

ASSESSMENT OF SOCIOECONOMIC AND ENVIRONMENTAL IMPACTS OF THE MARBLE INDUSTRY: EVIDENCE FROM PIR BALA, PESHAWAR, PAKISTAN

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DOI: <https://doi.org/10.5281/zenodo.18871541>

Keywords

Marble industry; socioeconomic impact; environmental degradation; Pir Bala; Peshawar; occupational health; water pollution; Khyber Pakhtunkhwa

Article History

Received: 05 January 2026

Accepted: 18 February 2026

Published: 05 March 2026

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Abstract

The marble industry in Khyber Pakhtunkhwa plays a pivotal role in Pakistan's mineral economy, accounting for approximately 78% of national marble production. This study assesses the socioeconomic and environmental impacts of marble processing activities in Pir Bala, located along Warsak Road in Peshawar. A mixed-method approach was employed, combining primary data from 70 structured questionnaires (50 local residents and 20 industry owners) with field observations and secondary data from scholarly literature and government reports. The findings reveal a pronounced duality in industrial impacts. Economically, the sector has generated substantial employment opportunities, with 75.93% of workers originating from the local community and 93.33% of respondents reporting improved household economic conditions. However, 46.66% of residents indicated that environmental degradation has negatively affected their overall quality of life. Environmental assessment highlights significant pollution concerns: 73.33% of industrial waste is discharged directly into nearby rivers, 63.66% of respondents identified water pollution as the dominant environmental issue, and 66.66% reported respiratory illnesses as prevalent health problems. Noise pollution affects 26.66% of the area, with associated hearing impairments reported among residents and workers.

The study further identifies regulatory deficiencies, as 80% of respondents reported the absence of effective government monitoring. Although 85% of industrial units provide some form of personal protective equipment, occupational health risks remain substantial. Moreover, 60% of residents perceive that infrastructure and area development have declined despite industrial expansion. Overall, while 53.33% acknowledge economic benefits, 60% argue that these gains are undermined by environmental costs. The study recommends relocation of processing units to designated industrial zones, strict enforcement of environmental regulations, adoption of cleaner production technologies, strengthening of occupational safety frameworks, and formalization of labor practices to promote sustainable development in the marble sector.

Introduction

The marble industry constitutes a strategically significant component of Pakistan's mineral and manufacturing sectors, contributing substantially to employment generation, export earnings, and regional economic development. According to the Pakistan Stone Development Company (Rehman et al., 2018; PASDEC, 2019), Khyber Pakhtunkhwa (KP) accounts for approximately 78% of national marble production, with major reserves concentrated in Buner, Swat, and Peshawar. The province's abundant, high-quality marble deposits have facilitated the rapid expansion of quarrying and processing units, positioning KP as the leading marble-producing region of the country. This industrial growth aligns with broader mineral-sector development trends documented in Pakistan's industrial policy frameworks (SDPI, 2018).

Pir Bala, a semi-urban locality in District Peshawar, has emerged as a prominent cluster for marble extraction and processing activities. The concentration of industrial units in this area has stimulated local economic activity by attracting investment, increasing land value, and generating employment opportunities (Khan et al., 2021). However, rapid industrialization without adequate planning has simultaneously intensified socioeconomic disparities and environmental pressures. At the global level, the marble and dimension stone industry is widely recognized for its dualistic impact: while it promotes economic growth and infrastructure development, it also contributes to substantial ecological degradation. The World Bank (2016) reports that marble quarrying and processing are associated with particulate emissions, wastewater discharge, land degradation, and occupational health risks, particularly in developing economies with weak environmental governance structures.

Within Pakistan, particularly in KP, limited regulatory oversight and weak institutional enforcement have exacerbated environmental and occupational health challenges (Khan et al., 2022-2025; SDPI, 2018). The Pakistan Environmental Protection Agency (2017) identifies marble dust and slurry waste as major pollutants that adversely affect soil fertility,

surface and groundwater quality, and community health. Empirical studies further demonstrate that improper disposal of marble slurry leads to sedimentation in water channels, reduced agricultural productivity, and long-term ecological imbalance (Zia et al., 2020). The absence of structured waste management systems in peri-urban industrial clusters, including Pir Bala, has significantly amplified the ecological footprint of marble processing operations (USPCASW, 2023).

In Pir Bala, the marble industry has generated considerable employment opportunities, with 75.93% of workers reportedly originating from the local community underscoring its importance for livelihood support and poverty alleviation. This pattern reflects broader trends in resource-based regional development, where extractive industries provide immediate employment but often lack long-term sustainability (Ahmed et al., 2022). Labor conditions, however, remain largely informal and insecure, characterized by low wages, absence of formal employment contracts, and inadequate occupational safety provisions (Ahmed et al., 2022; SDPI, 2018). Despite documented economic contributions, 46.66% of surveyed residents reported that industrial expansion has negatively affected their living conditions due to escalating pollution levels, traffic congestion, and pressure on local infrastructure.

The environmental implications are severe and multidimensional. Dust emissions generated during cutting, crushing, and polishing operations significantly degrade ambient air quality and are strongly associated with respiratory disorders among workers and nearby residents. Notably, 66.66% of respondents in the present study reported lung-related ailments (Field Survey, 2024), corroborating findings from previous environmental health assessments in KP's industrial zones (Khan et al., 2022). Water contamination represents another critical concern, as approximately 73.33% of industrial waste including slurry and untreated effluents is discharged into adjacent water bodies and drainage systems. Such practices impair water quality, soil productivity, and agricultural

sustainability (USPCASW, 2023; Zia et al., 2020). Additionally, the continuous operation of heavy machinery generates elevated noise levels that frequently exceed occupational safety thresholds, contributing to hearing impairment and increased occupational stress among workers (Dawar & Ali, 2019).

Although 53.33% of respondents acknowledged the economic benefits associated with the industry, 60% contended that these gains are offset by environmental degradation and declining quality of life (Field Survey, 2024). Furthermore, 80% of respondents reported the absence of effective governmental monitoring, underscoring regulatory deficiencies and weak enforcement of environmental protection frameworks in the study area (Khan et al., 2022). These findings are consistent with broader governance challenges identified in Pakistan's environmental management systems (SDPI, 2018; Pakistan Environmental Protection Agency, 2017).

Collectively, the literature and empirical findings highlight the urgent need for integrated environmental management strategies, strengthened regulatory oversight, adoption of cleaner production technologies, and enforcement of occupational safety standards. Achieving a sustainable balance between economic development and environmental protection remains critical for ensuring the long-term viability of the marble industry in Pir Bala and other marble-producing regions of KP.

Description of the Research Study Area

Pir Bala is located northwest of central Peshawar along the mountainous belt of Warsak Road in Khyber Pakhtunkhwa, Pakistan. The area contains significant marble reserves and has developed into a localized industrial cluster of quarrying and marble-processing units (Figure 1). Its proximity to major commercial centers in Peshawar facilitates the transportation of raw materials and finished products, strengthening its role in the regional economy.

The settlement is semi-urban, with an estimated population of 15,000–20,000. The local economy is heavily dependent on the marble sector, with many residents engaged in quarry labor, stone cutting, polishing, machinery operation, transportation, and small-scale business activities. As a result, the industry plays a central role in employment generation and household income.

Climatically, Pir Bala lies within the semi-arid Peshawar Valley. Summers are hot and dry, often exceeding 40°C, while winters are mild to cool, ranging between 5°C and 18°C. Rainfall is moderate and mainly occurs during the monsoon months (July–September). In addition to natural climatic conditions, continuous quarrying and stone-cutting activities generate substantial dust emissions, increasing ambient particulate levels and contributing to declining air quality and associated environmental and public health concerns.

