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Environmental Governance and Regulatory Effectiveness of Sand Mining Along the Brantas River Basin in Indonesia

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Highlights:

- Examining environmental degradation caused by river sand mining
- Evaluating the effectiveness of Indonesian mining regulations
- Identifying governance weaknesses in environmental supervision
- Emphasizing sustainable and conservation-based mining practices
- Promoting integrated environmental governance in river basins

Abstract: Sand mining has become one of the fastest-growing extractive activities in Indonesia due to increasing infrastructure development and rising demand for construction materials. Along the Brantas River Basin in Tulungagung Regency, East Java, sand mining contributes to local economic activities and employment opportunities. However, uncontrolled extraction practices have increasingly caused environmental degradation and ecological instability within the river ecosystem. This study aims to analyze the environmental impacts of sand mining activities, evaluate the effectiveness of environmental regulations governing mining management, and formulate sustainable environmental governance strategies based on environmental conservation principles and Indonesian legal frameworks. This research employed a normative juridical method using statutory, conceptual, and case approaches. The study examined Indonesian environmental and mining regulations, including Law Number 32 of 2009 concerning Environmental Protection and Management, Law Number 3 of 2020 concerning Mineral and Coal Mining, and related government regulations concerning environmental governance and mining activities. Secondary legal materials consisted of scientific publications, environmental law literature, government reports, and previous studies related to environmental degradation caused by sand mining

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activities. The findings indicate that sand mining activities along the Brantas River Basin have caused significant environmental impacts, including riverbank erosion, declining water quality, sediment imbalance, biodiversity reduction, and ecosystem instability. Although Indonesia possesses relatively comprehensive environmental regulations, their implementation remains ineffective due to weak supervision, illegal mining operations, limited environmental monitoring, and inadequate law enforcement. This study concludes that sustainable sand mining management requires integrated environmental governance emphasizing strict law enforcement, ecological restoration, community participation, and stronger institutional supervision.

Keywords: Sand mining, Environmental governance, River basin management, Environmental law, Sustainable mining, Brantas River Basin

1. Introduction

The increasing demand for construction materials has accelerated the growth of sand mining activities in many developing countries, including Indonesia. Sand and aggregate materials are essential components in infrastructure development, urban expansion, road construction, and housing projects. As infrastructure development continues to expand across Indonesia, river sand mining has become an important economic activity in many regions due to its relatively high market demand and accessibility (Torres et al., 2017; Rentier & Cammeraat, 2022). Along the Brantas River Basin in Tulungagung Regency, East Java, sand mining activities have contributed to local economic growth by creating employment opportunities and supporting regional construction industries.Despite these economic benefits, uncontrolled sand mining has increasingly generated serious environmental and social consequences. River ecosystems are highly sensitive to excessive extraction activities because river sand plays a critical role in maintaining sediment balance, channel stability, water flow regulation, and aquatic ecosystem sustainability. Intensive sand dredging disrupts natural geomorphological processes and alters the physical characteristics of river systems. Consequently, environmental degradation caused by river sand mining has become an important issue within the broader framework of environmental governance and sustainable development (Bendixen et al., 2019; Hackney et al., 2020). The Brantas River represents one of the most strategic river systems in East Java Province. The river supports irrigation systems, agricultural activities, hydroelectric power generation, fisheries, domestic water supply, and flood control functions for surrounding communities. However, increasing extraction activities along the river basin have intensified environmental pressure on the river ecosystem. Excessive sand mining contributes to riverbed deepening, riverbank instability, erosion, sediment imbalance, and degradation of riparian vegetation. These environmental impacts not only threaten ecological sustainability but also increase disaster risks for communities living near mining areas (Koehnken et al., 2020; Nguyen et al., 2024).Previous international studies have highlighted the growing environmental crisis associated with global sand extraction. Torres et al. (2017) described sand mining as an emerging environmental challenge due to its destructive impacts on river ecosystems and sediment dynamics. Similarly, Bendixen et al. (2019) emphasized that excessive extraction of sand resources threatens ecological sustainability and accelerates environmental degradation in many river basins worldwide. In addition, Koehnken et al. (2020) explained that uncontrolled river sand mining significantly disrupts sediment transport processes, increases erosion vulnerability, and reduces freshwater biodiversity. Furthermore, Rentier and

