Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 24 July 2026
Revised 28 Aug 2026
Accepted 12 Sep 2026

Natural Resources for Human Health 2026, Vol. 6 (23s): 263–274

KEYWORDS:
Sand extraction; agriculture; rural livelihoods; groundwater; vegetation; animal husbandry; Karnataka; natural resource; resource governance.

Mining the Lifeline: Unravelling the Hidden Impacts of Sand Extraction on Agriculture and Rural Livelihoods in Karnataka, India

Gangadhara Reddy N[1], Shashidhar Channappa[2], Premajyothi D[3], Damodara Achary[4]

[1]Faculty, Department of Social Work, Bangalore University, Jnanabharathi Campus, Bengaluru – 560056, https://orcid.org/0000-0001-9873-3648
E-Mail gangadhara@bub.ernet.in

[2]Associate Professor & Head, Department of Social Work, The Oxford College of Science, Arts, Commerce and Management, Bengaluru – 560102, https://orcid.org/0000-0001-7794-3267, E-mail: shashidhar.channappa@gmail.com

[3]Adjunct Faculty, Department of Social Work, CHRIST (Deemed to be University), Bengaluru – 560029, premajyothi.d@christuniversity.in

[4]Faculty, Department of studies and Research in Social work, Dr. Man Mohan Singh Bengaluru City University, Bengaluru – 560001, damodaracharyahr@gmail.com

ABSTRACT: Sand mining has intensified globally, generating interconnected social, economic and ecological problems that increasingly affect the natural-resource base and livelihoods of rural communities. Its impacts extend beyond river channels and extraction sites to agricultural land, water resources, vegetation, grazing areas and other resources supporting farming and allied activities. This study examines the association between sand extraction and agricultural and allied rural livelihood activities in Karnataka, India. A cross-sectional study was conducted among 400 farmers from four major river basins of Karnataka. Data were collected using a structured interview schedule and analysed using Pearson's Chi-square test of independence to test the hypotheses, with Cramér's V used to assess the strength of associations. The findings indicate significant associations between sand-extraction-related conditions and farmer-reported outcomes across agricultural production, water resources, vegetation and animal husbandry. Dust from sand transportation and contaminated water were associated with agricultural impacts, while water-body shrinkage and disrupted groundwater recharge were associated with sand extraction. Soil erosion, biodiversity loss, channel disturbance and reduced water-body capacity were associated with vegetation loss. The study highlights the need for integrated resource governance and scientifically regulated sand mining.

1. INTRODUCTION

Sand, together with gravel, is among the most extensively extracted natural resources globally and ranks second only to water in terms of the volume extracted. The United Nations Environment Programme (UNEP, 2022) estimates that approximately 50 billion tonnes of sand and gravel are consumed annually, reflecting the scale of demand generated by urbanization, population growth and infrastructure development. Sand is therefore a critical input for construction and economic development. However, its extraction has increasingly attracted environmental and social concerns because sand is a finite and spatially unevenly distributed resource. Intensive extraction, particularly from river systems, can alter sediment regimes, river morphology, groundwater processes and ecological systems, with potential consequences for communities whose livelihoods depend on land and water resources (UNEP, 2022; Rentier & Cammeraat, 2022).

In India, ordinary sand, except sand used for prescribed purposes, is classified as a "minor mineral" under Section 3(e) of the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act). Although classified as a minor mineral in the regulatory framework, the scale and intensity of its extraction have generated significant environmental and governance concerns. Riverine sand extraction is particularly consequential because sediment availability and movement are integral to river morphology, channel stability, groundwater recharge and aquatic and riparian ecosystems. Excessive removal of sediment may disturb these interconnected processes, resulting in riverbed degradation, bank erosion and changes in local hydrological conditions (Rentier & Cammeraat, 2022).

The increasing intensity of sand extraction in India is closely associated with expanding construction demand and urbanization. Dujardin et al. (2024), in a sub-continental assessment of riverine sand and gravel mining, identified evidence of mining in 61.6% of 808 randomly selected river reaches. Their findings further indicated that mining intensity was associated with demand-side factors, particularly proximity to urban centres and built-up areas. These findings demonstrate that sand extraction is not merely a localized environmental activity but is embedded within broader patterns of urban growth, infrastructure expansion and resource demand.

While the environmental implications of sand extraction have received considerable scholarly attention, its consequences for agriculture and allied livelihood activities remain comparatively underexplored. This constitutes an important research concern because rural agricultural production is dependent on interconnected resources, including productive soil, water availability, groundwater, vegetation and grazing resources. Disruption of these resources may affect not only crop cultivation but also livestock rearing and other agriculture-dependent livelihood activities. Consequently, the effects of sand extraction need to be examined beyond the immediate river environment and in relation to the productive resource base of rural communities.

Evidence from Karnataka provides an important foundation for such an inquiry. Hemalatha et al. (2005), examining the Uttara Pinakini River basin in Gauribidanur, reported that excessive sand extraction affected irrigation wells in riparian areas and was associated with reduced groundwater recharge. The study identified sand mining as a negative externality for riparian farmers, thereby establishing an important relationship between sand extraction, groundwater availability and agricultural production. Similarly, Hegde et al. (2008) examined sand extraction from agricultural fields in the Bengaluru region, where surface soil was removed and processed to obtain sand. Although the activity generated employment and economic returns, the removal and disturbance of agricultural soil raised concerns regarding the long-term productive capacity of agricultural land. Together, these studies indicate that the consequences of sand extraction may extend beyond river systems to the fundamental resources upon which agricultural production depends.

