BALANCING THE SCALES: ECONOMIC REWARDS AND ECOLOGICAL COSTS OF SAND MINING IN THE AJAY RIVER BASIN

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Abstract

This paper assesses the associated trade-offs between economic benefits and environmental costs of sand mining within the Ajay River Basin, Bardhhaman district of West Bengal, India. The sand mining industry provides for the demands of the construction industry in India and sustains the livelihoods of many workers, yet its uncontrolled growth has ravaged the ecosystem with ecological devastation that questions the sustainability of this natural resource in the long term. Two complementary analytical models-Resource Depletion Model and Economic Gains Model-have been applied to estimate and compare the economic gains and costs of sand mining on an annual basis. The Economic Gains Model computes revenue generation, employment generated, and economic multipliers, while the Resource Depletion Model estimates the net economic cost of environmental losses, which includes erosion of soils, loss of water quality, and loss of ecosystem services. The emphasis on the post-2010 decade reflects a dramatic increase in extraction associated with urbanisation and infrastructure growth. Data draws from government statistics, environmental reports, and local sources, thus allowing both spatial and temporal analysis of mining activities and their impacts. Results show that although sand mining yields substantial gross revenue and supports thousands of direct and indirect employments, almost two-thirds of its gross value is counterbalanced by quantifiable environmental degradation, resulting in a thin margin of net gain. The model-based assessment at the district level fills not only an important gap in the Indian sand mining literature but also provides a replicable decision-support tool for weighing economic necessities against environmental conservation. The results draw attention to the importance of regulation, careful tuning of extraction in response to replenishment levels, and the use of environmentally friendly substitutes to protect the economic as well as environmental sustainability of the Ajay River Basin.

JEL Classification: Q32, Q57, R58, O13
Keywords: Sand Mining; Ajay River Basin; Bardhaman District; Economic Impact; Environmental Degradation; Cost-Benefit Analysis; Sustainable Mining Practices

1. INTRODUCTION

Due to the fast-growing construction activities related to infrastructure development projects, sand mining has emerged as an important economic activity in India. The Ajay River Basin, spread over West Bengal's Bardhaman district, contains some of the richest sand deposits in the state and is hence a target for rampant extraction efforts. While the industry sustains livelihoods at the local level by generating new jobs and supporting native industries, the uncontrolled and excessive mining is causing soil erosion, loss of biodiversity, and depletion of groundwater. Such effects have created conflicting interests between short-term economic prosperity and long-term environmental sustainability.

Such tension illustrates general principles in environmental and resource economics. The Tragedy of the Commons (Hardin, 1968) shows how common resources, like riverbeds, will be overused in the absence of proper regulation. Negative externalities theory (Pigou, 1920) describes how environmental costs of degradation are never factored into the market price of sand and so create perverse

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incentives. Elinor Ostrom's approach to Common-Pool Resource Governance (1990) shows how localised, participatory regulation can counteract such overuse. In resource-dependent economies, these challenges can also resemble the Natural Resource Curse, whereby overdependence on extractive industries undermines sustainable development.

It is in this context that this research investigates the economic and environmental impacts of sand mining in the Ajay River Basin. The research question being proposed is: To what extent do the economic gains of sand mining in the Ajay River Basin of Bardhaman offset or exceed its environmental losses? The hypothesis is that although sand mining generates a lot of local income and jobs, it results in environmental costs that substantially reduce net economic benefits.

2. LITERATURE REVIEW

The theoretical basis for studying sand mining in the Ajay River Basin lies in a number of interrelated concepts in environmental economics and resource management. The Common-pool resource theory offers a starting analytical perspective. As outlined by Ostrom (1990) and anticipated in Hardin's (1968) Tragedy of the Commons, resources that are subtractable in use but difficult to exclude users from, such as river sand, tend to be overexploited when left to open access. When there are no enforceable property rights or effective collective management, individual players are motivated to maximise current extraction, even if it leads to an exhaustion of the resource for everyone in the long run.

A second theoretical underpinning arises from environmental externality literature. On the lines of Pigou's (1920) approach, unpriced production costs like soil erosion, sedimentation, and loss of biodiversity are levied on third parties and the environment, instead of being paid by extractors. For sand mining, these externalities can be drastic, such as the subversion of riverbanks to reductions in groundwater recharge, but they seldom find their way into the market price of sand.

These dynamics are inextricably linked to the concept of sustainability, specifically as set out in the Brundtland Commission definition of development: that which meets the needs of the present without compromising the ability of future generations to meet their own needs. The scholarly literature on the sustainable use of resources (e.g., Pearce and Turner, 1990; Daly, 1996) focuses on incorporating environmental constraints into economic planning, especially for non-renewable or very slowly renewable resources, such as river sand.

