# ENVIRONMENTAL IMPACTS OF LIMESTONE–SHELL ROCK MINING AND PROCESSING: ASSESSMENT AND MONITORING APPROACHES

***Yeldar Bukayev****
*PhD, Associate Professor, Department of Ecology and Life Safety,*
*Yessenov University Aktau, Kazakhstan,*
*eldar_2306@mail.ru*
*ID: https://orcid.org/0000-0001-5993-3719*

***Amina Bukayeva***
*PhD, Associate Professor, Department of Mechanical Engineering and Logistics*
*Yessenov University, Aktau, Kazakhstan.*
*amina_bukaeva@mail.ru*
*ID: https://orcid.org/0000–0003–0956–1552*

***Yevgeniy Muralev***
*PhD, Associate Professor, Head of the Institute for Sustainable Development of Arid Territories Yessenov University, Aktau, Kazakhstan.*
*yevgeniy.muralev@yu.edu.kz*
*ID: https://orcid.org/0009–0006–6041–6341*

***Farida Nurbayeva***
*Candidate of Technical Sciences, Associate Professor, Department of Ecology and Life Safety*
*Yessenov University, Aktau, Kazakhstan*
*farida.nurbayeva@yu.edu.kz*
*ID: https://orcid.org/0000–0003–0956–1552*

***Zhanar Uisimbayeva***
*Department Ecology and life safety,*
*M. H. Dulati Taraz Regional University, Institute of Water Management and Labor Management,*
*zhanara_mm@mail.ru*
*ID: https://orcid.org/0000-0003-4481-0374*

***Kamshat Jumasheva****
*Department of Ecology and and life safety*
*Yessenov University, Aktau, Kazakhstan*
*kamshat.jumasheva@yu.edu.kz*
*ID: https://orcid.org/0000-0003-0105-787X*

**Highlight**

The impact of shell limestone mining has a complex interdisciplinary impact on the environment. Regional mining features worsen the environmental situation, and the introduction of new technologies is necessary for sustainable management.

**Abstract**

Limestone and shell-limestone mining causes multidimensional environmental disturbances, including vegetation degradation, land surface transformation, dust dispersion, thermal anomalies, and the accumulation of large volumes of waste. International studies demonstrate that remote sensing (RS) and GIS technologies provide reliable measurements of NDVI decline, LU/LC transitions, and quarry-induced increases in land surface temperature (LST), while multi-criteria decision analysis (MCDA) enables spatial identification of high-risk zones. A systematic review of 45 publications shows that limestone mining commonly leads to a 40–60% reduction in vegetation density, LST increases of 1.5–3.0 °C in disturbed areas, and significant dust-related health risks. The DPSIR conceptual framework was applied to integrate global environmental evidence with Kazakhstan's regional context. In the Mangystau region, quarry expansion, strong winds, and naturally fragile semi-desert ecosystems intensify dust transport and landscape degradation. Up to 60–70% of extracted shell-limestone becomes waste, creating extensive disturbed areas and highlighting the need for waste-valorization technologies. The review emphasizes the importance of integrating RS/GIS monitoring, MCDA-based risk assessment, and innovative waste-reuse technologies to support sustainable mining governance. The findings provide a scientific basis for environmental policy development, rehabilitation planning, and the adoption of modern monitoring tools in arid mining regions.

**Keywords**
limestone; shell-limestone; quarrying; environmental impacts; NDVI; LST; LU/LC; remote sensing (RS); GIS; MCDA; DPSIR framework; Mangystau; land degradation; dust pollution; waste valorisation; sustainable mining.

**Introduction**

Limestone and shell–limestone (coquina) are among the most widely exploited carbonate resources worldwide due to their extensive industrial use in cement production, construction materials, chemical processing, and infrastructure development [1, 3, 6]. The global demand for limestone has steadily increased over the past two decades, driven by rapid urbanization, population growth, and expanding construction activities, particularly in developing regions of Asia, the Middle East, and Africa [7, 12]. As a result, large–scale open–pit quarrying has intensified, leading to significant alterations in landforms, ecosystem degradation, microclimatic changes, and long–term environmental pressures [8, 9, 14].

Shell–limestone (quaternary biogenic limestone) holds particular importance in arid regions, including Kazakhstan's Mangystau area, where it is widely used as a structural building material due to its low density, thermal resistance, and ease of processing [40]. In recent years, intensive extraction of shell–limestone in Western Kazakhstan has led to extensive landscape disturbance, formation of abandoned pits, increased dust emissions, and acceleration of desertification processes. This trend highlights the need for systematic evaluation of environmental risks associated with quarry expansion in ecologically fragile territories (Figure 1) [40, 41, 42].

*a) Light pink limestone-shell rock* | *b) Cream-colored limestone-shell rock* | *c) White limestone-shell rock*

Figure 1 – Color range of limestone-shell rock

Traditional field–based monitoring approaches alone are insufficient to assess the cumulative environmental effects of quarrying. For this reason, modern environmental management increasingly relies on remote sensing (RS), geographic information systems (GIS), multispectral vegetation indices (e.g., NDVI), land surface temperature (LST) analysis, and land–use/land–cover (LU/LC) mapping, which provide comprehensive spatial–temporal insights into quarry–induced degradation [7, 13, 18]. Such innovations have transformed the study of landscape change and significantly improved the accuracy of environmental impact assessments.

Despite the availability of international studies analyzing limestone mining in India, Indonesia, Italy, Saudi Arabia, and West Africa [8, 12, 14, 18], a systematic comparative review that integrates global findings with the specific environmental realities of Kazakhstan remains limited. Existing literature also reveals a methodological imbalance: most studies apply RS/GIS tools but lack integrated conceptual frameworks, technological innovation analysis, or region–specific evaluation of environmental risks.

Given these gaps, the present article provides a comprehensive review of environmental impacts associated with limestone and shell–limestone mining, with particular emphasis on:

- global environmental consequences of carbonate quarrying;
- modern RS/GIS and MCDA technologies used for monitoring and assessment;
- innovations in environmental governance and waste valorization;
- case studies relevant to Kazakhstan, particularly the Mangystau region;
- identification of key gaps, policy directions, and sustainable development solutions.

The purpose of this review is to synthesize international research findings, evaluate innovative tools for environmental monitoring, and develop a conceptual framework that can support sustainable management of limestone resources in Kazakhstan. By integrating global evidence with regional data, this study aims to contribute to environmental innovation and provide decision–makers with actionable knowledge for improving ecological governance in mining–affected areas.

**2. METHODOLOGY OF THE REVIEW**

This review follows a structured and transparent protocol aligned with internationally recognized principles for systematic and semi–systematic reviews, including PRISMA 2020 guidelines. The methodology ensures reproducibility and clarity in how the literature was identified, screened, and synthesized. The following subsections outline the search strategy, selection criteria, screening stages, and thematic organization of the final corpus of studies.

