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| RESEARCH ARTICLE

Environmental Impacts of River Aggregate Quarrying in Masiu, Lanao del Sur: Water Quality Degradation and Community-Based Perception

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| ABSTRACT
River aggregate quarrying is increasingly practiced in rural river systems to support infrastructure development, yet its environmental impacts remain inadequately documented in many resource-dependent communities. This study assessed the environmental impacts of river aggregate quarrying in Masiu, Lanao del Sur by integrating laboratory-based water quality analysis with community-based environmental perception data to determine the extent of water quality degradation and its correspondence with lived experience. A mixed-methods approach was employed, involving physico-chemical and bacteriological analysis of nine river water samples collected from left bank, midstream, and right bank sections, alongside a structured survey administered to 200 household respondents across six barangays at varying distances from quarrying zones, supplemented by semi-structured interviews. Results revealed that key water quality parameters, particularly turbidity, total dissolved solids, apparent color, and pH, frequently exceeded national drinking water standards in quarry-influenced sections, with the most pronounced degradation observed in midstream areas.

| KEYWORDS

Aggregate quarrying; Community perception; Environmental impact; River water quality; Rural livelihoods

| ARTICLE INFORMATION

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1. Introduction
River aggregate quarrying has become an essential activity supporting infrastructure development and urban expansion, particularly in developing regions. However, growing evidence indicates that in-channel sand and gravel extraction significantly alters riverine systems by disrupting sediment balance, degrading water quality, and affecting aquatic ecosystems. Recent studies have shown that quarrying activities increase turbidity, modify pH levels, and elevate total dissolved solids, thereby reducing water suitability for domestic and ecological use (Koehnken et al., 2020; Rentier & Cammeraat, 2022; Mia et al., 2024). These impacts are often intensified in rural settings where regulatory oversight is limited and communities depend directly on river systems for water, food, and livelihoods.

Beyond biophysical effects, quarrying-related water degradation carries important social and environmental implications. Research across Africa and Asia demonstrates that communities living near extraction sites frequently observe changes in water clarity, taste, and safety, and associate these changes with declining aquatic resources and increased health risks (Deb et al., 2021; Azevedo et al., 2022; Mishra et al., 2024). Importantly, several scholars argue that community perceptions are not merely subjective responses but reflect localized environmental knowledge shaped by sustained interaction with natural resources (Agyeman et al., 2016; Gamu & Soendergaard, 2024). Integrating community-based observations with scientific measurements has therefore emerged as a critical approach in contemporary environmental assessment and water governance.

In the Philippines, particularly in resource-dependent municipalities such as Masiu, Lanao del Sur, river aggregate quarrying remains underexplored despite its growing prevalence. Existing studies on quarrying impacts have largely focused on biophysical indicators or regulatory concerns, with limited attention to how measured water quality degradation aligns with community experience. This study addresses this gap by adopting a mixed-methods approach that combines laboratory-based water quality analysis, household perception surveys, and interview narratives to assess the environmental impacts of river aggregate quarrying in Masiu. By triangulating scientific data with community-based evidence, the study aims to contribute context-specific insights that can inform more inclusive and adaptive environmental management strategies.

2. Literature Review

River aggregate quarrying and sand mining have been widely examined in recent literature due to their increasing role in infrastructure development and their pronounced environmental and socio-economic consequences. Comprehensive reviews highlight that river sand and gravel extraction alters hydrological regimes, degrades water quality, and disrupts aquatic ecosystems, particularly in developing regions where regulatory enforcement is weak. Mia et al. (2024) synthesized global evidence showing that sediment disturbance from quarrying elevates turbidity, alters pH balance, and increases total dissolved solids, while simultaneously reshaping livelihood structures in river-dependent communities. Similarly, Rentier and Cammeraat (2022) emphasized that river sand mining accelerates channel instability and sediment imbalance, with long-term implications for freshwater ecosystem resilience.