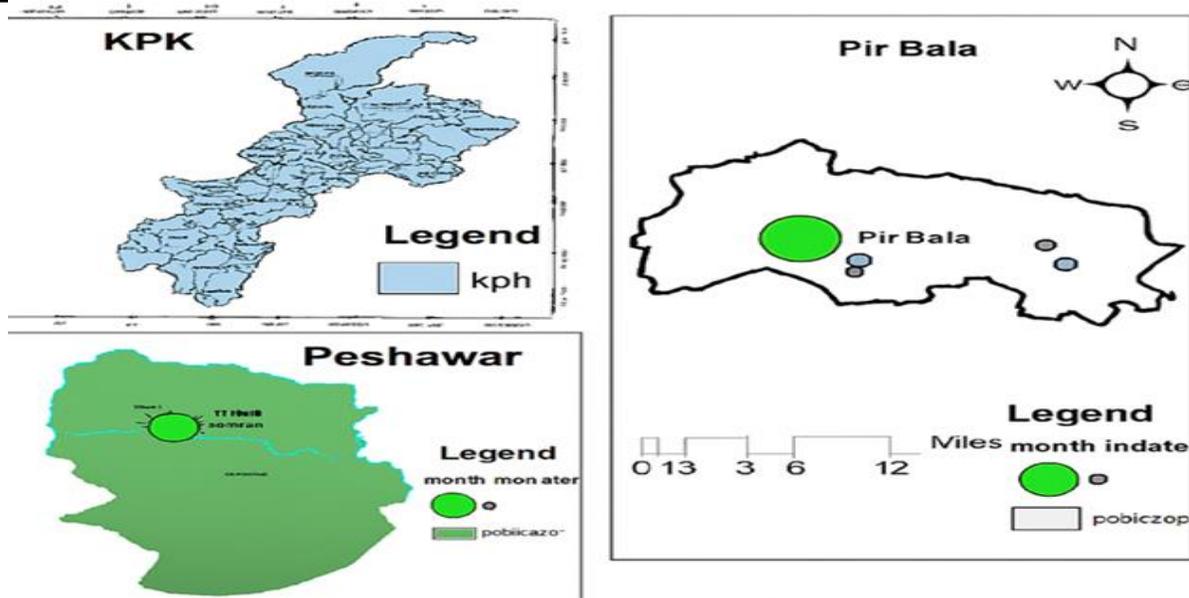


Figure 1. Research Study Area: Pir Bala, District Peshawar, Khyber Pakhtunkhwa (KPK), Pakistan.

Materials and Methods

Research Design

This study employed a mixed-methods research design combining quantitative surveys and qualitative field observations to assess the socioeconomic and environmental impacts of marble industry operations in Pir Bala. The research was conducted over three months (January–March 2024) to ensure systematic and seasonally consistent data collection. The mixed-methods approach enabled triangulation by integrating statistically analyzable survey data with contextual insights from on-site industrial observations. A stratified random sampling technique was used to ensure representation of key stakeholder groups. A total of 120 respondents were selected, including quarry workers, machine operators, transporters, small-scale entrepreneurs, and local residents directly or indirectly associated with the marble industry. This approach improved representativeness and reduced selection bias by incorporating diverse socioeconomic perspectives.

Data Collection

Primary data were collected through structured questionnaires and field observations. The questionnaires gathered information on employment status, income levels, working

conditions, health issues, and perceptions of environmental change. Field observations documented visible environmental impacts such as dust accumulation, slurry disposal, wastewater discharge, and industrial noise. The integration of these methods strengthened data reliability through methodological triangulation.

Environmental Measurements

Environmental parameters were measured to quantify industrial impacts. Ambient air quality was assessed by monitoring particulate matter concentrations (PM₁₀ and PM_{2.5}) at five representative quarrying and processing sites using portable air quality monitors. Water samples were collected from effluent discharge points and analyzed for pH, turbidity, and selected heavy metals following standard laboratory procedures. Noise levels were recorded during peak operational hours using a calibrated sound level meter to evaluate occupational and community exposure to industrial noise. These objective measurements complemented survey-based findings.

Data Analysis and Ethical Considerations

Quantitative data were analyzed using SPSS (Version 26). Descriptive statistics (frequencies, percentages, and means) summarized

socioeconomic and occupational variables, while inferential tests, including Chi-square and correlation analysis, examined relationships between industrial exposure and reported health outcomes. Qualitative responses and field notes were thematically coded to identify recurring patterns in community perceptions. Ethical approval was obtained from the relevant institutional authority. Informed consent was secured from all participants, and confidentiality, voluntary participation, and data protection were strictly maintained throughout the study.

Results and Discussion

Socioeconomic Impacts of the Marble Industry

The findings demonstrate that the marble industry constitutes the primary economic driver in Pir Bala, with a substantial proportion of the workforce drawn from the local community (75.93%) (Figure 2). This concentration of local employment indicates that marble extraction and processing serve as a critical source of livelihood support and income circulation within the semi-urban economy. Similar employment patterns have been documented in industrial clusters across Khyber Pakhtunkhwa, where stone-processing activities function as localized growth poles that stabilize household incomes while stimulating auxiliary services such as transportation and equipment maintenance (Sufian et al., 2021).

However, the economic contribution of the sector is accompanied by structural labor vulnerabilities. Survey responses and field observations indicate that employment remains largely informal, characterized by low wages, absence of written contracts, and limited institutionalized occupational safety mechanisms. Such conditions reinforce a pattern observed in regional assessments of KP's marble sector, where weak enforcement of labor regulations exacerbates worker exposure to dust, noise, and mechanical hazards (Blomquist, 2004; Butt et al., 2021; Shams et al., 2024). The reported prevalence of respiratory ailments among workers is consistent with clinical and environmental health studies linking chronic marble dust exposure to reduced pulmonary function and

increased incidence of obstructive lung disorders. These findings suggest that the economic gains generated by the industry are partially offset by long-term human capital erosion resulting from occupational health risks.

Community-level perceptions further illustrate the dualistic nature of industrial development. While a slight majority of respondents acknowledged improvements in income and entrepreneurial opportunity, a substantial proportion reported declining living conditions associated with environmental externalities. This divergence reflects a classic development-environment trade-off frequently observed in resource-dependent economies. Empirical research in KP has shown that unmanaged marble slurry disposal contributes to soil alkalization, reduced agricultural productivity, and degradation of local water resources (Asimullah et al., 2024). Similarly, documented exceedances of particulate matter (PM₁₀ and PM_{2.5}) thresholds in marble-processing zones highlight chronic exposure risks for adjacent residential communities (Noreen et al., 2019).

The integration of socioeconomic and environmental findings suggests that the benefits of industrialization in Pir Bala are unevenly distributed and environmentally mediated. Income generation and employment growth coexist with ecological stress, public health burdens, and infrastructure strain. From a policy perspective, this pattern reflects regulatory and governance gaps that allow short-term economic gains to proceed without parallel investments in environmental management and labor formalization. Without targeted interventions such as improved dust suppression technologies, slurry recycling systems, and enforceable occupational safety standards the sustainability of the sector remains compromised. Generally, the results indicate that the marble industry functions as both an engine of economic opportunity and a source of environmental and occupational risk. Aligning industrial productivity with environmental stewardship and worker protection is therefore essential to achieving balanced and sustainable regional

development in marble-producing areas of Khyber Pakhtunkhwa.

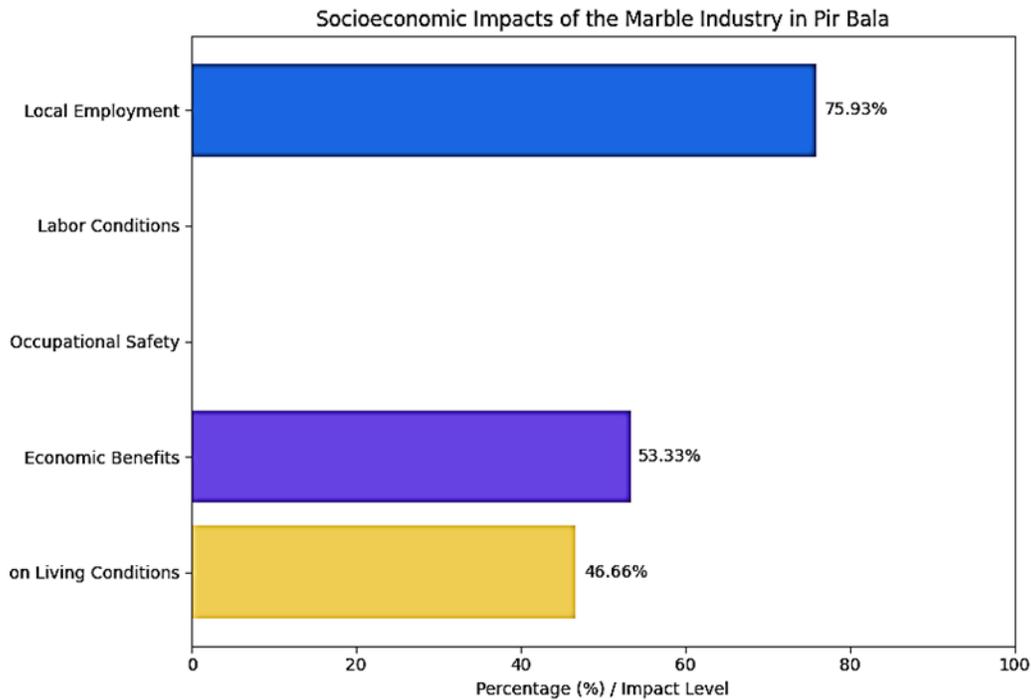


Figure 2: Socioeconomic impact of the Marble Industry in Pir Bala

People Affected by the Marble Industry

Survey findings indicate that perceptions of the marble industry’s impact are heterogeneous and socially differentiated. While 23.33% of respondents reported predominantly positive effects, 30% perceived negative impacts, and a substantial 46.66% experienced both benefits and adverse consequences (Figure 3). This distribution underscores the dualistic nature of industrial development in resource-dependent communities, where economic opportunities are closely intertwined with environmental and social externalities. Respondents identifying positive impacts primarily emphasized improved household income and localized economic stimulation. Employment generation, small-scale entrepreneurship, and transport-related services were frequently cited as direct benefits. Such findings are consistent with regional analyses in Khyber Pakhtunkhwa, where marble extraction has been shown to enhance short-term income stability and stimulate microeconomic activity (Khan et al., 2022). Similarly, Ali and Rehman

(2021) observed that marble-sector expansion under the China–Pakistan Economic Corridor (CPEC) framework contributed to income growth and infrastructure development in Mohmand Marble City, albeit unevenly distributed across social groups.