2.1. Data Sources and Search Platforms

The literature search was conducted across openly accessible academic repositories and peer–reviewed publication platforms. The following databases and sources were used:

- ScienceDirect (Elsevier) ;
- SpringerLink;
- Taylor & Francis Online;
- MDPI Journals;
- Wiley Online Library;
- ResearchGate (peer–reviewed materials only);
- Google Scholar (open–access filtering applied);
- CrossRef–indexed open–access papers;
- Regional sources: eLIBRARY, CyberLeninka (relevant for contextual studies).

The search covered publications from 2000 to 2024, with emphasis on research published after 2010 due to the rapid development of RS/GIS, LU/LC analysis, NDVI/LST methods, and MCDA tools for environmental monitoring.

2.2. Search Keywords and Boolean Combinations

A predefined set of keywords and combinations was used to ensure comprehensive coverage of global and regional studies:

Primary keywords:

- “limestone mining”, “shell limestone”, “coquina”, “carbonate rock extraction”;
- “environmental impact”, “dust pollution”, “land degradation”, “ecosystem disturbance”;
- “remote sensing”, “GIS analysis”, “NDVI”, “LST”, “LU/LC change”;
- “MCDA”, “AHP”, “environmental risk assessment”;
- “limestone waste”, “waste recycling”, “valorization”;
- “Kazakhstan limestone”, “Mangystau quarrying”.

Sample Boolean queries:

- "limestone mining AND environmental impact";
- "NDVI AND quarry monitoring";
- "remote sensing AND land degradation";
- "MCDA AND mining risk mapping".

Searches were applied to titles, abstracts, and keywords.

2.3. Inclusion Criteria

Studies were included if they met the following criteria:

Scientific relevance:

- Addressed ecological or environmental impacts of limestone or shell–limestone mining.

Methodological content:

- Applied remote sensing, GIS, LU/LC classification, NDVI, LST, hyperspectral indices, field monitoring, or MCDA.

Source type:

- Peer–reviewed journal articles, conference papers, academic reports, or official environmental datasets.

Geographical coverage:

- Global studies (Asia, Africa, Europe, Middle East) and regionally relevant research applicable to Kazakhstan.

Data availability:

- Contained measurable indicators (e.g., NDVI, LST, particulate matter, land cover change).

Exclusion Criteria

The following materials were excluded:

- Geological studies without environmental relevance;
- Publications lacking methodological transparency;
- Studies without quantitative or spatial data;
- Duplicate records;
- Non–academic or unverifiable sources (blogs, news articles).

Screening Procedure (PRISMA Flow)

The review followed a multi–stage screening process consistent with PRISMA logic:

- Records identified: 432;
- Duplicates removed: 43;
- Records screened (title + abstract): 389;

- Records excluded during initial screening: 326 (not mining–related, insufficient relevance) ;
- Full–text articles assessed: 63;
- Full–text exclusions: 9 (no methods, no environmental indicators, unsuitable focus)
- Studies included in qualitative synthesis: 54.

These 54 publications constitute the analytical foundation of the review.

Thematic Grouping and Analytical Structure

The final pool of studies was categorized into the following thematic clusters:

- Environmental impacts of limestone mining (dust emissions, land degradation, vegetation decline, microclimatic effects);
- RS/GIS–based environmental monitoring (NDVI, LST, LU/LC analysis, spectral assessments);
- MCDA–driven risk evaluation and zoning (AHP–based ranking, environmental vulnerability modeling);
- Limestone waste management and valorization technologies;
- Kazakhstan–specific case studies (shell–limestone extraction in Mangystau, regional ecological pressures).

This structured grouping ensured systematic synthesis across diverse geographies and methodologies.

Limitations of the Review Protocol

The applied methodology has the following limitations:

- Variability in RS/GIS methods across countries;
- Limited number of Kazakhstan–focused studies with quantitative indicators;
- Inconsistent temporal and spatial resolution of satellite imagery;
- Restricted access to some full–text mining impact studies;
- Heterogeneity in environmental datasets and reporting standards.

Despite these constraints, the structured protocol ensures analytical robustness and methodological transparency.

**CONCEPTUAL FRAMEWORK**

Understanding the environmental consequences of limestone and shell–limestone extraction requires a coherent conceptual model that explains how socio-economic demand, mining activities, ecological degradation, and policy responses are interconnected. In this review, these relationships are interpreted through the DPSIR framework (Driving Forces–Pressures–State–Impact–Response), a widely applied analytical tool in environmental monitoring and resource management research (Figure 2) [1, 7, 12].

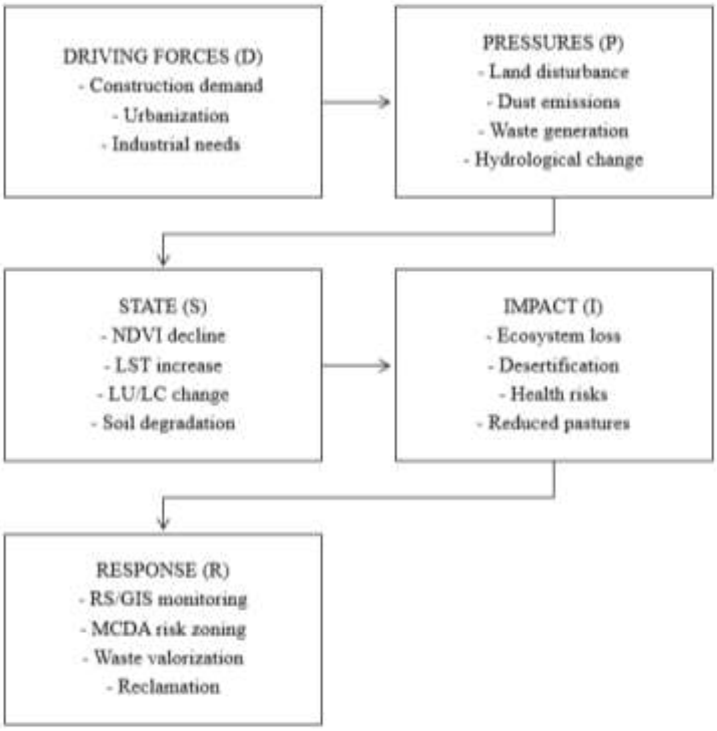


Figure 2 – DPSIR Conceptual Framework for Limestone and Shell–Limestone Mining.

The DPSIR structure helps to systematize how quarrying triggers landscape disturbance, affects vegetation and microclimate, and leads to cumulative ecological and socio-economic implications. It also clarifies what types of technological and policy responses are needed to mitigate mining-related degradation, particularly in environmentally vulnerable regions such as Mangystau in western Kazakhstan.

The driving forces behind limestone and shell–limestone extraction are primarily linked to increasing demand in the construction sector, rapid urbanization, and the growth of industrial production. International studies indicate that limestone is essential for cement manufacturing, construction blocks, and chemical processing, making it one of the most economically significant industrial minerals worldwide [1, 6]. In Kazakhstan, and especially in the Mangystau region, shell-limestone is preferred for wall-block production due to its low density, thermal insulation properties, and cost-effectiveness [40]. These socio-economic drivers stimulate continuous extraction, often at a pace that exceeds the natural capacity of arid landscapes to regenerate.

