ASSESSING ENVIRONMENTAL DEGRADATION AND HEALTH RISKS FROM SANDSTONE MINING IN JODHPUR DISTRICT, RAJASTHAN, USING GEOSPATIAL TECHNIQUES

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ABSTRACT
Rapid expansion of sandstone mining in Jodhpur District, Rajasthan, has intensified environmental degradation and raised significant public health concerns in this arid region. This study assesses the spatial extent of mining-induced land transformation and its associated environmental and health implications, utilising an integrated geospatial framework. Multi-temporal satellite imagery (2015–2025) was analysed to assess land-use and land-cover changes, revealing substantial conversion of agricultural land into quarry sites and expansion of mining operations toward peri-urban areas. Environmental quality was examined through field-based soil and water sampling (January 2026) and secondary air quality data obtained from CPCB monitoring stations (November 2025–January 2026). Results indicate elevated particulate matter concentrations ($PM_{2.5}$ and PM_{10}) in mining-dominated zones, increased groundwater mineralisation, as reflected in high TDS and hardness values, and localised soil salinisation near active quarries. These findings confirm spatially concentrated environmental stress in areas of intensive sandstone extraction.
A structured health survey of 400 respondents within a 10 km mining buffer revealed a high prevalence of respiratory disorders, skin diseases, silicosis symptoms, sleep disturbances, substance use, and anxiety-related conditions. GIS-based spatial overlay analysis demonstrated a clear convergence between environmental degradation hotspots and adverse health outcomes. The study highlights the urgent need for enhanced environmental monitoring, effective dust control strategies, and integrated public health interventions to ensure sustainable mining practices in arid mining landscapes.

KEYWORDS: Sandstone mining, Land-use change, Environment Degradation, GIS-based assessment, Community health

1. INTRODUCTION

Mining is a fundamental economic activity that provides essential raw materials, thereby supporting industrial growth and infrastructure development. Simultaneously, it is widely recognised as one of the most environmentally disruptive human activities, particularly when conducted intensively in semi-arid and ecologically sensitive regions (Singh & Kumar, 2020). In India, sandstone mining has experienced significant growth as a result of increasing demand from the construction industry. The Jodhpur district of Rajasthan represents one of the most prominent sandstone mining regions in the country, contributing significantly to national production. Rajasthan is home to hundreds of large quarries and numerous small-scale mining units, which operate across the arid landscape of Rajasthan, accounting for nearly 90% of India's sandstone output (Sharma et al., 2019). Despite the fact that sandstone mining offers employment and economic opportunities, its rapid and largely unregulated expansion has led to widespread environmental degradation and increasing public health concerns.

Environmental degradation in the Jodhpur district is primarily identified by extensive land-use and land-cover (LULC) changes driven by open-cast sandstone mining. Continuous excavation, waste dumping, removal of overburden and the construction of haul roads have resulted in the transformation of agricultural land, grazing areas, and natural scrub vegetation into degraded wastelands and open pits. In arid environments such as western Rajasthan, where rainfall is low and vegetation regeneration is slow, these moderations severely disrupt ecological balance. Remote sensing studies conducted in sandstone mining belts of Rajasthan have seen a consistent decrease in vegetation cover, fragmentation of agricultural land, and growth of barren areas over time (Meena & Ghosh, 2021; Prema Ram & Singh, 2023).

Sandstone mining in Jodhpur also significantly impacts the quality of air, water, and soil. Quarrying, drilling, blasting, stone cutting, and heavy vehicular movement produce large quantities of dust dominated by particulate matter (PM_{10} and $PM_{2.5}$), often rich in crystalline silica. Studies across Rajasthan's sandstone mining regions have consistently shown that dust concentrations in and around mining sites are high, often exceeding prescribed air quality standards (Choudhary et al., 2018; Gupta & Tiwari, 2020). These fine particles remain suspended in the atmosphere and are carried by wind, landing on agricultural fields, soil surfaces, and nearby water bodies. Water resources in mining-affected villages are further deteriorate due to sedimentation, contamination from mining debris, which reduces both water availability and quality (Meena et al., 2020). Physical disturbance and dust deposition also harm soil quality, leading to declining crop productivity and reduced fertility.