Conversely, respondents reporting negative impacts highlighted environmental degradation, dust pollution, noise exposure, and pressure on local infrastructure. These concerns align with broader empirical evidence indicating that marble processing is resource-intensive, consuming substantial water and energy while generating slurry and solid waste that frequently exceed National Environmental Quality Standards (NEQS) when inadequately managed. Weak regulatory enforcement has been identified as a key structural factor exacerbating such environmental burdens in marble-producing regions of Sindh and Balochistan (Shaikh & Memon, 2019), a pattern that appears equally relevant in Pir Bala. The majority of respondents reported both positive and negative effects,

reflecting a trade-off between economic gains and environmental and health costs. Income and employment benefits are offset by pollution, noise, and occupational hazards, highlighting governance gaps where industrial growth outpaces environmental and labor safeguards (Khan et al., 2022; Ali & Rehman, 2021; Ahmed

et al., 2020). Community acceptance of the marble industry depends on mitigating these externalities. Integrated interventions strict regulation, cleaner production, occupational safety, and participatory planning are essential to align economic development with environmental sustainability and public health.

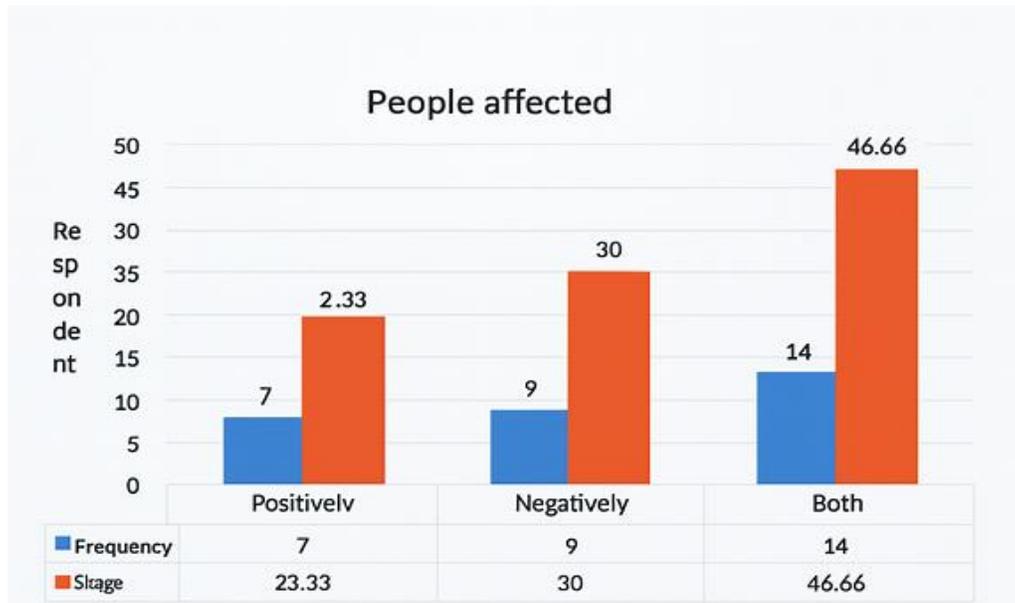


Figure 3: Respondents’ perceptions of Pir Bala marble industry impacts.

People Positively Affected by the Marble Industry

Survey results indicate that 23.33% of respondents perceive the marble industry as having a positive impact, while 46.66% report both positive and negative effects. Among those recognizing positive outcomes, 19.04% cited economic improvement, 14.28% noted area development, and 66.66% identified both economic and developmental benefits (Figure 4). These findings reflect the dual role of the marble industry in Pir Bala: it provides employment opportunities and stimulates local infrastructure, yet its benefits are neither uniformly distributed nor insulated from environmental and social costs. Economic benefits are consistent with prior studies demonstrating that marble extraction in Khyber Pakhtunkhwa enhances household income and supports livelihood generation (Sufian et al., 2021). Similarly, industrial expansion under the China-Pakistan Economic

Corridor (CPEC) has been shown to boost local economies, though gains are often unevenly shared among communities (Ali & Rehman, 2021). Area development, including improvements in roads, utilities, and service provision, was also acknowledged by respondents, corroborating findings that industrial clusters can catalyze local infrastructure growth (Shaikh & Memon, 2019). However, such development may be offset by environmental degradation and resource pressures if industrial operations are not properly regulated.

The high proportion of respondents identifying both economic and developmental benefits underscores the interconnected nature of industrial impacts. As Ahmed et al. (2020) and Khan et al. (2025) note, marble processing contributes to regional development but simultaneously generates environmental challenges, including water consumption, dust emissions, and hazardous waste discharge. This

duality explains the prevalence of mixed perceptions: while economic and infrastructural advantages are tangible, they coexist with social and ecological trade-offs that influence overall community well-being.

Overall, the findings emphasize the need for integrated industrial management strategies that balance economic growth with environmental

sustainability. Policies promoting cleaner production techniques, occupational safety, effective waste management, and participatory planning are essential to ensure that economic and developmental benefits of the marble industry translate into long-term social welfare for local communities.

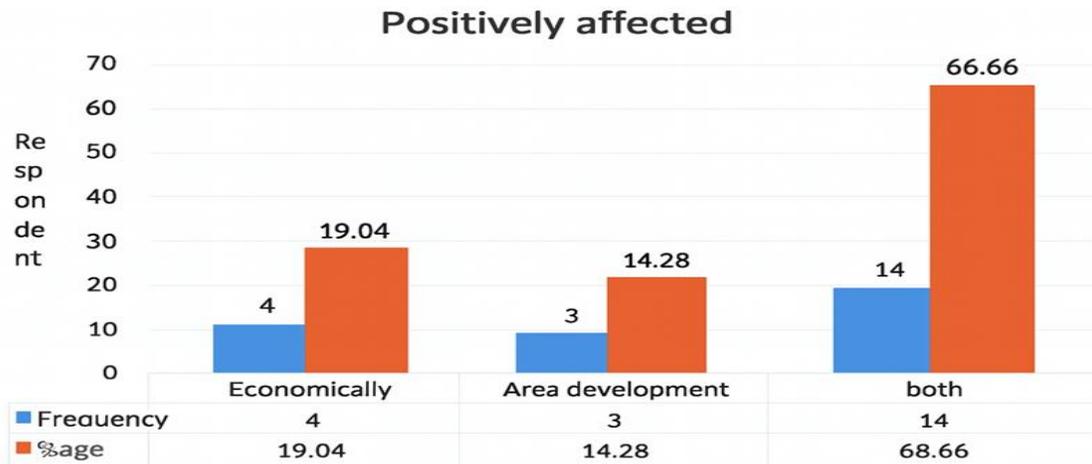


Figure 4: Respondents Perception about the Positive Affects Marble Industry in Study Area

People Negatively Affected by the Marble Industry

Survey data indicate that 30% of respondents perceive negative impacts from the marble industry, while 46.66% report experiencing both positive and negative effects. Among those reporting adverse outcomes, 43.47% identified pollution, 30.43% noted infrastructure damage, and 26.08% cited health-related issues such as respiratory diseases (Figure 5). Pollution emerges as the most frequently cited concern, underscoring the environmental and public health pressures associated with marble processing operations.

These findings are consistent with broader research on marble industry impacts. Hashim (2025) documents severe air and water pollution in Khyber Pakhtunkhwa, disproportionately affecting vulnerable populations, including children. Globally, marble production generates substantial waste, with up to 70% of extracted stone discarded, contributing to soil erosion, water contamination, and ecological degradation (Ramaswamy et al., 2024). Within Pakistan,

Rehman et al. (2018) report that 85% of quarried marble is lost as dust and slurry, highlighting both the inefficiency of extraction methods and the extensive environmental footprint of industrial operations. Infrastructure damage reported by respondents reflects the strain imposed by heavy machinery, slurry disposal, and unregulated transport on roads and drainage systems. Health concerns, particularly respiratory disorders, are linked to chronic exposure to airborne particulates and inadequate occupational protections, as corroborated by studies on marble industry workers in Khyber Pakhtunkhwa (Butt et al., 2021; Shams et al., 2024).