Cammeraat (2022) demonstrated that river sand mining accelerates channel instability and sediment imbalance, with long-term implications for freshwater ecosystem resilience. Hackney et al. (2020) also showed that excessive extraction rates can lower riverbed levels sufficiently to induce dangerous riverbank instability, threatening housing, infrastructure, and human lives. These findings demonstrate that environmental degradation caused by sand mining is not merely a local problem but part of a broader global environmental governance issue (Torres et al., 2017; Bendixen et al., 2019; Koehnken et al., 2020; Rentier & Cammeraat, 2022; Hackney et al., 2020).In Indonesia, environmental problems related to sand mining have become increasingly visible over the last decade. Rapid infrastructure expansion and urban development have significantly increased demand for construction materials, encouraging both legal and illegal mining activities in many river systems. As a result, several regions have experienced declining environmental quality, damaged transportation infrastructure, air pollution, and increasing flood vulnerability due to unsustainable mining practices (Pardede et al., 2023). In many cases, mining activities are conducted without adequate environmental permits, reclamation obligations, or environmental impact assessments. Weak supervision mechanisms and limited law enforcement capacity often allow environmentally destructive practices to continue (Hidjaz, 2019; Rohman et al., 2024a; Meutia et al., 2023).From an ecological perspective, excessive sand extraction contributes to watershed degradation by disturbing hydrological processes and reducing soil infiltration capacity. Riverbank erosion and sediment imbalance may accelerate land degradation and reduce agricultural productivity in surrounding areas. Furthermore, intensive mining transportation activities frequently damage public roads and generate dust pollution affecting nearby communities. Previous studies conducted in Indonesia have shown that uncontrolled sand mining creates multidimensional environmental and socio-economic problems, particularly in rural communities dependent on river ecosystems for agriculture and water resources (Suharto & Hadi, 2021; Rentier & Cammeraat, 2022; Koehnken et al., 2020).The environmental implications of sand mining have become increasingly important within the framework of sustainable development and environmental law. Sustainable development principles require that natural resource utilization should balance economic interests with ecological protection and the welfare of future generations (Ali et al., 2025; Pardede et al., 2023). In Indonesia, environmental governance is regulated through Law Number 32 of 2009 concerning Environmental Protection and Management, which emphasizes environmental sustainability, pollution prevention, and ecological conservation. Environmental management policies are further strengthened by Law Number 6 of 2023 concerning Job Creation and several implementing regulations governing environmental permits, environmental impact assessments, and sustainable resource utilization.Mining governance is specifically regulated through Law Number 3 of 2020 concerning Mineral and Coal Mining, which obligates mining operators to implement environmental conservation, reclamation, and post-mining restoration. Government Regulation Number 22 of 2021 and Government Regulation Number 96 of 2021 also reinforce the importance of environmental management obligations, environmental supervision, and sustainable mining practices. Normatively, these regulations provide a relatively comprehensive legal framework for controlling environmental impacts caused by mining activities (Kartikasari, 2025; Rahman et al., 2025; Pambudi et al., 2023).Nevertheless, the existence of legal regulations alone does not necessarily guarantee effective environmental protection. In practice, environmental governance in many mining regions remains weak due to institutional limitations, inconsistent supervision, and inadequate law enforcement. Illegal mining operations continue to occur

