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TREND EDITORIAL

The way forward to sustain environmental quality through sustainable sand mining and the use of manufactured sand as an alternative to natural sand

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Introduction

The rapid rise in urbanization and construction of large-scale infrastructure projects are driving increasing demands for concrete construction materials globally (Brunauer and Copland 1964), "Man consumes no material except water in such tremendous quantities." Concrete and cement composites are presently the most economical materials used in the construction industry. Over the most recent 15 years, the accessibility of good-quality sand dwindles gradually. Thus, the State and the Central Government of India has taken several steps to control and regulate unsustainable excavation of riverbed sand mining. This comes amidst to develop ecological concerns and a more noteworthy consciousness of the security of natural bounties.

Literature review

Worldwide consumption of sand has increased, and they are also extracted at a greater rate. In addition, it naturally has a major impact on the marine ecosystems (Torres et al. 2017). Time is running out for sand (Bendixen et al. 2019). The abundant supply of sand and gravel is diminishing rapidly in areas surrounding cities (Stebbins 2006). Indiscriminate sand mining threatens the existence of riverine habitats (Freedman et al. 2013). Every year, there is an increase in demand for sand in developing countries; therefore, sand is extracted between 32 and 50 billion tonnes globally (United Nations Environment Programme (UNEP 2019). This sand mining is a global activity, which leads to negative impacts socially and environmentally, and it finally affects the freshwater ecosystems (Lois Koehnken Max et al. 2020). Continuous extraction of sand decreases the amount of sediment supply by lowering the water table on the river beds. Despite the quantity of sand used in our day-to-day activities, our dependence on sand significantly increases (Marius Dan Gavriletea 2017). Through several years, natural sand is shaped by the erosion process, which is extracted at a speedier rate than their re-establishment. This leads to mine the greater quantities and to find an alternative substitute (Padmalal and Maya 2014). Excessive common river sand mining has made civil engineers search for an appropriate elective fine aggregate and such an elective material is "manufactured sand (M-sand)." This depletion of natural sand for the construction sector has led to the production of manufactured sand (Ilangovan et al. 2008). Figs 1, 2, and 3 depict sand mining in the river and beach.

Marine sand mining and impact on marine biodiversity

The main emphasis of this study is focused on a significant increase in marine sand mining. Due to a significant increase in marine sand mining, the seabed fauna and flora are affected as shown in Fig. 4. There is a net decline in faunal biomass due to the extraction and dredging of aggregates from the bottom zone of the sea. It also destroys the organisms, habitats, and ecosystems and eventually affects the biodiversity composition. Additionally, the fine aggregate particles are rejected by releasing dredging boats, vast dust plumes, and changing water turbidity. Thus, it ends in

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Fig. 1 Depletion of natural sand due to continuous sand mining

Fig. 2 Beach sand mining

Fig. 3 River sand mining in India

the major changes to aquatic and riparian habitats over large areas (Tillin et al. 2011).

It is imperative that continuous sand mining causes depletion of natural sand which ultimately leads to the degradation of rivers. Moreover, an excessive mining leads to riverbank erosion and deepening of rivers with enlargement of coastal inlets and river mouths. This excessive river sand mining leads to the destruction of aquatic lives, and it affects the entire ecosystem. In 2012, the Indian Supreme Court has directed the various state governments to subject sand mining to environmental assessments before issuing permits. In this connection, the court observed that "Excessive sand mining on either side of the river is one of the major causes of environmental degradation and it also causes a threat to the biodiversity. Over the years, India's rivers and ecology have been badly affected by the alarming rate of unrestricted sand mining." Likewise, the National Green Tribunal is another Indian court, which has issued orders to close down various sand mines in 2013, yet, this has not led to appraisals. Excessive river sand mining is considered as one of many recognized factors, which affect the riverine ecosystems to reach a rapid decline in biodiversity (World Wildlife Fund 2018). In the river banks of Hungarian Maros, sand mining has created a change in the morphology and frequency of levees, which leads to the gradual disconnection of the river from its floodplain (Kiss et al. 2018).