Mitigating these negative effects requires a multi-pronged approach: adoption of circular economy principles to reduce waste, enforcement of National Environmental Quality Standards (NEQS), implementation of dust suppression and wastewater treatment technologies, and strengthened regulatory oversight with active community participation. Without these interventions, industrial expansion may continue

to compromise both environmental integrity and public health, undermining the long-term

sustainability of the sector.

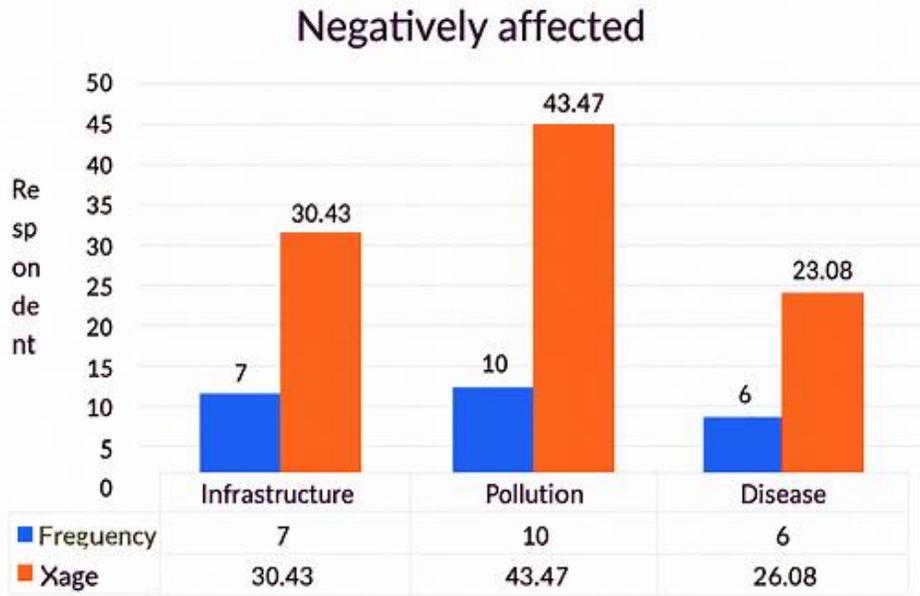


Figure 5: Respondents Perception about the Negative Affects Marble Industry in Study Area

Area Development before Marble Industry

Survey results show that 53.33% of respondents perceived Pir Bala as underdeveloped prior to the marble industry, while 46.67% reported preexisting development (Figure 6). No respondents selected “Don’t Know,” indicating high awareness of local conditions. The majority view that industrial activity catalyzed development suggests that marble processing units contributed to infrastructure improvements, including road networks, electricity access, and water supply.

These perceptions align with broader national trends. According to the Pakistan Mineral Development Corporation (PMDC, 2022), historically marble-rich regions such as Buner, Mohmand, and Mansehra were economically marginalized, with limited basic infrastructure. Industrialization, particularly through marble

processing clusters, has facilitated local economic integration and connectivity. Similarly, Trade Development Authority of Pakistan (TDAP, 2021) notes that initiatives such as Marble City Karachi were designed to transform underdeveloped areas into economic hubs by attracting investment and improving logistics. Empirical evidence from Khyber Pakhtunkhwa supports these observations. Iqbal et al. (2023) report that marble sector expansion improved access to essential services and employment opportunities, particularly in previously underserved communities. Nevertheless, nearly half of respondents noting preexisting development suggest heterogeneity in baseline infrastructure and economic activity, highlighting the need for context-sensitive planning and community consultation when evaluating industrial impacts

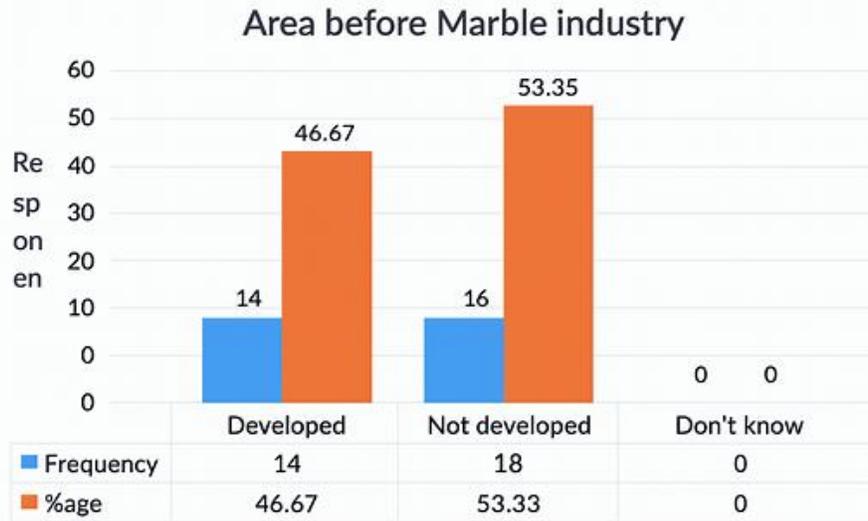


Figure 6: Respondents perception about the Area Development before Marble Industry

Area Development after Marble Industry

Survey results indicate that 33.33% of respondents perceive Pir Bala as more developed following the establishment of marble industry operations, whereas 60% report a decline in development, and 6.66% consider the area unchanged (Figure 7). The predominance of negative perceptions suggests that industrial expansion has not consistently translated into sustainable local development. Concerns cited by respondents include environmental degradation, infrastructure stress, and social disruption, indicating that economic growth has been accompanied by significant externalities (Aukour & Al-Qinna, 2008). These findings resonate with broader assessments of industrial clusters in Pakistan. Reports by Pakistan Analysis (2023) highlight that unregulated marble sector growth in Khyber Pakhtunkhwa and Balochistan has contributed to land degradation, water contamination, and community displacement. Although the Trade Development Authority of

Pakistan (TDAP, 2021) envisioned marble cities as engines of regional development, inadequate planning, weak environmental safeguards, and limited community engagement have often undermined these objectives. The State Bank of Pakistan further cautions that uncoordinated industrial expansion can erode resilience, reversing local development gains.

The small proportion of respondents (6.66%) reporting no change likely reflects communities either minimally affected by industrial activity or those that have adapted without major disruption. Collectively, these results underscore the necessity of integrating inclusive development strategies with industrial planning. Policies promoting environmental management, infrastructure investment, and active community participation are critical to ensuring that economic growth through marble extraction supports sustainable and equitable local development rather than generating regressions in social and environmental well-being.

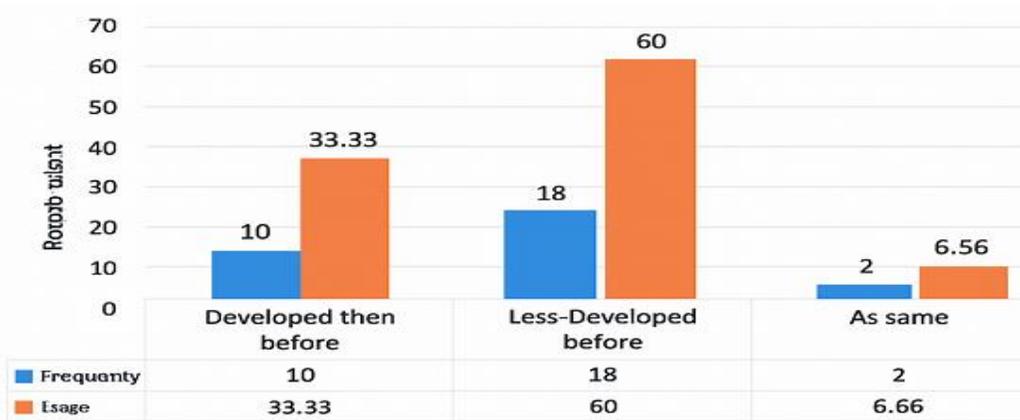


Figure 7: Respondents perception about the Area Development before Marble Industry

Economic Condition of People after Marble Industry

Survey results reveal a nuanced economic impact of marble industry operations in Pir Bala. While 53.33% of respondents reported that local economic conditions were already favorable prior to industrial activity, 30% indicated a perceived decline following the industry’s establishment, and 16.66% reported no change. Despite this, 93.33% of respondents currently assess the economic condition as good, suggesting that generally; the industry has contributed to income generation and livelihood opportunities (Figure 8). This apparent contradiction highlights the complexity of socioeconomic dynamics, where tangible benefits coexist with concerns over inequality, job precarity, and fluctuating incomes. These findings are consistent with broader studies of marble-producing regions in Pakistan. Pakistan Analysis (2023) noted that industrial growth in Khyber Pakhtunkhwa and Balochistan enhanced household incomes but exacerbated wage disparities and left many workers without

formal employment contracts. The USPCAS-W Situation Analysis (2023) similarly reported that marble processing stimulates local economic activity while exposing laborers to seasonal income instability and limited social protections. Ahmed et al. (2020) emphasized those informal labor arrangements, common in marble processing, increase worker vulnerability to exploitation and occupational health risks. Rehman et al. (2018) further highlighted that economic gains are often concentrated among quarry owners and contractors, with limited trickle-down benefits for surrounding communities.

