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ORIGINAL RESEARCH ARTICLE

Gravel and River sand mining activities in Maroua (Far-North Region, Cameroon): Environmental and Socioeconomic aspects

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ABSTRACT

Sand and gravel mining are amongst the main factors that induces significant impacts on environment, as a result of growing need for building materials and as a source of income for rural communities. This study was conducted to assess the socio-economic and environmental effects of these activities in Maroua, Cameroon. Its objectives include a description of artisanal mining method and identification of its socio-economic and environmental impacts. The study was conducted in a multidisciplinary approach. During the fieldwork, data were collected using questionnaires and focused group discussions were undertaken with those responsible for managing natural resources in the that area. The results reveal that sand mining activity alter river morphology at a faster rate than normal river process, where river reduction of the extraction areas is significantly larger. These activities were responsible for quick resource depletion and adversely affecting the environment and causing disturbances such as, ecological balance, soil degradation, pollution, infrastructure destruction, as well as conflict between miners and communities. Despite the negative impacts, mining activities generate income for all parties involved in the value chain, including the government. Accordingly, based on the research results, there are concerns about sustainable extraction practices by implementing strict rules and government policies.

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INTRODUCTION

Compared to other natural resources, sand and gravel are the most mined materials on Earth for direct application (Bendixen *et al.*, 2021; Malathy *et al.*, 2022; Mao *et al.*, 2022). They are essential in building, infrastructure development, recreation, water filtration, and numerous manufacturing and industrial activities (Lekomo *et al.*, 2021; Malathy *et al.*, 2022). In industrial sector, sand is a primary component in the production of glass, and manufacturing silicon chips manufacturing used in electronics. Due to its excellent heat conductivity, foundry sand is a premium natural silica sand used to create metal casting molds (Malathy *et al.*, 2022). In addition, products of industrial sand are versatile: computer and TV screens, fiber optics, fiberglass insulation, toothpaste, pigments in paints and sealants, in weather-resistant caulking, golf-course sand traps, and many more. The demand for these materials has been steadily increasing, driven by population growth, urbanization, and economic development, particularly in emerging developing countries (Hackney *et al.*, 2020; Kagonbé *et al.*, 2020). With economic growth, the rate of their extraction has gone up threefold during the last 20 years (Xiao *et al.*, 2022). Generally,

the exploitation of these materials depends on several parameters, notably the geology, geomorphology, technical measures, and existing legislation in the area. The extraction of sand and gravel is prevalent at various scales throughout in both industrialized and developing nations.

However, in Cameroon, gravel and sand is obtained from crushing natural rocks and from riverbed, respectively. Rapid urbanization is a significant driver of demand for these materials, leading to unsustainable extraction from mining sites in many emerging and developing countries, particularly in Cameroon (UN Environment, 2022; Pilkey *et al.*, 2022). In the northern region of Cameroon, their mining involves multiple actors, including truck owners, drivers, loaders, contractors, and individuals. (Kagonbé *et al.*, 2020). Unfortunately, these mining activities are being conducted without any regulation or control. This exploitation has been carried out, and often still is, using outdated methods and basic tools (Bhattacharya *et al.*, 2019; Kagonbé *et al.*, 2020; Lekomo *et al.*, 2021) and their exploitation poses enormous environmental and social problems. These environmental effects are perceptible in soil, water, air, and the overall environmental balance, on which human life depends. However, it is worth noting that the effects of these activities are not only negative; they also have positive impacts on the economy and quality of life of the people. The objective of this present investigation is to assess the socio-economic and environmental impacts of river sand and gravel mining in Maroua. The result of this research would help policymakers and researchers identify potential area for intervention as well.