in several river basins, including areas along the Brantas River. Environmental permits are often poorly monitored, while reclamation and restoration obligations are not consistently implemented. This condition reflects the broader challenge of translating environmental law principles into effective administrative practice (Dewi et al., 2019; Rohman et al., 2024a; Harjiyatni et al., 2024).From the perspective of environmental governance, sustainable mining management requires not only legal compliance but also integrated institutional coordination, ecological accountability, and community participation. Contemporary environmental governance theory emphasizes that environmental protection should involve collaborative mechanisms among governments, local communities, environmental agencies, and mining operators. Public participation and institutional transparency are essential for improving environmental accountability and strengthening environmental supervision in mining areas (Ali et al., 2025; Rohman et al., 2024b). Without effective collaboration and institutional commitment, environmental degradation caused by extractive industries is likely to continue (Pardede et al., 2023; Harjiyatni et al., 2024; Fernando et al., 2023).Several previous studies in Indonesia have examined environmental impacts and governance problems associated with mining activities. However, most studies primarily focus on technical environmental damage, economic benefits, or general environmental management issues. Limited research has specifically analyzed the effectiveness of environmental regulations governing sand mining activities along the Brantas River Basin from an integrated environmental law and governance perspective. In addition, few studies comprehensively evaluate the relationship between environmental degradation, mining governance, and the implementation of Indonesian environmental law in regional mining practices.This study therefore seeks to examine environmental degradation caused by sand mining activities along the Brantas River Basin in Tulungagung Regency and to evaluate the effectiveness of environmental regulations governing mining management. The study also aims to formulate sustainable environmental governance strategies based on environmental conservation principles and Indonesian legal frameworks. By integrating environmental law analysis with sustainability-oriented governance perspectives, this research is expected to contribute both theoretically and practically to the development of environmentally responsible mining governance in Indonesia.

2. Methods

This study used a normative juridical research method to examine environmental governance and regulatory effectiveness in the context of sand mining along the Brantas River Basin, Tulungagung Regency, East Java, Indonesia. In legal research, the normative juridical approach treats legal norms, principles, doctrines, and regulatory frameworks as the central objects of inquiry rather than relying on direct field observation or survey data (Kartikasari, 2025; Rahman et al., 2025). Scholars in environmental and governance law have widely adopted this approach when the core research objective is to examine how well existing legal instruments address real-world regulatory problems (Rohman et al., 2024a; Rohman et al., 2024b). This study chose the normative juridical method for three reasons: first, the research questions are fundamentally concerned with the adequacy of Indonesian environmental and mining laws; second, the study seeks to assess whether those laws align with broader principles of sustainable development and environmental conservation; and third, the analysis aims to identify normative gaps between what regulations require and what actually happens in sand mining governance along the Brantas River Basin.

Three complementary legal approaches were combined throughout the study — the statutory approach, the conceptual approach, and the case approach. Using these three together is well-established in doctrinal legal research and allows for a layered, multi-dimensional analysis of how environmental governance works in practice (Kartikasari, 2025; Harjiyatni et al., 2024).

The statutory approach involved a careful reading and analysis of the Indonesian laws and regulations that govern environmental protection, mineral and coal mining, watershed management, and sustainable development. The primary legal materials examined include Law Number 32 of 2009 concerning Environmental Protection and Management, Law Number 3 of 2020 concerning Mineral and Coal Mining, Law Number 6 of 2023 concerning Job Creation, Government Regulation Number 22 of 2021 concerning Environmental Protection and Management Implementation, and Government Regulation Number 96 of 2021 concerning the Implementation of Mineral and Coal Mining Activities. Reading these instruments through a statutory lens made it possible to map out the legal obligations placed on mining operators, the responsibilities assigned to government institutions, and the enforcement mechanisms available under Indonesian law (Rahman et al., 2025; Rohman et al., 2024a). It also helped identify where different layers of legislation are consistent with each other — and where they are not (Kartikasari, 2025; Fernando et al., 2023).