From the methodological perspective, the default approach to balancing alternative economic and environmental considerations is cost–benefit analysis (CBA). Traditional CBA entails discounting future flows of costs and benefits to their net present value (NPV) and comparing benefit–cost ratios (BCRs) or using internal rates of return (IRRs) (Boardman et al., 2018). In a full-scale CBA, it can be data-intensive, taking long time series and valuing non-market impacts. In contexts like Bardhaman, where data is disaggregated and localised, the methodology can be fit into a resource depletion model. This reduced structure holds the core logic of CBA, of quantified benefits being compared explicitly with monetised costs, but implements this in a one-period framework based on locally observable parameters so that economic–environmental trade-off analysis can be carried out meaningfully under data limitations.

Empirical research on sand mining is double-sided: research that reports the physical and environmental impacts of extraction and studies that evaluate the economic and social impacts. Padmalal and Maya's edited book Sand Mining: Environmental Impacts and Selected Case Studies (2014) continues to be the most frequently cited synthesis of riverine and coastal environmental impacts; it systematically records how channel incision, bed degradation and bank collapse ensue following prolonged extraction and relates those physical alterations to agricultural, fishing, and riverine habitat losses. Regionally, Mukhopadhyay (2010) gives a geo-environmental evaluation of sand splay and flood dynamic problems in the lower Ajay, illustrating how sediment redistribution following extraction affects farmland inundation, flood behaviour, and local depositional patterns, as well as local drainage. Ghosh and Jana's Damodar system river-sensitivity study (2021) suggests a reach-classification methodology that determines sensitive stretches not acceptable for quarrying and derives erosion-rate functions directly applicable in economic damage calculation.

The Global Initiative report on Indian sand markets (Mahadevan 2019) chronicles market and governance failure at the hands of informal extraction networks from an economic and social point of view. The report finds that illicit supply chains capture the lion's share of rents, create informal jobs, lower fiscal yields of formal leasing regimes and increase environmental impacts. Complementary empirical research (e.g., Baker et al. 2023) investigates the coastal and riverine settlements and finds that employment from sand extraction is seasonal, localised among a few workers, and not necessarily a stable route out of poverty; indirect employment in transport and logistics is bigger but still informal and insecure. These findings suggest that simple counts of jobs overstate the gains in livelihoods that are sustainable unless they are adjusted for seasonality and natural feedback on agriculture and fisheries.

Methodological analogies from our strategy for empirical cost–benefit analysis and valuation have been drawn in some specialised studies. Lima, Ferreira, and Coelho (2023) apply a traditional CBA to assess sand bypassing systems, generating net present value, benefit–cost ratios, and break-even years for engineered coastal interventions. Although coastal, their approach demonstrates how physical erosion or accretion models are monetarised into benefits and provides a structural framework applicable to riverine settings. A study on the Ping River Basin, Thailand, by analysts estimates sediment yield based on spatial data and calculates benefit–cost ratios from environmental cost proxies versus commercial sediment values. Likewise, a watershed study in Tunisia coupled sediment-control measures with a SWAT model and conducted a classical CBA to determine the most cost-effective strategy for soil conservation. Although not directly concerned with sand mining as such, these studies demonstrate that physical–economic coupling is possible and useful when organised into a comparative study. At a more general level, the Council for Scientific and Industrial Research (CSIR) report on the external costs of sand mining from rivers in South Africa illustrates how damages to the environment, for example, in the loss of ecosystem services and fisheries, can be monetised systematically. Although its estuarine environment is dissimilar from that of the Ajay River Basin, its methodology of measuring unvalued environmental losses in conjunction with extraction gains is similar to our assumptions for our resource depletion model.

With these precedents in mind, our methodology takes cues from cost–benefit analysis but is not a textbook CBA. We employ a static, one-period resource depletion valuation model. This selection is intentional. It would take a complete CBA for sand mining to have exhaustive time-series information on extraction levels, market prices, agricultural productions, and ecosystem service values over decades, as well as sound discount rates to compute net present values or benefit–cost ratios. For the Ajay River Basin, longitudinal and disaggregated data of this type simply do not exist in the public domain, and what does exist is too inconsistent across sources. Instead of constructing a long-term forecast on weak foundations, we concentrate on comparing annualised economic benefits and annualised environmental costs for one representative period, based on the most up-to-date and reliable district-level statistics.

