JOURNAL OF INTERDISCIPLINARY PERSPECTIVES

ISSN Print: 2984-8288, ISSN Online: 2984-8385
Vol. 2, No. 8, pp. 36-46, August 2024

Environmental and Socioeconomic Impact Analysis of Quarry Operations in General Santos City on its Host Communities

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Date received: June 2, 2024
Date revised: June 14, 2024
Date accepted: June 20, 2024

Originality: 95%
Grammarly Score: 99%
Similarity: 5%

Recommended citation:
Ngilay, J.N., & Flores, L. (2024). Environmental and socioeconomic impact analysis of quarry operations in General Santos City on its host communities. *Journal of Interdisciplinary Perspectives*, 2(8), 36-46. https://doi.org/10.69569/jip.2024.0251

Abstract. Several international policies have been formulated to address the environmental and social impacts of the quarrying industry. However, this multifaceted issue persists, particularly in the Buayan River System in General Santos City. This study examined the environmental and socioeconomic repercussions of quarry operations in General Santos City, focusing on 14 commercial sand and gravel quarries along the Buayan River system. A mixed-methods approach was employed, collecting quantitative data through structured questionnaires, direct observations, and secondary data analysis, and incorporating qualitative insights from key informant interviews. Stakeholders within a 500-meter radius of the quarries were sampled using Quantum Geographic Information System (QGIS) to ensure representation. The findings revealed significant environmental impacts, including increased dust levels, soil erosion, and changes in water quality, which have adversely affected the local ecosystem and residents' health. The socioeconomic effects were mixed: while quarrying created jobs and improved infrastructure, it also showed deficiencies in community engagement and training programs. Regulatory analysis identified strengths in collaboration but highlighted weaknesses in enforcement, fee systems, and monitoring. The results indicated that although quarrying provides economic benefits, enhanced regulatory enforcement and sustainable practices are imperative to mitigate associated costs. Recommendations include strengthening enforcement, improving community engagement, updating fee structures, and implementing sustainable quarrying practices in General Santos City. By incorporating these recommendations, General Santos City can ensure the quarrying industry operates responsibly, balancing economic benefits with environmental and social well-being.

Keywords: Environmental impact; Quarrying operations; Socioeconomic effects; General Santos City.

1.0 Introduction

Quarrying, the process of extracting natural resources such as rocks, sand, and gravel from the earth's surface, is integral to various industries, notably construction. According to the United States Geological Survey (2021), quarrying is characterized as "the extraction of stone from the earth's crust using methods such as cutting, blasting, or drilling." These extracted materials fulfill various purposes, such as construction, landscaping, and road building, underscoring its importance for socio-economic advancement. For example, the European Aggregates Association highlights its significant role in the European economy, with an estimated turnover of around €18 billion and employment of approximately 200,000 individuals (European Aggregates Association, 2017-2018).

On the other hand, Quarrying can have significant environmental repercussions, negatively impacting surrounding communities. Concerns such as soil erosion, water pollution, biodiversity loss, and habitat

destruction pose serious threats to human health, ecosystems, and the local economy. Endalew, Tasew, and Tolahun (2019) highlighted various socio-environmental consequences of stone quarrying. These include reduced agricultural productivity, impediments to farming, habitat destruction, deforestation, changes in land use and landscape, obstruction of animal movement, erosion and sedimentation, loss of aesthetic value, fatalities among livestock and humans, property damage, dust-induced air pollution, and health problems like stress, coughs, and colds. Furthermore, international policies such as the Sustainable Development Goals (SDGs) emphasize responsible and sustainable quarrying practices, aligning industry needs with community welfare. In the Philippines, the mining industry operates under the Philippine Mining Act of 1995 (R.A. No. 7942), promoting responsible exploration, development, and utilization of mineral resources. Regulatory frameworks, including the Philippine Environmental Impact Statement System (PD 1586), oversee environmental impact assessments for quarry projects, ensuring compliance with legal requirements. Despite its economic significance, the quarry industry presents environmental and socio-economic concerns, particularly in rural communities. Hence, evaluating the performance of quarry industries in General Santos City and analyzing their impact on host communities are imperative. This study aims to assess existing policies and regulations governing the industry's operations and determine their effectiveness in mitigating negative impacts. Through comprehensive research, insights can be gained into the challenges and opportunities confronting the quarrying industry, facilitating a more sustainable and equitable development trajectory.

2.0 Methodology

2.1 Research Design

The study utilized a mixed-methods approach, systematically integrating quantitative and qualitative methodologies to gain a more comprehensive understanding of the research question (Tashakkori & Newman, 2010). This aligns with the pragmatic stance of mixed-methods research, where both quantitative and qualitative data are collected and analyzed (Tashakkori & Newman, 2010).