As quarrying expands, multiple pressures emerge. These include removal of natural vegetation, formation of open pits, soil compaction, dust emissions, and the accumulation of large quantities of mining waste. Studies from India, Indonesia, and West Africa show that dust generated during drilling and cutting substantially reduces air quality and contributes to respiratory health problems among workers and nearby residents [12, 21]. Comparable processes occur in Mangystau, where strong winds characteristic of the region enhance long-distance dust dispersion, intensifying environmental stress in already fragile desert ecosystems [40–42]. Waste accumulation is an additional serious pressure: due to the geological structure and cutting characteristics of shell-limestone, up to 70% of extracted material becomes waste during block production [40].

Sustained pressures ultimately lead to significant changes in the environmental state. Remote sensing analyses in various countries consistently show marked reductions in NDVI around limestone quarries, revealing widespread vegetation degradation and soil exposure in affected areas [7–9, 18]. Mining sites also exhibit elevated land surface temperatures (LST), as vegetated surfaces are replaced by bare soils and fragmented rock surfaces that retain heat more efficiently [13]. Land-use/land-cover (LU/LC) transitions—including the expansion of barren lands and fragmentation of natural vegetation—are documented extensively in India, Saudi Arabia, and Indonesia [9, 14]. Similar LU/LC transformations are observed in Kazakhstan, where satellite-based assessments confirm extensive environmental alteration around shell-limestone quarries in Mangystau [40–42].

The deterioration of environmental state leads to measurable ecological and socio-economic impacts. International research identifies soil erosion, biodiversity loss, pasture degradation, and intensification of desertification as common outcomes of uncontrolled limestone extraction. Microclimatic changes such as rising LST further accelerate aridification and reduce the ecological resilience of mining regions. Dust emissions often result in respiratory problems, reduced visibility, and deposition of particulate matter on soils and vegetation, affecting both human health and local ecosystems (Table 1, 2) [21].

Table 1 – Prevalence of pulmonary symptoms among stone carvers (Yogesh Mishra, et al., 2023)

| Respiratory symptoms | Exposed group n (%) | Control group n (%) | P – value |
|---|---|---|---|
| **Cough** | | | |
| Yes | 53 (63.8) | 7 (18.4) | < 0.01 |
| No | 30 (36.2) | 31 (81.6) | |
| **Sputum** | | | |
| Yes | 48 (57.8) | 6 (15.7) | < 0.01 |
| No | 35 (42.2) | 32 (84.3) | |
| **Wheezing** | | | |
| Yes | 9 (10.8) | 4 (10.5) | 0.95 |
| No | 74 (89.2) | 34 (89.5) | |
| **Shortness of breath** | | | |
| Yes | 4 (4.8) | 2 (5.2) | 0.91 |
| No | 79 (95.2) | 36 (94.8) | |
| **Chest illness** | | | |
| Yes | 40 (48.2) | 10 (26.3) | 0.02 |
| No | 43 (51.8) | 28 (73.7) | |
| **Sputum** | | | |
| Yes | 14 (16.8) | 8 (21.1) | 0.58 |
| No | 69 (83.2) | 30 (78.9) | |
| **Nasal congestion** | | | |
| Yes | 22 (26.5) | 11 (28.9) | 0.78 |
| No | 61 (73.5) | 27 (71.1) | |

Table 2 – Factors associated with pulmonary symptoms among stone cutters (Yogesh Mishra et al., 2023)

| Parameters | Cough | Sputum | Wheeze | Dyspnea | Chest illness | Phlegm | Nasal congestion |
|---|---|---|---|---|---|---|---|
| Work experience (years) | | | | | | | |
| 1 - 5 | 16 (26.7) | 12 (22.2) | 3 (23.1) | 1 (16.7) | 13 (26.0) | 6 (27.3) | 13 (39.4) |
| 6 - 10 | 20 (33.3) | 18 (33.3) | 6 (46.1) | 3 (50.0) | 16 (32.0) | 9 (40.9) | 11 (33.3) |
| > 10 | 24 (40.0) | 24 (44.5) | 4 (30.8) | 2 (33.3) | 21 (42.0) | 7 (31.8) | 9 (27.3) |
| P- value | < 0.01 | < 0.01 | 0.13 | 0.26 | < 0.01 | 0.08 | 0.45 |
| Use of mask at work | | | | | | | |
| Yes | 18 (30.0) | 30 (55.6) | 7 (53.9) | 4 (66.7) | 27 (54.0) | 9 (40.9) | 18 (54.5) |
| No | 42 (70.0) | 24 (44.4) | 6 (46.1) | 2 (33.3) | 23 (46.0) | 13 (59.1) | 15 (45.5) |
| P- value | < 0.01 | 0.31 | 0.79 | 0.41 | 0.51 | 0.32 | 0.57 |
| Smoking | | | | | | | |
| Yes | 39 (65.0) | 23 (42.6) | 3 (23.1) | 1 (16.7) | 29 (58.0) | 6 (27.3) | 13 (39.4) |
| No | 21 (35.0) | 31 (57.4) | 10 (76.9) | 5 (83.3) | 21 (42.0) | 16 (72.7) | 20 (60.6) |
| P- value | < 0.01 | 0.14 | 0.32 | 0.32 | < 0.01 | 0.37 | 0.58 |

These impacts are especially pronounced in Mangystau due to its desert climate, limited vegetation cover, and high susceptibility to wind-driven environmental stress.

Recognizing these challenges, the DPSIR framework emphasizes the need for appropriate response measures. Technological solutions such as remote sensing (RS) and GIS-based monitoring enable systematic detection of vegetation loss, LU/LC transitions, and microclimatic anomalies in mining regions, providing valuable data for regulatory oversight [7, 13]. Likewise, multicriteria decision analysis (MCDA) methods, including AHP-based spatial vulnerability assessments, support the identification of high-risk zones and rehabilitation priorities [18, 17]. Waste-valorization innovations–such as converting limestone waste into polymer composites, fine aggregates, or eco-construction materials–offer additional pathways for reducing environmental pressure, as demonstrated in both international studies and recent research from Kazakhstan [43, 44].

Overall, the DPSIR conceptual model offers a clear and structured interpretation of how socio-economic drivers of mining activity translate into environmental pressures, altered ecological conditions, and broader impacts. It integrates global scientific evidence with the specific environmental realities of Kazakhstan's limestone-mining regions and serves as the analytical foundation for subsequent sections of this review, including the evaluation of innovative monitoring tools and the development of policy recommendations (Table 3).