The potential effects of sand extraction on agricultural resources have also received judicial attention in India. In Harbans Singh v. State of Haryana & Others (O.A. No. 306/2022), the National Green Tribunal directed assessment of the potential effects of sand mining from agricultural land on soil fertility, groundwater conditions and post-mining restoration. The proceedings also highlighted the importance of assessing mining depth, sand replenishment and appropriate environmental safeguards. Although judicial proceedings do not constitute empirical evidence in themselves, they demonstrate the institutional recognition of the need to consider agricultural productivity and groundwater conditions within the broader assessment of sand-mining impacts.

Evidence from outside Karnataka further indicates that sand extraction can affect agricultural land and rural livelihood systems. Hemmler et al. (2024), based on farmer interviews and physical and chemical assessments of mined and unmined agricultural fields in the Accra region of Ghana, documented agricultural land loss, crop destruction, reductions in soil carbon and macronutrients, and increased soil compaction following sand mining. Their findings provide empirical evidence of the potential relationship between sand extraction and deterioration of agricultural soil conditions. However, the methodological approach of the present study differs from that of Hemmler et al. (2024). Whereas their study incorporated direct physical and chemical measurements of soil, the present research primarily examines community-reported experiences and statistical associations relating to agricultural and allied activities. Accordingly, the findings of the present study are interpreted as evidence of reported changes and perceived impacts rather than as direct measurements of environmental degradation or definitive evidence of causality.

The relationship between sand extraction and agriculture can therefore be understood through a set of interconnected resource pathways. Changes in groundwater availability may affect irrigation and crop cultivation; disturbance of soil resources may influence agricultural productivity; degradation of vegetation and grazing resources may affect livestock production; and

changes in water and land resources may generate cumulative consequences for rural livelihood systems. Such interdependencies suggest that the agricultural implications of sand extraction cannot be adequately understood by examining individual environmental variables in isolation.

Despite growing scholarly and policy attention to sand extraction, a significant empirical gap remains in relation to its integrated implications for agriculture and allied activities in Karnataka. Existing Karnataka-based studies have largely focused on groundwater impacts and extraction from agricultural land, while research from other regions has examined environmental degradation, livelihood dependence and resource conflicts. Comparatively limited empirical research has examined, within a unified framework, the relationships among crop production, soil fertility, soil erosion, groundwater, vegetation, grazing resources and livestock activities in communities affected by sand extraction.

The present study addresses this gap by examining the implications of sand extraction for agriculture and allied activities among affected rural communities in Karnataka. Agriculture is conceptualized as an interconnected productive-resource system comprising five dimensions: (i) cultivation and crop production; (ii) soil fertility and soil erosion; (iii) groundwater and water resources; (iv) vegetation and grazing resources; and (v) livestock and animal husbandry. The study specifically examines whether reported changes in water resources, soil conditions, vegetation and grazing resources associated with sand extraction are statistically associated with changes in crop production and livestock-related activities.

By adopting an integrated agricultural and livelihood perspective, the study extends the predominantly river-centred discourse on sand mining towards its less visible consequences for rural productive resources. It consequently conceptualizes sand extraction not solely as an environmental or mineral-governance issue, but also as a potential factor affecting the resource base, productive capacity and livelihood sustainability of agricultural communities in Karnataka.

REVIEW OF LITERATURE

Sand extraction has increasingly emerged as a significant natural-resource and environmental concern because its consequences extend beyond extraction sites to interconnected riverine, hydrological, terrestrial and livelihood systems. Rentier and Cammeraat (2022), in a systematic review of river sand mining, documented a broad range of physical, biological, chemical and anthropogenic consequences, including riverbed degradation, deterioration of water and soil quality, biodiversity loss, restricted access to water and adverse effects on agricultural activities. The authors further emphasized that these effects may be spatially extensive and cumulative, particularly where extraction intensity exceeds the natural replenishment capacity of river systems. Such consequences are particularly relevant to rural communities who's agricultural and livelihood systems depend substantially on land, water and other natural resources.

Agricultural production is particularly vulnerable to sand extraction where mining occurs on or adjacent to cultivated land. Removal of surface material may result in direct loss of agricultural land, destruction of standing crops and modification of soil properties, thereby affecting the productive capacity of agricultural systems. Evidence from Karnataka is provided by Hegde et al. (2008), who examined sand extraction from agricultural fields in the Bengaluru region, where surface soils were removed and washed to obtain sand for construction-related purposes. Although the activity generated employment and income opportunities, the study identified substantial ecological costs associated with the removal and disturbance of agricultural land. The findings illustrate the tension between short-term economic returns from sand extraction and the longer-term productive value of agricultural resources.