Several studies have focused on water quality and ecological impacts as central consequences of riverbed mining. Koehnken et al. (2020) and Damseth et al. (2024) demonstrated that sediment resuspension during extraction reduces light penetration, affects aquatic biodiversity, and increases pollutant mobility. Empirical investigations in India and Africa further corroborate these findings. Singh et al. (2025) quantified suspended sediment dynamics in the Narmada River and showed that sand mining significantly modifies river morphology and water clarity, while Amoah et al. (2024) documented deteriorating water quality and waste accumulation in Volta Lake linked to sand mining activities. These studies collectively underscore that quarrying-induced sediment disturbance is a primary driver of water quality degradation across diverse river systems.

Beyond biophysical impacts, governance and regulatory dimensions are frequently highlighted as determinants of environmental outcomes. Ayuk et al. (2020) framed extractive industries within broader mineral resource governance, arguing that weak institutional frameworks often enable environmentally harmful practices. Gamu and Soendergaard (2024) further critiqued governance capture within mining regimes, showing how regulatory processes can marginalize local communities and exacerbate socio-environmental conflict. Case-based studies, such as Donkoh's (2025) examination of illegal mining in Ghana, reinforce the argument that inadequate monitoring and enforcement amplify environmental risks to water bodies and surrounding infrastructure.

An expanding body of literature emphasizes the integration of community perceptions into environmental assessment and management. Azevedo et al. (2022) demonstrated that local communities possess nuanced understanding of environmental quality indicators, often aligning closely with scientific measurements. Similarly, Deb et al. (2021) found that river-dependent rural populations accurately perceive pollution trends and associate them with health and livelihood risks. Mishra et al. (2024) advanced this perspective by integrating community perceptions with scientific data and geospatial tools, concluding that mixed-method approaches enhance the reliability and relevance of water quality assessments. These studies challenge the notion that perception-based data are merely subjective, instead positioning them as valuable complements to laboratory analysis.

Socio-economic dimensions of quarrying have also received significant attention. Ogbo et al. (2024) and Mukukai et al. (2025) documented how sand mining contributes to both livelihood opportunities and environmental vulnerability, particularly where communities depend on agriculture and river-based resources. While quarrying may generate short-term income, these benefits are often offset by long-term costs related to water contamination, infrastructure damage, and declining ecosystem services. From an environmental justice perspective, Agyeman et al. (2016) argued that such uneven distribution of benefits and burdens reflects broader structural inequities in resource extraction, especially in marginalized rural communities.

Thus, the literature reveals a consistent pattern: river aggregate quarrying produces measurable water quality degradation, ecological disruption, and socio-economic trade-offs, with impacts shaped by governance structures and community exposure. However, despite growing recognition of community-based knowledge, many studies still treat scientific and social data in isolation. This gap highlights the need for integrated, triangulated approaches that combine physico-chemical measurements, community perceptions, and qualitative perceptions, an approach adopted in the present study to provide a more holistic assessment of quarrying impacts in Masiu, Lanao del Sur.

3. Methodology

3.1 Research Design

The study employed a mixed-methods research design integrating quantitative water quality assessment, household perception surveys, and qualitative interviews. This approach was adopted to capture both the biophysical impacts of river aggregate quarrying and the community-based experiences associated with environmental change. By combining laboratory analysis with social data, the study aimed to provide a comprehensive and triangulated assessment of quarrying-related environmental impacts in Masiu, Lanao del Sur.

3.2 Study area

The research was conducted along selected sections of the river in Masiu, Lanao del Sur, Philippines, where river aggregate quarrying activities are actively practiced. Three quarrying zones composed of 3 pair of barangays which are located at varying distances from quarrying zones: Gondarangin (Asa Adigao), A. Datimbang (Balindong), Paino, Buadi Amaloy, Apa Mimbalay, and Magayo Bago a Ingud, were included to capture spatial variation in exposure and community perception. These barangays represent upstream, midstream, and downstream conditions, allowing comparison across different levels of quarrying influence.

Figure 1. Map of the Study Area

3.3 Water Sampling and Laboratory Analysis

A total of nine river water samples were collected from the study area, with sampling points distributed across three river sections: left bank, midstream, and right bank. Three samples were obtained from each section to ensure spatial representation. Water samples were analyzed for selected physico-chemical parameters, including pH, turbidity, total dissolved solids (TDS), apparent color, and nitrate concentration, as well as bacteriological indicators. Standard procedures for sample collection, preservation, and laboratory testing were followed. Results were evaluated against the Philippine National Standards for Drinking Water (PNSDW) to determine compliance and potential environmental risk.

