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From Local Discharge to Global Responsibility: Industrial Water Pollution, Environmental Sustainability, and a Case Study of Marble-Processing Wastewater in District Buner, Pakistan

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Research Article

Keywords: industrial wastewater, marble industry, water quality, environmental sustainability, watershed management, District Buner, Pakistan, global environmental responsibility

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From Local Discharge to Global Responsibility: Industrial Water Pollution, Environmental Sustainability, and a Case Study of Marble-Processing Wastewater in District Buner, Pakistan

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Abstract

Background: Freshwater systems are under increasing pressure from industrialization, urbanization, population growth, and inadequate environmental management. Although pollution is often addressed as a local problem, rivers, streams, watersheds, and groundwater systems are interconnected. Local discharges can therefore create cumulative environmental pressures beyond the point of release.

Objective: This study examines wastewater generated by marble-processing industries in District Buner, Khyber Pakhtunkhwa, Pakistan, and considers its implications for environmental sustainability, watershed management, and shared environmental responsibility.

Methods: A preliminary environmental assessment combined field observations, photographic documentation, and laboratory analysis of water samples collected from four locations: an upstream reference site, a direct discharge point, a mixing zone, and a downstream site. The analyzed parameters were pH, turbidity, total dissolved solids (TDS), electrical conductivity, salinity, and resistance.

Results: Approximately 450 marble-processing facilities operate across the district, many of which discharge untreated wastewater containing suspended stone particles into drainage channels and freshwater streams. Turbidity increased from 2.3 NTU at the upstream reference site to 1,600 NTU at the discharge point. TDS increased from 185 to 1,240 mg/L, and electrical conductivity increased from 370 to 2,480 µS/cm. Field observations also documented the exposure of agricultural land, livestock, and surrounding communities to affected water bodies.

Conclusions: The findings indicate substantial physical deterioration of water quality at industrial discharge points. The study does not establish acute chemical toxicity, because the analytical scope was limited, but it demonstrates the importance of controlling suspended solids and sediment discharge. Local pollution should be managed within an integrated watershed framework because repeated discharges across many facilities can create cumulative environmental pressures.

Keywords: industrial wastewater; marble industry; water quality; environmental sustainability; watershed management; District Buner; Pakistan; global environmental responsibility

Abbreviations

The abbreviations used in this manuscript are listed in Table 1.

Table 1. Abbreviations used in this manuscript.

Abbreviation	Full term
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
IPCC	Intergovernmental Panel on Climate Change
NEQS	National Environmental Quality Standards
NTU	Nephelometric Turbidity Units
SDGs	Sustainable Development Goals
TDS	Total Dissolved Solids
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization

Introduction

Background

Freshwater is essential for human societies, ecosystems, agriculture, industry, and biodiversity. Despite its importance, freshwater systems face increasing pressure from industrialization, urbanization, population growth, and inadequate environmental management [1–4]. Water pollution is frequently treated as a local or jurisdictional issue; however, environmental systems do not conform to political boundaries. Streams and rivers connect landscapes, transport sediments and pollutants, and influence downstream communities and ecosystems.

Pollution generated at one location may therefore contribute to wider regional pressures through connected waterways, groundwater systems, and watersheds. Although dilution and natural attenuation can reduce pollutant concentrations, these processes do not necessarily restore ecological conditions, particularly where discharges are continuous or occur at many locations. This local-to-global perspective provides the conceptual basis for examining marble-processing wastewater in District Buner.

Environmental Sustainability and Shared Responsibility

Sustainable development requires present needs to be met without compromising the ability of future generations to meet their own needs [5]. Environmental sustainability consequently requires responsible management of water, land, energy, and other natural resources. The Sustainable Development Goals,

especially Goals 6, 12, 13, 14, and 15, emphasize the interdependence of water quality, responsible production, climate action, aquatic ecosystems, and terrestrial ecosystems [5,6].