International empirical evidence further demonstrates the implications of sand extraction for agricultural land and soil resources. Hemmler et al. (2024), drawing on farmer interviews and comparative physical and chemical analyses of mined and unmined agricultural fields around Accra, Ghana, documented substantial agricultural land loss and destruction of food crops following sand mining. Mined fields exhibited reductions in soil carbon and major nutrients, including nitrogen, phosphorus, potassium and magnesium, together with increases in soil bulk density and penetration resistance. Alterations in soil texture, pH and moisture were also observed. The study further reported that a considerable proportion of mined fields were not subsequently returned to cultivation, while fields where cultivation resumed exhibited reduced productivity. These findings indicate that the agricultural consequences of sand extraction may extend beyond immediate crop losses to longer-term deterioration in soil quality, land usability and productive capacity, although the magnitude and persistence of such effects may vary according to extraction depth, soil characteristics, extraction techniques, hydrological conditions and subsequent land reclamation.

Water resources constitute another important pathway through which sand extraction may influence agricultural systems. Riverbed sediments contribute to infiltration, temporary water storage and surface-water–groundwater exchange; consequently, intensive sediment removal may alter channel morphology and, under particular hydrogeological conditions, affect groundwater recharge and availability (Rentier & Cammeraat, 2022). Evidence from Karnataka demonstrates the agricultural significance of this relationship. Hemalatha, Chandrakanth and Nagaraj (2005), studying sand mining along the Uttara Pinakini River in Gauribidanur, reported a higher incidence of irrigation-well failure in sand-mining areas and lower groundwater extraction per well compared with non-mining areas. The authors associated excessive sand extraction with reduced groundwater recharge and identified negative economic externalities for riparian farmers. These findings are particularly relevant to agricultural systems dependent on groundwater for irrigation, although hydrological responses may vary according to river morphology, extraction intensity, sediment characteristics and aquifer conditions.

Water quality represents an additional dimension of the relationship between sand extraction and agricultural water resources. Manjunatha, Chengappa and Chandrakanth (2006), examining externalities associated with sand mining and distillery effluent in water streams, highlighted the role of riverbed sand in water retention and recharge and reported changes in riverbed conditions associated with excessive extraction. The study also identified water-quality concerns in affected streams. However, because sand mining was examined alongside distillery effluent, the reported contamination cannot be attributed exclusively to sand extraction. The study is therefore relevant primarily for demonstrating the broader water-resource pressures that may arise in river systems subjected to sediment extraction and other anthropogenic activities.

The implications of sand extraction extend beyond crop cultivation and irrigation to livestock production and other allied rural activities that depend on common-property natural resources. Grazing lands, lake beds, stream margins, vegetation and communal lands provide fodder and can reduce the costs of livestock maintenance, particularly for small and marginal livestock holders. Sand extraction and associated sand-filtering or processing activities undertaken in streams, lake beds, *Rajakaluve* (Stormwater Drain) and *Gomala* (Grazing) lands may therefore affect agricultural livelihoods by reducing the availability of grazing areas and natural vegetation. Rentier and Cammeraat (2022) identified impacts on biodiversity, riparian vegetation and floodplain environments among the documented consequences of river sand mining, indicating potential implications for the ecological resources that support livestock-based livelihoods.

Karnataka-specific evidence provides a more direct illustration of this relationship. Reddy, G. N. and Lokesha, M. U. (2022), in their study of the Chitravathi River Basin in Chikkaballapur district, reported that grazing lands had declined in association with sand mining and related sand-filtering activities. The extraction and processing of sand from streams and lake beds reduced areas available for livestock grazing and affected access to natural fodder, with implications for animal husbandry and dairy farming. Although geographically specific, this evidence demonstrates that the consequences of sand extraction may extend beyond cultivated agricultural land and irrigation systems to common-property resources supporting livestock-based components of the rural economy.

Taken together, the literature indicates that the consequences of sand extraction operate through multiple and interconnected pathways. Direct effects may include the removal of agricultural land and destruction of crops, while indirect effects may involve changes in soil condition, groundwater availability, water quality, vegetation and grazing resources. These changes can subsequently influence crop cultivation, irrigation, livestock production, dairy activities and household livelihood strategies. The evidence therefore suggests that the agricultural consequences of sand extraction should not be understood solely as changes occurring within river channels or extraction sites, but as changes affecting the broader productive-resource base on which rural communities depend.

Despite the growing body of research on the environmental consequences of sand extraction, important empirical gaps remain in the Karnataka context. Existing studies have predominantly examined individual consequences within specific locations, for instance, extraction from agricultural fields (Hegde et al., 2008), groundwater and irrigation-well impacts in the Uttara Pinakini basin (Hemalatha et al., 2005), and grazing and livestock-related consequences in the Chitravathi basin (Reddy & Lokesha, 2022). While these studies establish important resource-specific impacts, they do not provide a comparative, farmer-level assessment of how sand extraction affects multiple components of agricultural and allied livelihoods across different river-basin settings.

More specifically, limited empirical research has simultaneously examined crop production, soil fertility and erosion, groundwater and other water resources, vegetation, grazing availability, livestock and dairy activities within a single analytical framework. The implications of associated sand-filtering or processing activities for agricultural and common-property

resources have also received comparatively little systematic attention. Furthermore, much of the existing evidence is confined to individual river basins or particular environmental indicators, leaving limited understanding of whether similar livelihood consequences are reported across different river systems in Karnataka. The literature therefore lacks an integrated assessment connecting changes in natural-resource conditions with their reported consequences for agricultural and allied activities at the community level.