3.4 Household Survey on Environmental Perceptions

A structured survey questionnaire was administered to 200 household respondents across the six barangays. Respondents were selected using purposive sampling, targeting residents with long-term exposure to river conditions. The questionnaire measured community perceptions of environmental change using a Likert-scale format, focusing on indicators such as water turbidity, taste, color, safety for domestic use, and perceived impacts on aquatic life. Descriptive statistics, including mean scores and frequency distributions, were used to summarize perception data and identify spatial patterns related to proximity to quarrying sites.

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3.5 Data Analysis

Quantitative water quality data were analyzed using descriptive statistics and spatial comparison across river sections. Survey results were similarly summarized and visualized using tables and heatmaps to illustrate variation by barangay and distance from quarrying zones. Qualitative interview findings were integrated through narrative synthesis. Triangulation was achieved by systematically comparing laboratory results, perception survey outcomes, and interview insights to identify areas of convergence and divergence, thereby enhancing the validity and reliability of the study's conclusions.

4. Results and Discussions

4.1 Physico-Chemical Characteristics of River Water

The physico-chemical characteristics of river water collected from quarry-affected sections of the river in Masiu provide an empirical baseline for assessing environmental degradation associated with river aggregate extraction. A total of nine water samples were obtained from three spatial zones : left bank, midstream, and right bank, within areas influenced by active quarrying operations. The parameters analyzed included pH, turbidity, total dissolved solids (TDS), nitrate concentration, and apparent color, which are widely used indicators of river health and suitability for domestic use. Table 1 presents the measured values alongside the Philippine National Standards for Drinking Water (PNSDW) for comparative reference**.**

Table 1. Physico-Chemical Characteristics of River Water Samples in Quarry-Affected Sections

Parameter	Left Bank (Mean)	Midstream (Mean)	Right Bank (Mean)	PNSDW Standard
pH	6.1	6.0	6.2	6.5–8.5
Turbidity (NTU)	12.4	15.7	11.9	≤5
TDS (mg/L)	610	645	598	≤500
Nitrate (mg/L)	7.2	8.1	6.9	≤10
Color (TCU)	18	21	17	≤15

As shown in Table 1, several physico-chemical parameters exceeded national drinking water standards, indicating compromised water quality in quarry-influenced sections of the river. The mean pH values across all sampling zones were consistently below the lower acceptable limit set by PNSDW, suggesting mildly acidic conditions. Such deviations are environmentally significant, as changes in pH can influence aquatic ecosystem stability and the solubility of contaminants, particularly in river systems experiencing sediment disturbance. Recent studies have similarly documented altered pH levels in rivers subjected to aggregate extraction, attributing these shifts to increased sediment resuspension and disruption of natural buffering processes (Amoah et al.,2024; Singh et al., 2025).

Turbidity levels were markedly elevated across all sampling locations, with the highest mean value recorded in midstream samples. These findings are consistent with the mechanical disturbance of riverbeds and banks caused by quarrying activities, which increase suspended sediments during and after extraction operations. Elevated turbidity not only reduces light penetration but also serves as a transport medium for attached pollutants and microbial contaminants. Comparable turbidity exceedances have been reported in quarry-impacted rivers in other developing regions, where extraction intensity and inadequate regulation contribute to persistent water quality deterioration (Rentier & Cammeraat, 2022; Mia et al., 2024Ba).

Total dissolved solids concentrations likewise exceeded recommended limits, particularly in midstream samples, reflecting the cumulative effects of disturbed sediments and altered hydrological conditions. While nitrate concentrations remained within permissible thresholds, their proximity to regulatory limits suggest increased nutrient loading, which may be exacerbated by land-use changes and surface runoff in quarry-adjacent areas. Apparent color values also surpassed acceptable standards, reinforcing visual and aesthetic degradation of the river, an issue frequently associated with fine sediment mobilization in extractive landscapes (Ayuk et al., 2020; Gamu & Soendergaard, 2024).

