, and increased vulnerability of coastlines to sea level rise, ultimately exacerbating climate-related issues (Nguyen *et al.,* 2024). In many regions, sand mining is occurring at unsustainable rates, with estimates suggesting the extraction of between 32 billion and 50 billion tonnes of sand and gravel annually (Mia *et al*., 2024; Ravanashree *et al.,* 2025). This unsustainable harvesting contributes to a decline in biodiversity and pollution of water bodies, which in turn threatens livelihoods dependent on fishing and agriculture (Akanwa *et al*., 2021). Moreover, the loss of natural sediment flow, particularly in river deltas, increases the likelihood of flooding as these areas lack the necessary sediment to build resilience against water surges. Consequently, effective regulation and alternative materials are crucial to mitigate the environmental and climatic impacts of sand mining

4.5.1 | Destruction of Riparian Vegetation

The destruction of riparian vegetation due to sand mining significantly impacts ecological health and riverine system stability (Rentier *et al*., 2022). Additionally, heavy machinery compacts the soil, which increases erosion by decreasing soil infiltration and generating overland flow. (Padmalal *et al*., 2014). Riparian zones, which act as a buffer zone between terrestrial and aquatic ecosystems, are degraded during sand extraction processes (Bhattacharya *et al.,* 2020). This disruption of land leads to a loss of biodiversity (Rathoure *et al*., 2020). Removing vegetation exacerbates soil erosion and increases river sediment load, altering hydrological regimes and potentially leading to riverbank collapse. Additionally, a lack of vegetation lowers the ecosystem's capacity to filter contaminants, which lowers the quality of the water. Water temperature is also impacted by the loss of shade from riparian vegetation, which can harm aquatic life, especially species that are sensitive to temperature. Sustainable sand mining methods and riparian vegetation restoration are crucial to lessen these effects and guarantee the resilience of riverine ecosystems.

4.5.2 | Acid Mine Drainage Formation

A mine with acid mine drainage (AMD) has the potential for long–term divesting impacts on rivers, streams and aquatic life. It concerns many metals such as gold, copper, silver and molybdenum, are often found in rock with sulphide minerals. When the sulphuric acid was dissolved with other harmful metals in the surrounding rocks.(Saviour, 2012) this harmful mineral may runoff into streams or rivers or leach into groundwater. The formation of acid mine drainage is a complex biological and mineral dissolution process Dold, 2014. This AMD has several environmental consequences, such as water quality degradation, Soil and Vegetation damage and Toxicity and Bioaccumulation in the food chain. The AMD in sand mining sites underscores the need for sustainable mining practices, proper management of sulfide-bearing sand deposits and effective treatment solutions to mitigate environmental impacts (Skousen *et al*., 2019, Ashraf *et al*., 2011 and Mishra and Lal, 2024).

4.5.3 | Erosion and Sedimentation

The extraction of sand from river bed disrupts the natural sediment balance within the river system and it is the rate of extraction exceeds the rate of deposition. This disruption affects the river morphology, aquatic habitats, water quality and downstream areas. Because of these impacts highlight the causes of increased riverbank erosion, lowering of riverbeds, sedimentation, and habitat disruption, altering of natural sediment transport, and decreased water quality and aquatic life (Padmalal and Maya, 2014 and Aliyu *et al*., 2021). With considerable sand mining operations, the disturbed river became deep and narrow, causing erosion both upstream and downstream of the mining sites.

4.6 | Impact on Groundwater

Mining operations result in an increase in the sediment load in surrounding bodies of water, which worsens the quality of the water. This debris can seep into the groundwater system and clog the aquifer material's pores, lowering its permeabil ity and lowering the quality of the water. Groundwater can g et contaminated with heavy metals and other dangerous mat erials due to chemical contaminants that seep in from minin g equipment, lubricants, and unintentional spills (Siddharam *et al*., 2025). By the effect of surface water and groundwater interaction leads to a reduction in stream flow and diminishes the natural recharge of adjacent groundwater systems (soni, *et al*., 2020). Sand mining destroys the surface and groundwater aquifer zones, leading to increased runoff and reduced filtration, which impacts groundwater recharge quality.

4.6.1 | Extensive Aquifer Dewatering

Sand mining involves the removal of overlying material, which can lower the water table. This process disrupts the natural recharge of groundwater, reducing the availability of groundwater for surrounding ecosystems and human use (Choudhary *et al.*, 2023). Mining activities can penetrate aquifers, causing a direct drawdown of water levels. This can result in a decrease in the aquifer's ability to store water and disrupt the natural flow paths within the aquifer system.