The present study addresses these specific gaps by examining farmer-reported agricultural and allied livelihood consequences of sand extraction across selected river basins in Karnataka**,** rather than restricting the analysis to a single river system or environmental outcome. It specifically examines the reported relationships between sand extraction and changes in crop cultivation, soil fertility and erosion, groundwater and water resources, vegetation, grazing, livestock and dairy activities, while also considering the role of associated sand-filtering activities. By bringing these dimensions together within a common analytical framework and examining statistical associations among them, the study seeks to provide a more comprehensive understanding of the livelihood consequences of sand extraction from the perspective of affected rural communities.

Aim and Objectives of the Study

The study aims to examine the effects of sand extraction for agriculture and allied rural livelihood activities among affected communities in Karnataka.

Objectives:

- To assess the reported effects of sand extraction on agricultural production, with particular reference to crop cultivation, soil fertility, soil erosion and water resources.
- To examine the reported effects of sand extraction and associated sand-filtering activities on vegetation, grazing resources, livestock, animal husbandry and dairy farming.
- To analyze the associations between sand-extraction-related changes in agricultural resources and their reported effects on agricultural and allied livelihood activities.

METHODS AND TECHNIQUES

The study adopted a cross-sectional descriptive and analytical research design to examine the implications of sand extraction for agriculture and allied rural livelihood activities in Karnataka. The study covered four river basins, namely Krishna, Tungabhadra, Uttara Pinakini and Shimsha, and included farming communities residing in villages located adjacent to the respective river basins. A total of 400 farmers, comprising 100 respondents from each river basin, were selected from eight Gram Panchayats, with two Gram Panchayats selected from each basin. Convenience sampling was employed for the selection of respondents. Farmers who had been engaged in agricultural activities for more than five years were included, along with respondents involved in allied activities such as animal husbandry, dairy farming, poultry and fishery, as well as farmer-cum-agricultural labourers.

Primary data were collected using a self-structured interview schedule administered through face-to-face interviews with farmers. The schedule was designed to capture farmers' experiences and perceptions of the impacts of sand extraction on agricultural productivity, animal husbandry, groundwater availability, and water quality, particularly contamination arising from sand-filtering activities. The data obtained were systematically coded, classified, and analyzed using appropriate descriptive and inferential statistical techniques to examine the nature and extent of these impacts.

Pearson's Chi-square (χ^2) test of independence was used to examine the statistical associations between selected sand-extraction-related conditions and reported agricultural and allied rural livelihood outcomes. Cramér's V was calculated to assess the strength of the observed associations. Statistical significance was set at $p < 0.05$. Given the cross-sectional study design and use of convenience sampling, the findings are interpreted as reported experiences and statistical associations rather than evidence of causal relationships. Furthermore, measures relating to soil fertility, groundwater availability and agricultural productivity are based on farmers' reported experiences and perceptions and do not represent direct physical, hydrogeological or laboratory measurements.

Results

The results are organised around four research hypotheses examining the association between sand mining and groundwater conditions, cultivation, local vegetation and animal husbandry. Pearson's Chi-square test was employed to assess the statistical significance of these associations at the 5% significance level. The results of the respective statistical tests are presented below.

Hypothesis – 1: Sand Mining and Groundwater

H_0: Sand mining has no direct impact on groundwater in its vicinity.

H_1: Sand mining has a direct impact on groundwater in its vicinity.

To empirically examine the hypothesis concerning the association between sand mining and groundwater-related conditions, Pearson's Chi-square test of independence was employed to assess the statistical significance of the relationship between sand mining and three selected groundwater-related indicators: (i) reduction in the water-storage capacity of water bodies associated with sand mining and sand-filtering activities; (ii) disruption of groundwater recharge mechanisms; and (iii) groundwater depletion attributed to sand mining. The analysis was undertaken with due consideration of variations in prevailing irrigation practices across the four river basins included in the study. The findings of the statistical analysis are presented in Table 1.

Table 1. Statistical Association between Sand Mining and Groundwater-Related Conditions

Groundwater-related indicator	Pearson χ^2	df	p-value	Decision
Shrinkage of water-storage capacity due to sand mining/filtering	137.081	9	<0.001	Reject H_0
Disruption of groundwater recharge mechanism	16.366	6	0.012	Reject H_0
Sand mining as a reason for groundwater depletion	5.483	6	0.484	Fail to reject H_0

Note: N = 400. Pearson's Chi-square test was applied at a significance level of $p < 0.05$.

A highly significant association was observed between sand mining and the reported shrinkage of water-storage capacity in water bodies ($\chi^2 = 137.081$, df = 9, $p < 0.001$), leading to rejection of the null hypothesis for this indicator. A statistically significant association was also observed between sand mining/sand-filtering activities and reported disruption of groundwater recharge mechanisms ($\chi^2 = 16.366$, df = 6, $p = 0.012$), indicating that the distribution of respondents' reports of recharge disruption differed significantly according to their reported experience of sand-mining-related activities.

In contrast, the association between sand mining and reported groundwater depletion was not statistically significant ($\chi^2 = 5.483$, df = 6, $p = 0.484$). Accordingly, the null hypothesis could not be rejected at the 5% significance level. This result should be interpreted specifically as a lack of sufficient statistical evidence, in the present sample, to establish an association between sand mining and reported groundwater depletion. It does not demonstrate that groundwater depletion does not occur or that sand mining has no effect on groundwater systems.