The degradation of environmental quality in sandstone mining areas has direct and indirect impacted the human health. Workers engaged in mining operations are exposed to silica-rich dust, making them highly vulnerable to occupational illness such as silicosis, chronic obstructive pulmonary disease (COPD), tuberculosis, asthma, and reduced lung function (Joshi et al., 2019). Epidemiological studies from Rajasthan have reported a high prevalence of silicosis and silico-tuberculosis among sandstone miners, reflecting prolonged exposure and inadequate use of protective measures (Kavita & Mishra, 2020). Non-resident migrant labourers, who often reside in temporary settlements near quarry sites, face the health risks due to poor housing, limited access to clean water, and inadequate healthcare services. Residents living near mining zones experience chronic respiratory problems, eye and skin irritation, sleep disturbance, and psychological stress, with children and elderly populations being particularly vulnerable (Gupta et al., 2021).These health impacts highlight the close interlink between mining-induced environmental degradation and community well-being.

Understanding the relationship between mining activities, environmental degradation, and human health requires an integrated assessment approach. In the present study, primary field surveys were conducted to evaluate soil and water quality in mining-affected areas, capturing site-specific environmental conditions. Health-related information was collected through structured primary surveys among mine workers and nearby residents to assess the prevalence of mining-associated health problems. Air quality was analysed using ground-based monitoring data obtained from the Central Pollution Control Board (CPCB) website. The data enabled spatial assessment of particulate matter distribution across the district. The integration of field-based observations with CPCB monitoring data provides a comprehensive framework for assessing mining impacts in a large and heterogeneous landscape.

Geographic Information Systems (GIS) and remote sensing play a critical role in integrating and analysing multi-source datasets in mining-impacted regions. Remote sensing enables continuous monitoring of land degradation, vegetation loss, and mining expansion over time, particularly in extensive and inaccessible areas such as western Rajasthan (Bhatnagar et al., 2024). High-resolution satellite images help clearly identify quarry boundaries, excavation pits, and surface disturbances that may not be visible in coarse-resolution data (Lambin et al., 2003). Freely available Google Earth imagery is particularly valuable because of its fine spatial detail and long temporal record, allowing easy comparison of landscapes before and after mining. GIS further supports the integration of these spatial indicators with environmental and health data to identify high-risk areas and inform better environmental planning (Gorelick et al., 2017; Mishra et al., 2020).

The primary objective of this paper is to assess the extent of environmental degradation caused by sandstone mining in the Jodhpur district and to examine its implications for human health using an integrated geospatial and field-based approach. Specifically, the study aims to (i) evaluate changes in land use and degradation of air, water, and soil quality in mining-affected areas, (ii) analyse health impacts on mine workers and nearby communities, and (iii) establish spatial linkages between mining intensity, environmental degradation, and health risks using GIS. The findings of this study are intended to support sustainable mining practices and informed decision-making for environmental and public health management in arid mining regions.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in the Jodhpur district of Rajasthan, focusing on sandstone mining areas located across selected tehsils, as illustrated in **Figure 1**. Within the Jodhpur district, the study was conducted in Jodhpur tehsil. A 10 km grid was generated with the centres of major mining areas as focal points. The spatial extent of this grid lies between approximately 26°26′00″–26°15′00″ N latitude and 72°51′00″–73°03′00″ E longitude within the arid to semi-arid climatic zone of western Rajasthan.

From the district, mining-intensive tehsils were identified, followed by the selection of a 10 km grid from the central portions of active mining areas to ensure representative exposure conditions. Geologically, the region is dominated by Jodhpur Sandstone of the Marwar Supergroup, characterised by horizontally bedded sedimentary formations. The landscape is rocky and quarried.