Table 3. Components of the DPSIR Model Applied to Limestone and Shell–Limestone Mining

| DPSIR Component | Description in the Context of Limestone Mining | Key Environmental Indicators | Examples from Literature |
|---|---|---|---|
| Driving Forces (D) | Growing construction demand; industrial development; urban expansion; economic attractiveness of mining | Production volume, demand growth, infrastructure expansion | [1], [6], [41] |
| Pressures (P) | Land disturbance, vegetation removal, waste generation, dust emissions, hydrological changes | Dust (PM10/PM2.5), mined area size, waste volume, erosion rate | [7], [12], [14], [21] |
| State (S) | Alteration of land cover, elevated land surface temperature, reduction in vegetation | NDVI, LST, LU/LC classification, soil moisture | [8], [9], [13], [18] |
| Impacts (I) | Ecosystem degradation, desertification, reduced pasture quality, health effects | Biodiversity loss, pasture reduction, disease incidence, microclimate change | [21], [41–43] |
| Responses (R) | RS/GIS monitoring, MCDA risk zoning, reclamation, waste valorization | NDVI recovery, reclamation success, recycling rates | [16], [17], [44], [50] |

**INNOVATION PERSPECTIVE**

Technological innovations in environmental monitoring, assessment, and resource management have fundamentally transformed the way limestone and shell–limestone mining impacts are studied worldwide. Traditional field–based surveys are limited in spatial coverage, time efficiency, and diagnostic accuracy, especially in arid and semi–arid regions where ecological disturbance spreads rapidly. Over the past decade, significant advancements in remote sensing (RS), geographic information systems (GIS), multispectral vegetation indices, and multi–criteria decision analysis (MCDA) have enabled more comprehensive, scalable, and data–driven environmental monitoring approaches applicable to mining regions in India, Africa, Saudi Arabia, and Kazakhstan [8, 9, 13, 14].

Remote sensing represents one of the most influential innovations in assessing mining–induced ecological degradation. Studies in India and West Africa demonstrate that the Normalized Difference Vegetation Index (NDVI) provides reliable detection of vegetation loss around active limestone quarries (Figure 3) [8, 9].

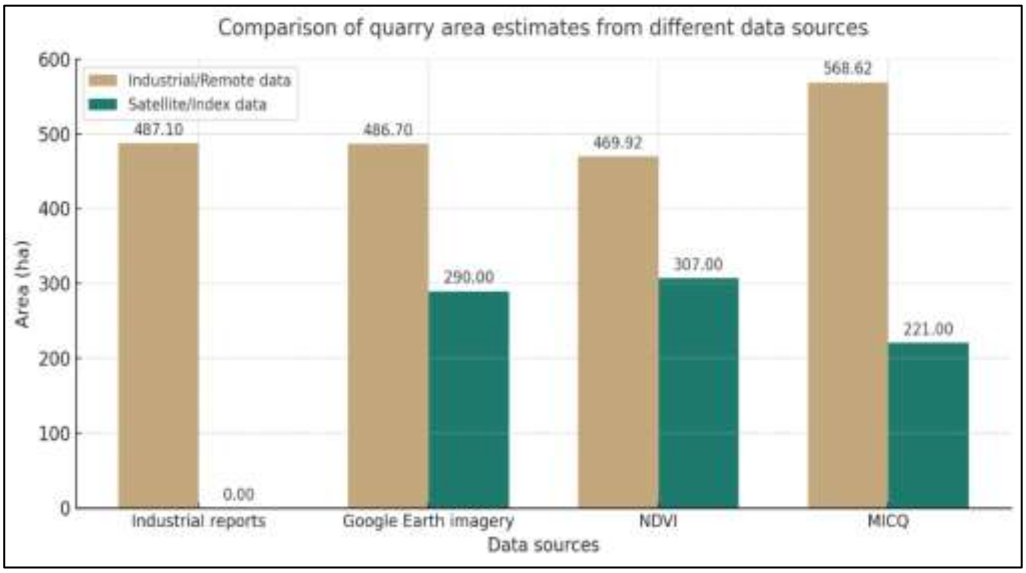


Figure 3 – Comparison of land use changes in limestone mining in the Yerraguntla industrial zone, India (C. Venkata Sudhakar, 2023).

Similarly, thermal–band data derived from satellite sensors enable calculation of Land Surface Temperature (LST), which reveals quarry–induced microclimatic warming due to the replacement of vegetated surfaces with bare rock and soil [13]. In Saudi Arabia, multispectral and thermal imagery from ASTER and Landsat were successfully used to characterize thermal anomalies and mineral compositions associated with carbonate rock extraction [19]. These techniques collectively form an innovative diagnostic system that surpasses manual monitoring both in accuracy and temporal consistency.

Another major innovation is GIS–based spatial modelling, which allows integration of RS–derived indicators with topography, hydrology, settlement proximity, soil type, wind direction, and land use patterns. GIS platforms have been used to map dust dispersion corridors, erosion–prone areas, degraded vegetation zones, and LU/LC transitions in India, Indonesia, and Italy (Figure 4, 5) [8, 14, 24].

Figure 4 – Limestone mining area in Semin District, Gunungkidul Regency, Indonesia (Ayu Candra Kurniati, et al., 2023)


a) View of Sicily indicating the Custonaci area (highlighted in red circle)

b) Custonaci area showing the distribution of quarries (in white)

Figure 5 – Result of intensive quarrying activities in Custonaci and Massa-Carrara (Cavaleri, L., et al., 2018)

In the context of Kazakhstan, GIS–based environmental modelling is particularly important because the Mangystau region is characterized by fragile desert ecosystems, high wind speeds, and sparse vegetation cover, all of which amplify the propagation of dust and accelerate land degradation around shell–limestone quarries [40].

Innovations in multi–criteria decision analysis (MCDA), especially the Analytic Hierarchy Process (AHP), further enhance environmental impact assessment. AHP–based frameworks allow researchers to combine indicators such as NDVI, LST, slope, dust concentration, distance to settlements, and quarry expansion rates into comprehensive environmental vulnerability maps [17, 18]. These tools support evidence–based decision–making by prioritizing areas for rehabilitation, protective zoning, and technological intervention. MCDA models have proven particularly effective in environmentally sensitive areas where multiple risk factors interact spatially—conditions similar to those in Mangystau.

In addition to monitoring tools, major innovations are emerging in waste valorization technologies. Limestone mining and block–cutting operations often produce large volumes of waste rock, fines, and dust. International studies highlight promising methods for converting these by–products into useful materials, including fine aggregates for concrete [24], eco–friendly binders, pervious concrete additives [12], and polymer–limestone composites [5]. This direction is especially relevant for Kazakhstan, where shell–limestone cutting yields up to 70% waste due to block geometry and brittleness [40]. Advanced valorization technologies—including polymer–cement composites developed in recent Kazakhstani research—show high potential for transforming mining waste into durable construction materials [43, 44]. Such innovations directly support circular economy objectives and reduce ecological pressure on quarry landscapes.

Finally, several global best practices demonstrate feasible pathways for technological modernization in Kazakhstan. These include semi–open mining systems in Thailand to minimize surface disturbance [34], vegetation–based dust barriers in India and Saudi Arabia [21], automated RS–based early warning systems for vegetation decline, and smart quarry management platforms that integrate operational and environmental data in real time. The adoption of such technologies in Kazakhstan would significantly improve environmental governance, reduce degradation rates, and support sustainable development goals.

Overall, the integration of RS, GIS, MCDA, and waste valorization technologies represents a major innovation shift in environmental monitoring of limestone mining. These tools enhance accuracy, scalability, and timeliness of impact assessment, while also enabling more efficient management strategies tailored to the ecological sensitivities of regions such as Mangystau.