This design is transparent and traceable in calculation so that every parameter, whether sand sale revenue, agricultural loss due to erosion, or water treatment cost, can be updated independently whenever improved data becomes available. It also accommodates the policy situation in Bardhaman, where most administrative and regulatory actions on sand leases are made on a yearly cycle. By basing the analysis on a one-year balance sheet, we can still identify the fundamental economic-environmental trade-off without exaggerating the accuracy of the available data. Briefly, our approach sacrifices the temporal richness of a full CBA for the sake of transparency, replicability, and applicability to policy-making.

3. DATA AND METHODOLOGY

3.1. Model Specification

The quantitative analysis is based on two linked formulations: the Resource Depletion Model, which captures the net economic impact of sand mining, and a subsidiary Economic Gains Model, which isolates the revenue-generating component of extraction.

3.1.1. Resource Depletion Model

The net economic impact (E) is computed as the total economic gains from sand extraction less the annualised costs of environmental degradation:

$$E = \sum_{i=1}^{n} C_i S_i - D \tag{1}$$

Where:

- E = Net economic impact (₹ per year)
- S_i = Sand extraction rate at mining unit i (m^3/year)
- C_i = Economic value per unit of sand extracted at site i (₹/m^3)
- D = Aggregate annual environmental degradation cost (₹), comprising:
  - Loss of agricultural productivity
  - Additional water treatment costs due to siltation and pollution
  - Loss of ecosystem services (flood regulation, biodiversity, habitat quality)
- n = Number of mining units in the Ajay River Basin

This formulation treats environmental losses as a direct subtraction from extraction benefits, providing a concise representation of the trade-off between short-term economic returns and long-term ecological costs.

3.1.2. Economic Gains Model

To calculate the gross economic value of sand extraction before environmental costs are accounted for, we define:

$$\textit{Economic Gains } (B) = \sum_{i=1}^{n} S_i C_i \tag{2}$$

Where:

- B = Total economic gains from sand extraction (₹ per year)
- S_i , C_i , n = As defined in Equation (1)

Equation (2) is essentially the revenue component of Equation (1), isolating the contribution of sand mining to the local economy through market sales of extracted sand. The difference between B and D then yields the net impact E.

3.2. Underlying Assumptions

The modelling framework relies on a set of conceptual and numerical assumptions designed to simplify estimation without losing analytical relevance. These are grouped into two categories: general modelling assumptions and parameter-specific numerical assumptions.

3.2.1. General Modelling Assumptions

- The sand extraction rate (S_i) is assumed to be uniform across different mining units, despite potential variations in mining intensity within the Bardhaman district.
- The economic value per unit of sand (C_i) is based on an average market price, assuming minimal price fluctuations due to local or seasonal demand.
- The cost of environmental degradation (D) is simplified to include only measurable factors like agricultural productivity loss and increased water treatment costs, excluding less tangible costs like loss of biodiversity.
- Secondary economic impacts, such as downstream effects on industries indirectly linked to sand mining, are not included in the model.
- The model assumes no significant technological advancements or policy changes influencing sand mining practices during the evaluation period (post-2010).
- External factors like regional or national economic trends are not accounted for, focusing solely on the local economic context of Bardhaman.
- Data from government reports and surveys are assumed to be accurate and representative of actual field conditions.
- Environmental costs are treated as additive rather than interactive, which simplifies complex interdependencies between ecological factors.

3.2.2. Numerical Assumptions for Calculating Economic Gains

The economic impact of sand mining in the Ajay River Basin can be evaluated by analysing its economic benefits (employment generation and revenues accrued) against the environmental degradation costs (losses in agriculture, water quality, and ecosystems). To make a clear and nearly accurate assessment, we make revised assumptions and calculations that align with actual production capacities, local demographics, and natural constraints.

Based on the operational constraints observed from the Mine Plan of Fakirpur Sand Mine, Purba Bradhaman, and adjusted for scale and geography, we assume:

1. **Production Capacity**:
   a. Total Annual Sand Extraction: 3,50,000 cubic metres (aggregate of 3-5 sand mines in the Ajay River Basin)
   b. Average Daily Production: 1,500 cubic metres (distributed across sites)
   c. Operational Days per year: 240 days (excluding monsoon months of June-September)
2. **Labour Productivity**:
   Sand handled per worker per day: 1.9 cubic metres (as per the Fakirpur Sand Mine model)
3. **Economic Value**:
   Average market price of sand: ₹ 300 per cubic metre (local market data)
4. **Environmental Degradation Costs (D)**:
   a. Agricultural Losses: Based on riverbank erosion and loss of arable land, estimated at approximately ₹4 crore annually (adjusted from similar reports)
   b. Water Treatment Costs: Increased costs due to siltation and pollution, estimated at approximately ₹1 crore annually.
   c. Ecosystem Damage Costs: Loss of ecosystem services (flood regulation, biodiversity, et cetera), estimated at approximately ₹2 crore annually.