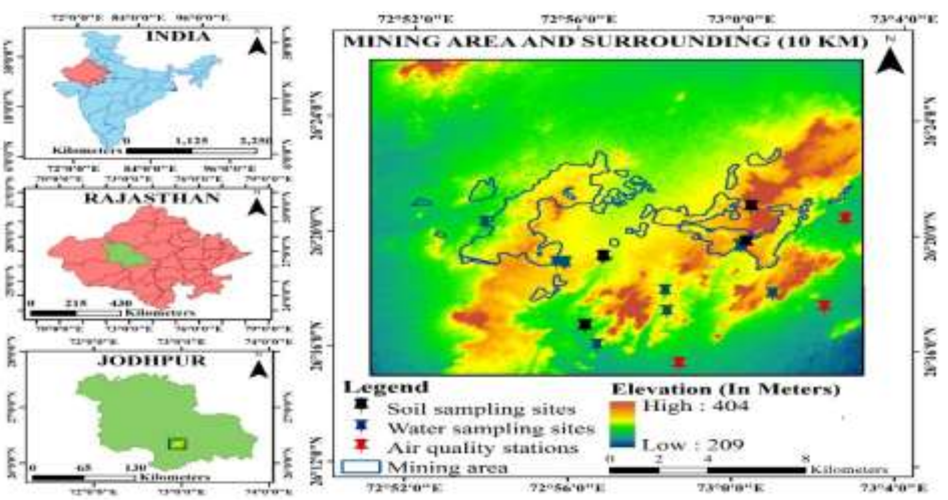


Figure 1 Location of the sandstone mining area in Jodhpur Tehsil, Rajasthan, India, showing the 10 km buffer zone with soil, water, and air quality sampling sites. Inset maps indicate the regional context within Rajasthan and India.

2.2 Data Types and Sources

The data sets incorporated in this study like the detailing their sources, time of acquisition and analytical focus have been depicted in **Table-1**. For examining the Spatial changes in sandstone mining and associated land use and environmental transformation for a certain period of time, Multi Temporal Google Earth Imagery was used whereas for the primary field surveys conducted in January 2026, involved the collection of soil and water samples to assess mining induced changes in certain critical physico - chemical properties.

For mining related air pollution and its associated impact on human health, the ambient air quality data was extracted from CPCB monitoring stations along with primary household health surveys conducted between November 2025 and January 2026. The combination of these data sets highlights the environmental and health affects due to sandstone mining in the study area.

Table 1 Data Sources and Acquisition Periods

Data	Source	Time of Acquisition	Description
Temporal high-resolution data	Google Earth Imagery	2015–2025 (multi-temporal)	Multi-temporal satellite imagery was utilised to monitor the expansion of sandstone mining areas over time and assess their impact on land use and the surrounding environment.
In-situ sample collection – Water quality sampling	Field survey and laboratory analysis	January 2026	Water samples from surface and groundwater sources in mining-affected areas were analysed for pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness, calcium, magnesium, chloride, sulphate, nitrate, fluoride, and turbidity to assess the impact of mining activities on water quality.
In-situ sample collection – Soil quality sampling	Field survey and laboratory analysis	January 2026	Soil samples from agricultural fields and mining-influenced areas were analysed for pH, electrical conductivity (EC), organic carbon, soil texture, bulk density, available nitrogen, phosphorus, potassium, and selected heavy metals such as iron and manganese to evaluate mining-induced soil degradation.
Air quality data	Central Pollution Control Board (CPCB)	November 2025 – January 2026	Secondary ambient air quality data from CPCB monitoring stations were used to assess mining-related air pollution by analysing PM_{10}, $PM_{2.5}$, sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO).
Human health survey	Structured questionnaire survey	November 2025 – January 2026	Primary health data were collected through household surveys to assess mining-related health impacts, including respiratory problems (cough, asthma, breathlessness, silicosis symptoms), eye irritation, skin diseases, occupational exposure duration, use of protective equipment, and frequency of medical consultation.