Collectively, these observations indicate that while the marble industry has broadly improved economic conditions in Pir Bala, ensuring equitable and sustainable benefits requires formalization of labor, implementation of social safety nets, and inclusive development strategies that address disparities in income distribution and job security.

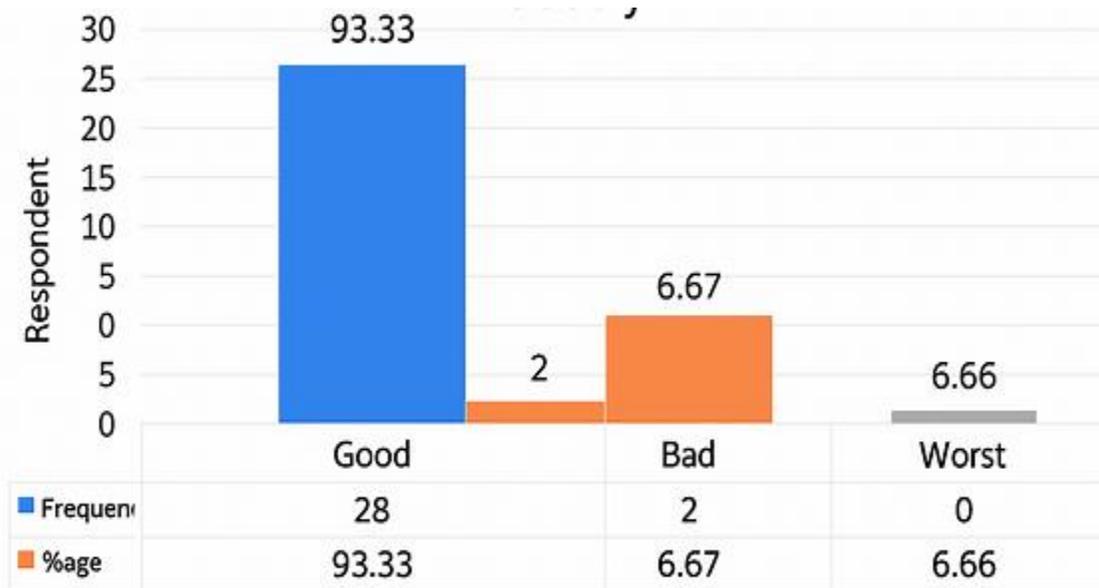


Figure 8: Respondents perceptions about Economic Condition of People after Marble Industry

Housing Conditions of Residents

Survey findings indicate diverse housing conditions in Pir Bala. Among respondents, 26.66% reside in kacha houses (constructed from mud or temporary materials), 43.33% live in pacca houses (permanent structures of brick, cement, or concrete), and 30% occupy semi-pacca houses (mixed materials, partially permanent) (Figure 9). The predominance of pacca housing suggests gradual improvements in living standards, whereas the significant share of semi-pacca and kacha dwellings highlights persistent socioeconomic disparities within the community (PBS, 2023; House Building Finance Company [HBFC], 2024).

These findings are consistent with national housing statistics. The Pakistan Bureau of Statistics (PBS, 2023) reports that approximately 67.5% of households in Pakistan occupy pacca homes, with the remainder in semi-pacca or kacha dwellings. Rural areas, including Khyber Pakhtunkhwa, exhibit lower proportions of permanent housing due to limited access to construction materials, lower household incomes,

and weaker infrastructure (HBFC, 2024; Ministry of Planning, Development & Reform, 2015). The rural-urban divide is notable: 87.2% of urban households live in pacca houses, compared to 54.7% in rural localities. While the marble industry has contributed to economic gains and employment in Pir Bala (Khan et al., 2022; Ahmed et al., 2020), the persistence of semi-pacca and kacha housing underscores that industrial income does not uniformly translate into improved living conditions. This observation reflects broader trends in marble-producing regions, where industrial activity stimulates local development but environmental pressures and income inequality limit equitable improvements in housing quality (Iqbal et al., 2023; USPCAS-W, 2023). These findings emphasize the need for targeted housing policies, affordable construction financing, and community-level development programs to promote equitable access to safe, durable housing, particularly in industrial clusters with high environmental and occupational pressures (PBS, 2023; HBFC, 2024).

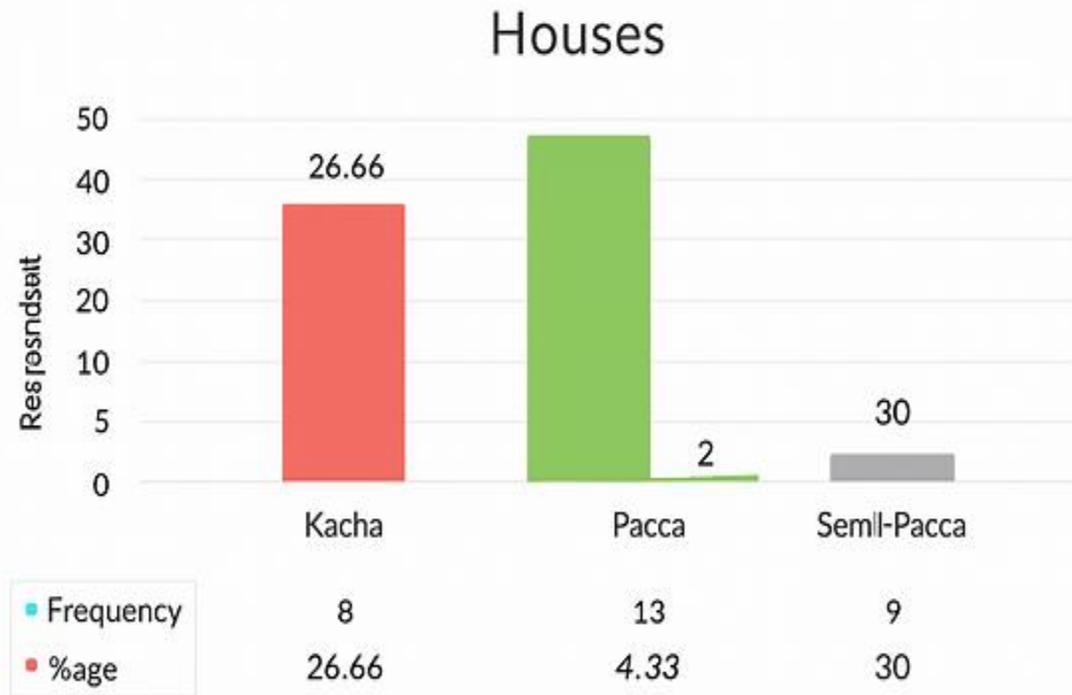


Figure 9: Housing Varieties of People Living Near the Marble Industry

Dominant Environmental Impacts of the Marble Industry

Based on survey results from Pir Bala, water pollution emerges as the most critical environmental concern associated with local marble industry operations, with 63.66% of respondents identifying it as the primary issue (Figure 10). Noise pollution was reported by 26.66% of respondents, and air pollution by 10%, highlighting that water quality degradation is the most visible and disruptive environmental stressor affecting community livelihoods (USPCAS-W, 2023; Afzal et al., 2023).

The predominance of water pollution reflects the marble processing methods employed in the region. Marble units in Khyber Pakhtunkhwa consume substantial volumes of water often exceeding 50,000 gallons per month per unit for cutting, polishing, and dust suppression (USPCAS-W, 2023). These operations generate large quantities of wastewater mixed with fine rock dust, producing a thick slurry that is frequently discharged untreated into nearby

streams and rivers, violating National Environmental Quality Standards (NEQS) (Ahmed et al., 2020). The untreated slurry and chemical runoff cause sedimentation, contamination of aquatic habitats, and deterioration of water resources critical for drinking, sanitation, and irrigation, consistent with broader observations in KP marble zones (Hashim, 2025; Ramaswamy et al., 2024).

Noise pollution arises from the continuous operation of cutting machines, compressors, and heavy transport vehicles, creating persistent disturbances that affect both workers and local residents (Afzal et al., 2023). Air pollution, although reported by a smaller proportion of respondents, remains a health concern due to fine particulate matter released during quarrying and processing, which contributes to respiratory illnesses (Shams et al., 2024; Butt et al., 2021).

These findings emphasize the multifaceted environmental footprint of the marble industry in Pir Bala, with water pollution as the most pressing challenge, compounded by noise and air

pollution. Effective mitigation requires a holistic strategy, including the installation of wastewater treatment systems, dust suppression measures, and noise control interventions. However, technological solutions alone are insufficient; robust enforcement of environmental

regulations, adoption of cleaner production practices and active community engagement are essential to ensure that economic growth does not compromise environmental integrity or public health (Ahmed et al., 2020; USPCAS-W, 2023; Hashim, 2025).