Hence, the consistent exceedance of turbidity, TDS, and color standards, paired with substandard pH levels, indicates that current quarrying practices pose environmental risks to river systems relied upon by local communities. These findings align with recent interdisciplinary studies emphasizing that small-scale and unregulated aggregate extraction can significantly alter river water quality, particularly in rural settings where monitoring and mitigation measures are limited (Donkoh, 2025; Amoah et al.,2024; Ikpi et al., 2024). Figure 2 below provides a visual representation of bank disturbance along the left shore of the river, where extraction activities have altered natural sediment structures.

Figure 2. Left Bank Quarrying Zone Showing Bank Disturbance and Sediment Exposure

4.2 Spatial Variation in Water Quality Across River Sections

Beyond overall water quality conditions, examining spatial variation across river sections provides further insight into how quarrying activities influence localized environmental conditions. Water samples collected from the left bank, midstream, and right bank revealed discernible differences in several physico-chemical parameters, suggesting uneven exposure to quarry-related disturbances. To assess whether these observed variations were statistically meaningful, a non-parametric Kruskal–Wallis H test was employed, given the limited sample size and non-normal distribution of environmental data. The results of this analysis are summarized in Table 2, which compares key parameters across river sections.

Table 2. Kruskal–Wallis Test Results for Spatial Variation in River Water Quality

Parameter	χ^2 (H)	df	p-value	Interpretation
pH	4.87	2	0.088	Not statistically significant
Turbidity	7.92	2	0.019	Statistically significant
TDS	6.34	2	0.042	Statistically significant
Nitrate	3.11	2	0.211	Not statistically significant
Color	5.96	2	0.051	Marginally significant

As shown in Table 2, statistically significant spatial differences were observed for turbidity and total dissolved solids, indicating that water quality degradation is not uniformly distributed across the river. Midstream samples consistently exhibited higher turbidity and TDS levels compared to samples collected from both riverbanks. This pattern suggests that active extraction within the river channel exerts a more pronounced influence on midstream water conditions, where sediment agitation and resuspension are most intense. Similar spatial gradients have been reported in recent studies of quarry-affected river systems, where mid-channel disturbance was identified as a critical driver of suspended solids and dissolved material concentrations (Rentier & Cammeraat, 2022; Singh et al., 2025).

In contrast, pH and nitrate concentrations did not exhibit statistically significant differences across river sections, although slight variations were observed. The relative uniformity of these parameters may reflect broader catchment-scale influences, such as upstream land use and natural geochemical buffering, which can moderate localized disturbances. Nonetheless, the consistently substandard pH levels across all sections reinforce the conclusion that quarrying-related impacts operate at both localized and system-wide scales. Recent environmental assessments have emphasized that while some water quality indicators respond immediately to point disturbances, others reflect cumulative effects over larger spatial extents (Amoah et al.,2024; Gamu & Soendergaard, 2024).

Color values approached statistical significance, with higher mean values again observed in midstream samples. Elevated color is often associated with fine suspended sediments and organic matter mobilized during extraction activities, contributing to reduced aesthetic quality and increased treatment costs for domestic use. The spatial concentration of color degradation in midstream zones aligns with documented patterns in aggregate-mining contexts, where riverbed excavation alters flow velocity and sediment transport dynamics (Mia et al., 2024; Donkoh, 2025).

Thus, the spatial analysis underscores that quarrying impacts on water quality are unevenly distributed within the river system, with midstream sections experiencing more severe degradation than adjacent banks. These findings highlight the importance of spatially targeted monitoring and regulation, as impacts may be underestimated if assessments rely solely on single-point sampling (Bolaji, 2025; Bayazidy et al., 2024). Recent interdisciplinary research similarly stresses that understanding intra-river variation is essential for designing effective environmental management strategies in extractive landscapes (Ayuk et al., 2020; Singh et al., 2025).