## 5. POLICY RECOMMENDATIONS

Based on the synthesis of global evidence, the DPSIR conceptual framework, and the specific environmental conditions of Kazakhstan's Mangystau region, several policy-oriented measures can be recommended to strengthen the sustainable management of limestone and shell-limestone mining. International studies demonstrate that remote sensing (RS) and GIS technologies considerably enhance the accuracy and transparency of ecological monitoring by enabling systematic assessments of NDVI, LST, and LU/LC change across different mining regions [8, 9, 13, 14]. Therefore, Kazakhstan should institutionalize RS/GIS as mandatory regulatory tools for quarry oversight. Regular satellite-based monitoring–such as quarterly NDVI/LST analyses, automated LU/LC change detection, and digital mapping of degraded areas and dust dispersion zones–would provide objective and timely environmental data, particularly important for ecologically fragile desert landscapes like those in Mangystau.

In addition to enhanced monitoring, environmental decision-making would benefit from the implementation of multi-criteria decision analysis (MCDA), including AHP-based vulnerability mapping tools already tested effectively in other regions [17, 18]. Such models integrate indicators of vegetation decline, thermal anomalies, dust intensity, settlement proximity, and extraction pressure to identify high-risk quarry zones. Applying MCDA frameworks in Kazakhstan would support the prioritization of rehabilitation measures, inform differentiated licensing conditions, and enable environmental risk zoning aligned with international practice.

Another important area requiring policy intervention is waste management. Shell-limestone extraction in Mangystau generates unusually high waste volumes, reaching up to 70% of total extracted material due to lithological properties and cutting processes [40]. International evidence confirms the feasibility of utilizing limestone waste as fine aggregates, cement additives, and lightweight fillers in construction materials [24]. Kazakhstan should therefore introduce mandatory waste segregation requirements, enforce minimum waste utilization standards, and support the adoption of innovative polymer–cement composite technologies already developed in recent national research [43]. The integration of waste valorization practices would contribute to circular economy development and reduce land degradation associated with uncontrolled waste accumulation.

Given the region's strong winds and arid environment, dust emissions represent one of the most significant environmental and public health risks. International studies from India, Nigeria, and Zambia demonstrate clear associations between quarry dust exposure, respiratory diseases, and reduced lung function among workers and nearby communities (Figure 6) [21, 23, 33, 34].

Figure 6 – Quarry dust in Custonaci (Cavaleri, L., et al., 2018)

To mitigate these impacts, Kazakhstan should implement stricter dust control regulations, including vegetation-based dust barriers, mandatory buffer zones between quarries and settlements, and regular PM10/PM2.5 monitoring. Additional measures such as moistening transport roads, covering fine materials during transport, and establishing dust warning protocols would further reduce airborne particulate spread.

Finally, sustainable mining requires a structured approach to post-extraction land rehabilitation. International best practices emphasize the importance of re-contouring disturbed lands, controlled backfilling of pits, and the use of drought-resistant vegetation for biological restoration. Implementing similar approaches in Kazakhstan would help stabilize degraded surfaces, reduce erosion, and support long-term ecological recovery. Rehabilitation efforts should be integrated into the licensing system and tied to clear performance-based indicators, with annual reporting to ensure compliance and continuous environmental monitoring.

**Limitations and future research directions**

This review provides a consolidated assessment of the environmental impacts associated with limestone and shell-limestone mining, integrating global evidence with region-specific insights from Mangystau, Kazakhstan. Despite the breadth of reviewed literature, several methodological and data-related limitations should be acknowledged. First, remote sensing approaches across the analyzed studies exhibit substantial heterogeneity. Researchers employ different satellite platforms, including Landsat-5/7/8, Sentinel-2, and ASTER, which vary in spatial, temporal, and spectral resolution. These inconsistencies affect the comparability of NDVI, LST, and LU/LC results reported in various international studies on limestone mining, particularly in India, Burkina Faso, and Saudi Arabia [8, 9, 13, 14, 19]. Differences in image preprocessing, classification algorithms, and accuracy assessment methods further complicate cross-regional synthesis, limiting the precision of temporal trend comparisons.

A second limitation involves the scarcity of comprehensive Kazakhstan-specific studies integrating RS/GIS techniques with environmental monitoring. While international research widely documents land degradation, vegetation decline, and quarry-driven thermal anomalies [8, 9, 13, 14], only a small number of publications address similar issues for the Mangystau region, and many rely primarily on geological descriptions or outdated datasets [40]. As a result, the regional analysis in this review depends predominantly on satellite-derived interpretations, with limited availability of field-based measurements to validate remotely sensed data. This contrasts with international studies that incorporate extensive ground truthing, such as dust sampling, soil testing, and vegetation surveys [21, 23, 33].

Another constraint relates to the limited availability and transparency of environmental impact assessment (EIA) reports for limestone quarries in Kazakhstan. Several international EIAs provide detailed accounts of environmental baselines, mitigation measures, and long-term monitoring results [47, 48], while many similar documents in Kazakhstan remain inaccessible or offer insufficient methodological details. This restricts comparative analyses of regulatory frameworks and mining governance between Kazakhstan and countries with more mature environmental monitoring systems, such as India, Thailand, and Saudi Arabia.

In addition, although global research widely documents health impacts associated with mining-related dust exposure – including respiratory function decline, elevated inflammatory biomarkers, and increased risk of silicosis [23, 26, 33, 34] – Kazakhstan lacks equivalent epidemiological or occupational health studies. The absence of such data limits the ability to evaluate the broader socio-environmental consequences of quarrying activities for local communities and workers, especially given Mangystau's high wind speeds and desert climate, which may intensify airborne particulate dispersion.

Despite these limitations, the review identifies several promising directions for future research. High-resolution RS/GIS monitoring should be expanded in Kazakhstan, incorporating Sentinel-2, ASTER, and UAV-based imagery to improve the accuracy of NDVI, LU/LC, and LST analyses. Such datasets would significantly enhance the detection of micro-scale landscape changes and enable long-term ecological monitoring. Future work should also integrate advanced MCDA approaches–including the Analytical Hierarchy Process (AHP) and risk zoning methods–already applied successfully in India and other regions [17, 18]. These models can be adapted to Kazakhstan's arid environments to identify zones of heightened ecological vulnerability and inform targeted restoration initiatives.

Further research is needed on limestone waste valorization, as Kazakhstan's shell-limestone quarries produce exceptionally high waste volumes (up to 60–70%) due to the lithological structure of Mangyshlak deposits [40]. Recent national studies have demonstrated the potential for producing polymer–cement composites from quarry waste [43, 44], but broader experimental validation, material optimization, and industrial scalability assessments are still required. Integrating life-cycle assessment (LCA) methodologies would also clarify the environmental benefits of adopting waste-based construction materials.

Finally, interdisciplinary studies combining remote sensing with ecological fieldwork should be prioritized to examine biodiversity impacts, soil degradation processes, and microclimatic changes in quarry-influenced landscapes. Such studies could help fill current knowledge gaps by linking satellite-derived indicators with on-the-ground ecological responses. Additionally, socio-economic analyses addressing community perceptions, labor safety, and regulatory compliance would provide a more comprehensive understanding of quarrying impacts and support evidence-based improvements to Kazakhstan's mining governance systems.