2.2 Research Locale

The study was carried out in the Buayan River area, situated between the boundaries of General Santos City and Sarangani Province in the Philippines. The coordinates for Buayan River are Latitude: 6° 5' 48" N and Longitude: 125° 14' 17" E, as derived from the Mindat.org base map data. Buayan River is of significant importance as it serves as the primary location for numerous government-permitted quarrying sites in General Santos City, responsible for a substantial portion of the area's quarrying activities. The Buayan River System encompasses four distinct Barangay communities—Buayan, Ligaya, Katangawan, and Tinagacan—that house legal quarry sites within the city. These barangays are integral to the research locale, offering diverse perspectives and experiences related to the study topic.

2.3 Research Participants

The research study's population sample frame included Quarry Workers and Community Households. Quarry Workers were selected from 14 active quarry sites along the Buayan River system, with 49 respondents chosen based on submitted Work Programs. Community Households' sample size was determined using QGIS Open Street Map and Mapflow, identifying approximately 686 buildings/houses within a 500-meter radius of the quarry sites. Utilizing Slovin's Formula, the sample size for Community Households was calculated as 157. Based on these calculations, a total sample size of 49 Quarry Workers and 157 Community Households was selected to represent their respective populations in the study.

2.4 Research Instrument

The study used validated questionnaires, interviews, and observations to collect primary data. Structured questionnaires were distributed among Quarry Workers to assess their daily challenges and the socioeconomic impact of quarrying on their lives. Separate questionnaires were given to Household Respondents to identify issues resulting from quarry operations. Key Informant Interviews were conducted with Regulatory Agencies to understand their quarry management practices. The observation method was employed to gather information on quarry activities, supplemented by photographs. Secondary data from various sources, including textbooks and government documents, were consulted to augment the data collection process and enhance understanding of the research topic.

2.5 Data Gathering Procedure

During the fieldwork phase, a comprehensive data collection approach was employed, combining quantitative and qualitative methods to engage diverse stakeholders. Prior to data collection, participant consent was obtained to uphold ethical standards. Quantitative data were gathered using focused questionnaires tailored for quarry workers and nearby residents, aiming to understand environmental and socio-economic impacts. Qualitative insights were obtained through Key Informant Interviews with stakeholders, shedding light on quarry management policies and practices. Extensive surveys were conducted in the study area, visiting quarries along the Buayan River to observe activities and their effects. Both primary (observation, interviews, questionnaires, photographs) and secondary (books, journals, internet sources) sources were utilized. This multifaceted approach facilitated a comprehensive understanding of quarrying challenges, impacts, and management practices, enriching the research findings with diverse perspectives.

2.6 Ethical Considerations

This research study adhered to ethical guidelines and received a certificate of exemption from ethics review from the Mindanao State University-General Santos Institutional Ethics Review Committee (MSU-General Santos IERC). The exemption was granted based on the necessary submitted requirements, confirming that the study protocol and related documents were reviewed and approved for implementation. The study, titled "Environmental and Socioeconomic Impact Analysis of Quarry Operations in General Santos City on Its Host Communities," was assigned Approval No. 026-2024-MSUGSC-IERC with a Study Protocol Code of 2024-026-SR. The approval, effective from January 23, 2024, to January 23, 2025, was given under the provisions that the study involves a non-sensitive survey and the participants' names are anonymized.

3.0 Results and Discussion

3.1 Impact of Quarrying Activities

Table 1 presents impact severity classifications adapted from commonly used ranges in risk assessment studies. The impact severity is categorized based on the percentage ranges of "YES" responses.

Table 1. Impact severity classification

YES Percentage Range	Impact Severity	Description (Implication)
0-20%	Insignificant	Minimal Impact (Barely noticeable ecological disruption)
21-40%	Minor	Short-term Impact (Potential for ecological disturbance, but likely temporary and recoverable)
41-60%	Moderate	Significant Impact (Substantial ecological disruption that may require intervention or mitigation strategies)
61-80%	Major	Major Short-term Impact (Severe ecological disruption that can have lasting effects)
81-100%	Catastrophic	Major Long-term Impact (Devastating ecological consequences, potentially irreversible)

Quarry Impact on Agriculture and Land

The systematic classification provided by Table 2 offers a comprehensive understanding of the severity of impacts stemming from quarrying activities in General Santos City, particularly concerning agriculture and land degradation. Responses are categorized into severity levels ranging from Insignificant to Catastrophic, offering nuanced insights into the varying degrees of impact experienced by the surveyed population. The study examined how quarrying affects nearby agriculture.

Over half (59.2%) of those surveyed felt the natural landscape was significantly altered by quarrying. An even greater concern (73.2%) was soil erosion, suggesting a major impact on soil quality and crop yields. The visual appearance of the area was also significantly affected, with 72.6% of people finding it altered by quarrying. While less concerning than erosion, a moderate number of people (42%) reported reduced soil fertility. There were also moderate impacts on agricultural infrastructure (42%) and potential long-term sustainability (45.9%). Although some reported a decline in crop yield (37.6%) and produce quality (33.1%), these effects were considered minor.

Interestingly, the environmental challenges documented in this study align with the findings of previous research undertaken in other regions impacted by quarrying, such as studies conducted in Nigeria and Ethiopia by Endalew, Tasew, and Tolahun (2019).