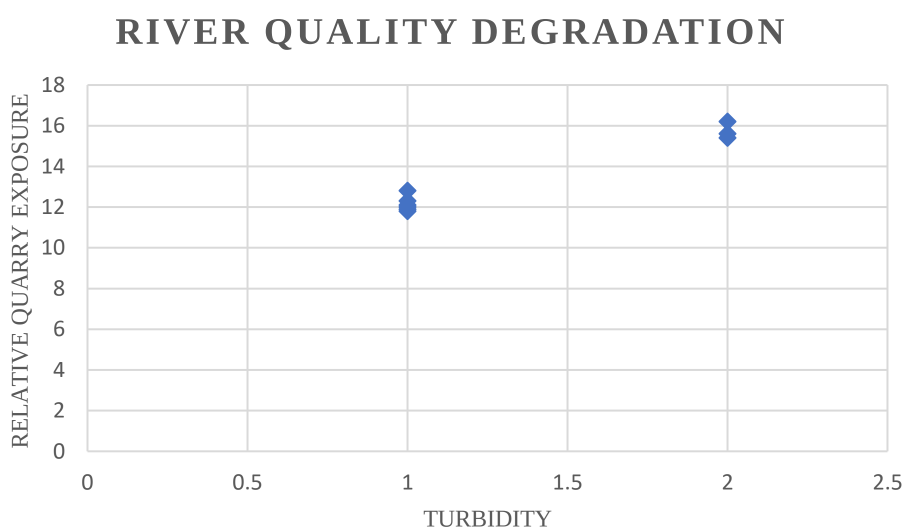

Figure 3. Scatter Plot Linking Quarrying Intensity and Water Quality Degradation

Figure 3 illustrates the relationship between relative quarrying exposure and turbidity levels across sampled river sections. Samples collected from areas with higher exposure to quarrying activity, represented by midstream locations, tend to cluster at higher turbidity values compared to those from riverbanks. While the figure does not establish causality, it implies a consistent association between increased riverbed disturbance and suspended sediment concentrations. Similar associations between extraction intensity and turbidity have been documented in recent quarry-affected river studies, emphasizing the sensitivity of sediment dynamics to in-channel aggregate extraction (Rentier & Cammeraat, 2022; Singh et al., 2025).

4.3 Community-based Perceptions on the Environmental impact of River Quarrying

Understanding how residents perceive environmental changes complements measured water quality data and stresses how ecological shifts are experienced socially. Results from the environmental perception survey indicate that most households in Masiu associate quarrying with noticeable deterioration in river water clarity, taste, and safety for domestic uses (see Table 3). Respondents particularly agreed that water turbidity and discoloration have worsened since the start of quarrying operations, with many reporting changes in sensory qualities such as taste and color. These perceptions align with empirical environmental assessments that find community knowledge often reflects actual changes in ecosystem services, especially in contexts where people rely directly on freshwater sources (Koehnken et al., 2020).

Table 3. Community Perceptions of River Water Quality Changes (n = 200)

Indicator	Mean Score (1–4)	Interpretation
Increased turbidity since quarrying	3.78	Agree
Water appears discolored	3.64	Agree
River water quality unsafe for drinking	3.81	Agree
River water has negative odor/taste	3.55	Agree
Decline in fish and aquatic life observed	3.42	Agree
Distance from quarry affects perception intensity	3.30	Agree

Community perceptions are not merely subjective impressions; they often serve as valid indicators of water quality and human health risk in settings impacted by extractive activities. For example, in artisanal and small-scale mining contexts, high proportions of local respondents recognize mining-related water pollution and link it to immediate health and livelihood concerns (Koehnken et al., 2020). Likewise, residents in industrial mining areas have associated water pollution with visible color changes, odor alterations, and reduced potability findings that resonate with those reported in Masiu, where over three-quarters of respondents acknowledged a decline in water quality post-quarrying (Deb et al.,, 2025).

Interview narratives further underscore these survey results. One long-time resident described how the river “used to taste fresh and clear,” but now “even children refuse to drink from it,” citing changes in color and sediment load following extraction activities. Another participant noted that the river is “no longer suitable” for cooking or bathing without prior treatment, reflecting concerns that echo household perceptions documented in other rural water systems affected by nearby extractive operations (Nawan et al., 2025). Research integrating community perceptions with water quality monitoring has found similar patterns, where local knowledge enhances understanding of spatial pollution gradients and temporal shifts in water characteristics (Mishra et al., 2024).

The perceived decline in aquatic life and fish catches reported by many respondents also reflects broader concerns about ecosystem impacts. Studies in other mining and quarrying regions have documented links between water quality degradation and loss of biodiversity, as sediment and pollutant loads stress aquatic organisms and disrupt food webs (Kashvi & Dar, 2025; Ogbo et al.,, 2024). In this study, residents near the midstream section where measured turbidity and total dissolved solids were highest were particularly likely to report decreases in visible aquatic fauna, suggesting that spatial patterns in environmental degradation are mirrored in lived experience.

