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Dynamics of Sand Extraction in Amazonian Fluvial Systems: Geological Aspects and Environmental Impacts in the Jamari Valley, Rondônia

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***Abstract*: Sand extraction is one of the most significant mining activities supporting the civil construction sector, forming an essential link in the infrastructure and urban development supply chain. In Brazil, this activity has considerable economic and social relevance, particularly in regions with substantial sedimentary potential, such as the Jamari Valley in the state of Rondônia. This study examines sand extraction in the region by addressing geological, productive, and environmental aspects associated with the activity. The results indicate that the Jamari Valley contains recent sedimentary formations predominantly composed of alluvial deposits, whose granulometric characteristics make them suitable for civil construction applications. However, the study also reveals significant environmental impacts arising from irregular extraction practices, including river siltation, riverbank degradation, loss of riparian vegetation, and alterations in hydrosedimentary dynamics. These impacts highlight the necessity of strengthening regulatory oversight and implementing public policies that promote sustainable extraction practices. Ensuring the sustainable use of sand resources, alongside strict adherence to environmental legislation, is crucial for maintaining the long-term viability of sand mining in the Jamari Valley.**

***Keywords*: sand extraction, sustainability, environmental impacts.**

1. Introduction

Civil construction is an economic sector fundamentally dependent on the extraction of natural resources, urban development, and the infrastructure that supports modern society. This dependency on raw materials such as sand, gravel, clay, and limestone introduces significant environmental challenges, including ecosystem degradation, resource depletion, and increased waste generation (Freitas et al., 2021).

Among these raw materials, sand stands out as one of the most widely used mineral inputs in contemporary society. It plays a central role in the construction industry, glass manufacturing, foundry mold production, and various industrial processes. In Brazil, sand is one of the highest-volume mineral commodities extracted, ranking prominently among natural aggregates used in infrastructure, building construction, and paving. Its broad availability and versatility drive high consumption and continuous technical and economic interest (ANM, 2023).

As a primary input for civil construction, the sand production chain encompasses extraction, processing, transport, and commercialization, generating thousands of direct and indirect jobs. Although it has low unit value, the high volume of material handled underscores its logistical relevance and considerable socioeconomic importance (Sindipedras, 2022).

Sand is an unconsolidated clastic sediment composed predominantly of quartz grains ranging from 0.06 to 2 mm in diameter, consisting mainly of silicon dioxide (SiO_2). The dominance of silica imparts high hardness, chemical stability, and abrasion resistance, making the material suitable for a wide variety of industrial and construction applications. In fluvial environments, sand used for construction typically originates from riverbed sediments extracted through suction dredging, which pumps water containing approximately 5–10% sand. Sand can also be obtained from pit mining in alluvial deposits located in valley bottoms, covered by thin soil layers (Bauer, 2013).

Laboratory tests conducted in accordance with NBR 7211 (2019) and NBR 7217 (2022) are essential for characterizing and controlling the quality of fine aggregates used in construction. These standards define key parameters such as grain-size distribution, fineness modulus, impurity content, and plasticity limits. Granulometric analysis, in particular, allows adequate classification of sands based on particle size distribution, ensuring compliance with technical requirements for each application. According to NBR 7211 (2019), construction sand predominantly consists of particles ranging from 0.075 mm to 4.75 mm, encompassing fine to coarse fractions. Such variations directly influence concrete and mortar properties, including workability, mechanical strength, and cement consumption, reinforcing the importance of rigorous quality control in construction processes.

The relevance of sand extraction in Brazil is evident from

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both economic and social perspectives. According to the National Mining Agency (ANM, 2023), the country is among the world's major aggregate producers, with sand accounting for a large share of national non-metallic mineral production. The activity is closely associated with urban expansion and infrastructure development, making it strategically important for economic growth. However, unregulated extraction can generate severe environmental impacts, such as riverbank degradation, channel alteration, and siltation. Conversely, prioritizing sustainable extraction practices, grounded in compliance with environmental regulations, is crucial for responsible mineral resource management (Souza et al., 2020).