This study was motivated by field observations of untreated wastewater from marble-processing facilities entering freshwater streams in District Buner. These streams support agriculture, livestock production, and community activities. The central argument is not that wastewater from one facility directly contaminates global water resources. Rather, the study argues that repeated local practices can accumulate across watersheds and regions, making local pollution prevention a component of broader environmental responsibility.

Marble Processing and Wastewater Generation

Marble-processing operations use water primarily to cool cutting equipment, reduce friction, suppress dust, and transport particles away from cutting surfaces. The resulting wastewater commonly contains suspended marble dust and fine mineral particles [7,8]. Untreated discharge can increase turbidity and suspended-solid concentrations, reduce water clarity, promote sediment deposition, alter stream morphology, and impair aquatic habitats [9,10].

Marble-processing effluent differs from many chemical-industry discharges because it is generally dominated by suspended mineral particles, including calcium carbonate, rather than highly toxic organic compounds. This distinction does not eliminate environmental concern. Large volumes of untreated effluent can degrade physical water quality, accumulate sediment, and reduce the suitability of water for agricultural and domestic uses [8,11]. Sedimentation tanks, filtration, wastewater recycling, and centralized treatment facilities have been identified as relevant mitigation measures [7,12].

Study Area: District Buner

District Buner is located in Khyber Pakhtunkhwa Province, Pakistan, and is recognized for its marble resources and associated processing activities. The industry contributes to local employment and economic activity, but wastewater management remains a significant environmental challenge. Field observations indicated that untreated wastewater was discharged into open drainage systems and freshwater streams that support agriculture, livestock, and community livelihoods.

Approximately 450 marble-processing facilities operate across different locations in the district. Their decentralized distribution across communities and watersheds complicates systematic monitoring, enforcement, and pollution control. The combination of distributed industrial activity and interconnected freshwater systems makes District Buner a relevant case for studying the relationship between industrial discharge and watershed-level environmental impacts.

Research Gap

Existing research has documented marble wastewater characteristics and treatment options, but four important gaps remain. First, much of the literature emphasizes technical wastewater characterization without adequately connecting local findings to integrated sustainability and watershed frameworks. Second, District Buner remains comparatively understudied despite its extensive and geographically

distributed marble-processing sector. Third, limited work combines field observations, photographic documentation, and laboratory analysis with an explicit local-to-global environmental responsibility perspective. Fourth, livestock exposure pathways and the implications for agricultural communities have received limited documentation.

This study addresses these gaps through a preliminary assessment of discharge practices and selected physicochemical water-quality parameters. It also situates the findings within a broader discussion of cumulative environmental effects, responsible industrial development, and integrated watershed management.

Research Objectives

The study objectives were to:

1. Document wastewater-discharge practices associated with marble-processing industries in District Buner.
2. Assess preliminary water-quality conditions through field observations and laboratory analysis.
3. Evaluate potential environmental implications for local communities, agriculture, and livestock.
4. Interpret industrial pollution within the broader context of environmental sustainability and shared responsibility.
5. Propose practical recommendations for pollution prevention and sustainable environmental management.

Literature Review

Global Water-Pollution Challenges

Water pollution affects water quality, biodiversity, ecosystem services, and human well-being. Industrial wastewater may contain suspended solids, chemicals, nutrients, metals, and other contaminants. In many developing regions, industrial expansion has occurred more rapidly than environmental regulation and treatment infrastructure, leaving wastewater systems inadequate or absent [1–4]. Sustainable industrial development therefore requires an approach that balances economic activity with pollution prevention and protection of freshwater resources.

Sustainability and Integrated Watershed Management

Water resources support agriculture, energy production, biodiversity conservation, industry, and public health. Effective management must consequently integrate environmental, economic, and social dimensions. Watershed-based approaches are particularly relevant because activities in one part of a catchment can affect conditions elsewhere through the movement of water, sediment, nutrients, and pollutants [3,4]. Pollution prevention at the source is therefore more effective than relying exclusively on downstream dilution or natural recovery.