It is important to note that perceptions varied by distance from quarry sites, with respondents living closer to extraction zones expressing stronger agreement with negative water quality changes than those farther away. This distance-based pattern is consistent with research that highlights proximity as a modifier of environmental concern and experiential exposure, particularly in rural mining and water-polluted contexts (Mukukai et al., 2025). Such spatial differences in perception are valuable for environmental planning, as they signal where community anxiety and perceived risk are most acute and may indicate areas for targeted intervention. Figure 3 presents a heatmap illustrating the spatial variation in community perceptions of water turbidity, taste, and safety across selected barangays in Masiu, Lanao del Sur.

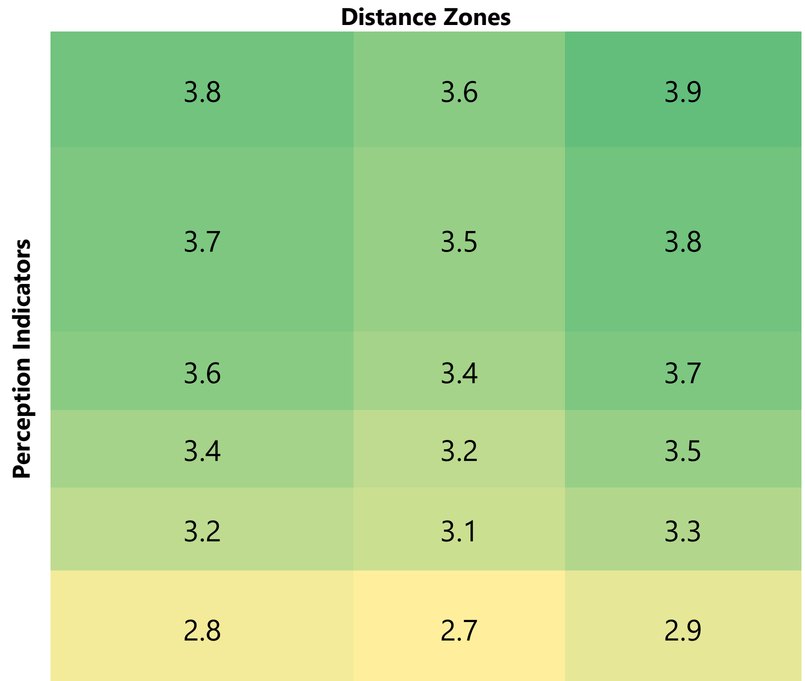

Figure 4. Spatial Distribution of Community Perceptions of River Water Degradation

The heatmap in Figure 4 reveals a clear spatial gradient in perceived environmental degradation, with barangays located closer to quarrying zones exhibiting higher perception scores across all indicators. Perceptions of turbidity and water safety were strongest in Gondarangin and A. Datimbang, while lower scores were observed in Magayo Bago a Ingud, the farthest barangay from active extraction sites. This pattern suggests that exposure and proximity play a significant role in shaping community awareness and experience of quarrying-related water quality changes. Community perspectives on water safety and ecosystem changes also intersect with concerns about health outcomes. Local observations of increased sickness following water use are echoed in research from other resource-dependent contexts, where perceived water contamination correlates with reported episodes of diarrheal and skin conditions (Mukukai et al., 2025). Importantly, the use of community perceptions alongside empirical water quality measures has been shown to improve water governance outcomes, as local knowledge often identifies nuanced changes that short-term water sampling alone might miss (Mishra et al., 2024).

Therefore, the convergence of survey results and interview in Masiu indicates that residents possess situated environmental knowledge regarding river degradation due to quarrying. Rather than being anecdotal, such perceptions are increasingly recognized as legitimate evidence in interdisciplinary environmental assessments, particularly when triangulated with measured data (Koehnken et al., 2020; Azevedo et al., 2022)

4.4 Triangulation of Measured Water Quality and Community Perceptions

The integration of laboratory-based water quality analysis, community perception survey results, and interview narratives provides a robust triangulation of evidence regarding river water degradation in Masiu, Lanao del Sur. Rather than relying on a single data source, this study adopts a multi-evidence approach to capture both the biophysical condition of the river and the lived experiences of affected communities. The convergence of these independent data streams strengthens confidence in the findings and reduces the likelihood that observed patterns are coincidental or perception-driven alone.