4.7 | Acid mine Drainage and Contaminant Leaching

Contaminated mining in soils can contribute to heavy metal pollution of nearby farmlands under rainfall conditions. The concentrations of heavy metals such as Cr, Ni, Cu, Zn, As, Cd, and Pb in these soils are often several to even twenty times higher than their natural background contaminated mining soils were several or even twenty times higher than their corresponding background values, In contrast, a significant amount (>50 %) of Cd, Zn, Cu and Pb were found in mobile forms (wang *et al.,* 2024). Sulfuric acid is formed during mining when when the sulphides in the rock are removed and exposed to air and water. This acid water dissolves with other harmful minerals in the surrounding rock. This acid mine drainage may runoff into streams, rivers and leach into groundwater. It impacts plants, fish and animals. Acid-mined streams have a pH value of 4 or lower (battery acid) (saviour, 2012).

4.8 | Impact on Physical Hydrogeology

Both surface water and groundwater can be impacted by subsidence. The pre-mining surface water and groundwater parameters usually determine how much such impacts modify the land use. Hydrologic systems are impacted by mining subsidence in ways that alter both water quality and quantity. If surface water such as streams, lakes and ponds are directly or indirectly related to open cracks, fissures, or pits created by subsidence, there may be a partial or whole loss of water that is drained to lower strata or mine workings. This kind of water resource depletion can affect aquatic life forms (SME, 1986), other life forms that may rely on surface water systems, and the appropriateness (quality and quantity) of those resources.

4.9 | Impacts on Local Groundwater Drainage, Flow and Discharge

The underground mine forms a new channel for the movement of water and air that did not previously exist. Groundwater seeping into the mine may come into contact with freshly exposed rock surfaces containing reactive and soluble minerals. The quality of groundwater in a mined area can be altered by mineralized rock, potentially leading to elevated metal concentrations. When an underground mine extends into the saturated zone, seeping water creates a hydraulic gradient that induces flow toward the mine, resulting in a decline in surrounding water levels, seeping water creates a hydraulic gradient that induces (Rajesh *et al*., 2025). There is usually a direct relationship between the depth of mining and static water level, results from water levels will decline more as the mine goes deeper and also decline relative to the location of the mine both aerially and vertically relative to recharge/discharge sources (Mining, 1997). Fractured rock within the groundwater strata can enhance vertical flow, leading to overlying aquifer drainage.

4.10 | Linkages Between Sand Mining Impacts on Groundwater and Sustainable Development Goals (SDGs)

The impacts of river sand mining on groundwater are closely linked with several United Nations Sustainable Development Goals (SDGs), particularly those related to water security, ecosystem protection, and climate resilience (Fig. 4). Excessive sand extraction alters riverbed morphology, reduces natural infiltration capacity, and disrupts surface water–groundwater interactions, resulting in declining groundwater levels and deterioration of water quality, directly affecting SDG 6 (Clean Water and Sanitation). Lowered groundwater tables and reduced recharge further weaken ecosystem resilience to climatic variability, contributing to challenges addressed under SDG 13 (Climate Action). In addition, sediment disturbance and increased turbidity degrade aquatic habitats, threatening biodiversity and aligning with concerns under SDG 14 (Life Below Water), while land degradation, vegetation loss, and ecosystem imbalance associated with mining activities impact terrestrial environments linked to SDG 15 (Life on Land). Therefore, sustainable regulation of sand mining and integrated groundwater management are essential to support progress toward these interconnected SDGs and ensure long-term environmental sustainability (Fig. 4).