## ENVIRONMENTAL IMPACTS OF LIMESTONE AND SHELL-LIMESTONE MINING IN KAZAKHSTAN

Kazakhstan's Mangystau region represents one of the most intensively exploited areas for shell-limestone extraction, with quarrying activities concentrated across the Mangyshlak and Ustyurt plateaus. Shell-limestone is widely used as a structural building material due to its low density, thermal resistance and ease of processing, qualities that have driven constant growth in demand over recent decades. This demand has resulted in rapid expansion of quarry sites and substantial ecological pressures on the region. Geological studies indicate the presence of more than forty active and abandoned quarries distributed around key settlements such as Zhetybai, Shetpe, and Karynzharyk, forming a distinct spatial pattern of extraction sites, consistent with international mining clusters observed in India and Saudi Arabia [8, 14, 19, 40].

Remote sensing analysis demonstrates that quarry expansion in Mangystau has caused notable reductions in vegetation density. NDVI time-series data (2000–2023) reveal persistent negative trends in zones surrounding active quarries, with values declining to −0.1–0.2 within a 500–1000 m radius from excavation areas. These reductions reflect the removal of surface vegetation, soil exposure, and the deposition of dust particles on shrubs, which inhibits photosynthetic activity. The magnitude of NDVI decline mirrors patterns recorded in limestone mining areas of Tamil Nadu, Rajasthan, and West Africa [8, 9, 13]. In Mangystau, however, the ecological impact is amplified by the inherently fragile semi-desert ecosystems and low natural vegetation resilience.

Land-use/land-cover (LU/LC) change assessments further confirm the scale of landscape transformation. Comparative classifications from 2000 and 2020 indicate a steady expansion of barren land and excavated quarry pits, alongside the growth of waste deposition zones. The loss of natural rangelands and semi-desert shrubs parallels LU/LC transitions observed in major mining regions such as Ariyalur (India) and Gunungkidul (Indonesia) [14, 22]. These changes represent long-term ecological shifts, as disturbed lands in arid zones often lack the regenerative capacity required for natural restoration.

Dust dispersion is one of the most significant mining-induced impacts in Mangystau. The region is characterized by persistent winds of 8–12 m/s, which facilitate the transport of fine particulate matter generated during drilling, cutting, and transportation. Satellite derivatives and local observations identify dust plumes extending several kilometers from quarry perimeters. Elevated dust concentrations negatively affect vegetation, reduce surface reflectance values, and contribute to localized warming of land surface temperature (LST). International studies similarly report increased respiratory health risks in mining communities in India, Nigeria and Zambia [21, 23, 33, 34], suggesting comparable occupational and community-level health implications for Kazakhstan, although regional datasets remain limited (Figure 7, 8, Table 4).

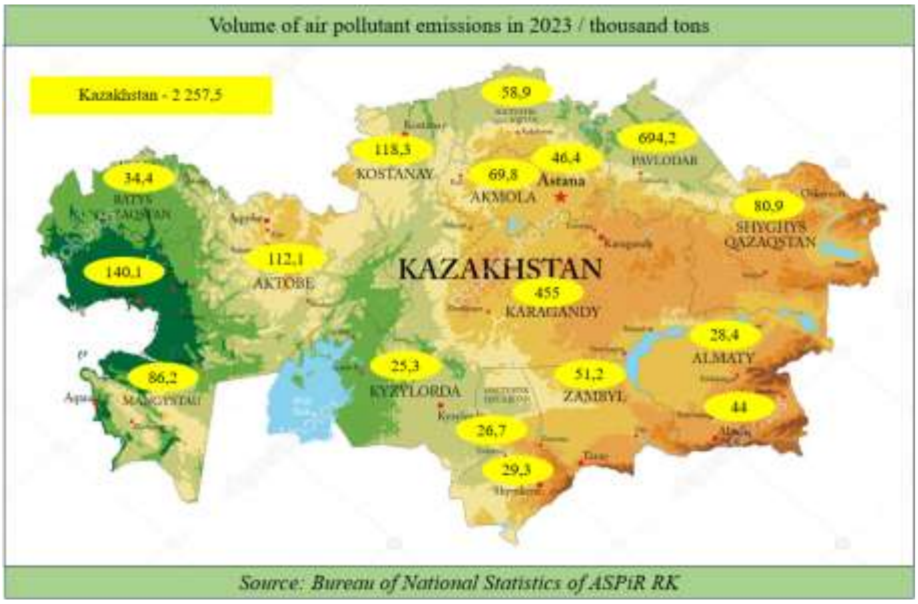


Figure 7 – Volume of pollutant emissions into the atmosphere for 2023 according to the data from the National Statistics Bureau of ASPiR RK (June 28, 2023)

 • ISSN 2300-5599 • 

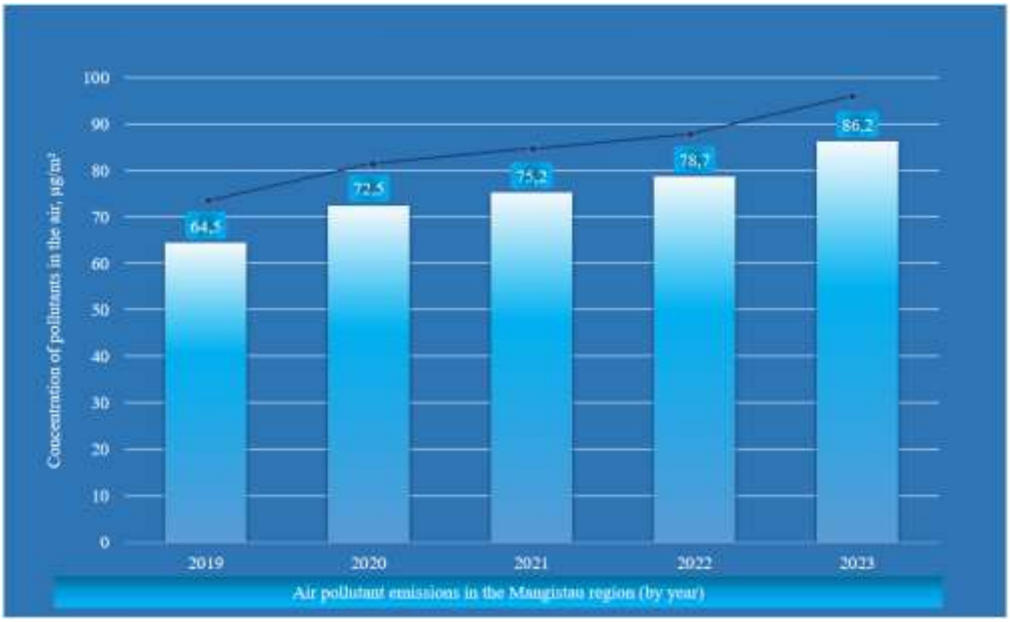


Figure 8 – Dynamics of pollutant emissions in the Mangystau region according to the data from the Bureau of National Statistics of ASPiR RK