3.3. Calculations

The numerical assumptions outlined in Section 3.2.2 are now applied to the model equations to estimate the gross economic gains, employment generated, and net economic impact of sand mining in the Ajay River Basin.

3.3.1. Revenue from Sand Extraction (Economic Gains)

Substituting the representative values (C = ₹ 300 per m^3, S = 350,000 m^3) into equation (2):
B = 300 × 350,000 = ₹ 105,000,000
= ₹ 10.5 crore annually
This figure represents the gross revenue generated from the sale of extracted sand, before accounting for environmental degradation costs.

3.3.2. Employment Generated

Direct employment is estimated using the labour productivity assumption:

$$\text{Workers per day} = \frac{\text{Average Daily Production}}{\text{Sand handled per worker per day}} = \frac{1500}{1.9} \approx 790 \text{ workers}$$

This translates to approximately 790 full-time-equivalent positions over the operational year (240 days). In addition, indirect employment in associated sectors (transportation, loading, retail, and logistics) is estimated at 4,000–5,000 individuals, based on proportional employment multipliers observed in the regional mining sector.

3.3.3. Net Economic Impact

From section 3.2.2.,
D = ₹ 4 crore + ₹ 1 crore + ₹ 2 crore = ₹ 7 crore
From equation (1):

$$E = B - D$$

Substituting the values:
E = ₹ 10.5 crore - ₹ 7 crore = ₹ 3.5 crore annually
This result indicates that while sand mining generates substantial revenue and supports thousands of livelihoods, nearly two-thirds of its gross economic value is offset by measurable environmental costs. The resulting net gain of ₹3.5 crore represents a modest positive balance when viewed purely in monetary terms and underscores the need for sustainable mining practices to preserve long-term viability.

4. ANALYSIS

Analysis and discussion of these findings are structured into three sections: one on the economic impact, discussing the contribution to local income and generation of employment from sand mining in the Ajay River Basin; the other on environmental cost, discussing the scale and monetary valuation of ecological degradation, against benefits; and, lastly, the one discussing social and socio-economic costs regarding how sand extraction affects livelihood, equity, and welfare at the community level. This threefold division thus enables a full comprehension of the various trade-offs in sand mining and integrates quantitative results from the model regarding resource depletion with qualitative field observations and secondary data.

4.1. Economic Impact

The economic gains model result indicates that sand mining in the Ajay River Basin yields a gross revenue of ₹10.5 crore annually. The figure corresponds to the summation of the total market value of sand produced in an operational year, using an aggregate production capability of 350,000 m^3 and an average market price of ₹300 per cubic meter. The activity supports about 790 full-time-equivalent jobs directly in extraction and a further 4,000–5,000 indirectly employed persons in transportation, handling, equipment maintenance, and retail sales of construction materials.

Even from a strictly monetary point of view, the sector contributes much to the local economy. It generates stable seasonal employment, especially of unskilled labour, and circulates funds in rural markets. The presence of ancillary service firms like truck operators, fuel vendors, and equipment contractors further embeds sand mining in the economy of the district.

But the relatively modest quantum of net economic gain of ₹3.5 crore a year after accounting for environmental costs shows that the sector's contribution to the district's long-term growth is marginal. Compared to farming, which is still the major livelihood base, sand mining gives better day wages but for a shorter working year due to the operational halt during the monsoon. This seasonal character brings about volatility of income for dependent families. What is more, the fact that economic profits are concentrated among contractors and leaseholders raises concerns with regard to just distribution since wage workers normally only appropriate a small fraction of the value created.

4.2. Environmental Consequences

It generates an environmental cost, which is evident from the degradation caused by extraction, reflected in its annualised loss amounting to ₹7 crore. The most significant contribution comes from arable land loss through riverbank erosion, at ₹4 crore, which decreases not only the area under cultivation but also affects the productivity of the adjacent farmland due to deposition and destabilisation.

Water quality impacts add a further cost of ₹1 crore per year, including the additional burden on municipalities and industries treating silt-laden or dirty river water. Increased turbidity, suspended solids, and pollution from mining activities interfere with aquatic ecosystems and raise operating costs for water infrastructure.

The cost of losing ecosystem services is estimated at ₹2 crore annually. These include the diminished flood regulation function of the river corridor, the loss of its biodiversity support function, and ecological connectivity. Monetization of such services is challenging to accomplish; the conservative estimate adopted in the model indicates that even incomplete accounting shows huge natural capital erosion.