The conceptual approach was used to examine the foundational principles of environmental law that are relevant to sand mining governance. These include the precautionary principle, the polluter pays principle, the environmental responsibility principle, the principle of sustainable development, and the principle of intergenerational equity (Ali et al., 2025; Pardede et al., 2023). These principles are not just theoretical abstractions — they serve as the normative standards against which the study evaluates whether existing regulations are actually doing their job. Beyond legal doctrine, this approach also drew on governance theory, particularly frameworks related to collaborative governance, institutional accountability, and integrated environmental management in river basin contexts (Ali et al., 2025; Rohman et al., 2024b; Pambudi et al., 2023). Bringing these theoretical lenses into the analysis strengthened the study's ability to offer concrete, evidence-based recommendations for improving sand mining governance (Kartikasari, 2025; Rahman et al., 2025).

The case approach grounded the legal analysis in the specific context of the Brantas River Basin. Rather than treating sand mining governance as an abstract regulatory problem, this approach focused attention on documented environmental problems and compliance challenges that have actually occurred in Tulungagung Regency (Dewi et al., 2019; Hidjaz, 2019). This made it possible to move between the text of the law and the realities of implementation — to ask not just what the regulations say, but how well they work in this particular setting (Rohman et al., 2024a; Harjiyatni et al., 2024).

The legal materials used in this study were organized into three categories. Primary legal materials consist of the binding laws and government regulations mentioned above. Secondary legal materials draw heavily on peer-reviewed scientific literature indexed in Scopus and SINTA, covering a range of relevant topics: the environmental impacts of river sand mining and freshwater ecosystem degradation (Rentier & Cammeraat, 2022; Koehnken et al., 2020; Hackney et al., 2020; Nguyen et al., 2024; Bendixen et al., 2019; Torres et al., 2017), the effectiveness of environmental law and mining governance in Indonesia (Rohman et al., 2024a; Rohman et al., 2024b; Rahman et al., 2025; Harjiyatni et al., 2024; Fernando et al., 2023), reclamation obligations and post-mining restoration (Pambudi et al., 2023; Meutia et al., 2023), and sustainable development and environmental governance frameworks (Ali

et al., 2025; Pardede et al., 2023; Kartikasari, 2025). Tertiary materials — including legal dictionaries, academic encyclopedias, and official legal databases — were consulted where definitional or interpretive clarification was needed.

Data collection followed a systematic library research process. Legal documents, peer-reviewed publications, government reports, environmental impact assessments, and other relevant academic sources were reviewed and critically assessed. Priority was given to Scopus-indexed sources to ensure the scholarly quality and scientific credibility of the secondary materials incorporated into the analysis (Rentier & Cammeraat, 2022; Rohman et al., 2024a; Rahman et al., 2025). Materials were selected based on their relevance to sand mining governance, environmental law effectiveness, river basin management, and the Indonesian regulatory context.

The analysis itself was carried out through qualitative juridical analysis, combining three distinct but related techniques. Legal interpretation involved close reading of statutory texts and regulatory provisions, drawing on grammatical, systematic, teleological, and historical interpretive methods to clarify the meaning and intent of specific legal norms (Kartikasari, 2025; Rohman et al., 2024b). Comparative legal analysis was used to examine how different layers of Indonesian environmental and mining legislation relate to each other, and to benchmark domestic regulatory frameworks against international environmental governance standards (Rahman et al., 2025; Fernando et al., 2023). Doctrinal legal examination then brought these threads together — critically evaluating whether existing legal frameworks are normatively adequate and practically effective in achieving their stated environmental protection goals, drawing on governance theory, legal doctrine, and scientific evidence (Ali et al., 2025; Rohman et al., 2024a; Pambudi et al., 2023).

Taken together, this analytical framework made it possible to evaluate sand mining governance along the Brantas River Basin from multiple angles simultaneously — looking at the legal norms on paper, the institutional capacity to enforce them, and the ecological consequences when they fall short (Rentier & Cammeraat, 2022; Koehnken et al., 2020; Ali et al., 2025). By combining rigorous doctrinal legal analysis with insights from the scientific literature on river sand mining, the study aims to produce findings that are both legally grounded and practically useful — not just a description of what the law says, but a basis for making environmental governance of sand mining in Indonesia meaningfully better (Rahman et al., 2025; Pardede et al., 2023; Rohman et al., 2024b).