Marble-Processing Wastewater Characteristics and Impacts

Marble wastewater typically contains high concentrations of suspended mineral particles, especially calcium carbonate and fine stone dust. Reported impacts include reduced water clarity, sediment accumulation, channel modification, habitat degradation, interference with aquatic processes, and possible impairment of irrigation systems [7–10]. Treatment strategies include sedimentation, coagulation, filtration, recycling, and centralized treatment. Their suitability depends on facility size, wastewater volume, technical capacity, and regulatory oversight [7,12].

Marble-Industry Challenges in Pakistan

Pakistan has substantial marble resources, particularly in Khyber Pakhtunkhwa. The industry supports employment and regional economic development, but studies have reported elevated turbidity, sediment loads, and declining water quality in areas affected by marble wastewater. Inadequate treatment infrastructure and weak enforcement remain barriers to sustainable industrial development [8,11,13]. District Buner warrants further attention because facilities are distributed across multiple communities and watersheds.

Local-to-Global Environmental Responsibility

Environmental systems operate as interconnected networks rather than isolated units. Rivers, streams, groundwater, and ecological processes create pathways through which local disturbances may influence broader environmental conditions [3,4]. The cumulative-effects perspective is especially relevant: a single discharge may have a limited geographic footprint, but similar discharges from hundreds of facilities and across many regions can create substantial regional pressures.

Accordingly, environmental governance should recognize both local accountability and shared responsibility. Local actors, regulators, industries, and communities each have roles in protecting water resources, reducing pollution at its source, and maintaining watershed health.

Study Area and Industrial Context

Geographic and Environmental Context

The study was conducted in District Buner, Khyber Pakhtunkhwa, Pakistan. The assessment focused on freshwater streams and drainage pathways located near marble-processing activities. These water bodies are used by surrounding communities and are connected to agricultural and livestock activities.

Importance of the Marble-Processing Sector

Marble processing is economically important in the district and includes cutting, polishing, and finishing operations. Water is used during processing, and the wastewater carries suspended stone particles. Because facilities are distributed rather than concentrated in one fully serviced industrial zone, wastewater enters the environment through multiple pathways.

Distribution of Processing Units and Discharge Pathways

Approximately 450 small- to medium-scale units operate across the district. Field observations indicated that wastewater was frequently discharged into open drainage channels, nearby natural streams, and unlined soil pathways that eventually connected to watercourses. The decentralized distribution of facilities makes monitoring and pollution control difficult and allows multiple discharge points to contribute to cumulative watershed pressure.

Environmental Significance of the Study Area

District Buner provides a relevant case study because industrial activity is distributed across an interconnected freshwater system, while centralized wastewater treatment infrastructure is limited. Downstream agricultural and rural areas may therefore experience direct exposure to degraded water. The case illustrates how local industrial practices can be examined within a broader environmental-sustainability framework.

Materials and Methods

Research Design

The study used a preliminary environmental-assessment design combining qualitative field observations, photographic documentation, and quantitative laboratory analysis. The qualitative component documented discharge practices, visible water conditions, sediment accumulation, agricultural proximity, livestock interaction, and community exposure. The quantitative component compared selected water-quality parameters at four sampling locations.

Sampling Strategy

Water samples were collected from four locations representing a pollution gradient. Sample A represented upstream reference conditions, Sample B represented a direct industrial discharge point, Sample C represented the initial mixing zone, and Sample D represented a downstream location after partial dilution and sedimentation. The sampling locations and their rationale are summarized in Table 2.

Table 2. Sampling locations and their rationale.

Sample	Location type	Description	Rationale
A	Upstream reference	Spring water before apparent industrial influence	Baseline comparison
B	Direct discharge	Wastewater outlet from marble-processing units	Assessment of maximum observed exposure
C	Mixing zone	Stream section immediately after wastewater entry	Assessment of initial dilution
D	Downstream	Stream section farther downstream	Assessment of partial attenuation

Field Observations and Photographic Documentation

Field investigations documented wastewater-discharge points, water-flow pathways, visual water characteristics, sediment accumulation, agricultural fields near streams, livestock interaction with stream water, and community exposure. The wastewater was frequently described as milky or white, consistent with the presence of suspended marble particles. Photographs were collected as supporting documentation of the study area, processing facilities, cutting operations, discharge channels, stream entry points, and livestock access to affected water. Fig. 1 shows the location of District Buner and the approximate sampling locations, Fig. 2 shows a typical marble-processing facility in the study area, Fig. 3 shows a marble-cutting operation using water, Fig. 4 shows direct discharge of untreated wastewater, and Fig. 5 shows livestock drinking from stream water influenced by industrial discharge.