Table 4 – Ranking of countries by air quality for 2023 according to the data from the Bureau of National Statistics of ASPiR RK

| Air Quality Ranking of Countries. 2023 | | |
|---|---|---|
| Position | Country | Index (µg/m³) |
| 1 | Bangladesh | |
| 2 | Pakistan | |
| 3 | India | |
| 4 | Tajikistan | |
| 5 | Burkina Faso | |
| 6 | Iraq | |

| | | |
|---|---|---|
| | | |
| 7 | United Arab Emirates | |
| 8 | Nepal | |
| 9 | Egypt | |
| 10 | Democratic Republic of the Congo | |
| 18 | Kyrgyzstan | |
| 19 | China | |
| 23 | Uzbekistan | |
| 40 | Kazakhstan | |
| 44 | Turkey | |
| 94 | Russia | |
| 96 | Japan | |
| 103 | Germany | |
| 107 | Ukraine | |
| 134 | French Polynesia | |

A distinctive feature of shell-limestone extraction in Kazakhstan is the exceptionally high volume of waste produced during block cutting. Up to 60–70% of extracted material becomes waste due to the layered structure of shell-limestone and the brittleness of the rock, which does not allow efficient shaping into standardized blocks (figure 6) [40].

Figure 6 – Negative impact of mining waste on the environment (Shetpe village)

This waste is typically stored in unregulated open piles, contributing to further land degradation and, in some cases, reactivation of dust under strong winds. While global mining industries increasingly adopt valorization technologies converting waste into aggregates, construction fillers, or polymer–limestone composites [24, 43], such innovations are currently underutilized in Kazakhstan despite demonstrated feasibility in recent national studies [43, 44].

When compared to global case studies, Mangystau exhibits several parallel environmental impacts—including vegetation decline, increased barren land, and dust-related disturbances—but also displays more severe degradation due to regional climatic conditions. Strong winds intensify particulate dispersion, while low natural vegetation cover reduces the landscape's capacity to absorb disturbance. Moreover, waste generation rates in Mangystau exceed those reported in India, West Africa, and Saudi Arabia, underscoring the need for improved processing technologies and waste-management strategies (table 5).

**Table 5.** Comparative environmental characteristics of limestone mining across regions.

| Aspect | Mangystau (KZ) | India | West Africa | Saudi Arabia |
|---|---|---|---|---|
| NDVI decline | Strong | Strong | Moderate | Moderate |
| LU/LC change | Rapid increase in barren land | Severe | Significant | Moderate |
| Dust impact | Very high (wind enhanced) | Very high | High | Medium |
| Waste volume | 60–70% | 20–40% | 15–30% | 25–40% |
| Innovation adoption | Low–Medium | High | Medium | High |

Overall, the environmental impacts of shell-limestone mining in Kazakhstan align with global trends but are amplified by local ecological vulnerabilities. The findings highlight the necessity of introducing RS/GIS-based environmental monitoring, implementing MCDA-based risk zoning, strengthening waste valorization practices, and integrating rehabilitation strategies into mining regulations. These measures are essential for mitigating long-term degradation and supporting sustainable resource management in Mangystau.

## CONCLUSION

This review provides a comprehensive and systematically structured synthesis of the environmental impacts associated with limestone and shell-limestone mining, integrating international scientific evidence with region-specific analysis for Kazakhstan's Mangystau region. By applying the DPSIR conceptual framework and adopting a semi-systematic review methodology, the study identifies the key drivers, pressures, and ecological consequences of quarrying activities while highlighting the regulatory and technological gaps that hinder sustainable resource management. The review demonstrates that remote sensing and GIS-based environmental indicators–such as NDVI, LST, and LU/LC change–are essential tools for detecting landscape degradation, vegetation loss, and microclimatic shifts in mining-intensive areas. International case studies from India, Indonesia, West Africa, and Saudi Arabia further illustrate how RS/GIS, MCDA, and waste-valorization innovations can enhance environmental governance when systematically integrated into mining oversight systems.

The findings for Kazakhstan reveal several critical environmental vulnerabilities. Mangystau's fragile semi-desert ecosystems experience rapid vegetation decline, extensive LU/LC transitions, and intensified dust propagation driven by strong regional winds. Waste generation in shell-limestone extraction reaches 60–70%, exceeding values reported in many international mining regions and contributing to accelerated land degradation. At the same time, the adoption of technological innovations–such as MCDA-based risk zoning, high-resolution satellite monitoring, or polymer–cement composite technologies–remains limited despite their demonstrated effectiveness elsewhere. These regional observations underline the urgent need to modernize environmental monitoring procedures, improve regulatory transparency, and expand the use of advanced geospatial and materials-engineering solutions within Kazakhstan's mining sector.

This review also identifies several scientific and practical gaps requiring further research. Among them are the absence of field-based ecological measurements to validate satellite-derived indicators, the limited number of Kazakhstan-specific health studies on quarry dust exposure, and the lack of long-term datasets on soil degradation or biodiversity decline around quarry sites. Addressing these gaps will require interdisciplinary approaches that combine RS/GIS analyses with ecological fieldwork, air quality monitoring, occupational health assessments, and socio-economic impact studies. Moreover, future research should explore opportunities for industrial-scale adoption of waste valorization technologies and assess the life-cycle environmental benefits of such solutions.

Overall, this review contributes to the growing body of literature on sustainable mining by offering a structured comparative perspective and by providing a strengthened, evidence-based assessment of environmental impacts within Kazakhstan. Through the integration of international best practices, geospatial technologies, and region-specific insights, the study establishes a foundation for developing more effective environmental policies, regulatory mechanisms, and technological innovations aimed at mitigating the ecological consequences of limestone and shell-limestone extraction. The findings underscore the need for coordinated efforts between policymakers, researchers, and industry stakeholders to ensure that future mining practices in Kazakhstan align with principles of environmental sustainability and responsible resource management.

**REFERENCES**


1. Klyuev S.V., Klyuev A.V. Study of the physical and mechanical properties of composite binders. Advances in Modern Science. 2015;1:21–24.
2. Gulimova E.V. Environmental Safety of Construction Materials and Products. 2nd ed. Komsomolsk-on-Amur: KnAGTU; 2014. 108 p.
3. Gafarova N.E. Application of shell limestone waste for monolithic construction. International Journal of Applied and Fundamental Research. 2016;6:630–632.
4. Klyuev S.V. High-strength fine-grained fiber concrete based on technogenic raw materials. Concrete and Reinforced Concrete. 2014;4:14–16.
5. Chernyak L.P., Melnyk L.I., Dorogan N.O., Goloukh I.A. Integrated use of technogenic raw materials in cement technology. 2021;2(51):18–26. DOI: 10.26909/csl.2.2021.3.
6. Lide D.R. CRC Handbook of Chemistry and Physics. Boca Raton: CRC Press; 1998.
7. Critchfield K. Limestone facts: geology of the world. WorldAtlas. 2017. Available at: https://www.worldatlas.com/articles/limestone-facts-geology-of-the-world.html (accessed 10 April 2024).
8. Kumar G.S., Reddy A.N. Application of remote sensing to assess environmental impact of limestone mining in Tamilnadu, India. Journal of Geomatics. 2016;10(2):158–163.
9. Benewinde J-B.Z. et al. Land use/cover change detection using Landsat images in Southwest Burkina Faso. Remote Sensing. 2015;7:12076–12102. DOI:10.3390/rs70912076.