Compared to gross revenues, these environmental costs consumed roughly two-thirds of the economic value generated. This conclusion shows the thin margin for net gain and the case for controlled, low-impact mining practices that can minimize the extent of ecological damage without compromising livelihoods.

4.3. Social and Socio-Economic Costs

Apart from the direct economic and environmental indicators, sand mining in the Ajay River Basin has direct social implications. Field observations and secondary information indicate that mining activities brought changes in the local employment pattern, with farm labourers shifting seasonally to mining employment based on more favourable wage rates. While this promises short-term financial benefits, it also threatens the availability of farm labour during the prime crop cycles and seasons of farming, thereby affecting the crop cycle and output.

In some villages, the proximity of mine sites has altered land-use and settlement patterns. The development of riverbank areas as loading points and routes of access tends to dislocate informal grazing grounds and common land. This affects households living on mixed livelihoods, particularly those with livestock. Also, increased truck traffic and riverbank activity have raised safety concerns, especially for women and children who used riverbanks to collect domestic water and socialise before.

Governance-based socio-economic impacts do exist, too. The extremely high profitability of sand mining is attractive to informal operators, who provoke competition over access and accusations of illicit extraction. These conflicts pressure the local administrative capacities and, in a few instances, polarise communities along patronage or political lines. Whereas legal mining can yield local development funds in the form of lease payments and royalties, this uneven application of regulations reduces the potential for those funds to be distributed equitably.

Taken together, the social forces suggest that, while sand mining injects money into rural economies, it reorients social relationships, land use values, and forms of community interaction-typically in directions which privilege short-term financial rewards over long-term stability and social cohesion.

5. CONCLUSION

This research aimed to enquire if the economic benefits of sand extraction in the Ajay River Basin, Bardhaman, balance out its environmental drawbacks. To answer that, under extreme data limitations, we used a straightforward, one-period resource-depletion model that contrasts annualised extraction returns with annualised environmental expenses, not a complete discounted cost–benefit calculation. This selection maintains accounting replicability and policy relevance to the district's year-to-year licensing regime.

The findings from our analysis, as discussed above, must be interpreted with due caution. Our analysis is non-discounted (static model), postulates average prices and constant extraction intensity per unit, and specifies additive (as opposed to interactive) environmental damages; causal inference is constrained by the sparsity of data on erosion processes, groundwater behaviour, and health effects. District-level statistics are employed as the best available surrogates, but disaggregated and long-panel monitoring do not exist. Collectively, these restrictions support the reading of reported values as conservative, revisable estimates and not exact totals.

Policy responses directly follow from the math and field conditions. The low margin of difference between gross and net benefits implies that even modest reductions in environmental costs (D) can significantly enhance the sector's net contribution.

For sustainable sand mining in Bardhaman, notably in the Ajay River Basin, a number of practical steps with key stakeholders must be taken.

Annual limits on the rates of replenishment of river sediments can be imposed; however, effective implementation can only be ensured with the watch of the West Bengal Pollution Control Board (WBPCB), as well as the joint involvement of the District Land and Land Reforms Department (DLLRD). The sand miners' licensing system must also be adequately established to prevent any unauthorised sand extraction activity, which is under frequent check by the Directorate of Mines and Minerals as well as third-party audits by accredited environmental organisations. Third, monitoring committees may be formed under the Panchayati Raj Institutions (PRIs) for the localised communities to verify compliance and hold people accountable.

Fourth, other materials such as manufactured sand (m-sand) could be promoted using incentives like subsidies and technical support by the Public Works Department (PWD) and the Ministry of Micro, Small, and Medium Enterprises (MSME). Fifth, riverbank stabilisation using vegetation or geotextiles could be undertaken under the Irrigation and Waterways Department to prevent erosion. Sixth, compulsory reclamation plans that oblige miners to restore depleted mining sites through afforestation or the restoration of waterbodies can be imposed by the Forest Department and local environmental NGOs.

Seventh, there should be regular studies about the environmental impact on the rivers of Bardhaman by university research collaborations like the University of Burdwan, independent researchers, and government agencies at the local level. Eighth, a multi-stakeholder task force should be developed, which will comprise the WBPCB, DLLRD representatives, the local civic institutions, and the industrial bodies from Asansol and Durgapur, so that proper planning and coordination are done. The last category is where NGOs must start and spread awareness programmes regarding the socio-economic and environmental impact of unrestricted sand mining and, with the help of local media outlets, foster further involvement from the broader community towards the conservation of resources.

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