In the Jamari Valley of Rondônia, geological conditions favor sand extraction, with recent sedimentary deposits and extensive alluvial plains resulting from fluvial processes that produce sands of varying granulometries suitable for construction. This setting supports intensification of extraction activities driven by growing regional demand (Meneguetti et al., 2012; CPRM, 2014; IPEA, 2012).

However, increasing extraction pressure has also generated socioenvironmental conflicts related to the resulting impacts, such as deforestation, riverbank erosion, siltation, and loss of aquatic biodiversity, which compromise ecological balance and the well-being of local communities (CETEM, 2019).

Given this scenario, the objective of the present study is to analyze sand extraction in the Jamari Valley (RO), focusing on sediment typology, production processes, and associated environmental impacts. The aim is to understand how this activity, essential to the construction sector, can be harmonized with natural resource conservation and the quality of life of local populations.

2. Geological and Sedimentary Aspects of the Jamari Valley

Brazil exhibits remarkable geological diversity resulting from a complex evolutionary history that spans from Archean crystalline rocks to recent continental and fluvial sedimentary deposits. This structural and lithological variety reflects millions of years of tectonic, metamorphic, and sedimentary processes that shaped the country's major geotectonic provinces and extensive sedimentary basins. According to the Geological Survey of Brazil (CPRM, 2023), the national geological framework is predominantly composed of ancient cratons and mobile belts, such as the Amazonian Craton and the Tocantins–Araguaia Belt, which form the structural foundation for Mesozoic and Cenozoic sedimentary basins hosting significant fluvial systems. This geological configuration, combined with tropical climatic conditions and a vast hydrographic network, promotes the continuous generation and reworking of sandy materials that constitute a large portion of the commercially exploited deposits used as construction aggregates.

Given this broad geological diversity, the combination of climatic variability and dense drainage networks has favored the development of recent depositional environments, including the Amazonian, Pantanal, and coastal floodplains. These environments are shaped by erosion, transport, and sedimentation processes that produce predominantly sandy deposits composed mainly of quartz and other light minerals, typically exhibiting high textural and compositional maturity. The interaction between gentle relief, humid climate, and major river basins, such as the Amazon, Madeira, and Tocantins, leads to the formation of extensive alluvial plains with considerable potential for low–geotechnical-impact mineral extraction (Moraes; Fernandes, 2021).

Within the Amazonian context, the state of Rondônia presents a transitional geological setting between ancient crystalline basement and more recent sedimentary cover. Located in the southwestern portion of the Brazilian Amazon, Rondônia is primarily composed of Archean and Proterozoic igneous and metamorphic rocks belonging to the Amazonian Craton, overlain by sedimentary formations associated with the Madeira River basin and its tributaries (CPRM, 2019). This structural and geomorphological arrangement explains the presence of broad alluvial plains, where intense weathering of granitic and gneissic rocks supplies abundant sandy material that is continuously redistributed by local fluvial systems. According to the State Secretariat for Environmental Development of Rondônia (SEDEST, 2021), the Jamari, Machado, and Candeias rivers are the primary sediment-transporting systems in the region, responsible for forming high-quality sand deposits suitable for civil construction.

The geological map of Rondônia (CPRM, 2019) reveals significant lithological and geomorphological variability, with elevations ranging from 100 to 600 m and widespread alluvial plains interspersed with gently undulating terrain. These factors, coupled with high rainfall and the seasonal regime characteristic of Amazonian rivers, generate frequent depositional cycles that form well-sorted sand deposits. Santos et al. (2022) report that sands extracted from these plains typically display medium to coarse granulometry, predominance of quartz, and low concentrations of heavy minerals, attributes that confer excellent technological quality for use in concretes and mortars.

Situated within this broader context, the Jamari Valley stands out as one of Rondônia's most significant geological and economic areas with respect to the occurrence of sandy deposits. Located in the northeastern sector of the state, the valley is drained by the Jamari River and its tributaries, forming a meandering fluvial system characterized by broad floodplains, wetlands, and alluvial terraces. The local geology consists primarily of Quaternary, mainly Holocene, sedimentary deposits formed through the continuous deposition of materials transported by moderate to high-energy river flows. According to Almeida, Brito, and Costa (2021), sands from the Jamari Valley exhibit sedimentological characteristics typical of active fluvial environments, including subrounded grains, good sorting, and predominance of medium to coarse fractions in active channels, while finer materials accumulate on floodplains and lateral bars.