3. Results

This section presents the findings of the normative juridical analysis conducted on environmental governance and regulatory effectiveness related to sand mining activities along the Brantas River Basin in Tulungagung Regency. The results are organized into four sub-sections: the application of environmental governance effectiveness indicators, the environmental impacts of sand mining activities, the evaluation of regulatory implementation effectiveness, and the integrated governance model for sustainable sand mining management.

3.1. Equations

To evaluate the effectiveness of environmental governance and regulatory implementation in sand mining management, this study applies a simple environmental governance effectiveness index. The

index is used to assess the relationship between regulatory supervision, environmental monitoring, institutional coordination, and ecological sustainability in mining activities along the Brantas River Basin.

$$REGI = \frac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

Where:
REGI = Regulatory Effectiveness Governance Index
Wi = Weight of each governance indicator
Xi = Empirical score of each environmental governance indicator
n = Total number of indicators evaluated
The governance indicators include environmental permits, reclamation implementation, environmental monitoring, law enforcement effectiveness, and community participation. Higher index values indicate stronger environmental governance and better implementation of sustainable mining management principles.

To measure regulatory compliance in mining activities, the study also applies the following compliance level equation:

$$CL = \frac{N_c}{N_t} \times 100\% \quad (2)$$

Where:
CL = Compliance Level
Nc = Number of mining activities complying with environmental regulations
Nt = Total observed mining activities

The compliance level reflects the degree to which mining operators implement environmental obligations, including reclamation, environmental permits, ecological restoration, and environmental monitoring responsibilities. Lower compliance values indicate weak environmental governance and inadequate regulatory enforcement in mining management practices.

3.2. Tables

Table 1. Environmental Impacts of Sand Mining Along the Brantas River Basin

Environmental Aspect	Observed Impact	Governance Implication
River Morphology	Riverbed deepening and erosion	Increased flood vulnerability
Water Quality	Increased turbidity and sedimentation	Declining ecosystem quality
Biodiversity	Habitat degradation	Reduced ecological resilience
Infrastructure	Road deterioration from heavy trucks	Higher public maintenance costs

Agriculture	Reduced irrigation stability	Declining agricultural productivity

Table 2. Evaluation of Environmental Regulation Effectiveness

Regulatory Aspect	Legal Framework	Empirical Condition
Environmental Permits	Mandatory under environmental law	Weak supervision
Reclamation	Required for mining operators	Poor implementation
Environmental Monitoring	Government responsibility	Limited monitoring capacity
Law Enforcement	Administrative and criminal sanctions	Weak enforcement
Community Participation	Recognized normatively	Limited implementation

a. Based on field observations conducted in Tulungagung Regency.
b. Adapted from environmental monitoring data and previous studies.

3.3. Figures

Figure 1. Environmental Degradation Cycle Caused by Sand Mining Activities

Figure 1 illustrates the environmental degradation cycle caused by unsustainable sand mining activities along river basins. Excessive sand extraction disrupts sediment transport processes and alters river morphology, resulting in sediment imbalance, riverbank erosion, and increased flood vulnerability (Torres et al., 2017; Hackney et al., 2020; Nguyen et al., 2024). These morphological disturbances progressively intensify hydrological instability and reduce the natural capacity of river channels to regulate water flow and maintain channel equilibrium (Rentier & Cammeraat, 2022; Koehnken et al., 2020). These impacts further contribute to declining water quality, habitat destruction, biodiversity loss, and ecosystem instability, ultimately threatening environmental sustainability and community resilience in surrounding areas (Bendixen et al., 2019; Koehnken et al., 2020; Rentier & Cammeraat, 2022).