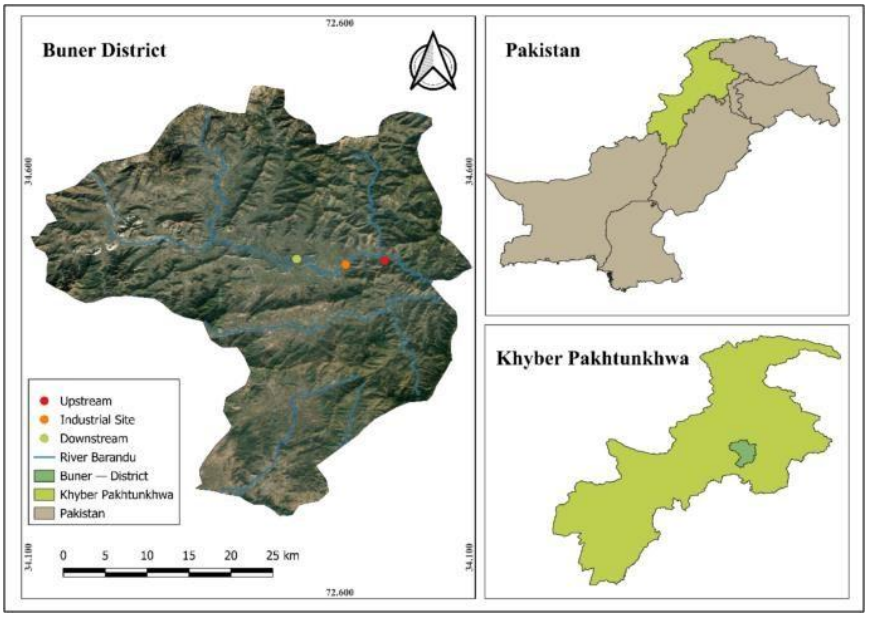


Figure 1. Location map of District Buner, Khyber Pakhtunkhwa, Pakistan, with approximate sampling locations.



Figure 2. Typical marble-processing facility in the study area.



Figure 3. Marble-cutting operation using water for cooling and particle removal.



Figure 4. Direct discharge of untreated wastewater from a marble-processing facility. The same field scene also documents wastewater moving toward a receiving watercourse; the supplied PDF did not contain a separate embedded image for the original Figure 5 caption.



Figure 5. Livestock drinking from stream water influenced by industrial discharge.

Sample Handling and Laboratory Analysis

Water samples were collected in clean polyethylene bottles, labeled at the point of collection, and transported to a university laboratory under controlled conditions. The reported analyses followed the available laboratory procedures.

Table 3. Parameters measured and analytical approaches.

Parameter	Analytical approach	Unit
pH	Electrometric measurement using a calibrated pH meter	—
Turbidity	Nephelometric measurement using a Hach 2100Q turbidimeter	NTU
TDS	Gravimetric measurement after filtration	mg/L
Electrical conductivity	Conductivity-meter measurement	µS/cm
Salinity	Calculated from conductivity measurements	ppm
Resistance	Conductivity-meter measurement	MΩ

Quality Control

The reported quality-control measures included triplicate analysis for each parameter, instrument calibration before measurement, the use of deionized water for blanks, and chain-of-custody documentation. The final journal submission should additionally report sampling dates, sample volumes, holding times, laboratory identification, detection limits, and the exact standard methods used.