Environmental effects of sand mining

The current study highlighted the impacts of bed degradation which leads to loss of properties, undermine bridge supports and pipelines, and the degradation of landscape, which cause a change in the morphology of the river bed, and it further constitutes one aspect of the aquatic habitat. Next, the lowering of the water table destroys the riparian vegetation as shown in Fig. 5. As a result of it, a change in morphology of the river and bank erosion destroys the riparian vegetative cover.

Excessive sediment deposition increases the turbidity to prevent the infiltration of light for photosynthesis, and so it eventually reduces the food accessibility of aquatic fauna. Moving on, an excessive pumping of groundwater in the process of mining the channels depletes the groundwater level by causing scarcity of irrigation and drinking water. In extreme cases, it leads to ground fissures and subsidence in adjacent areas. As the bed elevations and flood heights decrease, there is a decline in the hazard for the human habitat of floodplains. This leads to the damage in the engineer works, and the supply of overbank sediments on the floodplains is reduced as the flood heights decrease drastically. An unregulated and unscientific sand mining tends to increase the channel bank.

Impact of sand mining on ecosystems—quick scoping review (QSR)

The quick scoping review (QSR) approach is adopted to systematically quantify the documented impacts of sand mining on river systems. This QSR methodology identifies a conceptual model based on the factors connecting the sand mining activities and the potential direct and indirect impacts on the

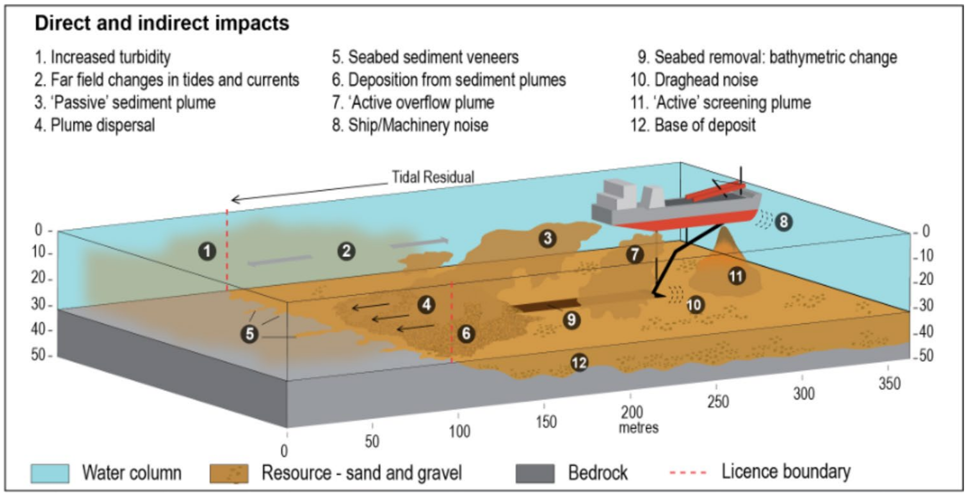

Fig. 4 Marine sand mining and impact on marine biodiversity (Tillin et al. 2011)

ecosystems (Collins et al. 2015). The various direct and indirect impacts of river sand mining are depicted in Fig. 6.

The abiotic impacts of sand mining are studied by the QSR approach (Lois Koehnken et al. 2020). This study includes the changes in the channel morphology, alterations in the movement and compositions of sediments, impacts on water quality, and the alterations related to the flow regime as depicted in Fig. 7. A detailed summary of the impacts associated with sand mining is structured by the QSR approach and is presented in Fig. 8.

Guidelines for sustainable sand mining

The broad principle for any sustainable sand mining guidelines preserves the natural resources by utilizing it for the present and future generations. The initial step involved in managing the river resource depends on the preparation of the district survey report. These processes involved in the guidelines are the identification of areas of deposition, where mining is allowed by forbidding the areas of erosion and proximity to infrastructural structures and installations. Similarly, satellite images are utilized for identifying areas of sand deposit and quantity. Correspondingly, the annual rate of replenishment and allowing time for replenishment after mining in the area is carried out. Measures for the protection of ecology and the environment are established for identifying the possible ways of scientific and systematic mining. A benchmark (BM) concerning for the mean sea level (MSL) is fixed for an essential in-mining channel reach (MCR) and no mining operation at the lower benchmark level (Sustainable Sand Mining Guidelines 2016, 2018). Also, permanent gauging facilities are made compulsory for mining the sites through excessive operations. The most established unit of administration is carried out by the district for an effective planning and monitoring. It is suggested that every district prepares this document by taking an account of the river