The non-significant result may partly reflect differences in irrigation and groundwater dependence across the four study basins. Farmers in the Krishna and Tungabhadra basins included in the study predominantly depend on canal irrigation, whereas groundwater sources are relatively more important for agricultural activities in the Shimsha and Uttara Pinakini basins. Consequently, groundwater depletion may be less directly experienced or perceived as an agricultural constraint in the canal-irrigated settings. When the four basins are considered together, such differences in exposure and dependence may reduce the consistency of the observed association and contribute to the non-significant chi-square result.

The distinction between recharge disruption and groundwater depletion is also important. A reported disruption in recharge represents a change in the process through which water enters and replenishes groundwater systems, whereas groundwater depletion reflects a reduction in the quantity of groundwater available over time. The former may occur without producing an immediately detectable or uniformly reported decline in groundwater levels because groundwater conditions are also influenced by rainfall, aquifer characteristics, abstraction rates, recharge from other sources and irrigation practices. Therefore, the present results suggest a statistically detectable association between sand-mining-related conditions and perceived recharge disruption, but insufficient evidence to establish a corresponding association with reported groundwater depletion across the combined sample.

Hypothesis 2: Sand Mining and Cultivation

H_0: Sand mining has no significant impact on cultivation.

H_1: Sand mining has a significant impact on cultivation.

To test the hypothesis, the associations between perceived soil-fertility loss due to sand mining and two cultivation-related factors such as dust generated during sand transportation and contaminated water affecting crop yields, were examined using Pearson's Chi-square test.

Table 2. Association between Sand Mining and Cultivation

Cultivation-related indicators	χ^2	df	p-value	Decision
Dust from sand transportation affecting crops/yields	135.579	8	<0.001	Reject H_0
Contaminated water affecting crop yields	111.816	6	<0.001	Reject H_0

Note: N = 400; significance level = $p < 0.05$.

The results demonstrate a highly significant association between perceived soil-fertility loss and the adverse effects of dust generated during sand transportation on crops and yields ($\chi^2 = 135.579$, df = 8, $p < 0.001$). A similarly significant association was observed between perceived soil-fertility loss and the adverse effects of contaminated water on crop yields ($\chi^2 = 111.816$, df = 6, $p < 0.001$). Thus, both relationships are statistically significant and provide evidence of an association between sand-mining-related activities and cultivation outcomes.

Collectively, the results suggest that the agricultural consequences of sand mining are experienced through multiple pathways, particularly dust exposure and water contamination, alongside perceived deterioration of soil fertility. Accordingly, H_0 is rejected and H_1 is supported for the relationships examined. However, because the study is cross-sectional and based on farmers' reported experiences, the findings demonstrate statistical associations rather than direct causal effects.

Hypothesis 3: Sand Mining and Local Vegetation

H_0: There is no significant association between sand mining and local vegetation.

H_1: There is a significant association between sand mining and local vegetation.

The relationship between sand mining and local vegetation was examined using five indicators: (i) soil erosion, (ii) loss of natural vegetation, (iii) damage to local biodiversity, (iv) impacts on *Rajakaluve* and feeder channels, and (v) drying of open wells previously used for irrigation. Pearson's chi-square test was used to assess the statistical association between respondents' perceptions of these environmental changes and the reported disappearance of natural vegetation.

Table 3. Chi-Square Test of Association between Sand Mining and Local Vegetation

Indicator	Pearson χ^2	df	p-value	Interpretation
Sand mining causes soil erosion	167.714	6	<0.001	Significant association
Sand mining causes severe damage to local biodiversity	144.920	6	<0.001	Significant association
Sand mining/filtering impacts *Rajakaluve* and feeder channels	33.082	9	<0.001	Significant association
Water capacity in water bodies shrinks due to sand mining/filtering	26.597	9	0.002	Significant association
Sand mining causes dryness of previously used open wells	7.687	6	0.262	Not statistically significant

Note: N = 400; significance level = $p < 0.05$.

The association between sand mining and local vegetation was assessed using five indicators. Significant associations were observed for soil erosion ($\chi^2 = 167.714$, df = 6, $p < 0.001$), damage to local biodiversity ($\chi^2 = 144.920$, df = 6, $p < 0.001$), impacts on *Gomala* and feeder channels ($\chi^2 = 33.082$, df = 9, $p < 0.001$), and shrinking water-storage capacity of water bodies ($\chi^2 = 26.597$, df = 9, $p = 0.002$). These results indicate that respondents reporting greater environmental changes associated with sand mining were also more likely to report the disappearance of natural vegetation. The statistically significant associations across these four indicators suggest that vegetation loss is related to multiple interconnected environmental conditions, rather than to a single pathway.

In contrast, the association between the drying of open wells previously used for irrigation and vegetation loss was not statistically significant ($\chi^2 = 7.687$, df = 6, $p = 0.262$). Since the p-value exceeds the 0.05 significance level, the null hypothesis cannot be rejected for this indicator. Thus, the present analysis does not provide sufficient statistical evidence to establish an association between reported open-well drying and reported vegetation loss in the combined sample. However, this non-significant result should not be interpreted as evidence that open-well drying has no relationship with vegetation loss. It indicates only that the observed association was not sufficiently strong or consistent across the study sample to reach statistical significance.