Table 2. Descriptive statistics of the quarry impact on agriculture and land

Question		Yes	No	% Yes	Impact Severity
1.	Have you noticed any changes in the natural landscape due to quarrying activities in your area?	93	64	59.2%	Moderate
2.	Do you believe that quarrying operations have led to increased soil erosion in the area?	115	42	73.2%	Major
3.	Do you think quarrying activities have impacted the visual aesthetics of the surrounding areas in General Santos City?	114	43	72.6%	Major
4.	Do you perceive a reduction in soil fertility due to quarrying activities?	66	91	42%	Moderate
5.	Have crop yields in the community decreased since the start of quarrying activities?	59	98	37.6%	Low
6.	Have farmers reported a decline in the quality of their produce since the quarrying operations began?	52	105	33.1%	Low
7.	Have there been instances of damage to agricultural infrastructure (e.g., irrigation channels, farm buildings) caused by quarrying?	66	91	42%	Moderate
8.	Do farmers perceive any long-term negative effects on the sustainability of agriculture due to ongoing quarrying operations?	72	85	45.9%	Moderate

Dust Impact from Quarrying Activities

The analysis of survey responses provides significant insights into the profound impact of dust emissions from quarrying activities, closely aligning with the findings of Sayara's (2016) research. Notably, 72% of respondents in this survey reported heightened dust levels near quarries, which corresponds to Sayara's finding that approximately 70% of participants identified persistent atmospheric contamination due to quarrying and stone-cutting operations. This parallel underscores a consistent recognition of dust as a major environmental issue in areas adjacent to quarries. Moreover, both studies highlight the multifaceted sources of dust emissions. While 42% of this research's respondents noted dust settling on plants near quarries, posing a moderate threat to vegetation growth, Sayara's study expands on this by indicating that dust generation is not solely attributed to on-site activities.

Table 3. Descriptive statistics of the dust impact from quarrying activities

Question		Yes	No	% Yes	Impact Severity
1.	Have you noticed an increase in dust levels in the vicinity of quarrying sites in the area?	113	44	72%	Major
2.	Have you observed dust particles settling on plants and affecting their growth near quarrying sites?	66	91	42%	Moderate
3.	Do you believe that the dust emissions from quarrying activities have negatively impacted the cleanliness of nearby communities?	99	58	63.1%	Major
4.	Do you think that quarrying activities contribute to the presence of dust indoors in residential areas near the quarry sites?	101	56	64.3%	Major
5.	Have you noticed an increase in the need for cleaning due to dust accumulation in your home or business premises near quarrying areas?	93	64	59.2%	Moderate

The transportation of trucks to and from quarry sites significantly contributes to dust emissions and other pollutants from fuel combustion, emphasizing the complexity of the issue and the necessity for comprehensive mitigation strategies. Regarding community impact, a majority of respondents reported a major negative effect on community cleanliness, potentially affecting residents' quality of life. Similarly, over 64.3% noted the contribution of quarrying activities to indoor dust presence. Sayara's findings resonate with these concerns, with approximately 70% of participants in her study verifying that the impact of dust extends beyond regular working hours, indicating a pervasive and continuous issue. In summary, the findings from both my research and Sayara's study underscore the significant impact of quarrying-related dust emissions on the environment and residents' health. The alignment between these independent studies emphasizes the urgent need for effective mitigation measures to safeguard well-being and reduce the environmental footprint of quarrying activities.

Noise and Vibration Impact from Quarrying Activities

Table 4. Descriptive statistics of the noise and vibration impact from quarrying activities

Question		Yes	No	% Yes	Impact Severity
1.	Have you noticed an increase in noise levels in the vicinity of quarrying sites?	85	72	54.10%	Moderate
2.	Do you believe that the noise generated by quarrying activities is disruptive to nearby residents?	72	85	45.90%	Moderate
3.	Do you think that quarrying activities have resulted in vibrations that are noticeable in nearby structures or homes?	69	88	43.90%	Moderate
4.	Have you observed cracks or damage to buildings or infrastructure that you attribute to the vibrations generated by quarrying?	59	98	37.60%	Minor
5.	Do you believe that the noise pollution and vibration from quarrying activities have negatively impacted the quality of life for nearby residents?	70	87	44.60%	Moderate

Noise is any unwelcome sound that irritates the human ear. Uncontrolled noise emissions in the sand and stone operation are increasing noise pollution among quarry workers and neighboring residents. Noise overload can cause problems ranging from discomfort to hearing impairment (Yakup & Payus, 2017). Table 4 shows that over half (54.1%) of respondents reported a moderate increase in noise levels near the quarries, while nearly half (45.9%) felt the noise disturbed their neighbors. These results suggest a noticeable but not severe impact on the noise environment. Similarly, vibrations were perceived as moderate. Almost half (43.9%) reported noticeable vibrations in their homes or structures, while a smaller portion (37.6%) experienced minor cracks or damage. This indicates some impact on infrastructure but not widespread or severe issues. Overall, over 44% of respondents felt a moderate negative impact on their quality of life. This suggests a manageable level of disruption from noise and vibrations. The study found that noise pollution and vibrations from quarrying, while acknowledged and affecting the surrounding area, are perceived as moderately severe. This opens the door for targeted strategies to address these concerns without needing drastic measures.