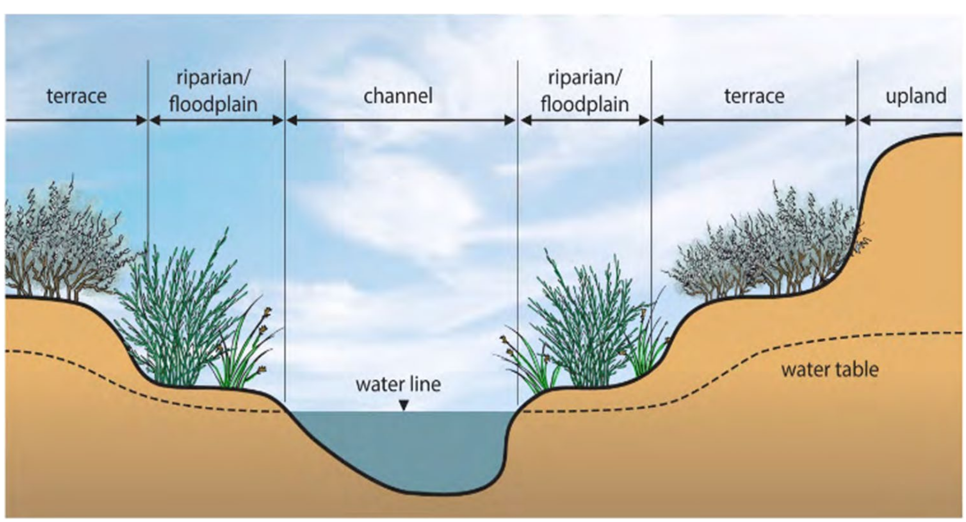

Fig. 5 Channel cross section. A Riparian zone. B Bank erosion (Stebbins, 2006)

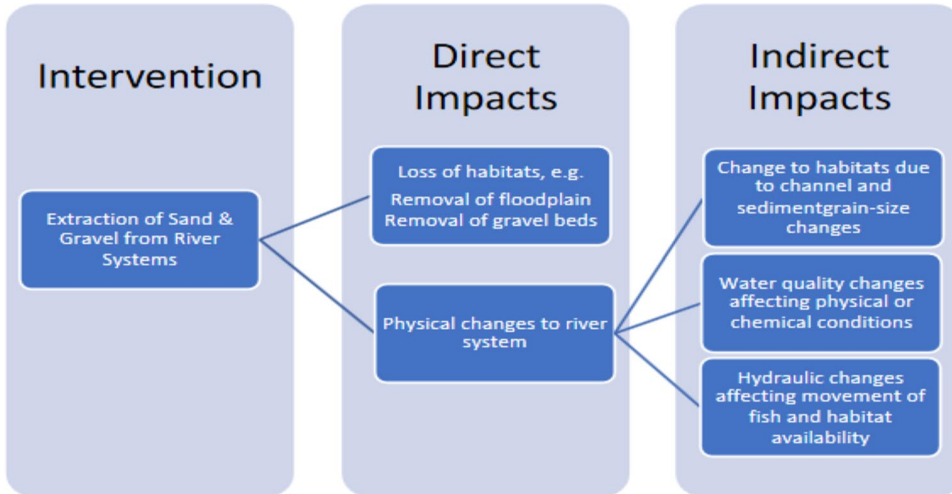

Fig. 6 Direct and indirect impacts of sand mining by the QSR approach (Lois Koehnken et al. 2020)

stretch in that district as an ecological unit. Besides, the production of aggregate in a particular area is a function of the availability of natural resources, the economy of the area, and the size of the population. Also, the various developmental and infrastructural projects are undertaken in that particular area and protection of bank erosion. The Malaysian Sand Mining Guidelines DID 2009 have given setbacks for sand mining from river systems, which is depicted in Fig. 9.