The non-significant finding may partly be explained by differences in irrigation practices across the four river basins. Open-well irrigation was reported in the Shimsha and Uttara Pinakini river basins, whereas it was not reported in the Krishna and Tungabhadra river basins, where farmers predominantly depended on canal irrigation. Consequently, the drying of open wells was a directly relevant experience for farmers in the Shimsha and Uttara Pinakini basins, while farmers in the Krishna and Tungabhadra basins had limited direct exposure to open-well irrigation and therefore limited familiarity with the drying of open wells as an agricultural water-related indicator. Because the chi-square analysis combined respondents from all four river basins, this variation in exposure, dependence and relevance of open wells may have reduced the consistency of the association between open-well drying and vegetation loss in the pooled sample.

Notably, four of the five indicators demonstrated statistically significant associations with local vegetation, providing support for H_1. The findings suggest that sand mining and associated sand-filtering activities are associated with vegetation degradation through interconnected pathways involving soil erosion, biodiversity loss, disturbance of Rajakaluve and feeder channels, and reduction in water-storage capacity. The stronger and statistically significant associations observed for these indicators may reflect their broader relevance across the study river basins compared with open-well drying, which was dependent on the local irrigation context. Nevertheless, given the cross-sectional design and reliance on respondent-reported information, these findings should be interpreted as statistical associations rather than evidence of direct causal relationships.

Hypothesis 4: Sand Mining and Animal Husbandry

H_0: Sand mining has no significant association with animal husbandry activities.

H_1: Sand mining has a significant association with animal husbandry activities.

The association between sand mining and animal husbandry was assessed using four indicators: availability of grazing land, loss of local vegetation, increasing costs of animal husbandry, and spatial restrictions on livestock-rearing activities. Pearson's chi-square test showed statistically significant associations for all four indicators ($p < 0.001$).

Table 4. Statistical Association between Sand Mining and Animal Husbandry

Indicator	χ^2	df	p-value
Reduced space for animal grazing	130.115	9	<0.001
Loss of local vegetation affecting livestock	80.989	9	<0.001
Reduction/encroachment of common grazing land increasing husbandry costs	104.855	9	<0.001

Note: N = 400; significance level = $p < 0.05$.

The strongest association was observed between reduced grazing space and perceived effects on animal husbandry (χ^2 = 130.115, df = 9, $p < 0.001$). Significant associations were also found between vegetation loss and livestock impacts (χ^2 = 80.989, df = 9, $p < 0.001$), reduction in common grazing land and increased husbandry costs (χ^2 = 104.855, df = 9, $p < 0.001$), and restrictions on animal husbandry and perceived sand-mining impacts (χ^2 = 75.989, df = 9, $p < 0.001$).

Collectively, all three indicators were significantly associated with animal husbandry, providing support for H_1 and leading to rejection of H_0 at the 5% significance level. The findings indicate that sand mining and associated sand-filtering activities are linked to animal-husbandry constraints primarily through loss of grazing space and vegetation, increased livestock-rearing costs, and reduced access to grazing resources. Given the cross-sectional design and reliance on respondents' perceptions, these results indicate statistical associations rather than causal effects.

DISCUSSION

The hypothesis-testing findings indicate that sand extraction is associated with multiple and interconnected dimensions of rural livelihoods. Rather than being confined to extraction sites, the reported effects extend across crop cultivation, soil and water resources, vegetation, grazing areas and animal husbandry. This multidimensional pattern is consistent with previous research identifying sand extraction as a socio-ecological pressure affecting land, water, ecosystems and livelihood systems simultaneously (Rentier & Cammeraat, 2022; Hemmler et al., 2024).

Sand extraction and associated transportation activities may influence crop-related conditions through several environmental pathways. Dust generated by sand-carrying vehicles and contaminated water were significantly associated with reported impacts on cultivation. Repeated movement of sand-laden vehicles along rural roads may deposit dust on adjoining fields, while disturbance of sediment and water systems may alter local environmental conditions. Similar evidence from sand-mining areas around Accra documents crop destruction, soil degradation, water-related problems and dust deposition affecting cultivated areas (Hemmler et al., 2024). This pathway is particularly relevant to the present study because fields in northern Karnataka may be located along routes used for sand transportation, including areas cultivating cotton and chilli. Dust deposition on leaves and flowers may interfere with pollinator activity and potentially affect crop productivity. In southern Karnataka, the implications may extend to sericulture, where mulberry leaves constitute the principal feed for silkworms. Dust deposition on mulberry foliage may reduce its suitability as feed and potentially affect silkworm growth and cocoon production. These observations suggest that transportation networks may extend the influence of sand mining well beyond immediate extraction locations.

The findings concerning water resources indicate associations between sand extraction, reduced water-storage capacity and disruption of groundwater recharge mechanism, although the relationship with reported groundwater depletion was not statistically significant. Earlier research in the Uttara Pinakini basin reported that excessive sand extraction affected irrigation wells and groundwater recharge, with implications for farming and irrigation costs (Hemalatha et al., 2005). The present findings similarly highlight the importance of sand-bearing river systems and associated water bodies within local resource systems. However, variation across river basins suggests that these effects are strongly influenced by local irrigation contexts. Traditional tank and lake irrigation has historically been important in the Shimsha and Uttara Pinakini basins, where greater dependence on local water bodies may make farmers more directly exposed to reductions in storage capacity. In contrast, communities in the Krishna and Tungabhadra basins included in the study predominantly depend on canal irrigation, which may reduce their immediate dependence on traditional tanks and lakes and consequently their recognition of changes in storage capacity. Similar differences may explain variation in reported groundwater impacts. Farmers in the Shimsha and Uttara Pinakini basins reported greater dependence on open wells and tube wells and were therefore more directly exposed to changes in groundwater availability, whereas greater dependence on canal irrigation in the Krishna and Tungabhadra basins may reduce immediate exposure to groundwater fluctuations.