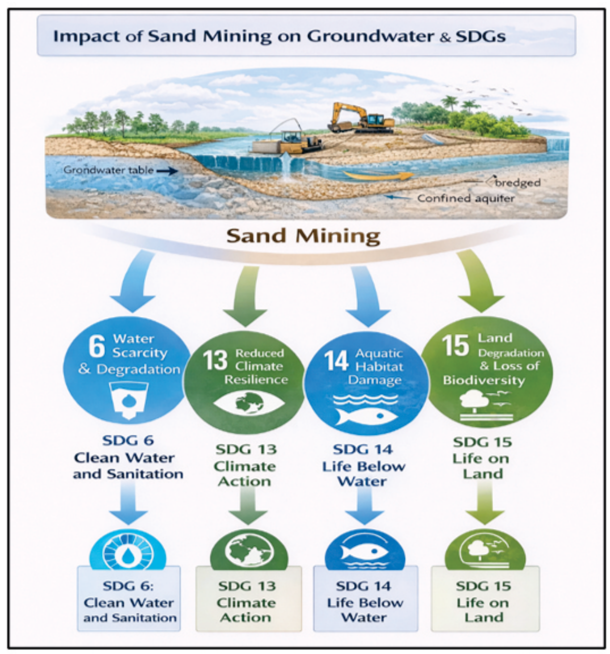

FIGURE 4 Conceptual illustration showing the impacts of river sand mining on groundwater systems and their linkages to key Sustainable Development Goals (SDGs), including clean water, climate action, aquatic ecosystem protection, and terrestrial biodiversity conservation

TABLE 1 Comparative synthesis of key studies examining the impacts of river sand mining on groundwater systems.

Study	Study Area/ Context	Focus of Study	Groundwater/ Hydrological Parameter Affected	Key Findings	Reported Magnitude / Quantitative Indicator
Kondolf (1994)	California, USA	Instream gravel and sand mining	River–aquifer interaction and channel morphology	Instream mining causes riverbed incision and reduces groundwater recharge potential.	Riverbed incision of 1–3 m reported in intensively mined reaches; significant reduction in lateral recharge to adjacent aquifers
Padmalal & Maya (2014)	Indian rivers	Environmental impacts of sand mining	Groundwater recharge and sediment balance	Excessive sand extraction reduces infiltration and disrupts natural recharge processes.	Infiltration capacity reductions of up to 40–60% reported in heavily mined riverbed sections
Rentier & Cammeraat (2022)	Global review	Environmental impacts of river sand mining	Sediment transport and hydrological connectivity	Sand mining alters river morphology and affects groundwater recharge pathways.	Global sand extraction estimated at 32–50 billion tonnes annually; hydrological connectivity loss qualitatively assessed across multiple basins
Koehnken *et al.*, (2020)	Global river basins	Sand mining impacts on freshwater ecosystems	River hydrology and sediment dynamics	Large-scale sand extraction modifies sediment balance and river hydrology.	Sediment deficits of 50–100% of natural supply reported in several intensively mined rivers globally
Naganna *et al.*, (2017)	Conceptual hydrogeological systems	Streambed hydraulic conductivity	Stream–aquifer interaction	Sediment characteristics control hydraulic conductivity and groundwater exchange.	Streambed hydraulic conductivity can decline by one to two orders of magnitude following removal of coarse sand layers
Ciszewski & Sobucki (2022)	Mining-affected rivers	Mining-induced subsidence	Riverbed stability and groundwater pathways	Subsidence caused by mining alters groundwater flow pathways.	Subsidence-induced channel adjustments of 0.5–2.0 m vertical displacement reported; qualitative assessment of groundwater pathway alteration.
Barman *et al*., (2019)	Alluvial rivers	Sand mining effects on channel flow	Channel hydraulics and sediment transport	Mining modifies flow characteristics influencing groundwater recharge.	Mining pit migration rates of several metres per year documented; recharge reduction qualitatively assessed.
Rovira *et al*., (2005)	Tordera River, Spain	Gravel mining impacts	Sediment budget and hydraulic gradient	Historical mining altered sediment dynamics and river–aquifer interactions.	Sediment budget deficit of approximately 60,000 m^3/year attributed to historical mining; channel incision of ~1 m over study period.
Aliyu et al., (2021)	River systems in Nigeria	Sand mining impacts on channel morphology	River hydrology and groundwater recharge	Channel morphology changes influence groundwater recharge conditions.	Channel widening of 15–30% and depth increases of up to 1.5 m reported in active mining zones
Ashraf et al. (2011)	Bestari Jaya, Malaysia	Environmental impacts of sand mining	Water quality and sediment transport	Mining increases suspended sediments and potential groundwater contamination.	TSS values exceeding 200 mg/L recorded downstream of mining sites; turbidity levels 3–5 times above baselineed in active mining zones
Saviour (2012)	Global review	Environmental effects of sand mining	Surface water and groundwater quality	Sand mining increases turbidity and degrades aquatic environments.	Heavy metal concentrations (Pb^{2+}, Zn^{2+}, Cu^{2+}) reported at 10–20 times background levels in mined catchments.
Liang & Thomson (2010)	Mining environments	Acid mine drainage processes	Groundwater chemistry and pH	Exposure of sulfide minerals can cause acid drainage and groundwater contamination.	Acid-impacted stream pH values of 4.0 or below recorded; dissolved metal concentrations (Fe, Mn) elevated 5–15 times above ambient levels.