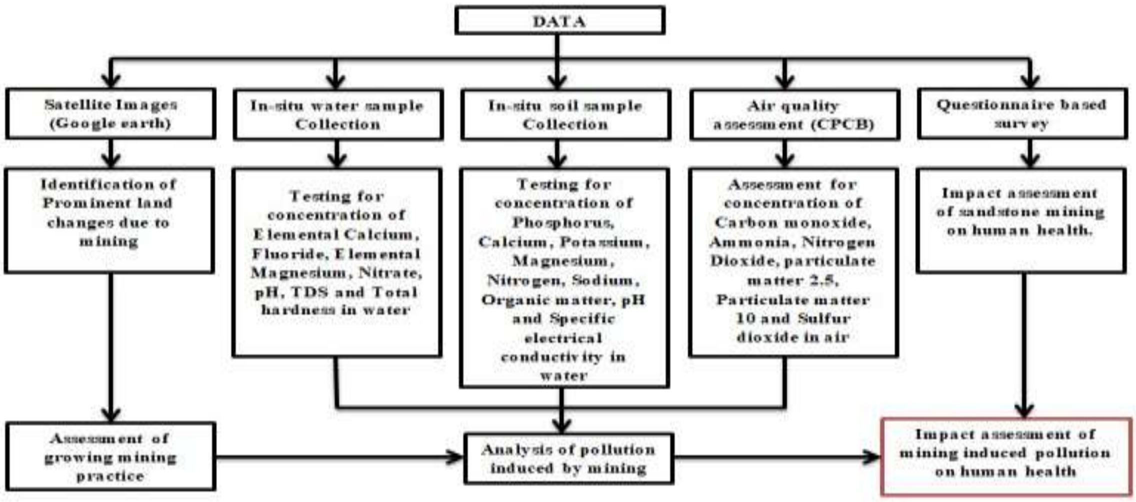


Figure 2 Methodological framework for assessing mining-induced environmental pollution and its human impacts.

2.3 Methodology

Subsequently, as illustrated in **Figure 2**, multi-source data sets were collected and integrated within the GIS framework. The Multi Temporal Satellite Imagery was the tool in analysing to identify and mark the key land use and land cover changes associated with sandstone mining expansion by using the data from USGS EarthExplorer (U.S. Geological

Survey, 2023). Mining lease boundaries and spatial layers were processed and analysed in a GIS environment (ESRI, 2023), to ensure accurate spatial representation.

The In-situ water and soil samples were collected from pre-selected locations within the 10km periphery of the study area (Singh et al., 2020). The laboratory analysis were conducted to examine vital physico-chemical parameters. The water samples were tested for pH, TDS, total hardness, calcium, potassium, magnesium, fluoride and nitrates while the soil samples were analysed for phosphorus, calcium, potassium, magnesium, nitrogen, sodium, organic matter, pH and electrical conductivity following the standard environmental assessment protocols

The air quality assessment was done in accordance with CPCB monitoring guidelines, covering $PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, and CO (CPCB, 2019). In addition, a structured questionnaire survey was administered to quarry workers to document physical and psychological health conditions. All the data sets for environment and health were combined together and analysed in GIS (ESRI, 2023), to evaluate pollution patterns and also to examine the relationship between mining activities, environmental degradation and associated human health impact within the mining influenced zone.

2.3.1 Land Conversion Due to Sandstone Mining

The transformation in land as a result of sandstone mining was assessed using Multi Temporal Satellite Imagery (e.g, Landsat 8/9 from USGS) and Visual Interpretation Techniques (Anderson et al., 1976). The satellite images for the years 2015 and 2025 were used to analyse the temporal progression of land conversion and also to examine the mining related activities have changed the place over a certain period of time. The changes in land were analysed to identify the transition of agricultural land, scrubland and open land into mining areas and degraded land. The spatial extent and the pattern of mining induced land degradation were mapped in accordance with the guidelines of Indian Council of Agricultural Research (ICAR, 2019)

2.3.2 Environmental Quality Assessment

1. Air Quality Assessment

Air quality was assessed using secondary data obtained from the Central Pollution Control Board (CPCB), Government of India (CPCB, 2022). Air quality monitoring stations located within and around the 10 km study grid were selected for analysis. The assessed parameters included $PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, and CO, which are closely associated with mining operations, vehicular movement, and material transportation (WHO, 2021). The geographic coordinates of the monitoring stations were mapped in a GIS environment and the pollutant concentration was derived from these points.

To generate the continuous distribution maps for each pollutant, spatial interpolation (e.g., Inverse Distance Weighting) was applied, allowing analysis of spatial variation in air quality across the study area (Li & Heap, 2011). The observed concentrations were compared with National Ambient Air Quality Standards (NAAQS) to assess pollution levels and potential exposure risks (CPCB, 2009).

2. Soil Quality Assessment

Soil quality assessment was carried out within the **10 km mining influence zone**. A total of **four soil samples**, labelled **S1, S2, S3, and S4**, were collected directly from the field at selected locations representing mining-affected areas, nearby agricultural fields, and surrounding non-mining zones. Approximately **1 kg of soil** was collected at each site following standard field sampling procedures. The samples were packed in clean plastic packets, properly labelled, and transported to the laboratory for analysis.