Impact of Quarrying on Water Resources and River Systems

T**able 5.** Descriptive statistics of the impact of quarrying on water resources and river systems

Description of Indicator		Yes	No	% Yes	Impact Severity
1.	Has there been a noticeable increase in water turbidity since the commencement of quarrying operations?	76	81	48.4%	Moderate
2.	Are there instances of spills or leaks of hazardous chemicals from the quarry into nearby water bodies?	43	114	27.4%	Minor
3.	Has the community observed changes in the color of water in rivers or streams near the quarry site?	60	97	38.2%	Minor
4.	Has the community witnessed the diversion of natural water channels as a direct consequence of quarrying operations?	87	70	55.4%	Moderate
5.	Have there been instances of public infrastructure damage, such as bridges or culverts, attributed to changes in water flow caused by quarrying?	87	70	55.4%	Moderate
6.	Have residents experienced instances of property damage directly attributed to changes in water flow caused by quarrying operations?	96	61	61.1%	Major
7.	Has the frequency of flooding in the community increased since the commencement of quarrying operations?	77	80	49%	Moderate
8.	Are there instances where residents have had to relocate due to water-related hazards exacerbated by quarrying activities?	66	91	42%	Moderate
9.	Do residents feel adequately informed about the potential impact of quarrying on water rechanneling and flooding?	77	80	49%	Moderate

The findings of Devi and Rongmei (2017) shed light on one of the most significant environmental repercussions of quarrying, particularly in relation to rivers. The study highlights how excessive sand and gravel extraction from riverbanks, often used as quarrying sites to meet demand, weakens the riverbed, altering the flow of the river and potentially changing its course. This alteration in water flow patterns is corroborated by a recent study examining the impacts of quarrying operations on communities near rivers. This research reports that 55.4% of respondents experienced changes in water flow patterns, classified as moderate severity, indicating noticeable but not critical problems. Furthermore, property damage resulting from changes in water flow was reported by 61.1% of respondents, categorized as a major impact. Additionally, 42% of individuals reported needing to relocate due to

water dangers, while 49% observed an increase in flooding, both classified as moderate severity. These findings underscore the complex effects of quarrying on rivers and adjacent communities, aligning with the environmental repercussions outlined by Devi et al. (2017).

Impact of Quarrying on Biodiversity

Table 6. Descriptive statistics of the impact of quarrying on biodiversity

	Description of Indicator	Yes	No	% Yes	Impact Severity
1.	Has the biodiversity in our community been negatively impacted by the presence of the quarry?	71	86	45.2%	Moderate
2.	Do you observe a decrease in the population of local plant species due to quarrying operations?	66	91	42%	Moderate
3.	Has there been a noticeable decline in the number of animal species in your community since the Commencement of quarrying activities?	49	108	31.2%	Minor
4.	Has the air and noise pollution from quarrying operations negatively impacted the behavior and abundance of local bird species?	54	103	34.4%	Minor

The findings of Cohen (2015) regarding the negative impact of quarrying on biodiversity align with the concerns highlighted in Table 6 of the surveyed area. Residents expressed significant apprehension regarding the decline in biodiversity, with 45.2% noting a decrease, indicating substantial ecological disruption. This sentiment was further supported by observations of fewer plants by 42% of residents and fewer animal species by over 31%. Additionally, the survey explored indirect impacts such as air and noise pollution, with approximately 34% of residents directly linking these factors to bird populations, thereby emphasizing the multifaceted environmental consequences of quarrying. These findings collectively suggest that quarrying activities likely have a moderate negative impact on the variety of plants and animals in the area, echoing Cohen's concerns about the potential destruction of habitats and the species they support due to quarrying activities. Even if habitats are not directly removed, they can still be indirectly affected by environmental impacts such as changes to groundwater or surface water, leading to habitat destruction.

On-Site Environmental Impacts of Quarrying

Table 7. Descriptive statistics of the on-site environmental impacts of quarrying

	Description of Indicator	Yes	No	% Yes	Impact Severity
1.	Is the air quality at the quarry site affected by dust and particulate matter during quarrying operations?	17	32	34.7%	Minor
2.	Have you experienced respiratory issues due to exposure to airborne pollutants at the quarry?	8	41	16.3%	Insignificant
3.	Is there a significant increase in noise levels during quarrying activities?	15	34	30.6%	Minor
4.	Do you find it challenging to communicate or work efficiently due to the noise generated by quarry machinery?	7	42	14.3%	Insignificant
5.	Has the water quality in nearby water bodies been negatively impacted by runoff or discharge from the quarry?	4	45	8.2%	Insignificant
6.	Have you observed changes in the color, odor, or clarity of water in the vicinity of the quarry?	13	36	26.5%	Minor
7.	Have you noticed a decline in local plant and animal species around the quarry area?	4	45	8.2%	Insignificant
8.	Do you feel that quarrying operations pose safety risks to workers, such as the potential for landslides or rockfalls?	10	39	20.4%	Insignificant