MATERIALS AND METHODS

Description of study area

The study was conducted in the Far North region of Cameroon, specifically in Diamaré division (Figure 1). The local climate is sudano-sahelian, with a long dry season, that extends from October to May and a short-wet season that extends from June to September (Figure 2). Rainfall vary between 700 and 900 mm/year and the atmospheric temperature is situated between 28 and 45°C (Figure 2). The hydrography is consisted of two sub-basins: *Mayo* Kaliao and *Mayo* Tsanaga (Figure 2), which are tributaries of the larger Lake Chad basin. The relief consists of two geomorphological units: hills, specifically inselbergs, and plains (Kagonbé *et al.*, 2023). Several major soil types can be distinguished, including vertisols with hydromorphic characteristics, often associated with lithosols, holomorphic, tropical ferruginous soils, and alluvial deposits (Kagonbé *et al.*, 2023). The basement consists of massive garnet-rich micaschist and volcanic rocks that have been affected by tectonics and are partly covered by recent quaternary sediments (Gountié *et al.*, 2022).

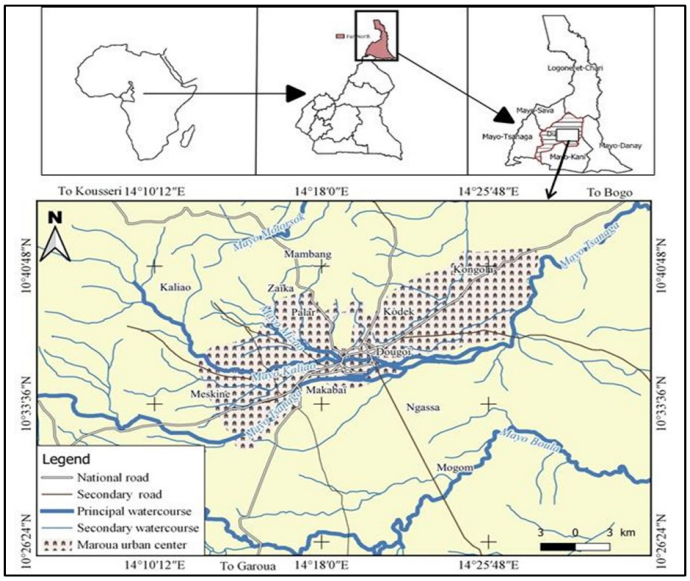

Figure 1. *Location of the study area.*

Methodology and data analyses

For this study, we conducted bibliographical, field, and laboratory research at various extraction sites. Initially, we conducted a literature review of books, journals, and reports focused on the environmental impacts of sand and gravel mining activities and their relation to sustainable development. This study has identified the limitations of previous research and established the scope of the current work, including the study area. Fieldwork was conducted during the rainy season (August-September 2023) and dry season (January-March 2023). After fieldwork, 10 gravel sites and river sand mining sites were chosen to conduct this research. Data collection was done through observation and interviews. The local population from the mining sites were questionnaire regarding the past and the present environmental effects on their lives. Furthermore, this phase was followed by observations and descriptions of the vegetation cover, soil degradation, distance from homes or structures, depth and scale of mining, presence of litter, and the presence of animals. Photographs were also taken to demonstrate the impacts of gravel and sand mining. GPS coordinates were used to record the locations of the watercourses and gravel sites that were surveyed. Then, the laboratory work was done by creating maps that display the location of the study area and the various watercourses. The software used for this task included QGIS and Google Earth.

RESULTS AND DISCUSSION

Description of river sand and gravel mining activities in Maroua

River sand is manly mined from the Tsanaga and Kaliao rivers that run through the town (Figure 2). More mining sites are located just from the urban centre and is a more organized process (Figure 3). Sand is extracted directly from the riverbed by the worker. The means of conveyance of the site determine whether the sand is mined simply. They include the use of trolley, bicycle, motorbike, tricycle, and trucks. However, the means of conveyance depends on the locality and accessibility of the mining site. The purchase price depends on the size of the conveyance vessel and the season (Table 1). These prices increase drastically during the rainy season (Table 1). The increase in prices is due to waterways being flooded and roads becoming difficult to access during the rainy season. Other factors, such as delivery distance and quantity requested, can