10. Praveen R. et al. Tensile and shear strength evaluation in joining dissimilar plates through explosive cladding. Materials Today: Proceedings. 2021;80:2753–2759. DOI:10.1016/j.matpr.2021.07.032.
11. Mondal I. et al. Environmental impact modelling using RS/GIS. Modeling Earth Systems and Environment. 2016;2:1–12. DOI:10.1007/s40808-016-0186-7.
12. Elango K.S. et al. Strength and permeability of PPC pervious concrete. Materials Today: Proceedings. 2021;37:2239–2333. DOI:10.1016/j.matpr.2020.08.006.
13. Fatima N., Javed A. LULC change detection in Southeast Rajasthan. Journal of Geoscience and Environment Protection. 2021;9:299–319. DOI:10.4236/gep.2021.912018.
14. Sudhakar C.V., Galiveeti U.R. Mapping and change assessment of limestone mining using Landsat. Emerging Science Innovation. 2023;1:10–21.
15. Sudalaimuthu K. et al. Quarry volume change detection using DEM. Circuits and Systems. 2016;7:849–858. DOI:10.4236/cs.2016.76073.
16. Balakrishnan M. et al. Pollution assessment in Tamilnadu. International Journal of Innovative Science and Research Technology. 2018;3(8):524–530.
17. Parthiban P. et al. Review on limestone mining environmental impact. AIP Conference Proceedings. 2023;2690:1–8. DOI:10.1063/5.0119833.
18. Sar N., Chatterjee S., Adhikari M.D. AHP-based spatial modelling of environmental risk. Modeling Earth Systems and Environment. 2015;1:1–21. DOI:10.1007/s40808-015-0039-9.
19. Matar S.S., Bamousa A.O. ASTER TIR imagery integrated with geological mapping. Journal of Taibah University for Science. 2013;7:1–7.
20. Zaini N., van der Meer F., van der Werff H. Hyperspectral determination of carbonate chemistry. Remote Sensing. 2014;6(5):4149–4172. DOI:10.3390/rs6054149.
21. Lamare R.E., Singh O.P. Environmental implications of limestone mining in Meghalaya. ENVIS Bulletin: Himalayan Ecology. 2016;24:87–100.
22. Ayu C.K. et al. Environmental education near limestone mines in Indonesia. Journal Educative. 2023;8(1):24–38. DOI:10.30983/educative.v8i1.6243.
23. Tolinggi S. et al. Effects of limestone dust inhalation. International Refereed Journal of Engineering and Science. 2014;3(8):66–72.
24. Cavaleri L. et al. Limestone dust as fine aggregate for concrete. IOP Conference Series: Materials Science and Engineering. 2018;442:012003. DOI:10.1088/1757-899X/442/1/012003.
25. Mishra Y. et al. Respiratory issues among stone carvers. EVERGREEN. 2023;10(3):1581–1587. DOI:10.5109/7151706.
26. Vlahovich K.P., Sood A. Occupational lung diseases. Pulmonary Therapy. 2021;7:75–87.
27. Priya S.V. et al. Lung function study in stone sculptors. Indian Journal of Respiratory Care. 2022;11(3):261–266.
28. Tiwari R.R. et al. Serum copper levels in stone crushing workers. Indian Journal of Physiology and Pharmacology. 2004;48(3):337–342.
29. Patel J., Robbins M. Silicosis in Khambhat. New Solutions. 2011;21(1):117–139.
30. Rivai A.T. et al. Mineralogy and environmental implications in Indonesia. Evergreen. 2019;6(1):18–28.
31. Sahu S. et al. Ergonomics assessment of sculptors. International Journal of Occupational Safety and Ergonomics. 2013;19(3):455–462.
32. Saldaña, D., Montealegre, K., Castro, C., & Rey, M. (2025). Genomic Biomarkers and Clinical Perspectives of Fluoropyrimidines in Cancer Treatment. A Literature Review. Genetics and Molecular Research, 24(2), 1-21.
33. Parrey, M. (2025). Determination of the role of RAGE rs1800625 polymorphism in diabetic retinopathy in South Asian Population. Genetics and Molecular Research, 24(1), 1-8.
34. Carpentieri-Pipolo, V. (2025). Root System Architecture in Wheat: Implications for the Breeding Program. Genetics and Molecular Research, 24(2), 1-14.
35. Al-Shammaa, N. F. K. (2025). Enhancing Women's Fertility: Insights and StrategiesBased on Scientific Evidence. Genetics and Molecular Research, 24(1), 1-11.
36. dos Santos, D. G., de Avellar, G. S., da Costa Parrella, R. A., dos Santos, N. M., Damasceno, N. C. R., Rezende, K. A. S., ... & Mentes, S. M. (2025). Biology and Life Table of Melanaphis sorghi (Theobald, 1904)(Hemiptera: Aphididae) on Sweet Sorghum Hybrids (Sorghum bicolor). Genetics and Molecular Research, 24(2), 1-12.
37. Yingratanasuk T. et al. Silica exposure of stone carvers in Thailand. International Journal of Occupational and Environmental Health. 2013;8(4):301–308.
38. Nwibo A.N. et al. Pulmonary problems among quarry workers in Nigeria. The International Journal of Occupational and Environmental Medicine. 2012;3(4):178–185.

39. Muneku E., Naidoo S. Dust exposure among quarry workers in Zambia. Occupational Health Southern Africa. 2015;21(6):4–9.
40. Antao V. et al. Silicosis among stone carvers in Brazil. American Journal of Industrial Medicine. 2004;45(2):194–201.
41. Arumugam E. et al. Pulmonary function in quarry workers. Lung India. 2021;38(6):558–563.
42. Harsh Ganapathi, Phukan M. Environmental hazards of limestone mining. Environmental Processes and Management. 2020:121–134.
43. Kundal M. Environmental impact assessment of Malundha mine. Excel Environ Tech. 2017:201–228.
44. Meshcheryakov S.V., Potulov O.E. Mangyshlak and Ustyurt Shell Limestone. Alma-Ata: Nauka; 1974.
45. EGOV.KZ. Waste reduction, recycling and reuse. https://egov.kz (accessed 10 April 2024).
46. [42] Bureau of National Statistics ASPiR RK. Air protection in Kazakhstan. https://stat.gov.kz (accessed 10 April 2024).
47. Bukayev Ye.Z., Mutalibova G.K., Bukayeva A. Polymer–cement composition from limestone-shell waste. News of NAS RK. Geology and Technical Sciences. 2022;2(452):73–88.
48. Bukayev Ye., Nurbayeva F., Bukayeva A. Chemical–mineralogical composition of limestone-shell from Zhetibai. News of NAS RK. Geology and Technical Sciences. 2025;3(471):27–38.
49. UNDP. Managing Mining for Sustainable Development. UNDP Bangkok; 2018.