Table 7 provides an analysis of the impact of quarrying activities on the occupational environment based on workers' perceptions Dust and noise were the top concerns, with over 30% of workers mentioning each. However, fewer workers reported actual health problems from dust (16.3%) or communication issues due to noise (14.3%). Observations showed minimal dust, possibly due to dust suppression methods using water. Similarly, water quality concerns were reported by a small percentage (8.2%), though a larger portion (26.5%) noticed changes in the water itself. There weren't many worries about worker safety or biodiversity loss. Overall, the negative impacts on the work environment seem minor based on worker experiences. However, the study suggests keeping a close eye on these issues and finding better ways to manage them to ensure long-term sustainability of the quarrying operations.

Socioeconomic Impact of Quarry Operations on its Host Communities

Table 8. Descriptive statistics of the socioeconomic impact of quarry operations on its host communities

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mode
1. Quarry provided employment opportunities.	10 (6.5%)	8 (5.2%)	28 (18.2%)	65 (42.2%)	46 (29.9%)	4 (mode)
2. Quarry contributed to an increase in the income levels.	2 (1.3%)	9 (5.8%)	38 (24.7%)	64 (41.6%)	44 (28.6%)	4 (mode)
3. The quarry industry improved the infrastructure development.	3 (1.9%)	17 (11%)	36 (23.4%)	68 44.2%)	33 (21.4%)	4 (mode)
4. The quarry industry has positively impacted the overall quality of life in the host community.	3 (1.9%)	23 (14.9%)	74 (48.1%)	40 (26%)	16 (10.4%)	3 (mode)
5. The quarry industry actively participated in community development projects.	6 (3.9%)	19 (12.3%)	54 (35.1%)	20 (37.7%)	20 (13%)	4 (mode)
6. The quarry industry provided training and skill development opportunities.	7 (4.5%)	17 (11%)	43 (27.9%)	76 (49.4%)	14 (9.1%)	4 (mode)
7. Quarry contributed to an increase in business opportunities.	4 (2.6%)	15 (9.7%)	58 (37.7%)	24 (36.4%)	24 (15.6%)	3 (mode)
8. quarry industry contributed to an increase in property values	2 (1.3%)	14 (9.1%)	51 (33.1%)	64 (41.6%)	25 (16.2%)	4 (mode)

Table 8 outlines the socioeconomic effects of quarry operations on host communities, gauged through a Likert scale from "Strongly Disagree" to "Strongly Agree." The survey delves into multiple facets of the quarry's influence, including employment opportunities, income levels, infrastructure, quality of life, community projects, training, business prospects, and property values. Results indicate widespread agreement that the quarry positively impacts employment, income, infrastructure, and skill development. However, perceptions regarding overall quality of life vary, with significant numbers expressing neutrality or negativity. Likewise, opinions on the quarry's involvement in community projects, business opportunities, and property values are mixed. This underscores the nuanced and diverse perspectives on the socioeconomic implications of quarry operations, emphasizing the necessity for comprehensive research to comprehend their full impact on communities.

Impact of Quarrying on Local Health and Well-being

Table 9. Descriptive statistics of the impact of quarrying on local health and well-being

Description of Indicator	Yes	No	% Yes	Impact Severity
1. Have you experienced any respiratory problems or illnesses that you attribute to the quarry industry?	52	105	33.1%	Minor
2. Have you witnessed any cases of allergies or skin irritations in individuals living near quarry sites?	59	98	37.6%	Minor
3. Have you observed any negative impacts on the mental health and well-being of individuals living in the host communities due to the quarry industry?	68	89	43.3%	Moderate
4. Have you personally sought medical treatment or consultation for health issues related to the quarry industry?	33	124	21%	Minor
5. Do you think that the quarry industry has taken sufficient measures to protect the health and safety of the local population?	78	79	49.7%	Moderate

The production of dust during quarrying operations is a prominent and intrusive impact that has the potential to cause irritation. Despite its high visibility, Howard and Cameron (as cited in Sayara, 2016) noted that apprehensions regarding the impact of dust may not necessarily align with its factual consequences on the well-being of individuals and the ecosystem. Table 9 provides a comprehensive view of the impact of quarrying on local health and well-being, detailing various health-related consequences associated with quarry operations in the study area. The findings reveal that 33.1% of respondents experienced respiratory issues attributed to quarry operations, indicating a noticeable but not overwhelmingly prevalent problem, possibly transient or recoverable. Similarly, cases of allergies or skin irritations reported by 37.6% of respondents fall within the "Minor" impact

severity range, suggesting they are noticeable but not significant or long-lasting disruptions. Mental health impacts, affirmed by 43.3% of respondents, shift the impact severity to "Moderate," indicating a more substantial disruption potentially necessitating intervention. Seeking medical treatment for quarry-related health issues was reported by 21% of respondents, indicating a "Minor" impact severity, suggesting relatively low overall health impacts requiring medical intervention. Perceptions of the adequacy of measures taken by the quarry industry to protect local health and safety, with a response rate of 49.7%, fall within the "Moderate" impact severity range, indicating ongoing concerns among a significant portion of the population and suggesting a need for further intervention or improvement in safety measures. These findings highlight the importance of addressing both the perceived and actual health impacts of quarrying dust, emphasizing the need for enhanced mitigation strategies to protect community well-being effectively.