Beyond these sedimentary attributes, the underlying geological structure plays a key role in the region's depositional dynamics. The crystalline basement of the Jamari Plateau serves as an important source area, supplying mineral fragments

derived from the weathering of granites and gneisses, which are subsequently transported and deposited in low-lying areas. The humid climate and annual flood regime enhance the reworking of these sediments, ensuring continuous renewal of sandy deposits along the fluvial channels. Consequently, the Jamari Valley exhibits significant mineral potential, with sandy layers typically ranging from 2 to 6 m in thickness and displaying good lateral continuity (SEDEST, 2021).

Overall, the Jamari Valley represents a geologically and geomorphologically important environment within Rondônia, characterized by alluvial sandy deposits with high technological quality and considerable economic relevance. These deposits are the direct product of the interactions between basement weathering, fluvial transport, and recent sedimentation processes forming a dynamic landscape strongly influenced by regional hydrological variability (CPRM, 2023).

3. Productive Dynamics and Mining Methods in Sand Extraction in the Jamari Valley

Sand extraction in the Jamari Valley, located in the central region of Rondônia, constitutes one of the most significant non-metallic mineral activities in the state, supplying a substantial portion of the regional demand of the civil construction sector. This prominence results from the abundance of recent alluvial deposits, ease of access, and proximity to key urban centers such as Ariquemes, Itapuã do Oeste, and Cacaulândia. The Jamari River and its tributaries form the principal hydrographic system responsible for the development of extensive floodplains containing fluvial and colluvial sand deposits, characterized by high mineralogical purity and well-developed granulometric sorting (CPRM, 2020).

Production in the region is primarily based on fluvial and mechanized extraction methods, with hydraulic dredging being the predominant technique. This method consists of suctioning sandy material from the riverbed using high-pressure pumps installed on floating platforms. After extraction, the material is transported to decantation areas and subsequently washed and screened to remove fine fractions and impurities. In more structured operations, beneficiation also includes granulometric classification using vibrating screens, enabling the production and commercial distribution of different sand types (fine, medium, and coarse), according to market specifications (Silva et al., 2021).

Extraction is carried out year-round but intensifies during the dry season (June to October), when water levels are lower and sandbanks become more accessible. During the flood season, operations may be partially halted due to increased turbidity and reduced access to mining areas. Mechanized extraction on riverbanks, performed using excavators and wheel loaders, supplements fluvial operations, particularly in small deposits near urban zones. Manual collection still occurs in some riverside communities, primarily to meet local or subsistence needs.

A typical operational structure in the Jamari Valley includes: an extraction area, dredge or excavator, beneficiation platform, stockpile yard, sedimentation basins, and truck loading system. Although the sector remains predominantly semi-mechanized, some enterprises have begun adopting more efficient environmental management practices, such as water reuse during washing processes and the installation of sediment containment barriers.

The Jamari Valley accounts for a substantial share of Rondônia's sand production. According to data from the National Mining Agency (ANM, 2023), statewide production exceeded 2.8 million tonnes in 2022, with Ariquemes identified as the principal producing municipality. Most enterprises in the region are small to medium in scale and operate under the Simplified Environmental Licensing (LAS) framework and garimpeira mining authorization, consistent with Brazil's mineral regulatory framework (ANM, 2019).

Productive dynamics are largely defined by the use of floating dredges that suction sediment directly from the river channel before conveying it to beneficiation areas, where decantation, washing, and stockpiling occur prior to commercialization. This operational flow underscores the region's role as an important supplier of construction aggregates in Rondônia. Figure 1 conceptually illustrates the extraction and beneficiation sequence characteristic of sand dredging operations in the Jamari River.