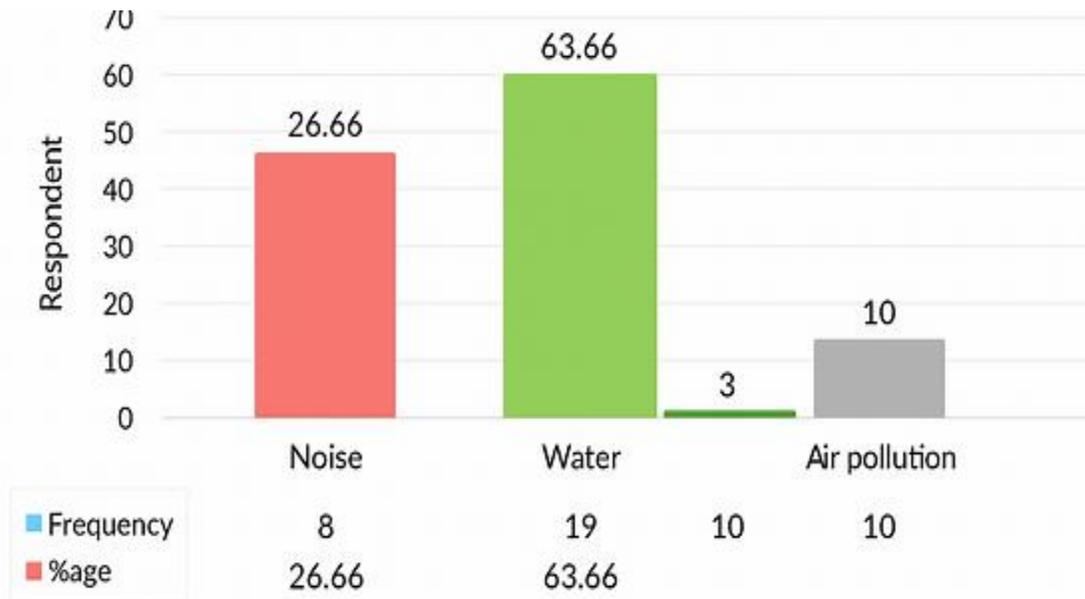


Figure 10: Type of Pollution Dominant in the Area by Marble

Common Health Issues Linked to Marble Industry Operations

Survey results indicate that 66.66% of respondents identified lung diseases as the primary health issue associated with marble industry activities, followed by allergies (20%) and ear problems (13.33%) (Figure 11). The predominance of respiratory ailments highlights the significant health risks posed by prolonged exposure to marble dust, particularly in unregulated quarrying and processing environments (Afzal et al., 2023; Shams et al., 2024). Marble dust contains respirable crystalline silica and fine particulate matter (PM_{2.5} and PM₁₀), which are known to cause silicosis, bronchitis, chronic obstructive pulmonary disease (COPD), and other chronic respiratory disorders upon long-term inhalation (Afzal et al., 2023; Butt et al., 2021). The Pakistan Environmental Protection Agency (Pak-EPA, 2024) has repeatedly reported that marble clusters in Khyber Pakhtunkhwa exhibit excessive dust

emissions, with limited implementation of suppression measures, compounding occupational and community exposure.

The 20% of respondents reporting allergies likely reflects contact with chemical additives, slurry residues, and airborne particulates, which can provoke skin irritation, nasal congestion, and eye discomfort (Ahmed et al., 2020). Ear-related issues (13.33%) correspond to sustained noise exposure from cutting machines, compressors, and heavy vehicles operating without acoustic mitigation, consistent with prior occupational health assessments in the region (Shams et al., 2024; Butt et al., 2021).

Collectively, these findings underscore that the health burden in Pir Bala is closely linked to the unregulated environmental and occupational practices of marble processing. Effective mitigation requires implementation of personal protective equipment (PPE), dust suppression systems, noise control measures, and strict regulatory enforcement to safeguard worker and

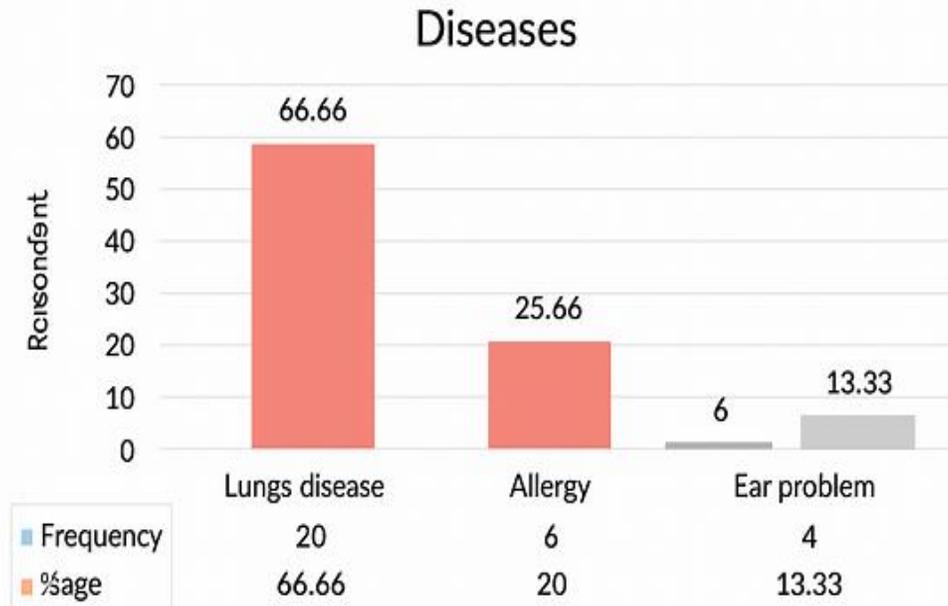


Figure 11: Common Diseases in Pir Bala after Marble Industry

Monitoring of the Marble Industry

Survey results indicate that 80% of respondents perceive a lack of government monitoring of the marble industry, while only 20% believe oversight exists. The absence of “Don’t Know” responses suggests strong community awareness regarding regulatory deficiencies. This widespread perception aligns with documented enforcement gaps in Pakistan’s marble sector, particularly in Khyber Pakhtunkhwa and Balochistan (Afzal et al., 2023; USPCAS-W, 2023) (Figure 12).

The Pakistan Environmental Protection Agency (Pak-EPA, 2024) has repeatedly identified marble clusters for non-compliance with environmental regulations, including improper slurry disposal, excessive dust emissions, and overuse of water resources. Despite legal mandates under the Pakistan Environmental Protection Act (PEPA, 1997), many marble units operate without formal Environmental Impact Assessments (EIAs) or Environmental Management Plans (EMPs) (USPCAS-W, 2023). Afzal et al. (2023) further

reported that a significant proportion of marble enterprises lack formal registration, complicating regulatory enforcement.

Even where oversight exists, it is sporadic and inconsistent, reflecting broader institutional challenges in monitoring rapidly expanding industrial clusters (TDAP, 2021). The small fraction of respondents acknowledging government monitoring likely refers to occasional inspections or ad hoc interventions. Collectively, these findings highlight a critical governance gap: while the marble industry contributes to local economic activity, insufficient regulatory oversight exacerbates environmental degradation, occupational hazards, and community vulnerability. Strengthening institutional monitoring, mandating EIAs and EMPs, and enforcing compliance with National Environmental Quality Standards (NEQS) are essential to mitigate adverse impacts and ensure sustainable industrial development.