Socioeconomic Impact of Quarry Operations on Quarry Workers

Table 10. Descriptive statistics of the socioeconomic impact of quarry operations on quarry workers

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mode
1. The quarry industry provides stable employment opportunities for quarry workers.	0 (0%)	4 (8.2%)	1 (2.0%)	14 (28.6%)	30 (61.2%)	5 (mode)
2. Quarry workers receive fair and competitive wages for their work	1 (2.0%)	3 (6.1%)	8 (16.3%)	12 (24.5%)	25 (51.0%)	5 (mode)
3. Quarry workers have access to appropriate safety measures and protective equipment	2 (4.1%)	4 (8.2%)	4 (8.2%)	23 (46.9%)	16 (32.6%)	4 (mode)
4. The quarry industry provides opportunities for skills development and career advancement for quarry workers.	1 (2.0%)	6 (12.2%)	5 (10.2%)	18 (36.7%)	19 (38.8%)	5 (mode)
5. Quarry workers have adequate access to healthcare and medical benefits.	1 (2.0%)	6 (12.2%)	6 (12.2%)	19 (38.8%)	17 (34.7%)	4 (mode)
6. Quarry workers are satisfied with their working conditions	1 (2.0%)	3 (6.1%)	8 (16.3%)	17 (34.7%)	20 (40.8%)	5 (mode)
7. Quarry workers have opportunities for participation and representation in decision-making processes within the quarry industry	0 (0%)	4 (8.2%)	7 (14.3%)	19 (38.8%)	19 (38.8%)	4&5 (mode)
8. The quarry industry provides training and educational programs for the professional development of quarry workers.	0 (0%)	5 (10.2%)	13 (26.5%)	16 (32.6.%)	15 (30.6%)	4 (mode)
9. Quarry workers feel a sense of job security within the quarry industry	0 (0%)	3 (6.1%)	8 (16.3%)	17 (34.7%)	21 (42.9%)	5 (mode)
10. The quarry industry promotes a healthy work-life balance for quarry workers	0 (0%)	4 (8.2%)	7 (14.3%)	16 (32.6%)	22 (44.9%)	5 (mode)
11. The quarry industry fosters a positive and inclusive work environment for quarry workers.	0 (0%)	3 (6.1%)	6 (6.1%)	16 (32.6%)	24 (48.9%)	5 (mode)

According to Sumani (2019), the practice of small-scale industrial sand and gravel mining has both advantageous and detrimental effects on socio-economic and environmental aspects. The extraction of sand and gravel offers various benefits, such as creating employment opportunities, generating income, providing building and construction materials, and serving as a means of subsistence for numerous stakeholders involved in the sand and gravel extraction value chain.

Data from Table 10 indicates that a significant majority of respondents perceive the quarry industry as providing numerous beneficial aspects for quarry workers, including stable employment opportunities, fair wages, safety measures, skills development, healthcare access, job satisfaction, participation in decision-making, training programs, job security, work-life balance, and a positive work environment. However, challenges such as the lack of strong agreement on training and educational programs underscore areas needing improvement. Greater investment in training programs and enhanced worker involvement in decision-making processes are essential for a more empowered and resilient workforce. In conclusion, while the quarry industry brings positive socioeconomic impacts, addressing challenges related to training programs and worker participation is crucial for fostering a more satisfied and empowered workforce, benefiting both individuals and the community.

3.2 Challenges, Strategies, and Expected Benefits in Sand and Gravel Extraction Regulation

Table 12. Challenges, strategies, and expected benefits in sand and gravel extraction regulation

Challenge/Weaknesses	Description	Strategy	Expected Benefits
Outdated Extraction Fee System & Absence of Standardized Tariff	Unfair fee structures, inconsistent pricing, and insufficient revenue collection.	Conduct a review of the extraction fee system to ensure it reflects current market value. Establish a standardized tariff system for sand and gravel based on type and quantity.	Fairer compensation for extracted materials. Increased revenue collection for local governments.
Manpower Shortage for Monitoring	Need for more personnel for continuous oversight and enforcement.	Increase the number of quarry checkers. Combine CENRO personnel with Barangay Quarry Checkers for a well-rounded team with regulatory knowledge and local insights. Foster community trust and encourage residents to report potential issues.	Stronger monitoring presence. Broader geographical coverage with frequent site visits. Improved detection of non-compliant practices.
Inadequate Enforcement Mechanisms & Expansion Beyond Designated Boundaries	Weak enforcement allows non-compliance and unauthorized expansion.	Implement stricter enforcement mechanisms with increased inspections. Establish clear and deterrent penalties for non-compliance, including potential license revocation. Utilize technology like satellite imagery to identify unauthorized expansion.	Reduced instances of non-compliance and unauthorized operations. Protection of designated boundaries and surrounding areas.
Unclear Accountability in Agreements & Dependence on External Agencies	Lack of clear mechanisms to ensure operator accountability and potential delays in addressing non-compliance due to reliance on external agencies.	Develop clear agreements with operators outlining their obligations and establish mechanisms to ensure compliance. Reduce reliance on external agencies by strengthening internal monitoring capabilities or collaborating with them for more efficient oversight.	Improved operator accountability. Timelier responses to non-compliance issues.
Operator Concerns about Compliance	Operators may hesitate to comply due to various circumstances.	Engage with operators to address their concerns about regulations. Highlight the long-term benefits of compliance for the industry and the environment. Consider offering incentives for responsible practices.	Increased understanding and acceptance of regulations. Greater industry cooperation in achieving sustainable practices.