The findings further demonstrate associations between sand-extraction-related environmental changes and reported vegetation loss. Farmers identified soil erosion, biodiversity loss, disturbance of *Rajakaluve* and feeder channels, and reduced water-body capacity as important conditions associated with vegetation degradation. These processes are ecologically interconnected because vegetation persistence depends on soil stability, moisture availability and functioning drainage and water systems. Evidence from sand-mining communities in Ghana similarly documents loss of trees and natural vegetation, wildlife habitat and cattle-grazing areas (Hemmler et al., 2024). The present findings therefore suggest that vegetation degradation represents not only an ecological concern but also a reduction in resources available for farming and livestock activities.

The implications for animal husbandry are particularly important in light of Karnataka-specific evidence. Reddy, G. N. and Lokesha, M. U. (2022), in their study of the Chitravathi River Basin in Chikkaballapur district, found that sand mining and associated sand-filtering activities were linked to substantial reduction in natural vegetation and common grazing areas. Their study documented the use of *Gomala* lands, river and lake beds, Rajakaluve and feeder channels as common spaces for livestock grazing and watering, and reported that degradation and encroachment of these resources restricted animal-husbandry activities and increased the cost of livestock maintenance. Only households with access to irrigation for fodder cultivation were reported to have greater capacity to sustain dairy activities. The present findings complement this evidence by demonstrating similar associations between reduced grazing space, vegetation loss, common-grazing-land constraints and animal-husbandry outcomes across a broader multi-basin context. Thus, the Chitravathi study provides a particularly relevant local explanation of how sand mining and sand filtering can translate environmental disturbance into livelihood constraints.

The loss of common grazing resources can increase dependence on purchased fodder and other inputs, potentially raising maintenance costs. This livelihood pathway is also consistent with international evidence showing that sand mining can reduce access to productive land and natural resources and consequently affect household income and livelihood security (Asare et al., 2024; Hemmler et al., 2024). The implications are particularly relevant in mixed farming systems, where crop cultivation, livestock rearing, dairy farming, sericulture and other allied activities collectively contribute to household income, food security and livelihood diversification. A decline in grazing land, vegetation or water availability may therefore influence several components of household livelihoods simultaneously.

The findings support a cascading interpretation in which disturbance associated with sand extraction may alter soil and water conditions, contribute to vegetation degradation, reduce access to grazing resources and increase constraints on livestock production. Agriculture, water resources, vegetation and animal husbandry should consequently be understood as interconnected elements of rural livelihood systems rather than as independent environmental outcomes. This interpretation is consistent with Rentier and Cammeraat (2022), who emphasized the interconnected environmental consequences of river sand mining, and with the Karnataka-specific evidence of Reddy and Lakesha (2022), which demonstrates how degradation of common-property resources can directly affect livestock-based livelihoods.

Overall, the findings extend the understanding of sand-extraction impacts from physical environmental degradation to broader livelihood vulnerability. The expression of these effects varies according to local ecological conditions, irrigation systems and communities' dependence on particular natural resources. This contextual variation is important because similar extraction activities may produce different livelihood consequences across river basins depending on the availability of alternative water sources, the role of common-property resources and the structure of local production systems. The present study therefore contributes to the literature by connecting farmer-reported resource changes across multiple river-basin contexts with their implications for crop cultivation and allied livelihood activities.

The findings should, however, be interpreted within the methodological limitations of the study. The cross-sectional design, convenience sampling and reliance on farmers' reported experiences permit identification of statistical associations and perceived environmental and livelihood changes but do not establish definitive causal relationships. In particular, reported groundwater depletion and recharge-related changes would require hydrogeological measurements and longitudinal monitoring for causal confirmation. Similarly, the potential effects of dust deposition on crop productivity and sericulture require direct agronomic and biological measurements to establish their magnitude. Nevertheless, the consistency of reported changes across interconnected resource domains provides important empirical evidence for understanding the livelihood dimensions of sand extraction and supports the need for stronger environmental regulation and livelihood-oriented management in Karnataka.

CONCLUSION

The findings establish that the consequences of sand extraction extend beyond riverine ecosystems to agricultural land, soil fertility, groundwater resources, natural vegetation, common grazing spaces, animal husbandry and rural livelihoods. The study highlights the interconnected nature of these environmental and socioeconomic impacts, demonstrating that sand mining is not merely a resource-extraction activity but also a significant concern for environmental sustainability and rural livelihood security. The observed statistical associations between sand-mining-related activities and selected agricultural and ecological indicators underscore the need to integrate ecological conservation, agricultural protection and livelihood considerations into sand-resource governance.