4.11 | Integrated Impacts of River Sand Mining on Groundwater Systems

A synthesis of the reviewed literature (Table 1) indicates that river sand mining influences groundwater systems through interconnected hydro geomorphological and geochemical processes that alter sediment structure, recharge pathways, and river–aquifer interactions (Naganna *et al.,* 2017; Koehnken *et al.*, 2020). Riverbed sand deposits typically act as highly permeable layers that facilitate infiltration and enable dynamic exchange between surface water and adjacent aquifers (Chakraborty, 2021). Excessive extraction of these sediments disrupts the natural filtration and recharge functions of riverbeds, leading to reduced infiltration capacity and declining groundwater levels in surrounding floodplain aquifers (Kondolf, 1994; Padmalal and Maya, 2014; Rentier and Cammeraat, 2022). Studies conducted across multiple river basins have consistently reported that sand removal modifies channel morphology, increases suspended sediment loads, and reduces groundwater recharge potential in nearby areas.

One of the primary mechanisms linking sand mining to groundwater decline is riverbed incision and channel deepening (Ciszewski and Sobucki 2022). Intensive sediment extraction disturbs the natural sediment balance of rivers, causing erosion and lowering of the riverbed elevation (Barman *et al*., 2019; Khoi *et al.,* 2020). These geomorphological changes alter hydraulic gradients between surface water and groundwater systems and may convert gaining streams into losing streams, thereby reducing lateral recharge to adjacent aquifers (Rovira *et al*., 2005; Aliyu *et al*., 2021; Panth *et al*., 2025). Such modifications can significantly influence groundwater flow regimes, particularly in alluvial river basins where river–aquifer connectivity plays a critical role in sustaining groundwater storage.

In addition to hydrological changes, sand mining also contributes to groundwater quality degradation through increased sediment transport and contaminant mobilization. Disturbance of sediments during mining activities generates high concentrations of suspended particles, which may carry nutrients, heavy metals, and other pollutants into groundwater systems (Ashraf *et al.,* 2011; Saviour, 2012). Furthermore, the exposure of sulfide-bearing minerals during mining can trigger acid mine drainage processes that release dissolved metals and lower groundwater pH levels, posing risks to aquatic ecosystems and drinking water sources (Talukder *et al*., 2024; Liang and Thomson, 2010). Recent studies also indicate that sand mining activities can increase turbidity and sediment loads in rivers, which further impacts water quality and hadrochemical processes in connected aquifers.

Hydrogeological alterations caused by mining operations may also affect groundwater flow pathways and aquifer stability. The creation of excavation pits, fractures, and subsidence zones can modify subsurface permeability and generate artificial drainage pathways that redirect groundwater flow toward mining sites. These structural changes may enhance vertical groundwater leakage in fractured rock environments but often result in long-term groundwater depletion in sediment-dominated river basins (Booth, 2005; Mace and Jones, 2023). The magnitude of these impacts varies depending on geological conditions, sediment replenishment rates, and mining intensity. However, a broad consensus across the literature indicates that uncontrolled sand mining disrupts natural recharge processes, alters groundwater flow dynamics, and increases contamination risks.

Overall, the collective evidence demonstrates that sand mining has multidimensional impacts on groundwater systems, including reduced recharge, altered hydraulic gradients, and deterioration of groundwater quality. These effects are particularly pronounced in regions experiencing rapid urbanization and high demand for construction materials. Consequently, recent studies emphasize the need for integrated sediment management, hydrogeological monitoring, and scientifically informed regulation of sand extraction to ensure the sustainable use of groundwater resources and protect riverine ecosystems.

4.12 | Perspective on Sustainable Groundwater Management Plan

Groundwater management is a multifaceted discipline involving the expertise of geologist, engineers, economists and ecologists. However, its fundamental objective revolves around maintaining a long-term balance between supply and demand. In mining areas, groundwater faces significant challenges that threaten both its quantity and quality. Quantity issues can result from extensive aquifer dewatering, disruptions to local groundwater drainage patterns, and alterations to flow and discharge regimes. Quality concerns, on the other hand, often stem from contaminant leaching caused by acid mine drainage and its associated impacts on the physical hydrogeology of the region.