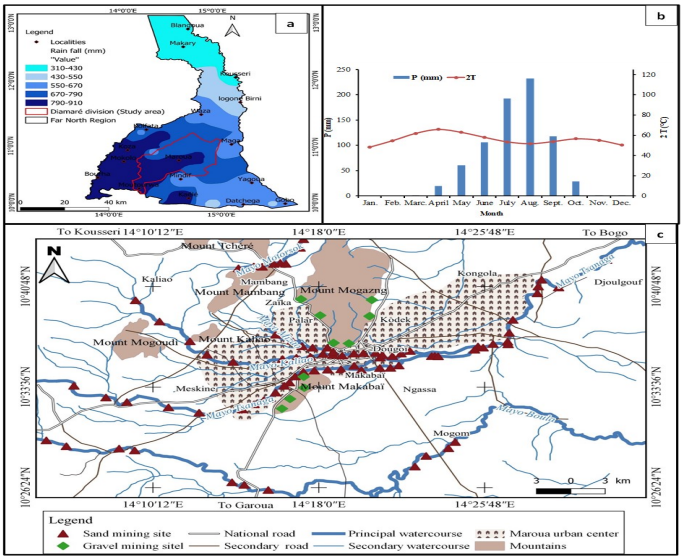

Figure 2. *a) Rainfall distribution map, b) Ombrothermal diagram (mean annual rainfall data of Far North Region, 2002-2012) and c) Spatial distributions of sand and gravel mining sites.*

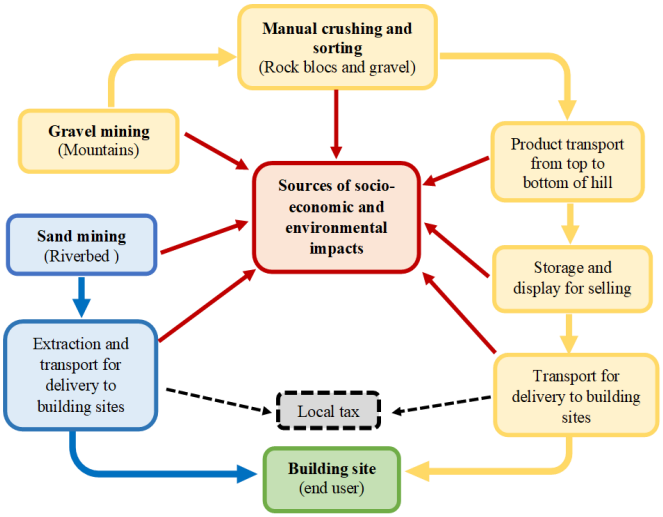

Figure 3. *River sand and gravel mining supply chain in the study area.*

also influence the purchase price. The further the delivery point is from the extraction site, the more the price tends to increase slightly. Conversely, the greater the quantity required, the lower the price may be.

Gravel is extracted from the sides of the mountain, commonly referred to as *Hosseré* (hill in the local language), depending on the size of the outcrop being mined (Figure 3). The process consists of four main stages. Firstly, the rock on the mountain is broken using a sledgehammer or crowbar, which produces large rock blocks of various sizes. The second stage entails transporting the rock blocks from the top of the hill to the bottom, where they are sorted and crushed. Transportation is done by carrying the blocks on the head using old cans cut in halves or by simply stacking those on top of each other. The third stage involves manual crushing using small hammers or home-made tools. The final stage involves storing the gravel obtained in 50 kg bags or creating piles along the road for sale. Unlike the purchase price of sand, which varies with the season, the purchase price of gravel remains relatively constant throughout the year (Table 1).