The sustainable sand mining management plan

The available natural resources are utilized in an efficient and environmentally friendly manner in a scientific and systematic way. It focuses with an objective focusing on the sustainable development policy for the protection of ecology and the environment. Sustainable development is designed on the three pillars, which include economic, social, and environmental. Sustainable development in any part of the country will not achieve it, if the environment protects the people below the poverty line. Similarly, the sustainable development cannot be achieved through an inappropriate economic growth. These guidelines support promoting environmental protection, elementary concept, physiological, limiting negative hydrological and social impacts leading to sustainable economic development. At the district level, these factors are accounted for in the most efficient manner. The sustainable mining management plan needs to be dynamic. A survey has been carried out by the District Environment Impact Assessment Authority (DEIAA) with the assistance of other departments in the district at regular intervals. This sand mining process is permitted by

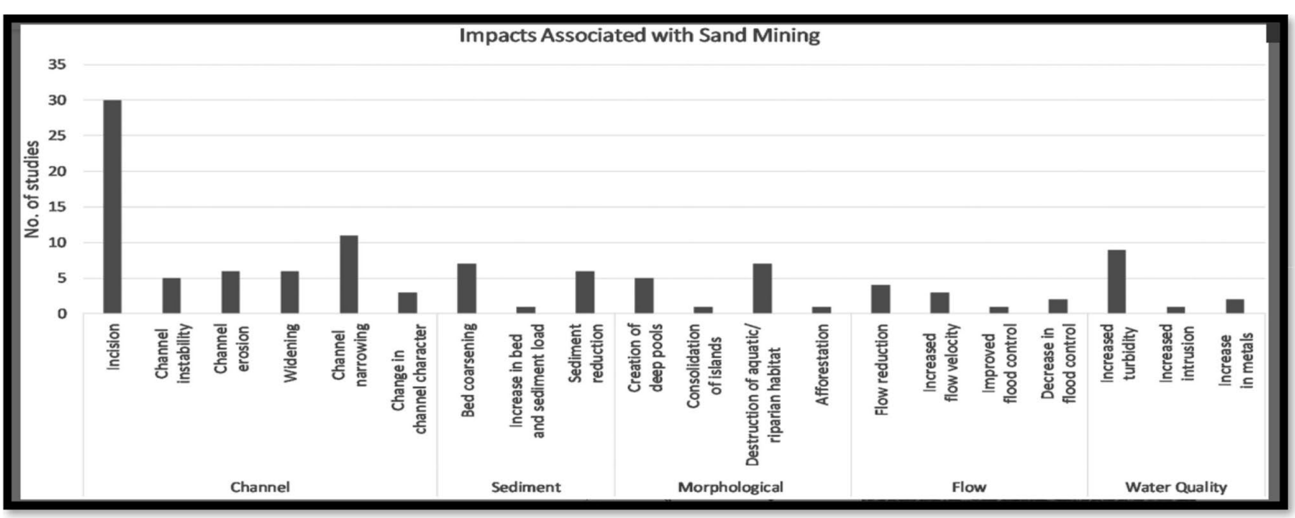

Fig. 7 Summary of impacts associated with sand mining identified by the QSR approach (Lois Koehnken Max et al. 2020)