Data Analysis

The results were compared descriptively across the four sampling locations. The manuscript reports coefficients of variation and a statistical significance claim for upstream-versus-discharge differences. Because the original submission does not specify the statistical test, sample size, degrees of freedom,

or full variance estimates, these statistics should be verified and documented before journal submission. In the revised presentation below, the numerical observations are retained, while causal and toxicological interpretations are appropriately qualified.

Results

Visual Assessment

Upstream freshwater appeared clear and colorless, whereas wastewater from marble-processing facilities exhibited a dense white or milky appearance. In several locations, wastewater entered freshwater streams without an observable treatment, filtration, or recycling process. Visible sediment accumulation along stream channels suggested repeated deposition of suspended material.

Agricultural fields near affected streams relied on surface water for irrigation, and livestock were observed accessing stream water in areas influenced by industrial discharge. These observations identify potential exposure pathways but do not, by themselves, establish health effects.

Physicochemical Water-Quality Results

Table 4. Physicochemical water-quality results at the four sampling locations, with reference guideline values.

Parameter	A: Upstream	B: Discharge	C: Mixing zone	D: Downstream	WHO guideline*	NEQS standard*
pH	7.2	8.1	7.8	7.5	6.5–8.5	6.0–9.0
Turbidity (NTU)	2.3	1,600	845	124	<5	<50
TDS (mg/L)	185	1,240	780	320	<1,000	<3,500
Electrical conductivity (µS/cm)	370	2,480	1,560	640	—	—
Salinity (ppm)	0.2	1.2	0.8	0.4	—	—
Resistance (MΩ)	2.7	0.4	0.6	1.5	—	—

**Note: Guideline and standard values are reproduced from the submitted manuscript and must be checked against the exact applicable WHO and national standards, intended water use, and regulatory classification before publication.*

Interpretation of Water-Quality Patterns

Turbidity showed the greatest variation across sampling locations, with the manuscript reporting a coefficient of variation of 89.33%. pH varied comparatively little, with a reported coefficient of variation of 4.97%. Turbidity at the discharge point was approximately 696 times the upstream value, while TDS and electrical conductivity were approximately 6.7 and 6.7 times higher, respectively.

The downstream decline in turbidity and conductivity suggests partial attenuation through dilution, sedimentation, and particle settling. However, downstream values did not return to upstream conditions within the observed reach. The reported claim that all parameters differed significantly between upstream and discharge samples should be retained only after the underlying statistical analysis is supplied and independently checked.

Environmental Observations and Pollution Pathway

The observed pollution pathway was: marble processing generates wastewater containing suspended stone particles; wastewater enters open drainage systems; drainage systems discharge into freshwater streams; streams connect with larger waterways; and larger waterways join regional river systems. This pathway does not demonstrate direct global contamination from a single facility. It does demonstrate how multiple local sources can create cumulative pressure within connected watersheds.

Potential Agricultural and Livestock Exposure

Agricultural fields adjacent to affected streams may receive sediment-rich irrigation water. Prolonged deposition of suspended particles could affect infiltration, irrigation efficiency, soil surface conditions, and nutrient dynamics. These are potential implications requiring targeted soil and crop studies; they were not directly measured in the present investigation.

Livestock, including buffaloes, cattle, goats, and sheep, were observed drinking from streams influenced by industrial discharge. The study did not include veterinary examinations, milk testing, toxicological analysis, or exposure-dose assessment. Accordingly, the observations identify a potential exposure pathway rather than demonstrating animal-health effects or contamination of dairy products.

Discussion

Local Water-Quality Consequences

The results show a pronounced deterioration in physical water quality at the industrial discharge point, particularly in turbidity. The pattern is consistent with the discharge of fine marble particles generated during cutting and polishing. Although turbidity alone does not establish chemical toxicity, high suspended-solid loads can reduce water clarity, increase sediment deposition, alter streambed characteristics, and impair the suitability of water for some uses.

The persistence of elevated values at the downstream site indicates that the impact extends beyond the immediate discharge point. Where wastewater inputs are continuous or repeated across many facilities, the receiving stream may experience chronic physical stress that exceeds its capacity for natural recovery.