Effective groundwater management requires a comprehensive approach that begins with awareness of both the quality and quantity of available groundwater. Monitoring is essential to identify existing or potential problems, particularly in overexploited or critical areas, such as those under stress from mining and urbanization. Practices such as rainwater harvesting and aquifer recharge are vital for sustainable groundwater use, along with measures like deepening and rejuvenating wells and protecting water bodies. Additionally, clear and widely accepted water laws and rights, or a system of incentives and disincentives, are necessary to regulate groundwater use effectively. Surveillance plays a crucial role in ensuring adherence to these regulatory measures or incentivized practices. Moreover, it is important for government planning and society to recognize the critical importance of groundwater resources.

Strategies for sustainable groundwater development require focused efforts in two key areas: (i) groundwater assessment and (ii) monitoring and regulation. To achieve this, the following recommendations are proposed:

Groundwater management initiatives have to concentrate on safeguarding resources in certain geographical areas designated as "Stress Aquifers." A specific "State Groundwater Policy" that prioritizes sustainability and groundwater conservation must be created in order to handle the particular difficulties faced by regions impacted by mining. This strategy ought to include the creation of thorough "Aquifer Management Plans" that are intended to lessen the effects of mining operations and guarantee the long-term security of groundwater (Raghavendra *et al.,* 2015).

5 | CONCLUSIONS

River sand mining plays an important role in supporting construction activities and economic development; however, unregulated and excessive extraction has emerged as a major threat to groundwater systems and associated ecosystems. This review highlights that sand removal significantly alters riverbed morphology, reduces infiltration capacity, and disrupts the natural interaction between surface water and groundwater. The loss of sand layers, which function as natural filters and recharge media, leads to groundwater table decline, reduced aquifer storage, and deterioration of groundwater quality due to increased turbidity, contaminant transport, and acid mine drainage processes. Beyond hydrogeological impacts, sand mining also contributes to ecological degradation, biodiversity loss, and increased vulnerability of communities dependent on groundwater resources. The synthesis further demonstrates that these impacts are closely linked with global sustainability challenges, particularly those addressed under SDGs related to clean water, climate resilience, and ecosystem protection. Therefore, achieving a balance between resource extraction and environmental conservation is essential for long-term groundwater sustainability.

Key Findings and Recommendations

- Excessive sand mining lowers groundwater tables by reducing natural recharge and altering hydraulic connectivity between rivers and aquifers.
- Removal of sand layers diminishes natural filtration capacity, leading to groundwater quality degradation and increased contamination risks.
- Hydrogeological disturbances such as aquifer dewatering, subsidence, and altered groundwater flow patterns significantly affect water availability.
- Ecological impacts include riparian habitat destruction, biodiversity loss, and degradation of aquatic ecosystems.
- Sand mining pressures directly influence Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land).
- Sustainable groundwater management requires regulated mining practices supported by environmental impact assessments and strict policy enforcement.
- Adoption of alternative construction materials such as manufactured sand (M-sand) and recycled aggregates can reduce dependency on river sand.
- Integrated governance involving policymakers, scientists, and local communities is necessary to ensure effective implementation of sustainable management strategies.

Overall, sustainable regulation, scientific monitoring, and ecosystem-based management approaches are crucial to minimizing the adverse impacts of sand mining and ensuring the protection and resilience of groundwater resources for future generations.

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CONFLICT OF INTEREST

The authors confirm that there are no known financial or personal conflicts of interest that could have influenced the findings or interpretations presented in this study.

DATA AVAILABILITY STATEMENT

Data is available with the corresponding author and can be provided on request.

AUTHOR'S CONTRIBUTION

B.N. Pavithra contributed to literature collection, data compilation, and preparation of the initial draft of the manuscript; Siddharam assisted in systematic literature review and data analysis; L. Aiswarya contributed to thematic analysis and drafting of specific sections; and R.G. Munivenkatappa, as the corresponding author, conceptualized and designed the study, supervised the overall research work, critically revised the manuscript, and finalized it for submission. M. Sandeepika supported in data interpretation and manuscript organization. J.B. Kambale and Sankeerth K contributed to literature review, editing, and formatting. All authors reviewed and approved the final version of the manuscript.

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