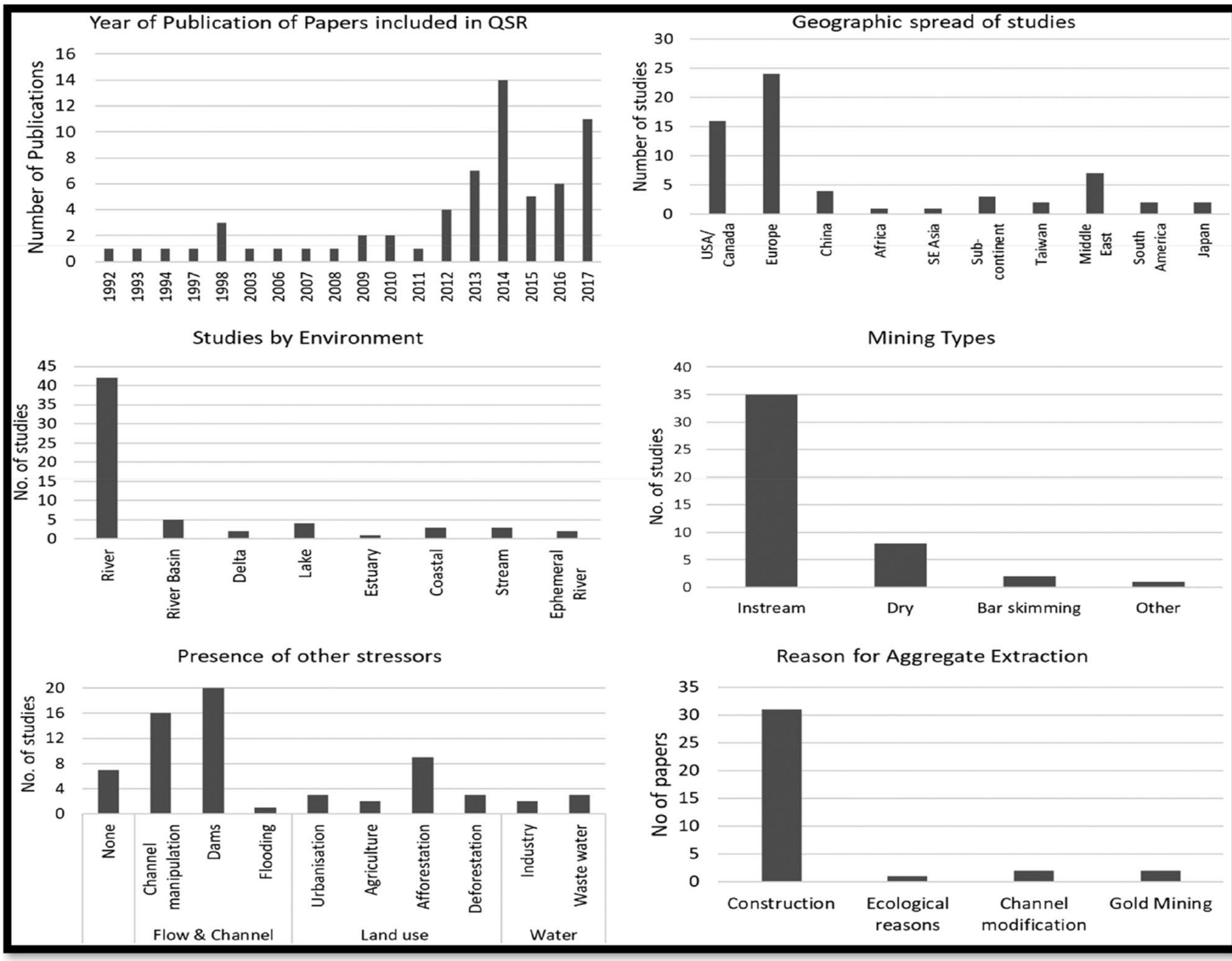

Fig. 8 Details of the papers are included in the review by the QSR approach (Lois Koehnken Max et al. 2020)

depending on the measured annual replenishment volume. So, an absolute elevation is maintained below without any extraction, and this extraction on the river bed methods is limited to bar skimming. This mining is initiated from the downstream portion of the bar, and it is only allowed during dry seasons. So, this plan should include a long-term monitoring program along with a record of the annual status.

Demand–supply assessment

A gap assessment is performed by the State for analyzing the demand–supply situation and, accordingly, the rules/regulations and policies are framed by the State. Annual replenishment study is carried out across Tamil Nadu in all districts as per the district survey report (DSR), which is prescribed in the Sustainable Sand Mining Guidelines by the Ministry of Environment, Forest and Climate Change (MoEFCC 2018). Since the need for undertaking the annual replenishment study is well understood, the assessments are not undertaken presently at the state level. The guidelines prescribed in "Enforcement & Monitoring Guidelines for sand mining (MoEFCC 2020)" emphasize the methodology adopted for the replenishment study. Correspondingly, an adequate amount of sand replenishes, and then, excavation is limited in that area. The district survey report (2019) for sand in Vellar River Perambalur District, Tamil Nadu, recommends 261 million metric tonne (MMT) mineable sand at an annual replenishment rate of 7.25 MMT. This annual replenishment volume of sand for various rivers across Tamil Nadu is studied from the district survey report of that particular district. The Public Works Department (PWD) of Tamil Nadu has estimated the demand for the sand as 53.71 million tonne per annum (MTPA). In the year 2016–2017, the total supply of sand is 18.36 metric tonne (MT) with 15.12 MT from river sand and 3.24 MT from M-sand (Sand Mining Framework Government of India 2018). The deficit in the State is estimated at 35.56 MT, and to meet this