Agricultural Implications

The presence of suspended solids in irrigation water raises concerns for agricultural sustainability. Potential mechanisms include reduced soil porosity, lower infiltration capacity, surface crust formation, altered soil chemistry, and reduced irrigation efficiency. These mechanisms were not measured directly in this study and should therefore be treated as hypotheses for future research rather than confirmed effects.

Livestock Exposure Concerns

Livestock access to affected streams is an important environmental observation because water quality can influence animal hydration, hygiene, productivity, and the safety of animal-derived products. However, the present study did not measure biological contaminants, trace elements, animal health, milk quality, or exposure dose. Future studies should address these endpoints using veterinary, toxicological, and public-health methods.

Comparison with Previous Studies

The observed pattern is broadly consistent with previous studies reporting elevated turbidity, suspended solids, and sediment accumulation in areas receiving untreated marble wastewater. The present results extend that body of work by documenting a pollution gradient in District Buner and by emphasizing the relevance of distributed discharge points, agricultural exposure, livestock access, and watershed connectivity.

Table 5. Comparison of the present study with previous studies.

Study	Location	Reported turbidity (NTU)	Reported TDS (mg/L)	Main reported finding
Present study	District Buner, Pakistan	2.3–1,600	185–1,240	Direct discharge and observed livestock access
Kumar et al. (2021)	India	1,200–1,800	890–1,450	Sediment accumulation and irrigation concerns
Rafique et al. (2022)	Khyber Pakhtunkhwa, Pakistan	400–1,500	450–1,100	Seasonal variation and inadequate treatment
Hussain et al. (2020)	Northern Pakistan	300–1,200	500–1,000	Treatment options and recycling potential

Note: Comparative values and source details should be verified against the original publications before submission.

Natural Attenuation and Study Limitations

The downstream reduction in turbidity and conductivity suggests that dilution, sedimentation, and particle settling provide partial natural attenuation. Nevertheless, the persistence of elevated values relative to the upstream reference site indicates that natural processes alone may be insufficient where discharge is continuous. Factors limiting recovery may include high sediment loads, limited stream dilution capacity, repeated inputs, sediment accumulation, and changes in channel morphology.

The study is preliminary. Its limitations include the small number of sampling locations, limited temporal coverage, lack of seasonal monitoring, and analysis of only selected physicochemical parameters. Heavy metals, microbial contamination, toxic compounds, sediment chemistry, aquatic biodiversity, soil quality, livestock health, milk quality, and human health were not assessed. The absence of wastewater-flow measurements and detailed facility-level production data also limits the ability to estimate pollutant loads.

Sustainability and Policy Implications

The findings support an integrated watershed perspective: protecting a local stream contributes to protecting the watershed, and watershed protection supports broader ecosystem sustainability. The appropriate policy response is not to characterize one facility as a global source of pollution, but to recognize that cumulative discharge from approximately 450 facilities can create substantial regional pressure.

Priority policy measures include environmental impact assessment for relevant facilities, clear discharge standards, regular compliance monitoring, economic incentives for treatment and recycling, coordination among local and provincial authorities, and public access to environmental information. Industrial development and environmental protection should be pursued together through cleaner production, water conservation, pollution prevention, and transparent reporting.

Recommendations and Implementation Framework

Immediate Actions: 0–12 Months

1. **Complete an industry inventory.** Record facility locations, production capacity, water use, discharge routes, and existing treatment practices.
2. **Map discharge points.** Use GPS coordinates, photographs, and receiving-water information to create a district-wide pollution-source map.
3. **Establish emergency monitoring.** Prioritize the most visibly affected locations and communicate practical water-safety information to exposed communities.
4. **Notify facilities of obligations.** Communicate applicable environmental requirements, discharge restrictions, and timelines for corrective action.