Impacts of river sand and gravel mining activities in study area

Impact on environment: River sand and gravel extraction can have serious environmental impacts in the end, depending on the geomorphic or geologic setting. The severity of these impacts is determined by the rate, methods, and execution of the extraction process (Doloksaribu *et al.*, 2020; Koehnken *et al.*, 2020; Rentier and Cammeraat, 2022). Table 2 below and Figure 4 lists the identified environmental impacts associated with the sand and gravel mining activities in Maroua. It is clear that sand mining operation can have direct impacts on the environment, causing ecosystem damage and indirect impacts, affecting channel morphology, which in turn affects the distribution of habitats and ecosystem functioning (Bhattacharya *et al.*, 2019; Arsyad *et al.*, 2020; Talukdar and Das, 2020; Rentier and Cammeraat, 2022). This can lead to deterioration in the quality of the riverine environment (Zou *et al.*, 2019; Arsyad *et al.*, 2020; Bhattacharya *et al.*, 2020; Talukdar and Das, 2020). Additionally, many recent researches have shown that stagnant water collects in ponds after sand excavation, creates breeding grounds for mosquitoes and other disease-causing organisms (Shin *et al.*, 2020; Adza *et al.*, 2022; Zou *et al.*, 2019; Rangel-Buitrago *et al.*, 2022; Adza *et al.*, 2022). Furthermore, non-biodegradable plastic waste, such as packages of adulterated whisky, bottles, fragments of nylon fabric, leather goods, and pieces of metal from damaged equipment, is often left on-site during the extraction phase (Kagonbé *et al.*, 2023). These wastes have a long-term persistence in ecosystems, as they are not readily biodegradable (Kagonbé *et al.*, 2023). Sedimentation covers riverbed environments, restricts light penetration, and impairs the survival of aquatic organisms. This work identified some of the most common environmental problems experienced on the site: damage to air and soil quality caused by fuel, exhaust fumes, soil compaction, and destruction of the road due to truck traffic (Table 2). Some researchers have also stated that the physical impacts of sand mining, such as water quality degradation, destabilization of channel and riverbanks. The findings of this study, as well as those of Adza *et al.* (2022) and Edokpolo *et al.* (2019) indicate that decreased air quality has serious negative impacts on plants and humans.

Impacts on local communities: Illegal sand mining along riverbeds and in mountainous areas has far-reaching impacts on society, creating disturbances in the lives and livelihoods of local populations, particularly those living near riverbanks. However, when handicraft workers interrogated on about the relationship between their activities and social problems, they reported no socially related issues in Maroua. The interaction between sand and gravel mining operations, citizen neighbours, and the government has become more confrontational due to the increased excavation of these materials. Conflicts have centred on environmental and social issues, such as noise, truck traffic, dust, stream water quality, reclamation, biodegradation, pollution, and visually unpleasant landscapes. The dust generated during sand and gravel transportation causes poor

Table 1. Variation price of sand in Maroua with a season (Data compilation 2022-2023).

Means of conveyance		Trolley	Bicycle	Motorcycle	Tricycle	Trucks	Trucks 20tone
Price of sand during à dry season	FCFA	600	200-300	800-1000	1200-1500	10000-12000	25000-30000
	EUR	0.92	0.31-0.46	1.23-1.54	1.84-2.31	15.37-18.45	38.44-61.50
The price of sand during a rainy season	FCFA	1000	400-600	1500-1700	2500-3000	12000-15000	35000-40000
	EUR	1.54	0.61-0.92	2.31-2.61	3.84-4.61	18.45-23.06	53.81-60.50
The price of gravel during a throughout the year	FCFA	//	//	1000-1500	12000-14000	60000-70000	120000-150000
	EUR	//	//	1.54-2.31	18.42-23.03	92.10-107.45	184.20-230.25

Table 2. Summary of the potential impacts of sand and gravel mining activities (Data compilation).