The protection of agricultural land should be a priority in regulating sand-related activities. Sand extraction, dumping and storage on fertile Patta/agricultural lands should be strictly prohibited to prevent the degradation and loss of cultivable land, deterioration of soil fertility and potential threats to long-term food security. Similarly, appropriate buffer zones should be established around cultivated areas to minimise dust deposition on crops and reduce potential interference with plant growth, pollinator activity and pollination efficiency. Unscientific and excessive extraction from riverbeds, streams and lake beds must be strictly regulated, particularly in ecologically sensitive locations. Extraction permissions should be guided by scientific assessments of sediment replenishment, river morphology, groundwater recharge and biodiversity. Where environmentally suitable, regulated harvesting from replenishable non-riverbed sources may be explored as an alternative, subject to statutory clearances and periodic environmental assessments.

Strengthening regulatory enforcement is equally important to address unauthorised extraction and transportation. Systematic surveillance of sand-carrying vehicles, supported by GIS-based mapping, GPS-enabled tracking and digital transit permits, would facilitate the monitoring of sand movement from extraction sites to designated construction destinations. Such mechanisms can improve traceability, strengthen institutional accountability and facilitate timely intervention against illegal mining. At the local level, vigilance committees should be established under Gram Panchayats, or appropriate monitoring and reporting responsibilities should be assigned to existing Biodiversity Management Committees (BMCs), consistent with their statutory mandate. Meaningful participation of farmers, livestock rearers and local communities can further strengthen environmental monitoring and community-based resource governance.

Additionally, political interference and vested interests in sand-mining operations must be addressed through transparent licensing procedures, independent environmental assessments and impartial enforcement of statutory provisions. Public disclosure of mining permissions, authorised extraction quantities and transportation records, together with periodic compliance audits, would improve transparency and reduce opportunities for regulatory violations. Environmental restoration should also constitute an integral component of sand-mining governance, with particular emphasis on rehabilitating degraded vegetation, common grazing lands, traditional water bodies and damaged drainage channels. Such interventions are essential to protect the natural resource base supporting agricultural production and livestock-dependent livelihoods.

Overall, sustainable sand-resource management requires a transition from extraction-centred regulation towards an integrated framework combining scientific resource assessment, ecological restoration, technological monitoring, institutional accountability and community participation. Ensuring that economic demands for construction materials do not compromise environmental integrity, agricultural sustainability and rural livelihood security is fundamental to achieving equitable and ecologically responsible resource governance.

REFERENCES:

[1] Asare, K. Y., Mensah, J. V., Boateng, J. A., Tenkorang, E. Y., & Hemmler, K. (2024). Economic and socio-ecological effects of sand mining on livelihoods in the Gomoa East District and Ga South Municipality, Ghana. The Extractive Industries and Society, 19, 101487. https://doi.org/10.1016/j.exis.2024.101487

[2] Dar, S. A., Ganie, D. H., Teeli, J. I., & Bhat, S. U. (2023). A policy approach for sustainable governance of sand mining activities in NW Kashmir Himalayas. The Extractive Industries and Society, 13, 101204. https://doi.org/10.1016/j.exis.2022.101204.

[3] Dujardin, E., Vercruysse, K., Cohen, S., Poesen, J., & Vanmaercke, M. (2024). Mapping and modeling riverine sand and gravel mining at the sub-continental scale: A case study for India. Science of the Total Environment, 912, 169200. https://doi.org/10.1016/j.scitotenv.2023.169200

[4] Hegde, R., Kumar, R. S. C., Anil Kumar, K. S., & Srinivas, S. (2008). Sand extraction from agricultural fields around Bangalore: Ecological disaster or economic boon? Current Science, 95(2), 243–248.

[5] Hemalatha, A. C., Chandrakanth, M. G., & Nagaraj, N. (2005). Effect of sand mining on groundwater depletion in Karnataka. V International R&D Conference of the Central Board of Irrigation and Power, Bangalore.

[6] Hemalatha, A. C., Chandrakanth, M. G., & Nagaraj, N. (2005). Effect of sand mining on groundwater depletion in Karnataka. Conference Paper, University of Agricultural Sciences, Bangalore, 1–15. https://doi.org/10.22004/ag.econ.43619

[7] Hemmler, K. S., Asare, K. Y., Tenkorang, E. Y., et al. (2024). Sand mining deteriorates soil fertility and farming livelihoods around Accra, Ghana. Scientific Reports, 14, 17063. https://doi.org/10.1038/s41598-024-66656-z.

[8] Matovu, B., Brouwer, F., Bleischwitz, R., Aljanabi, F., & Alkoyak-Yildiz, M. (2023). Resource nexus perspectives in the Blue Economy of India: The case of sand mining in Kerala. Environmental Science & Policy, 151, 103617. https://doi.org/10.1016/j.envsci.2023.103617.

[9] Mines and Minerals (Development and Regulation) Act, 1957, Section 3(e), Government of India.

[10] Reddy, G. N., & Lokesh, M. U. (2022). An explanatory study on sand mining at Chitravathi River Basin and its impact on animal husbandry. Journal of the Oriental Institute, 71(2), 58–63.

[11] Rentier, E. S., & Cammeraat, L. H. (2022). The environmental impacts of river sand mining. Science of the Total Environment, 838, 155877. https://doi.org/10.1016/j.scitotenv.2022.155877.

[12] UNEP. (2022). Sand and Sustainability: 10 Strategic Recommendations to Avert a Crisis. United Nations Environment Programme.

[13] United Nations Environment Programme (UNEP). (2022). Sand and Sustainability: 10 Strategic Recommendations to Avert a Crisis. Nairobi: United Nations Environment Programme.