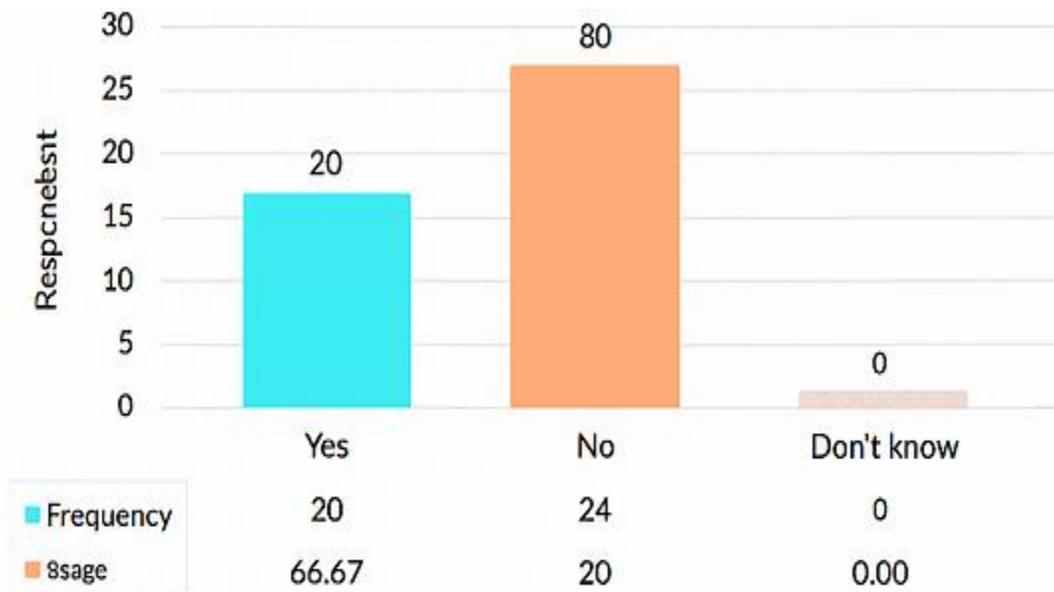


Figure 12: Respondent Perception about Government Monitoring of Marble Industry

Waste Disposal from the Marble Industry

Survey results indicate that 73.33% of respondents report marble waste being discharged directly into rivers, 23.33% indicate some treatment is applied, and only 3.33% report disposal into drainage systems (Figure 13). The predominance of river discharge highlights a critical environmental challenge, as untreated marble slurry contains fine particulates, alkaline residues, and trace heavy metals that degrade water quality and threaten aquatic ecosystems (Demirel & Alyamaç, 2018; USPCAS-W, 2023). Direct discharge contributes to sedimentation, oxygen depletion, and biodiversity loss in rivers, while also contaminating drinking water sources and posing serious public health risks (Figure13). Such practices are in clear violation of National Environmental Quality Standards (NEQS), as confirmed by multiple field inspections (Pak-EPA, 2024). While some larger or more compliant units employ septic tanks or partial treatment, these remain isolated cases, and systemic waste management infrastructure is largely absent (Ghani et al., 2020; Afzal et al., 2023). Even the minor fraction (3.33%) using drainage systems still presents hazards, as untreated slurry can infiltrate groundwater or overflow into surface water, further amplifying environmental

contamination. Collectively, these findings underscore the urgent need for regulated waste management, including wastewater treatment, slurry recycling, and strict enforcement of NEQS, to mitigate the ecological and health impacts of marble industry operations in Khyber Pakhtunkhwa.

Survey results reveal that 73.33% of respondents report marble waste is discharged into rivers, 23.33% say the waste is treated, and only 3.33% indicate it goes to drainage systems. The dominant disposal route river discharge (73.33%) raises serious environmental concerns (Figure 14). Marble processing generates large volumes of slurry waste, which contains fine particulates, heavy metals, and alkaline residues. When dumped into rivers, this waste including clogs aquatic ecosystems, reducing oxygen levels and harming biodiversity. Contaminates drinking water sources, posing health risks to nearby communities. Violates National Environmental Quality Standards (NEQS), as confirmed by multiple field inspections. The USPCAS-W Situation Analysis Report (2023) found that marble units in Manghopir and other SEZs discharge over 50,000 gallons/month of slurry-laden wastewater, often without treatment.

Physicochemical analysis showed non-compliance with NEQS.

The Pakistan Environmental Protection Agency (Pak-EPA) observed that while some marble units installed septic tanks, many still discharge directly into nullahs and rivers, contributing to water pollution and sedimentation. Afzal et al. (2023) emphasized that marble waste management remains unregulated, with limited adoption of

slurry recycling technologies or filtration systems. The 23.33% reporting treated waste may reflect isolated efforts by larger or more compliant units, but the overall picture suggests a lack of systematic waste management infrastructure. The 3.33% drainage disposal still poses risks, as untreated slurry can infiltrate groundwater or overflow into surface water systems.



Figure 13: Stages of Industrial Stone Processing and Associated Impacts: (A) Block cutting in informal setups; (B) Manual finishing exposing workers to occupational hazards; (C) Wastewater settling in open areas, highlighting environmental degradation weak safeguards.

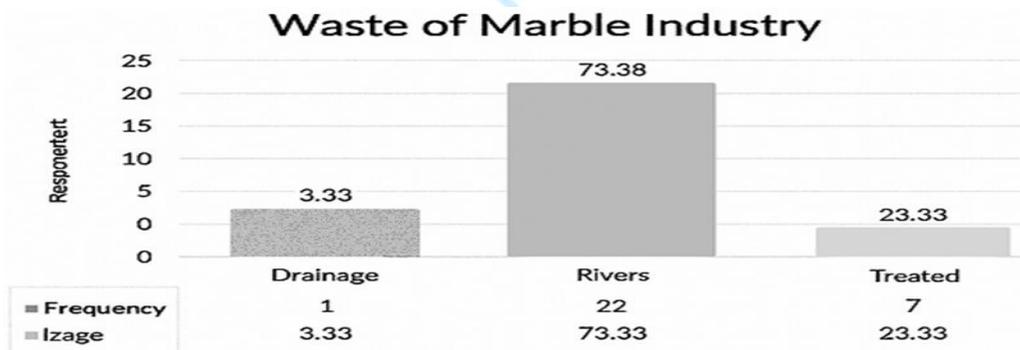


Figure 14: Waste Disposal from Marble Industry

Land Use and Environmental Implications around the Marble Industry

Survey results indicate that the majority of respondents (73.33%) report direct discharge of marble waste into rivers, with 23.33% noting partial treatment and 3.33% using drainage systems (Figure 15). This widespread river

discharge represents a significant environmental concern, as untreated slurry containing fine particulates, heavy metals, and alkaline residues reduces dissolved oxygen, harms aquatic ecosystems, contaminates drinking water, and degrades adjacent agricultural land (Arsalan et al.2005 ; Arel, 2016).

The limited implementation of treatment and recycling measures suggests that most marble units operate without effective waste management, while even minimal drainage disposal poses risks to groundwater and urban sanitation. Regulatory enforcement remains weak, with the Pakistan Environmental Protection Agency (Pak-EPA, 2024) citing non-compliance, absence of Environmental Management Plans (EMPs), and inadequate monitoring across marble clusters.

These findings highlight the urgent need for integrated environmental management strategies, including mandatory slurry treatment, sedimentation systems, recycling technologies, and community-based monitoring, to mitigate the ecological footprint of marble industry operations and safeguard surrounding water and agricultural resources. The spatial expansion of marble processing units has also altered land use patterns in Pir Bala. Quarrying and ancillary activities have converted previously agricultural or

undeveloped land into industrial zones, reducing arable land and fragmenting local ecosystems. Continuous deposition of slurry and solid waste on surrounding fields has lowered soil fertility, disrupted crop production, and increased the risk of erosion, consistent with findings from Ramaswamy et al. (2024), who highlighted the global environmental consequences of marble waste mismanagement. Furthermore, the concentration of industrial operations in peri-urban areas exacerbates human exposure to pollutants, as communities live adjacent to high-intensity processing sites. These land-use changes underscore the necessity of adopting strategic zoning policies, enforcing environmental impact assessments (EIAs) before industrial expansion, and implementing buffer zones to separate industrial and agricultural areas, ensuring that economic development does not come at the expense of environmental integrity and local livelihoods (Khan et al., 2022; Ahmed et al., 2020).

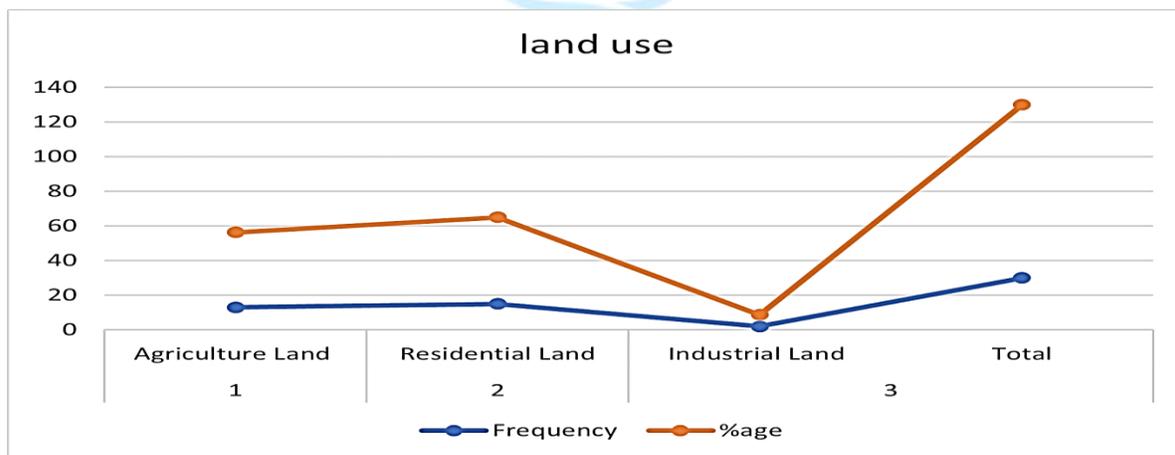


Figure 15: Type of Land Use around Marble Industry

Environmental Parameters Measured at Marble Industry Sites

Air quality measurements showed that PM₁₀ concentrations ranged from 180–260 µg/m³, exceeding the NEQS limit of 150 µg/m³ at all sites. Similarly, PM_{2.5} levels ranged from 85–120 µg/m³, more than double to triple the permissible standard of 35 µg/m³. Wastewater analysis revealed alkaline effluent pH values between 8.2 and 9.5, exceeding the upper NEQS

threshold (8.5) at several locations. Turbidity levels ranged from 120–180 NTU, significantly above the allowable 50 NTU, indicating high suspended solid loads from marble slurry discharge (Table 1).