Fig. 1. Sand dredging process in the Jamari Valley, RO
Source: Authors, 2025

The sand extraction sector generates direct socioeconomic benefits in the region, creating employment for dredge operators, equipment handlers, truck drivers, and small suppliers. It also stimulates indirect economic activity in construction, road transport, and commercial sectors. However, the expansion of extraction activities presents environmental and regulatory challenges, particularly regarding irregular

Table 1
Summarizes the principal extraction and processing methods used in the region, highlighting their operational advantages and environmental limitations

Extraction Method	Technical Description	Advantages	Environmental Limitations
Hydraulic dredging	Subaquatic suction via pumps and flexible hoses	High productivity and continuous operation	Increased turbidity, risk of riverbank erosion, and siltation
Mechanized bank extraction	Excavators and loaders operating on exposed margins	Low cost, ease of production control	Soil compaction, removal of riparian vegetation
Manual collection	Small-scale, artisanal sediment removal	Low impact and simple execution	Limited production, lower economic efficiency

occupation of riverbanks, absence of post-mining rehabilitation, and risks of erosion and siltation. These concerns underscore the need for territorial planning and strengthened oversight, as outlined in ANM Portaria No. 155/2016 and state-level water resource management guidelines (Oliveira; Nascimento, 2023).

4. Environmental Impacts of Sand Mining in the Jamari Valley

Sand extraction in the Jamari Valley is an activity of substantial economic relevance; however, its environmental implications require careful examination given the ecological fragility of the Amazon region. When conducted without adequate environmental controls, sand mining can generate a series of impacts affecting both the physical environment and local socioeconomic systems, reflecting the complex interactions between human activities and natural landscapes. Numerous studies demonstrate that unregulated or poorly managed extraction can produce significant, often irreversible, degradation of ecosystems and landscape structure (Silva, 2018; Elói et al., 2019).

In terms of physical environmental impacts, continuous removal of sandy material alters local geomorphology by destabilizing slopes, modifying river channel morphology, and promoting erosional processes that contribute to siltation. Vieira et al. (2019) observed that extraction in fixed dunes and river margins leads to landscape degradation, exposure of the water table, and alteration of natural topography. When combined with riparian vegetation removal, these disturbances reduce soil cohesion and increase surface runoff. In floodplains and low-gradient fluvial environments, common in the Jamari Valley, such processes may intensify flooding frequency, disrupt hydrological regimes, and alter sediment transport pathways.

Degradation of the biotic environment constitutes another significant impact associated with sand mining. Vegetation removal compromises terrestrial and aquatic habitats, reduces biodiversity, and disrupts ecological balance in riparian and wetland ecosystems. Increased turbidity and sedimentation hinder photosynthesis, alter oxygenation levels, and affect reproductive cycles of aquatic fauna, resulting in declines in fish populations and benthic organisms. Additionally, noise and vibration generated by heavy machinery disturb terrestrial fauna, promoting habitat displacement and fragmentation. In Amazonian environments, where ecological connectivity is essential for biodiversity maintenance, these alterations represent a major threat to environmental integrity (Vieira et al., 2019).

Water quality degradation is another central concern. Extraction directly from fluvial channels increases turbidity and suspended sediment loads and may introduce hydrocarbon contaminants from machinery and fuel. Changes in the physical and chemical properties of water compromise its suitability for domestic consumption, livestock, irrigation, and recreation, while accelerating siltation processes and obstructing natural flow channels (Oliveira et al., 2012). In the Jamari Valley, where local communities rely heavily on surface and groundwater resources, such impacts extend beyond ecological consequences to affect public health and food security.

Socioenvironmental impacts also merit attention, as sand extraction influences territorial occupation, local livelihoods, and economic dynamics. Although the activity generates employment and contributes to municipal revenues, its economic benefits are often short-term, whereas environmental degradation persists over decades. Pinheiro et al. (2019) highlight an imbalance between immediate economic gains and long-term environmental losses, resulting in diminished quality of life for local populations. Increased dust emissions, noise, and truck traffic directly affect nearby communities. Furthermore, illegal sand extraction, documented in several regions of Brazil, exacerbates environmental degradation and undermines efforts to establish responsible and sustainable mining practices.