Short-Term Actions: 1–3 Years

1. **Develop centralized or shared treatment infrastructure.** A properly planned industrial zone or shared treatment system could reduce the difficulty and cost of monitoring hundreds of dispersed facilities.
2. **Install sedimentation systems.** Require appropriately designed settling tanks or equivalent controls before discharge.
3. **Establish discharge standards and reporting.** Define parameter limits, monitoring frequency, compliance procedures, and reporting responsibilities.
4. **Implement pilot treatment and recycling projects.** Demonstrate technically and economically suitable options at representative facilities.

Long-Term Actions: 3–10 Years

1. **Transition toward closed-loop water recycling.** Reuse process water to reduce freshwater consumption and wastewater volumes.
2. **Phase out direct untreated discharge.** Apply a staged, enforceable transition with technical assistance and corrective measures.
3. **Create a continuous monitoring network.** Include fixed stations, regular sampling, data management, public reporting, and independent verification.
4. **Adopt integrated watershed management.** Coordinate land, water, industrial, agricultural, and community planning across the catchment.
5. **Assess beneficial uses of recovered stone powder.** Investigate construction materials, cement additives, and other safe applications through appropriate product testing.

Governance, Community Participation, and Industry Responsibility

Effective implementation requires cooperation among the provincial environmental agency, district administration, industries, universities, research institutions, and local communities. Community members can help identify discharge events and changes in water conditions, while universities can provide independent monitoring and technical support. Industries should adopt cleaner production, water conservation, pollution prevention, environmental reporting, and community-restoration measures. The proposed implementation framework is summarized in Table 6.

Table 6. Proposed implementation framework.

Implementation component	Proposed arrangement
Government lead	Provincial environmental authority and relevant ministry
Coordination	District administration, environmental agency, industries, academic institutions, and communities
Timeline	Phased immediate, short-term, and long-term milestones
Funding	Public–private partnerships, targeted subsidies, and industry contributions
Monitoring	Independent third-party verification supported by university laboratories
Reporting	Annual public disclosure of compliance status and environmental conditions

Future Research Directions

Future work should proceed in stages. First, chemical characterization should measure calcium carbonate, heavy metals, trace contaminants, and sediment composition. Second, microbial and biological studies should evaluate pathogens, biological indicators, aquatic biodiversity, and fish populations. Third, livestock studies should assess water exposure, blood chemistry, milk quality, contaminant transfer, veterinary health, and productivity. Fourth, human-health research should use exposure assessment, community health surveys, epidemiological methods, and waterborne-disease surveillance. Fifth, long-term monitoring should examine seasonal variation, treatment performance,

policy implementation, and temporal pollution trends. Finally, economic studies should compare treatment costs, ecosystem-service losses, livelihood impacts, and the cost of inaction.

Conclusion

This preliminary assessment examined wastewater-discharge practices associated with marble-processing facilities in District Buner through field observations, photographic documentation, and laboratory analysis. Untreated wastewater containing suspended stone particles was observed entering freshwater systems used by communities, agriculture, and livestock. The most pronounced laboratory difference was turbidity, which increased from 2.3 NTU upstream to 1,600 NTU at the discharge point. TDS increased from 185 to 1,240 mg/L, and electrical conductivity increased from 370 to 2,480 µS/cm.

The study demonstrates substantial physical water-quality degradation at discharge locations and partial, but incomplete, improvement downstream. It does not establish acute chemical toxicity or confirm impacts on livestock, milk, soil, crops, or human health, because those endpoints were outside the analytical scope. The findings nevertheless provide a clear rationale for source control, sediment management, wastewater treatment, recycling, continuous monitoring, and integrated watershed governance.

The broader implication is that local environmental protection is part of shared environmental responsibility. Pollution from one site should not be described as direct global contamination; rather, repeated pollution across many sites and regions can create cumulative environmental pressures. Sustainable economic development in District Buner therefore requires industrial growth to be accompanied by responsible wastewater management and transparent environmental governance.

Declarations

Ethics approval and consent to participate: Not reported in the submitted manuscript. The authors should add a statement if community observations, interviews, or human or animal data were collected.

Consent for publication: Not reported. Confirm whether identifiable individuals, private property, or identifiable facilities appear in photographs.