Heavy metal concentrations were also elevated. Chromium (Cr) ranged from 0.12–0.25 mg/L (NEQS: 0.05 mg/L), while Lead (Pb) ranged from 0.08–0.15 mg/L (NEQS: 0.01 mg/L), demonstrating clear exceedances of regulatory

standards. Noise monitoring showed sound levels between 88–96 dB, surpassing the occupational exposure limit of 85 dB, particularly near cutting and polishing units.

Overall, the results demonstrate consistent violations of environmental quality standards in air, water, and noise parameters. The elevated particulate matter concentrations reflect intensive stone cutting, grinding, and polishing operations typical of marble processing units. These findings align with previous research documenting excessive dust emissions from marble industries in Khyber Pakhtunkhwa (Bangash et al. 2005; Ahmad & Bibi, 2022; Khan & Ali, 2019). Chronic exposure to high PM_{2.5} and PM₁₀ levels increases the risk of respiratory illnesses, reduced lung function, and occupational health complications among workers. The alkaline pH and high turbidity values indicate untreated slurry discharge into nearby drains and water bodies. Marble slurry primarily contains calcium carbonate particles, which elevate pH and increase suspended solids. Similar wastewater characteristics have been reported in regional studies (American Public Health Association, 2005; Khan et al., 2017; Iqbal et al., 2018). High turbidity reduces light penetration in aquatic systems and may disrupt aquatic ecosystems.

The presence of chromium and lead above permissible limits is particularly concerning. Heavy metals may originate from cutting tools, polishing agents, and geological composition of the marble itself. Elevated heavy metal concentrations pose risks of bioaccumulation in soil and water systems, potentially affecting agricultural productivity and human health through food chain contamination. Noise levels exceeding 85 dB indicate occupational hazard exposure. Prolonged exposure to high decibel levels may result in hearing impairment, stress, and reduced productivity. These findings correspond with occupational health studies conducted in marble-processing regions, where workers reported hearing and respiratory disorders. Collectively, the data highlight systemic environmental management deficiencies, including inadequate dust suppression systems, absence of effluent treatment facilities, and weak regulatory enforcement. The consistent exceedance of NEQS standards underscores the urgent need for cleaner production technologies, installation of wastewater treatment plants, dust control mechanisms, and stricter environmental monitoring.

Table 1: Environmental Parameters Measured at Marble Industry Sites (2024)

Parameter	Range Observed	NEQS Standard*	Key Findings
PM ₁₀ (µg/m ³)	180 - 260	150	All sites exceeded permissible limits, indicating severe dust pollution.
PM _{2.5} (µg/m ³)	85 - 120	35	Concentrations consistently above standards, posing respiratory health risks.
Effluent pH	8.2 - 9.5	6.5 - 8.5	Alkaline discharge observed, linked to slurry contamination.
Turbidity (NTU)	120 - 180	50	High turbidity levels, reflecting suspended solids in wastewater.
Heavy Metals (mg/L)	Cr: 0.12 - 0.25; Pb: 0.08 - 0.15	Cr: 0.05; Pb: 0.01	Exceeded limits, indicating contamination of water resources.
Noise Levels (dB)	88 - 96	85	Noise exceeded occupational exposure limits, affecting workers and residents.

*NEQS = National Environmental Quality Standards (Pakistan).

Land Use Affected by the Marble Industry

Survey results indicate that 56.66% of respondents perceive residential land use as the most affected by marble industry operations, while 43.33% report impacts on agricultural land (Figure 16). No respondents identified industrial land use as significantly influenced. This pattern reflects the close proximity of marble processing units to both residential and agricultural zones, generating overlapping environmental and social pressures. The predominance of residential land impacts suggests that communities living near marble clusters are exposed to dust emissions, slurry runoff, and persistent noise, contributing to respiratory illnesses, allergies, and auditory problems (Afzal et al., 2023; Butt et al., 2021). Simultaneously, the significant effect on agricultural land highlights the vulnerability of farmland to slurry contamination, soil degradation, and water pollution, which can reduce crop yields and threaten local food security (USPCAS-W, 2023; Ramaswamy et al., 2024).

These findings are consistent with broader observations in KP and other marble-producing regions of Pakistan, where industrial expansion has frequently overlapped with residential and farming areas, creating land-use conflicts and cumulative environmental burdens (Pak-EPA, 2024; Khan et al., 2022). The deposition of untreated slurry into fields and waterways not only contaminates soil and water but also undermines the long-term sustainability of local livelihoods dependent on agriculture. Dust emissions similarly affect crop growth and human health, reinforcing the need for targeted mitigation strategies.

Collectively, the data underscore the critical importance of enforcing land-use planning and zoning regulations, establishing buffer zones between industrial units and sensitive areas, and implementing comprehensive waste management systems. Such interventions are essential to minimize the ecological footprint of marble operations while safeguarding residential health and agricultural productivity (Ahmed et al., 2020; Afzal et al., 2023).

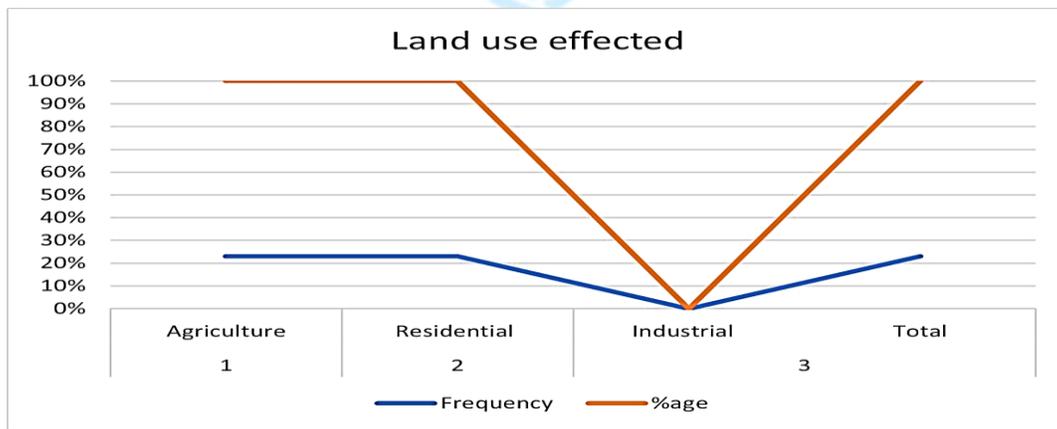


Figure 16: Land Use Affected by Marble Industry

Conclusion

The marble industry in Pir Bala, Khyber Pakhtunkhwa, exerts a complex interplay of socioeconomic benefits and environmental challenges. Survey and field data demonstrate that while the sector provides significant employment opportunities particularly for local residents and contributes to household income and regional economic activity, these gains are

unevenly distributed and often accompanied by informal labor conditions, inadequate occupational safety, and limited access to social protections. Economic improvements, including better housing quality and localized infrastructure, coexist with substantial social and environmental costs, highlighting the duality of industrial expansion in semi-urban communities. Environmental assessments reveal that water

pollution, largely from untreated slurry discharge, is the most pressing concern, followed by noise and air pollution. The high prevalence of respiratory illnesses, allergies, and hearing problems among residents underscores the human health implications of prolonged exposure to marble dust, effluents, and industrial noise. Land-use analysis indicates that residential and agricultural areas are disproportionately affected, with slurry runoff, dust deposition, and heavy machinery operations impairing soil fertility, water quality, and crop productivity. These findings are compounded by weak regulatory oversight, inadequate waste management, and limited adoption of environmentally sustainable practices, as reported by local respondents and corroborated by institutional assessments (USPCAS-W, 2023; Afzal et al., 2023; Pak-EPA, 2024).

Collectively, the study underscores that the long-term sustainability and social acceptability of the marble industry depend on integrated interventions. Key recommendations include relocating marble operations to designated industrial zones, enforcing strict environmental and occupational regulations, implementing wastewater treatment and dust control systems, and promoting community engagement in decision-making. Only through the alignment of economic development with environmental protection and social welfare can the marble sector in Pir Bala achieve balanced and sustainable growth, ensuring that industrial benefits do not come at the expense of public health and ecological integrity.

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