Another critical concern involves the often-irreversible nature of impacts associated with inadequately managed sand mining. The literature indicates that extraction sites without proper recovery methods may experience long-term soil degradation, loss of geomorphic stability, and reduced natural regeneration capacity. In the Amazon, where fluvial and floodplain ecosystems exhibit high ecological complexity, environmental recovery becomes even more challenging. Consequently, adopting sustainable practices is imperative. Essential measures include: rigorous environmental licensing, monitoring of water turbidity, noise and emissions control, enforcement of riparian buffer zones, and implementation of comprehensive post-mining rehabilitation plans (Oliveira et al., 2012).

These strategies align with principles of integrated environmental management and are fundamental for ensuring the long-term sustainability of sand mining in the Jamari Valley.

5. Results and Discussion

The integrated analysis of the geological, productive, and environmental dimensions of sand extraction in the Jamari Valley reveals a complex dynamic that directly influences both regional economic development and local ecosystems. Geologically, the region is characterized by recent alluvial deposits derived from the transport and deposition of sediments weathered from crystalline basement rocks composed predominantly of granites and gneisses. These deposits contain quartz-rich sands with medium to coarse granulometry, high homogeneity, and low fine content, attributes that provide excellent technical suitability for civil construction applications. The sedimentary configuration of the valley, combined with the relatively low energy of fluvial transport processes, results in well-rounded, well-sorted grains, reinforcing the region's naturally favorable extraction potential.

Granulometric characterization of collected sands reveals significant variation among deposits, allowing classification into coarse, medium, and fine fractions, as summarized in Table 2. This typological differentiation directly influences industrial applicability: coarse sands are commonly used for structural concrete, medium sands for mortar production, and fine sands

for surface finishing. These findings illustrate the extent to which geological factors condition productive potential and industrial uses.

Table 2
Subdivision of sand fractions based on grain diameter

Diameter (mm)	Denomination
2.00 – 1.00	Very coarse sand
1.00 – 0.50	Coarse sand
0.50 – 0.21	Medium sand
0.21 – 0.10	Fine sand
0.10 – 0.05	Very fine sand

In the fluvial systems of the Jamari Valley, three principal sand classes are extracted: fine, medium, and coarse. This granulometric diversity supports regional market demand and strengthens local commercial dynamics. Sedimentological studies conducted in the Jamari River basin indicate that fine and medium sand fractions predominate, with coarse sands occurring primarily in higher-energy channel sectors. According to the technical classification adopted for fine aggregates (ABNT, 2016), fine sands have mean grain diameters between 0.06 mm and 0.20 mm, medium sands between 0.20 mm and 0.60 mm, and coarse sands between 0.60 mm and 2.00 mm. These ranges guide their application in civil construction and shape production practices in the region.

From a productive standpoint, sand extraction constitutes a significant source of employment and income, especially in peri-urban and riverside communities. Operations are predominantly artisanal or semi-mechanized and rely on excavators, dredges, and screening equipment, as illustrated conceptually in Figure 2. Although production is continuous throughout the year, it is strongly constrained by hydrological seasonality, with higher productivity during the dry season, when sandbanks are more accessible and operational risks are reduced.

Fig. 2. Productive sand extraction activities in the Jamari Valley
Source: Authors, 2025

Environmental impacts observed along the Jamari River and its tributaries are substantial and warrant careful consideration. Sediment removal alters channel morphology and riverbank stability, increases water turbidity, and accelerates siltation processes. Moreover, extraction activities often result in the suppression of riparian vegetation, which compromises ecological functions such as soil stabilization, biodiversity support, and water quality regulation. These impacts underscore the need for effective environmental planning, continuous monitoring, and adoption of low-impact extraction techniques.

6. Conclusion

The present study highlights the growing importance of sand extraction in the Jamari Valley, demonstrating its significant economic and social relevance while underscoring the environmental and territorial management challenges associated with the activity. The integrated analysis of geological, productive, and environmental aspects combined with field observations and current regulatory frameworks enabled the development of a diagnostic overview of the region's extractive dynamics. This diagnosis reveals notable advances but also structural and operational weaknesses that constrain the sustainability and full regularization of the sector.