Table 12 provides a detailed examination of the challenges identified through Key Informant Interviews in regulating sand and gravel extraction. It also proposes corresponding strategies and outlines the expected benefits aimed at addressing these obstacles effectively.

Table 13. Technologies and mitigating strategies

Sustainable Practice	Benefit	Target Environmental Impact
NACI Dikes	Promotes natural plant growth, stabilizes banks, creates aquatic habitat	Erosion prevention, healthy river ecosystem
Bamboo Planting	A cost-effective, fast-growing root network binds soil particles and minimizes downstream sedimentation.	Erosion control, healthy river ecosystem
Dust Suppression & Noise Barriers	Improves air quality, protects human health, minimizes noise pollution	A healthy environment for communities and wildlife
Erosion Control Measures (buffer zone & blankets)	Natural barrier against erosion minimizes sedimentation	Water quality protection, healthy aquatic life
Suction Dredging Techniques	Minimizes disturbance to riverbed habitat and reduces suspension of sediment.	Healthy riverbed environment, aquatic life protection

Table 13 presents key technologies and mitigation strategies highlighted by key informants to minimize the environmental impact of quarrying operations. This focus on specific examples related to riverbank rehabilitation and broader environmental protection. Table 14 outlines the multifaceted impacts of quarrying activities and provides a detailed set of recommendations to mitigate these effects. Key areas assessed include water and air quality, ecological health, spatial planning, road maintenance, dust control, health impacts, economic implications, skill development, data management, stakeholder capacity building, enforcement collaboration, regulatory compliance, and sustainability standards. Each assessment area identifies specific findings and pairs

them with actionable recommendations to address both environmental and socio-economic challenges posed by quarrying operations.

Table 14. Recommendations

Area of Assessment	Findings	Recommendations
Water and Air Quality Assessment	Quarrying operations affected water resources, leading to increased turbidity, changes in flow patterns, and more frequent flooding. Air quality is compromised by elevated dust levels.	Establish baseline data and conduct ongoing monitoring of surface and groundwater quality for potential contaminants like sediment runoff, blasting materials, and microbial contamination. Monitor air quality for dust particles and other pollutants.
Ecological Studies	Biodiversity declines, with residents reporting less plant and animal life due to quarrying activities.	Conduct a quantitative analysis of flora and fauna populations before, during, and after quarrying. Assess impacts on endangered or threatened species, migratory patterns, soil health, and potential contamination risks.
Quarrying in Spatial Planning	Lack of integration of quarrying activities into long-term spatial planning results in unplanned and unsustainable land use.	Integrate quarrying activities into spatial planning processes, considering geological assessments and environmental impacts for long-term sustainability. Identify suitable areas for quarrying, minimize community and ecosystem impacts, and explore alternative sources of aggregates.
Road Maintenance	Quarry trucks damage local roads, causing significant inconvenience and safety hazards for residents.	Enforce the "Daan Ko, Sagot Ko" policy, requiring operators to maintain roads damaged by hauling trucks, ensuring safer and more reliable transportation routes.
Dust Control Measures	Increased dust levels from quarrying activities adversely affect air quality and health.	Implement and enforce dust control measures such as water spraying and planting trees around the quarry sites to serve as dust filters.
Ensuring Accountability for Road Repairs	Lack of clear procedures for holding operators accountable for road repairs, leading to unresolved road damage issues.	Establish clear procedures for holding operators accountable through consultations and dispute resolution processes to ensure timely and effective road repairs.
Health Impact Assessment	Significant health impacts on residents and workers due to dust exposure and noise pollution. Residents reported increased dust levels affecting air quality and health; workers faced potential changes in water quality and noise levels.	Partner with medical professionals to administer comprehensive, long-term health evaluations, including health screenings, monitoring respiratory conditions, and investigating hearing impairments. Integrate assessments of mental health to address stress from dust exposure and other factors.
Economic Analysis	Quarrying provides economic benefits such as job creation and infrastructure improvements, but concerns exist about the long-term viability and costs of environmental degradation.	Analyze tax revenue, infrastructure costs, crowding out effects on local businesses, and long-term economic viability. Assess the cost-effectiveness of sustainable practices and reclamation efforts after quarrying.
Skill Development	Mixed socio-economic impacts of quarrying. Lack of community engagement and ineffective training programs lead to resident dissatisfaction.	Offer programs focusing on skills development that are aligned with community needs. Partner with local technical schools to provide training in equipment maintenance and other relevant skills to improve community well-being and economic prospects.
Data Management for Oversight	Effective monitoring and enforcement are hindered by insufficient data collection and lack of transparency.	Develop a comprehensive data collection plan for all environmental and health monitoring activities. Ensure transparency by making data publicly available in an accessible format. Regularly review and update data collection methods and analysis procedures.
Building Capacity with Stakeholders	Lack of community engagement and dissatisfaction with training programs offered by quarry operators.	Partner with barangays to educate residents about the quarrying project, its potential impacts, and mitigation strategies. Empower residents to participate in informed decision-making.
Collaboration with Barangays in Enforcement	Weak enforcement and insufficient monitoring were identified as major issues.	Establish a collaborative approach with barangays to monitor compliance with environmental regulations and safety protocols. This includes joint inspections, training programs for barangay officials, and open communication channels.
Clear Mechanism for Penalty of Non-compliance	Unclear accountability and weak enforcement mechanisms highlighted as significant challenges.	Define a clear and transparent system for penalties in case of non-compliance with regulations. Communicate this system to all stakeholders and enforce it consistently to ensure responsible quarry operation.
Enhanced Enforcement and Monitoring	Weak enforcement mechanisms, insufficient monitoring, and unclear accountability compromise the effectiveness of current regulations.	Allocate additional manpower and other resources for regular inspections, monitoring programs, and penalties for non-compliance to ensure strict adherence to regulations.
Voluntary Sustainability Standards	Varying adoption of sustainability practices among operators, leading to inconsistent environmental and social performance.	Encourage the adoption of voluntary sustainability standards, such as ISO 14001 certification, to promote environmentally responsible practices.
Performance-Based Incentives and Penalties	Need to drive adherence to sustainable practices through incentives and penalties.	Implement incentives for outstanding sustainability performance and penalize non-compliance. Reward operators with tax breaks for exceptional performance and enforce penalties for non-compliance to ensure responsible practices.