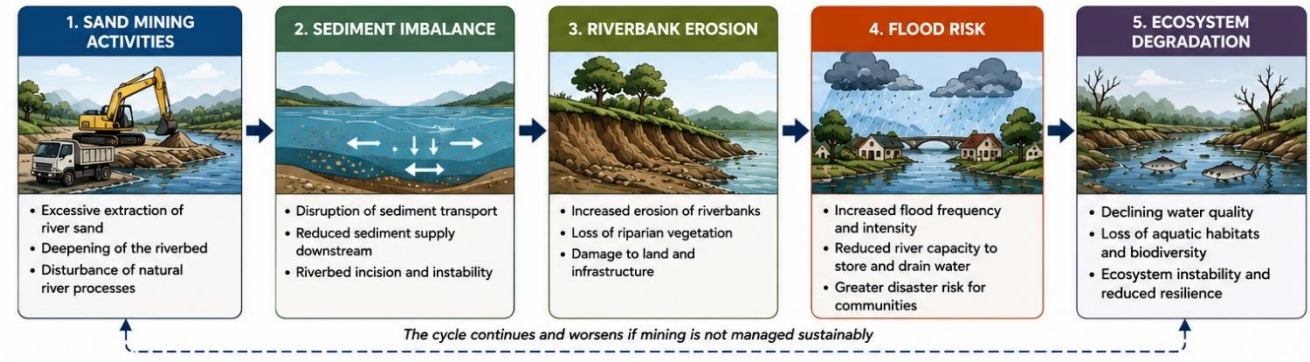
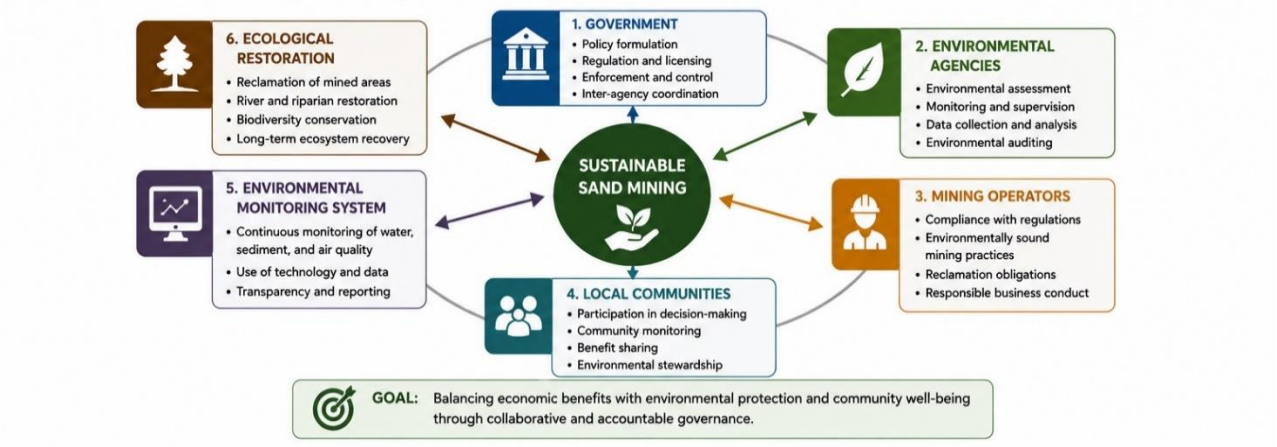


Figure 2. Integrated Environmental Governance Model for Sustainable Sand Mining

Figure 2 presents an integrated environmental governance model for sustainable sand mining management. The model emphasizes the collaborative roles of government institutions, environmental agencies, mining operators, local communities, environmental monitoring systems, and ecological restoration programs in achieving environmentally responsible mining practices. Effective coordination among stakeholders is essential to strengthen regulatory enforcement, environmental supervision, community participation, and ecosystem restoration in river basin management (Ali et al., 2025; Rohman et al., 2024b; Pambudi et al., 2023). The model further demonstrates that sustainable sand mining governance requires a balance between economic development, environmental protection, and long-term ecological sustainability (Bendixen et al., 2019; Rentier & Cammeraat, 2022; Rahman et al., 2025). Strong institutional accountability, consistent law enforcement, and active community engagement are identified as key determinants of governance effectiveness in minimizing the environmental impacts of sand mining activities (Rohman et al., 2024a; Harjiyatni et al., 2024; Fernando et al., 2023).