Measured water quality parameters discussed in previous sections indicate elevated turbidity and total dissolved solids, alongside pH values that frequently fall outside recommended standards for domestic water use. These laboratory results establish an objective baseline of water quality degradation. When examined alongside community-based perception data (Table 3), a strong alignment becomes evident. Respondents overwhelmingly reported increased water turbidity, changes in taste and color, and reduced suitability of river water for household use. This correspondence suggests that residents' assessments are grounded in observable and measurable environmental changes rather than abstract concern, a pattern widely reported in community-based water quality studies where daily interaction with water sources heightens environmental awareness (Azevedo et al., 2022; Mishra et al, 2024; Koehnken et al., 2020).

Interview narratives further deepen this triangulation by providing contextual and temporal insights that bridge quantitative measurements and perception scores. Participants consistently described gradual yet persistent deterioration in river conditions, noting that changes became more pronounced following quarrying activities and periods of active extraction. Accounts of sediment-laden water, altered taste, and reduced reliance on the river for drinking and cooking correspond directly with elevated turbidity and dissolved solids recorded in sampled locations. Such qualitative evidence complements the spatial trends identified in measured data, particularly the heightened degradation observed in midstream and near-quarry sections, and aligns with findings from other quarry-affected river systems where in-channel extraction disrupts sediment dynamics over time (Donkoh, 2025; Singh et al., 2025).

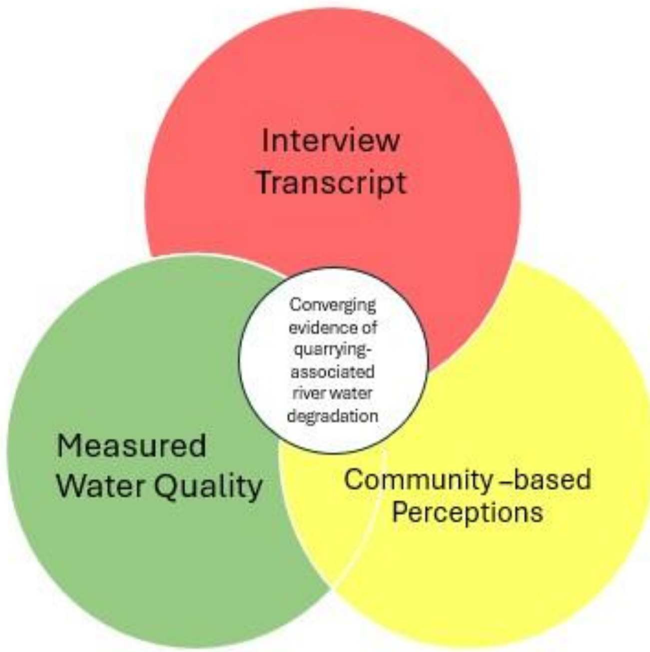

Figure 5. Triangulation framework correlating measured water quality, community-based perceptions, and interview narratives

The triangulation framework is visually summarized in Figure 5, which illustrates the convergence of three independent evidence streams: measured water quality indicators, community-based perception survey results, and interview transcript insights. The overlapping center of the diagram emphasizes that all three sources independently point toward a shared conclusion namely, the presence of quarrying-associated river water degradation. By presenting this synthesis graphically, the figure clarifies how scientific measurements, community observations, and lived experiences reinforce rather than contradict one another. Such visual triangulation has been increasingly employed in interdisciplinary environmental research to communicate complex mixed-method findings in a transparent and accessible manner (Agyeman et al., 2016; Sharma et al., 2024).

Importantly, this triangulated evidence also highlights the socio-environmental implications of water quality decline. Interview data reveal adaptive household responses, including reduced direct consumption of river water and increased dependence on alternative sources, reflecting perceived health risks. These behavioral adjustments mirror trends documented in recent environmental health literature, where sensory indicators of water contamination often prompt changes in household practices even in the absence of formal advisories (Amoah et al., 2024; Mukukai et al., 2025). When considered together, the measured data, perception scores, and narratives suggest that quarrying-related environmental changes have tangible consequences for water use, health perceptions, and daily decision-making (Hemmler et al., 2024).