From a geological perspective, the Jamari Valley contains recent alluvial formations and high-quality sedimentary deposits composed mainly of quartz-rich sands with medium to coarse granulometry, good sorting, and low fine content. These characteristics give the material substantial technical potential for use in civil construction, particularly in concrete and mortar production. Nevertheless, this potential remains unevenly and insufficiently planned, with a lack of detailed studies on available volumes, granulometric variability, and the environmental carrying capacity of fluvial systems. The absence of a systematic geological mapping program specifically aimed at managing non-metallic mineral resources limits the region's ability to formulate effective public policies for rational resource use.

From a productive standpoint, the research demonstrates that sand extraction generates employment and income for local communities, serving as an important economic vector that complements agriculture and construction activities. However, most operations remain semi-artisanal, employing dredging and excavation techniques with limited mechanization and minimal technical oversight. Combined with insufficient regulatory enforcement and the absence of formal mining plans and continuous environmental monitoring, this condition fosters irregularities, inefficiencies, and cumulative impacts. Although simplified licensing procedures established at state and federal levels facilitate formalization, they may also weaken control over extraction volumes and post-mining rehabilitation efforts. Thus, technical strengthening of mining enterprises aligned with the Brazilian Mining Code (BRASIL, 1967) and the National Environmental Policy (BRASIL, 1981) is essential to ensuring equilibrium between productivity and environmental conservation.

Environmentally, the impacts observed along the Jamari River and its tributaries are significant and require immediate attention. Key issues include channel siltation, riverbank erosion, increased turbidity, and degradation of riparian vegetation effects largely exacerbated by the lack of mitigation measures and inadequate post-lavra rehabilitation. These impacts alter the natural dynamics of aquatic ecosystems and directly affect local biodiversity and the subsistence practices of riverside populations. The absence of Recovery Plans for Degraded Areas and post-extraction monitoring contradicts the guidelines of CONAMA Resolution No. 237 (1997), which mandates environmental licensing and systematic oversight of mining activities. Consequently, environmental management of

sand extraction in the Jamari Valley must be restructured according to sustainability principles, incorporating low-impact dredging techniques, vegetation restoration, and hydro sedimentary control measures.

Based on the findings of this study, a set of integrated and phased actions is recommended to improve management of sand extraction in the region. First, it is essential to implement a Regional Management Plan for Non-Metallic Mineral Resources, coordinated by the National Mining Agency (ANM, 2017), the State Secretariat for Environmental Development, and municipalities in the Jamari Valley. This plan should systematize mapping, licensing, and monitoring of extractive activities. Second, establishing technical capacity-building programs for operators and local cooperatives, focused on best mining practices, safety standards, and environmental rehabilitation, may foster cultural change within the sector, promoting regulatory compliance and operational efficiency.

The adoption of remote monitoring technologies, such as drones and georeferenced systems, is also crucial for real-time oversight, enhancing transparency and regulatory enforcement. Incorporating environmental and economic performance indicators: including extraction volume per hectare, rehabilitated areas, and temporal variations in water turbidity into monitoring reports would support informed decision-making. Additionally, targeted environmental incentives and compensation policies could encourage sustainable practices and investments in cleaner technologies.

From a governance perspective, effective coordination among environmental agencies, municipal authorities, mining producers, and riverside communities is fundamental to building a participatory and sustainable management model. Establishing local mining oversight councils and strengthening environmental licenses with enforceable rehabilitation and monitoring requirements represent necessary advances to ensure that extractive activity not only generates economic returns but also preserves natural resources and maintains the quality of life of local populations.

Finally, while this study offers a comprehensive multidimensional analysis of sand extraction in the Jamari Valley, certain limitations must be acknowledged. These include limited availability of official data on annual extraction volumes, absence of consolidated records of licensed areas, and restricted access to detailed geotechnical information. Addressing these gaps is essential for future research and for the development of more robust, evidence-based management strategies.

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