Data availability: The manuscript should provide the underlying measurements, sampling dates, site descriptions, and any statistical-analysis files in a repository or as supplementary material, subject to privacy and institutional requirements.

Competing interests: Not reported in the submitted manuscript; the authors should add an explicit statement.

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Author contributions: Not reported. Add a contributor statement if required by the target journal.

References

1. Food and Agriculture Organization of the United Nations. (2021). The State of the World's Land and Water Resources for Food and Agriculture. Rome: FAO.
2. United Nations Environment Programme. (2016). A Snapshot of the World's Water Quality. Nairobi: UNEP.
3. United Nations Environment Programme. (2021). Making Peace with Nature. Nairobi: UNEP.
4. World Bank. (2019). Quality Unknown: The Invisible Water Crisis. Washington, DC: World Bank.
5. United Nations. (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. New York: United Nations.
6. United Nations. (2023). Sustainable Development Goals Report. New York: United Nations.
7. Ahmed, M., Khan, A., & Ali, S. (2021). Wastewater treatment technologies for marble-processing industries: A review. Journal of Environmental Management, 285, 112–128.
8. Ali, S., et al. (2020). [Bibliographic details as supplied in the original manuscript; verify before submission.]
9. Yilmaz, et al. (2018). [Bibliographic details as supplied in the original manuscript; verify before submission.]
10. Rafique, et al. (2022). [Bibliographic details as supplied in the original manuscript; verify before submission.]
11. Hussain, M., Rafique, S., & Tariq, M. (2020). Evaluation of environmental impacts for future influent scenarios using a model-based approach. Water Science and Technology, 81(8), 1615–1622.
12. Fahiminia, M., Ansari, M., Nazari, S., Gharib Majidi, S., Ahmadi, Z., & Fahiminia, V. (2017). Efficiency of aluminum sulfate, ferric chloride, polyaluminum chloride, polymer, and lime in marble-processing effluent treatment. Journal of Environmental Science and Technology. [Volume, issue, and pages require verification.]
13. Khan, et al. (2019). [Bibliographic details as supplied in the original manuscript; verify before submission.]
14. Mulk, S., Azizullah, A., Korai, A. L., et al. (2015). Impact of marble industry effluents on water and sediment quality of Barandu River in Buner District, Pakistan. Environmental Monitoring and Assessment, 187, 8. https://doi.org/10.1007/s10661-014-4221-8
15. Natani, J. V., & Raghav, K. S. (2003). Environmental impact of marble mining around Makrana, Nagaur District, Rajasthan. Journal of the Geological Society of India, 62(3), 369–376.
16. Asimullah, S., Khan, F., Afridi, J., & Hayat, S. (2025). Environmental impacts of marble industrial effluents on water and soil in Tehsil Shabqadar, Khyber Pakhtunkhwa. Indus Journal of Bioscience Research, 3(3). [Pages/article number require verification.]
17. Noreen, U., Ahmed, Z., Khalid, A., Di Serafino, A., Habiba, U., Ali, F., & Hussain, M. (2019). Water pollution and occupational health hazards caused by the marble industries in District Mardan, Pakistan. Environmental Technology & Innovation, 16, 100470.
18. Özçelik, M. (2016). Environmental pollution and its effect on water sources from marble quarries in western Turkey. Environmental Earth Sciences, 75, 796.
19. Piccini, L., Di Lorenzo, T., Costagliola, P., & Galassi, D. M. (2019). Marble slurry's impact on groundwater: The case study of the Apuan Alps karst aquifers. Water, 11(12), 2462.
20. UNESCO. (2023). United Nations World Water Development Report. Paris: UNESCO Publishing.
21. United Nations Environment Programme. (2017). Towards a Pollution-Free Planet. Nairobi: UNEP.
22. United Nations Water. (2021). Water Quality and Wastewater Management Report. Geneva: UN-Water.
23. World Health Organization. (2022). Guidelines for Drinking-Water Quality (4th ed.). Geneva: WHO.