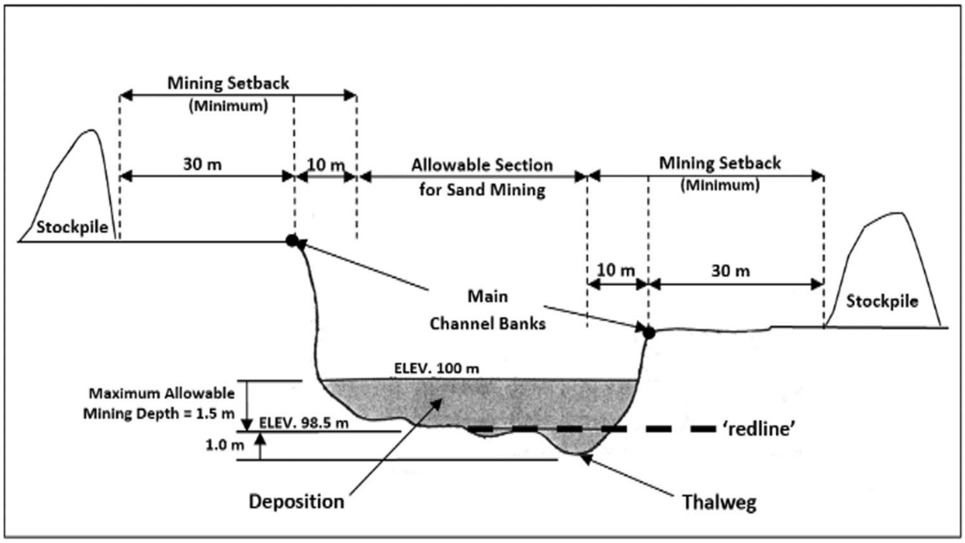

Fig. 9 Example of setbacks for sand extraction from river systems provided by the Malaysian Sand Mining Guidelines (DID, 2009)

deficit, the Public Works Department (PWD) has issued the circular by instructing its officials to use manufactured sand in government projects as an alternative to river sand. On average, there is a demand for 25,000 loads of M-sand daily across Tamil Nadu. In this regard, the government has permitted 358 M-sand manufacturing units to push the State for M-sand to meet the demand–supply gap. This transition enables the sustainable use of sand to manufacture it in the future.

The scarcity of river sand forces the builders to look for an alternative material and many have started using manufactured sand as a substitute for construction activity. The necessity for the use of manufactured sand increases with the river sand supply dropping by over 80%. In India, Tamil Nadu occupies the second longest sandy beach area covering about 1.076 km (670 miles). To mention in particular, the Palar, Vaigai, and Cauvery River basins have been subjected to illegal sand mining continuously. In Tamil Nadu, each measuring 200 cubic feet of sand is mined approximately every day between 5500 and 6000 truckloads (SibiArasu 2017). Continuous extraction of river sand has a huge impact on the river beds, which has resulted in a decrease in the amount of sediment supply and lowering of the water table.