4.0 Conclusion

This study advances the field by providing a comprehensive analysis of the multifaceted interplay between quarrying activities and their impact on surrounding communities in General Santos City. It highlights the dual nature of quarrying, which, while offering significant economic advantages such as job creation and infrastructure development, also presents environmental challenges like air , water and noise pollution. The current regulatory framework, characterized by a collaborative approach and clear legal parameters, has notable strengths. However, its effectiveness is hampered by weaknesses such as weak enforcement and outdated fee systems. This research underscores the necessity for sustainable practices, including the reclamation of abandoned quarries and

responsible land use, coupled with stricter enforcement measures and enhanced communication with residents. By striking a balance between economic development, environmental protection, and community well-being, General Santos City can pave the way for a more sustainable future for its quarrying industry. To further advance the state of knowledge in this field, future research should focus on establishing baseline data and conducting ongoing monitoring of surface and groundwater quality for potential contaminants, as well as air quality for dust particles and other pollutants. Additionally, a quantitative analysis of flora and fauna populations before, during, and after quarrying operations is essential, alongside health impact assessments to evaluate respiratory issues, allergies, skin irritations, and mental health effects on local populations. Investigating the social dynamics between quarry operators and local communities and enhancing community engagement in decision-making processes related to quarrying activities are also critical areas for future study. By addressing these areas, future research can build on the findings of this study, providing deeper insights and more robust solutions for mitigating the adverse impacts of quarrying while maximizing its economic benefits.

5.0 Contributions of Authors

Author 1 played a critical role in the development of the research concept, the design of the methodology, data collection and analysis, the drafting of the initial manuscript, and the overall management of the project's progression. Author 2 provided overarching supervision and guidance throughout the entire research process, from initial conceptualization to final completion. His contributions included substantial insights and expertise that significantly enhanced the study's conceptual framework and methodological approach. Additionally, he played a pivotal role in the manuscript's review, ensuring its scholarly rigor and coherence.

6.0 Funding

This work received no specific grant from any funding agency.

7.0 Conflict of Interests

The authors declare no conflicts of interest about the publication of this paper.

8.0 Acknowledgement

The researcher begins by expressing her gratitude to Almighty Allah, thanking him for his blessings and guidance in completing the study. She then acknowledges her adviser, Dr. Leonard V. Flores, for his expertise and contributions throughout the research process. Recognition is given to the reviewers, Dr. Alfie Maria Custodio and Mr. Allan Marcilla,MiSDS, for their help in refining the research. Mr. Manuel Torres Jr. is also thanked for his support and providing essential informations. Gratitude is expressed to colleagues and collaborators who have been supportive. The researcher then thanks her family for their unwavering love and encouragement, especially her husband Marc Jay and daughter Aezre Euzaeiouh Jeigh, who are described as her inspiration and driving force.

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