Activities	Sources of impacts	Component of the environment affected	Potential impacts
Sand mining activities	Extraction	Landscape	Increase erosion
			Destruction of habitation
			Impact on riverine vegetation
			Waste generation
		River systems	Riverbed deepening and widening
			Riverbed bank and slop instability
			Modifications in channel morphology
			Impact on groundwater and surface drainage
		Socioeconomic	Increase in alcohol consumption and conflicts among workers
			Risk of work-related accidents
			Delinquency and precocious abandon of studies
			Employment creation and profitability
			Secondary business opportunities
			Corruption and human exploitation
	Transport for building site	Atmosphere/Soil/ air quality	Dust pollution
			Air pollution resulting from CO_2 emissions by trucks
			Trucks that collect this sand cause serious soil compaction
			Noise and vibration
Gravel mining activities	Extraction	Landscape	Landslide
			Falling boulder
			Waste generation
	Transport for building site	Atmosphere/air quality	Dust pollution
			Air pollution resulting from CO_2 emissions by trucks
			Noise and vibration
		Socioeconomic	Increase in alcohol consumption
			Conflicts among workers
			Risk of work-related accidents
			Delinquency and precocious abandon of studies
			Corruption, violence, and human exploitation
			Increase in the number of deaths due to drowning
			Employment creation and profitability
			Development of commercial activities along the villages promotes river sand mining

Figure 4. *Some pictures showing the proximity of mining site in habitation a and b) Bank Erosion of River due to Sand Mining; c) Landslide; d-i) Infrastructures near gravel site mining.*

Table 3. Roles and responsibilities of key ministerial departments related to environment management in Cameroon.

Ministerial department	Key responsibilities related to sustainable environment management	Statutory order
Ministry of Environment and Nature Protection	This is the most powerful ministry with varied responsibilities for environmental protection. Required to collaborate with other agencies to define measures for the rational management of natural resources; Effective control of investigation and pollution in the field; Specify the criteria (project specific) and supervise environmental impact assessments; Negotiate international accords and conventions which are related to environmental protection.	Decree No. 2005/0577/PM of 23/02/05 7], Order No. 006/MINEP of 08/03/05
Ministry of Mines, Industries and Technological Development	Responsible for the elaboration of developmental strategies to govern and control classified establishments or industries	Order No. 006/MINEP of 08/03/05/ Decree No. 99/818/PM of 9/11/99,Order No.13/MINMEE/DMG/SL of 19/04/77, Law02/MINMEE/DMG/SDAMI of 4/01/9
Ministry of Transport	Develop strategies for industrial development and the control of classified and commercial installations for pollution, security, hygiene, and industrial nuisance; define standards for industrial pollution; list of dangerous, obnoxious, and polluting facilities to inform the public; develop regulations governing installation and exploitation of facilities classified as dangerous, obnoxious and polluting. The Ministry of Transport has a department of maritime affairs and navigable ways. Responsible for the protection of the marine, fluvial, and lacustrine environment including routine inspection and location of pollution and taking action against polluters	
Ministry of Territorial Administration and Decentralization	Follow up and implement regulations for the organization and functioning of Councils; Oversees the execution of the budget of the government's council support fund (FEICOM); Restoration of hygiene and public sanitation; supervise urban Councils which are responsible for follow-up and control industrial waste management, management of all public spaces and infrastructure; sweeping of streets, collection, transportation and treatment of household waste	Circular letter No. 0040/LC/MINAT/DCTD of 04/04/00, Order No. 00072/MINAT/MINVILLE of 21/05/00; Law No. 714/23 of 5/12/74; Law no. 2004/18 of 22/07/04
Ministry of Urban Development and Housing	Develop and implement urban restructuring, management strategies, sanitation, and drainage; Define and enforce standards for hygiene/sanitation, collection and/or treatment of household waste; liaise with international agencies for urban development	Order No. 00072/MINAT/MINVILL of 21/05/00
Ministry of Public Health	Creates hygiene and sanitation units in councils; provides technical support to the hygiene and Sanitation Units of Councils; Proposes standards for collection, transportation, and treatment of industrial, and domestic waste and emptying of septic tanks; Designs and implements public education campaigns on hygiene and sanitation	Order No. D67/NS/NN/ST/SG/BMPHP/NNPA of 11/08/87, Circular letter No. D69/N6/DMHK/SHPA of August 1980
Ministry of Finance/Ministry of economy and planification	Financial control of organizations benefiting from supplementary budgets and autonomous public establishments, i.e. Councils; Responsible for managing the Finance Law as enacted by Parliament	Constitution Decree No. 2004/320 of 08/12/04