The Kerala government is reportedly the first State to start using M-sand extensively for construction. It has started popularizing the M-sand in 2004 after facing an acute shortage of natural sand. On the other hand, the accessibility of manufactured sand is troublesome except in Kerala and in a few sections of Southern and Western India. It has a demand of 50,000 tonnes of M-sand per day, but the manufacturers do only 25,000 tonnes. So, it has mooted the idea of desilting reservoirs to quarry sand without causing ecological damage to rivers. Also, there is a broad consensus on the need to desilt dams, as it has yielded not only sand but also clay for the brick and tile industry. According to reports, M-sand is broadly utilized across the globe and specialists from all over the world. It has become mandatory for utilizing the M-sand owing to its consistent gradation and zero contamination. Consistently, Karnataka gathers around 9 million tonnes per year of sand, out of which a major share is sourced from riverbed mining. The Center for Study of Science, Technology, and Policy (CSTEP) has led an examination to assess the present interest for sand in Karnataka. It is reported that it has produced 26 million tonnes per year in 2014 and this is expected to increase to 56–81 million tonnes for each year by 2030. This appeal has prompted a look through an elective material, for example, M-sand with a specific end goal to take care of the demand. Furthermore, the State Government of Karnataka has made it obligatory for the Public Works Department (PWD) to utilize M-sand for the development of structures, bridges, and different works in September 2013.

Consistently, 47 and 59 billion tonnes of development material are mined all-inclusive (Steinberger et al. 2010), out of which, the speediest and the biggest extraction share (68 to 85%) is for fine aggregate (sand) and (32 to 50%) is for coarse aggregate (Krausmann et al. 2009). In a roundabout way, the worldwide utilization of aggregates is evaluated through the generation of cement for concrete, as concrete is made of cement, sand, gravel, and water. In 2012, 3.7 billion tonnes of cement is generated by 150 nations (US Geological Survey. 2013a). Also, the construction industry requires around six to seven times more huge amounts of sand and gravel for every tonne of cement and the world utilization of aggregates surpasses 40 billion tonnes per year (US Geological Survey. 2013b). One approach to reduce the usage of sand is to enhance the utilization of existing structures and foundations. Reused construction materials and quarry dust are the substitute for river sand.

An investigation is led by the Indian Institute of Science (IISc), Government of Karnataka, on the appropriateness of

M-sand as a fine aggregate. This examination details that the physical qualities of M-sand are like river sand, yet it is contrasted with it. This M-sand substituted concrete has a higher compressive strength of 6–9% and higher flexure strength of 12–15%. Also, the specialized examination has demonstrated that manufactured sand is utilized as another option to river sand. As of late, the Karnataka State Cabinet has chosen to give 5% sponsorship on enthusiasm to set up the manufactured sand units in areas that need normal sand assets, as announced in *The Hindu*. Keeping in mind the end goal to make a request, the State Government of Karnataka has additionally energized the utilization of produced sand in all government ventures. Today, the Bangalore Airport and the Bangalore Metro are the portion of the real tasks that have used this manufactured sand. Owing to the shortage of naturally available river sand, M-sand has emerged as a sustainable alternative for the construction industry. Manufactured sand is used as an alternative construction material thereby reducing the demand and dependence on naturally occurring sand.

According to reports, M-sand is broadly utilized across the globe and specialists from all over the world. The demand is mandatory for the utilization of M-sand, owing to its consistent gradation and zero contamination. The transition to manufactured sand enables the future sustainable use of sand.

Manufactured sand, a solution, and a viable alternative to river sand

The growing demand for the fine aggregate in the construction industry has driven our attention to the use of manufactured sand. Besides, the global scarcity of natural sand and the remote location of sandpits has led to the use of manufactured sand. There are various factors that have driven us towards the production of M-sand such as global scarcity for river sand, growing demand for fine aggregate, the remote location of sandpits, and the presence of impurities like silt and clay in natural sand. This depletion of natural sand is due to continuous sand mining of the river sand globally, which has led to the use of manufactured sand as an alternative. The International Center for Aggregates Research (ICAR) has given the promising results on the use of manufactured micro fines up to 17% in concrete. Hence, sand dredging is heavily taxed, and it is banned almost now in Tamil Nadu. Now, the river sand is available on the river beds, which contains about 5 to 20% silt and clay impurities (Fate 2014). The presence of even minor quantities of silt and clay impurities affects the strength, and it damages the screed and concrete (Sreenivasa.G. 2012). Hence, the river sand is processed well before use to bring the impurities to the acceptable limit. About 65 to 80% of the concrete mix is composed of sand and aggregates. In the UK alone, it requires 200 million tonnes of aggregates every year for their construction purposes. This demand for sand in the State of India stood for 24 million tonnes a year, against the supply of 14 million tonnes (Nagesh Prabhu. 2015). The location of licensed sand pits in remote areas has led to high transportation costs. This low-value by-product obtained from rock crushers is effectively and efficiently used in the production of high-value products in the construction industry.