4.5 Policy and Environmental Consequences of River Quarrying in Masiu, Lanao del Sur

The convergence of laboratory-measured water quality degradation, community-based perceptions, and interview narratives underscores the need for more responsive and context-sensitive environmental governance of river aggregate quarrying in Masiu, Lanao del Sur. The findings indicate that current quarrying practices have implications not only for riverine ecosystems but also for household water security and community well-being. As such, environmental management strategies should move beyond compliance-based regulation toward adaptive, locally informed approaches that recognize both biophysical indicators and lived experience as legitimate inputs to decision-making. (

1. First, the documented elevation in turbidity and total dissolved solids, coupled with widespread community concern regarding water safety, highlights the importance of strengthening routine water quality monitoring in quarry-affected river systems. Local government units, in coordination with environmental agencies, may consider establishing regular monitoring schedules that include both laboratory testing and community reporting mechanisms. Integrating community observations into monitoring frameworks has been shown to improve early detection of environmental degradation and foster greater trust between regulators and affected populations (Azevedo et al., 2022; Mishra et al., 2024). In resource-limited settings, such hybrid monitoring approaches can enhance coverage while maintaining scientific credibility.
2. Second, the spatial patterns identified in this study particularly the concentration of impacts near midstream and in-channel extraction zones suggest that quarrying regulations should incorporate spatial planning measures. These may include the designation of buffer zones, restrictions on extraction during periods of high flow, and limits on in-channel quarrying intensity. Recent environmental management literature emphasizes that spatially explicit regulation is more effective than uniform rules in mitigating sediment disturbance and protecting downstream water quality (Donkoh, 2025; Singh et al., 202). Applying such measures in Masiu could help reduce localized degradation while allowing controlled economic activity to continue.
3. Third, the adaptive behaviors reported in interviews, such as reduced reliance on river water and increased household expenditure on alternative sources, point to indirect socio-environmental costs that are often overlooked in quarrying policies. Environmental management frameworks should therefore account for these hidden burdens when assessing the overall sustainability of quarrying operations. Incorporating community feedback into environmental impact assessments and permit renewals can help ensure that management decisions reflect not only physical thresholds but also social acceptability and equity considerations (Agyeman et al., 2016; Sharma et al., 2024).
4. Finally, triangulated evidence supports the value of participatory environmental governance. Engaging local residents in monitoring, reporting, and dialogue processes can enhance compliance, improve data quality, and strengthen accountability. Studies from similar extractive contexts demonstrate that when communities are recognized as active stakeholders rather than passive recipients of environmental risk, policy interventions are more likely to be effective and durable (Amoah et al., 2024; Mukukai et al., 2025; Koehnken et al., 2020). For Masiu, adopting community-informed management strategies could serve as a foundation for policy development that balances livelihood needs with long-term environmental protection.

5. Conclusion

This study examined the environmental impacts of river aggregate quarrying in Masiu, Lanao del Sur through an integrated assessment combining laboratory-based water quality analysis, community perception surveys, and interview narratives. The findings indicate consistent patterns of river water degradation characterized by elevated turbidity and total dissolved solids, alongside pH levels that frequently fall outside recommended standards for domestic use. These measured conditions correspond closely with community perceptions of declining water clarity, altered taste, and reduced suitability of river water for household purposes. The spatial alignment between degraded water quality parameters and areas of active quarrying, particularly within midstream sections, further reinforces the presence of localized environmental stress associated with extraction activities.

By triangulating scientific measurements with community-based knowledge and lived experience, the study demonstrates the value of mixed-method approaches in environmental impact assessment, particularly in resource-dependent and rural contexts. The convergence of multiple evidence streams enhances the credibility of the findings and highlights the importance of incorporating community perspectives into environmental monitoring and policy development. Overall, the results underscore the need for more adaptive and participatory management of river aggregate quarrying to safeguard water quality and community well-being, while providing a baseline for future research and policy interventions aimed at promoting environmentally sustainable extractive practices.

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