visibility for other road users, leading to an increased risk of accidents (Edokpolo *et al.*, 2019; Sahu *et al.*, 2020; Ottaviano *et al.*, 2022; Moussa, 2023). Additionally, the dust that rises in the atmosphere can cause serious respiratory diseases among the people in this area (European Environment Agency, 2019; World Health Organization, 2021; Ottaviano *et al.*, 2022), which have resulted in fatalities in Maroua. According to World Health Organization (2021), noise pollution is reported as the third most important environmental pollution in metropolitan. In other parts of the world, studies on noise and air pollution have shown that these exposures can increase the risk of viral infection due to a decreased immune system (European Environment Agency, 2019; World Health Organization, 2021; Ottaviano *et al.*, 2022). A study conducted in New York on the association of noise level and constituent air pollutants showed that the noise threshold limit was exceeded and the constituent air pollutant includes nitrogen oxides and particle pollution (World Health Organization, 2021). World Health Organization (2021) report revealed that individuals involved in mining activities are more susceptible to diseases such as diarrhoea, malaria, tuberculosis, and sexually transmitted infections. Additionally, most of the respondents indicated that sand mining had led to social issues such as drug and substance abuse, criminal activities, school dropout, and violence (Table 2). Rangel-Buitrago *et al.* (2023) have also reported instances of human exploitation, particularly of women and children, which poses a threat to the health and safety of those without access to basic services such as water and sanitation.

Table 4. Key legislative aspects related to pollution due to mining activities in Cameroon.

Legislation	Specific sections related to pollution due to mining activities	Text of Implementation
Law No. 96/12 of 5/08 1996 Law on Environmental Management which sets the legal framework for environmental management in Cameroon including protection of the atmosphere, marine and continental waters, soils and subsoils, and biodiversity	Article 21: Protection of the Atmosphere	Decree N°. 2005/0577/PM of 23/02/05 and Order N°. 006/ MINEP of 08/03/05
	Article 30: Protection of continental waters	None
	Article 31: Protection of coastal and marine waters	None
	Articles 36 and 38: Protection of soils and subsoils	None
	Article 47–53: Waste disposal on land	None
	Article 57: Dangerous waste	None
Law N°. 98/005 of 4/04/1998 The National Water Code institutes a water regime and its enabling instruments which specify the conditions and restrictions concerning the use of water resources for industrial purposes as well as the conditions for the dumping of industrial waste in the aquatic environment	Article 4: Protection of surface and groundwater from industrial pollution	Decree N°. 2001/163/PM of 08/05/01
	Article 5: List of substances whose discharge into surface and groundwater is prohibited	Decree N°. 2001/164/PM of 08/05/01
	Article 6: Anti-pollution measures and devices	None
	Article 7: Watershed Protection	Decree N°. 2001/165/PM of 08/05/01
Law N°. 98/015 of 14 July 1998 The law governing classified and dangerous establishments	Article 3: Categories of classified establishments	Decree N°. 99/818/PM of 09/11/99
	Article 8: Standards of waste emissions from classified establishments	None
Law N°. 001 of 16 April 2003. Institutes the Mining Code	Article 50: Mining waste treatment and pollution prevention	None
	Articles 60 and 75: Environmental management and site rehabilitation	None