Advantages of using manufactured sand in concrete

The particles are cubical with definite and consistent particle size distribution, and the fine content is generally higher than natural sand. This surface texture of the particles is rough and has higher crushing strength. This particle size distribution is thick, and the surfaces are less weathered than the normal sand. M-sand created from hard rock has the lower difference in mineralogy. There are no organic impurities in M-sand, and the presence of silt is less than 3% by weight, and this M-sand has a consistent gradation. It is produced by conforming to zone II grading as per IS 383 (1970). This has perfect grading and is angular in shape, which in turn increases the compressive strength by 10–15%. It has also consistently graded with greater precession by constantly removing the micro fines, and hence, it has a higher “fineness module index” than the natural sand. M-sand is more cost-effective than the river sand, since it is produced in areas very close to the construction site thereby reducing the cost of transportation. This manufactured sand is used in compliance with the new European Standards, as per EN 13, 139 (2006). The Cement Concrete and Aggregates Australia (CCAA) has carried out extensive research and has developed the guidelines to support the replacement of natural sand with manufactured sand. This M-sand produced from hard rock has consistent particle size distribution, and it is more cost-effective than river sand. Besides, it is produced in areas very close to the construction site thereby reducing the cost of transportation.

Table 1 shows the number of impurities present in river sand. This river sand contains 5 to 20% of clay and silt, 2 to 4% of marine products, and 6 to 10% of oversized materials, whereas manufactured sand is free from these impurities.

Table 1 Comparison of impurities in river sand and M-sand (Aswath 2015)

SI. no	Impurities present	River sand	Manufactured sand
1	Clay and silt	5 to 20%	Nil
2	Marine products	2 to 4%	Nil
3	Oversized materials	6 to 10%	Nil

Manufactured sand is utilized in many nations such as Norway, South Africa, India, and Australia. In the USA, limestone and granite record for 86% of the rock; it is used to produce manufactured sand, while the rest are from basalt, dolomite, sandstone, and quartzite (Ahn and Fowler 2001). The molten igneous rocks have produced about 10 to 30% of quarry fines. Limestone contains dolomite, and chalk quarries commonly deliver around 20 to 25% of fines, though sandstone quarries create up to 35% of fines, as given by Manning 2004).

The aggregates obtained from the Vertical Shaft Impact (VSI) crushers are more cubical than the other crushers. This shape of the particles obtained from other jaw crushers is flaky. So, the crushed aggregate from the VSI crusher acquires improved particle shape, and it reduces surface roughness than the other crushers.

From the experimental work, it is noticed that legitimately prepared M-sand enhances the strength and durability characteristics of concrete through better bonding than the river sand (Vijaya and Senthil Selvan 2015). By the year 2050, the global population would reach 9 billion, and accordingly, the construction activities are expected to grow with a long-term trend of sand scarcity, which needs to respond by the construction material industry. By taking action now, many research work is related to the strength and corrosion behavior of concrete containing manufactured sand to address this growing global challenge (Vijaya and Senthil Selvan 2018), and it has laid foundations for more sustainable use of sand in the future.

Conclusion

- The large-scale mining of river sand below the existing streambed level has adverse impacts on the existing environment.
- It is therefore concluded that the mining of sand should be subjected to a strict regulatory regime and should be carried out based on the approved framework of the mining plan. Also, it should provide rehabilitation and reclamation of the mined-out zones in the future.
- So far, the inherent deficiencies of natural river sand are extensively used for the modification of concrete properties by incorporating manufactured sand as a partial replacement for river sand.
- It can also be concluded that the M-sand can be utilized as an efficient fine aggregate in concrete in order to meet the global scarcity of river sand in the future.
- The use of M-sand eliminates the global scarcity of river sand, and it prevents associated environmental problems such as indiscriminate sand mining and soil erosion, thereby enhancing and contributing to environmental sustainability.

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Author contribution Both the authors equally contributed to the preparation of the manuscript.

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Declarations

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Consent to participate Yes
Consent for publication Yes

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