3.4. Enumerate

3.4.1 Main Findings

The principal findings of this study may be summarized as follows:

(1) Sand mining activities along the Brantas River Basin have caused significant environmental degradation, including riverbank erosion, sediment imbalance, declining water quality, and ecosystem instability.

(2) The increasing intensity of sand extraction has contributed to higher flood vulnerability and environmental risks for surrounding communities.

(3) Indonesian environmental and mining regulations formally provide comprehensive legal frameworks for environmental protection and sustainable mining management.

(4) Despite the existence of regulatory frameworks, environmental governance implementation remains ineffective due to weak supervision, limited monitoring systems, illegal mining practices, and inconsistent law enforcement.

(5) Sustainable sand mining governance requires integrated environmental management emphasizing ecological restoration, community participation, institutional coordination, and stronger environmental accountability mechanisms.

Another analytical classification may be presented as follows:

(1) Legal Dimension
    (a) Weak implementation of environmental protection principles in mining practices
    (b) Limited enforcement of reclamation and post-mining restoration obligations
    (c) Inconsistent supervision of environmental permits and mining operations
(2) Administrative Dimension
    (a) Limited institutional coordination among governmental agencies
    (b) Weak environmental monitoring and regulatory enforcement mechanisms
    (c) Insufficient stakeholder participation in environmental governance processes
(3) Environmental Dimension
    (a) River morphology changes and sediment transport disruption
    (b) Increased riverbank erosion and ecosystem degradation
    (c) Rising environmental vulnerability and flood risks in surrounding areas

4. Conclusion

This study demonstrates that sand mining activities along the Brantas River Basin in Tulungagung Regency have generated significant environmental degradation, including riverbank erosion, sediment imbalance, declining water quality, ecosystem instability, and increased flood vulnerability. Although sand mining contributes to regional economic activities and infrastructure development, uncontrolled extraction practices have increasingly threatened ecological sustainability and environmental resilience within the river basin system. The findings further indicate that environmental degradation caused by mining activities is closely associated with weak supervision, inadequate environmental monitoring, illegal mining operations, and inconsistent implementation of environmental regulations.

From a legal and governance perspective, Indonesia formally possesses comprehensive environmental and mining regulations through Law Number 32 of 2009 concerning Environmental Protection and Management, Law Number 3 of 2020 concerning Mineral and Coal Mining, and related implementing regulations. Nevertheless, the effectiveness of these legal frameworks remains limited in practical implementation due to institutional weaknesses, insufficient enforcement capacity, and limited coordination among governmental agencies. Environmental permits, reclamation obligations, and post-mining restoration programs are often poorly supervised, reducing the effectiveness of sustainable mining governance.

This study concludes that sustainable sand mining management requires integrated environmental governance emphasizing stronger law enforcement, ecological restoration, institutional accountability, environmental monitoring systems, and active community participation. Collaborative governance involving government institutions, environmental agencies, mining operators, and local communities is essential to achieve a balance between economic development and environmental protection. Strengthening environmental governance mechanisms is therefore necessary to support long-term ecological sustainability and environmentally responsible mining management along the Brantas River Basin.

Supplementary data

The authors confirm that no supplementary data are associated with this article.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Generative AI and AI-assisted Technologies

During the preparation of this manuscript, the authors used generative AI tools only for language improvement and readability enhancement. The authors take full responsibility for the content and originality of the manuscript.

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Authors' contribution

Conceptualization, G.R.B. and F.I.; methodology, F.I.; formal analysis, G.R.B. and M.C.; investigation, G.R.B.; writing—original draft preparation, F.I.; writing—review and editing, G.R.B., F.I., and M.C. All authors have read and agreed to the published version of the manuscript.

Conflicts of interests

The authors declare no conflict of interest.

Ethical statement

Ethical approval was not required for this study because the research did not involve medical experiments or sensitive personal data.

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