Impacts on the local economy: The potential benefits of sand and gravel mining make it an attractive industry that requires the active involvement of the government and local communities for sustainable development. It is noted that many youths' people in the area are unemployed and have turned to sand and gravel mining as a means of earning a living. Some other work (Krausmann *et al*., 2020; Bari *et al*., 2022) also state that these activities are excessively dependent on the economic conditions of local people, mainly poverty and unemployment. The study has revealed that commercial activities in the villages promote sand and gravel mining, generating income for most Indigenous communities. The major driving forces behind sand mining are identified as these two factors. This is supported by the involvement of different age groups, including teenagers, in these activities. The majority of those involved in sand mining are from poor areas with inadequate road networks and substandard housing conditions. The issues faced by these individuals are their physical and financial inabilities to access social services, such as healthcare and education. As a result, they are forced to rely on natural resources for their livelihoods. This reliance leads to interactions with the land, soils, water, forests, wetlands, and other resources, which can have an impact on their well-being and the environment. It is important to note that any actions taken by these individuals can have consequences on the environment. When asked about the importance of sand and gravel mining in their communities, the respondents stated that it serves as a source of income for many in the community and has been referred to as a 'gold mine'. Additionally, the community has been able to build a community hall with the generated income. Finally, sand and gravel mining help to diversify the local economy and provides a source of income and job opportunities for many members of the community.

Measures to combat degradation caused by mining activities in Cameroon

Several Ministerial Departments in Cameroon have mandates to implement pollution management regulations in response to the negative impact of mining activities (Table 3). Various laws and regulations have been reviewed to regulate these activities. Table 4 provides a summary of the key laws related to the management of environmental pollution caused by mining activities in Cameroon. There is currently no coordinated approach to sustainable environmental management due to the numerous Ministerial Departments with varying responsibilities related to this area. However, the legislation and regulatory agenda for pollution resulting from mining activities is unclear and passive, making enforcement complicated. According to Edumebong (2021), these laws are an attempt by the government to enhance its efforts towards achieving sustainable development. Local policies are put in place to restrict unsustainable mining activities, and international policies are crucial. Regarding the Kyoto Protocol on Carbon Emissions Limitation, the International Union of River Sand Resources should limit sand mining in all countries and provide recommendations on river sand trade from a macro perspective (Xiao *et al*., 2022). It is worth noting that developed countries such as the USA and China have shown greater concern for river sand resources than Cameroon.

Conclusion and recommendations

In a nutshell, this study assesses the impacts of gravel and sand mining activities in Maroua metropolis. It is clear that due to the increasing population and growing demand for housing infrastructure in the country, these activities will continue to pose significant social and environmental problems. Sand mining operations affected significantly affect river morphology, which in turn affects the distribution of habitats and ecosystem functioning. Additionally, these activities are a main cause of pollution: the dust generated during transportation causes poor visibility for other road users, leading to an increased risk of accidents; decreased air quality has serious negative impacts on plants and humans. To this end, several management and mitigation strategies can minimize the related impacts identified above, including: Evaluation of the feasibility and sustainability of mining projects before granting permits. Implementation and enforcement of strict environmental regulations related to mining activities. Establishment of penalties for non-compliance and regularly monitor mining operations. Involve local communities in the decision-making process regarding mining activities. Ensuring that communities benefit from mining activities through job opportunities, infrastructure development, and revenue sharing. Mandate mining companies to develop and implement comprehensive mine closure plans. Allocating funds for the rehabilitation and restoration of mined areas to their pre-mining conditions. Identifying and protect areas of high biodiversity value from mining activities. Implementing measures to minimize habitat destruction and fragmentation. Monitor and managing water quality in and around mining sites to prevent pollution. Implementing proper drainage systems and sediment control measures to prevent water contamination.

Authors contribution

Conceptualization and methodology, BPK; Software, ANH; Formal analysis, CD; Investigation, PD; Resources, BN; Data curation, EY; Writing-original draft preparation and writing-review and editing, PV and APL; Visualization and supervision, BL. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare no conflict of interest.

Ethical approval: Not applicable.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

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