Laboratory testing was conducted for pH, electrical conductivity, calcium, magnesium, sodium, potassium, nitrogen, phosphorus, and organic matter using standard analytical procedures prescribed by the **Soil Survey of India (SSAC, 2010)**. Each parameter was analysed in **three replicate trials**, and the reported values represent the **actual result derived from the average of the three trials**, ensuring analytical reliability. These parameters were selected to assess soil salinity, nutrient status, and overall fertility, which are commonly influenced by mining activities and dust deposition (Alloway, 2013).

Soil sampling was carried out in **January 2026**, and the ambient **temperature at the time of sampling** was also recorded. The geographic coordinates of all sampling locations were documented during field collection and subsequently plotted using GIS techniques to enable spatial analysis of soil quality variations in relation to mining influence.

3. Water Quality Assessment

Water quality assessment was conducted within the **10 km study area** to evaluate the influence of sandstone mining on local water resources. A total of **13 water samples** were collected from commonly used groundwater sources and selected surface water bodies across the study area. Approximately **1 litre of water** was collected at each location using pre-sanitised, clean bottles. The samples were properly sealed, labelled as **W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13**, and transported to the laboratory for analysis.

Laboratory analysis was carried out following standard procedures prescribed by the **Bureau of Indian Standards (BIS 10500:2012)** and relevant **IS: 3025 methods**. The parameters analysed included **pH, total dissolved solids (TDS), total hardness, calcium, magnesium, fluoride, and nitrate**, selected due to their sensitivity to mining-related contamination and their importance for drinking water quality assessment (CGWB, 2021).

During fieldwork, the exact coordinates of each sampling location were recorded at the sites from where the water samples were collected. Later, these locations were imported into the GIS environment, where the laboratory results were attached to their respective points. After entering all the values, spatial interpolation was carried out to understand and visualise how water quality varied across the study area, particularly in areas influenced by sandstone mining activities.

2.3.3 Health Impact Assessment

A community-based health survey was conducted within the **10 km mining influence zone** to assess the health impacts of sandstone mining. As shown in **Table 2, seven locations** were selected for the survey—**Keru, Fedusar, Kaliberi, Bhurbiberi, Pabumagra, Sodo ki Dhani, and Keru-A**—based on the **highest concentration of sandstone mines**, as identified from records of the **Department of Mines and Geology, Jodhpur (Rajasthan)**. These locations collectively accounted for a total sample size of **400 respondents**.

Respondents were selected using a **multistage purposive sampling approach**, based on a **95% confidence level and a 5% margin of error** (Kothari & Garg, 2004). The study population included **mine workers and non-mine workers**, ensuring representation across different exposure groups. Mine workers comprised quarry labourers, drillers, drivers, and pulley operators, while non-mine workers included residents living in close proximity to mining sites and individuals engaged in other occupations.

Primary data were collected through **face-to-face interviews** using a **structured questionnaire** developed specifically for this study. The questionnaire captured information on respiratory ailments, skin and eye problems, musculoskeletal disorders, and general health conditions, along with socio-economic characteristics and duration of exposure to mining activities (WHO, 2017). Participation in the survey was voluntary, and **informed consent** was obtained from all respondents prior to data collection

Table 2 Sample distribution (n = 400) across major active quarry areas in Jodhpur.

S.No	Name of Areas(maximum active Quarry)	Sample size (95% level of confidence)
1.	Keru	57
2.	Fedusar	57
3.	Kaliberi	57
4.	Bhuriberi	57
5.	Pabumagra	57
6.	Sodo ki dhani	57
7.	Keru -A	57
	Total	400

2.3.4 Integration of Environmental and Health Data

Environmental quality data (air, soil, and water), land conversion information, and health survey results were integrated within the GIS environment to see the impact of sandstone mining on environment and health.

3. RESULTS

3.1 Land Conversion Due to Sandstone Mining

Multi-temporal satellite imagery from 2015 and 2025, as presented in **Figure 3**, clearly shows the spatial expansion of sandstone mining activities within the study area. In all comparative images, the **left side represents the year 2015**, while the **right side represents 2025**, allowing a clear visual understanding of land use changes over the ten years.

Figure (a) highlights the conversion of agricultural land into mining areas. The 2025 image clearly shows that previously cultivated fields visible in 2015 have been transformed into active quarry zones, indicating direct land use change due to mining expansion.

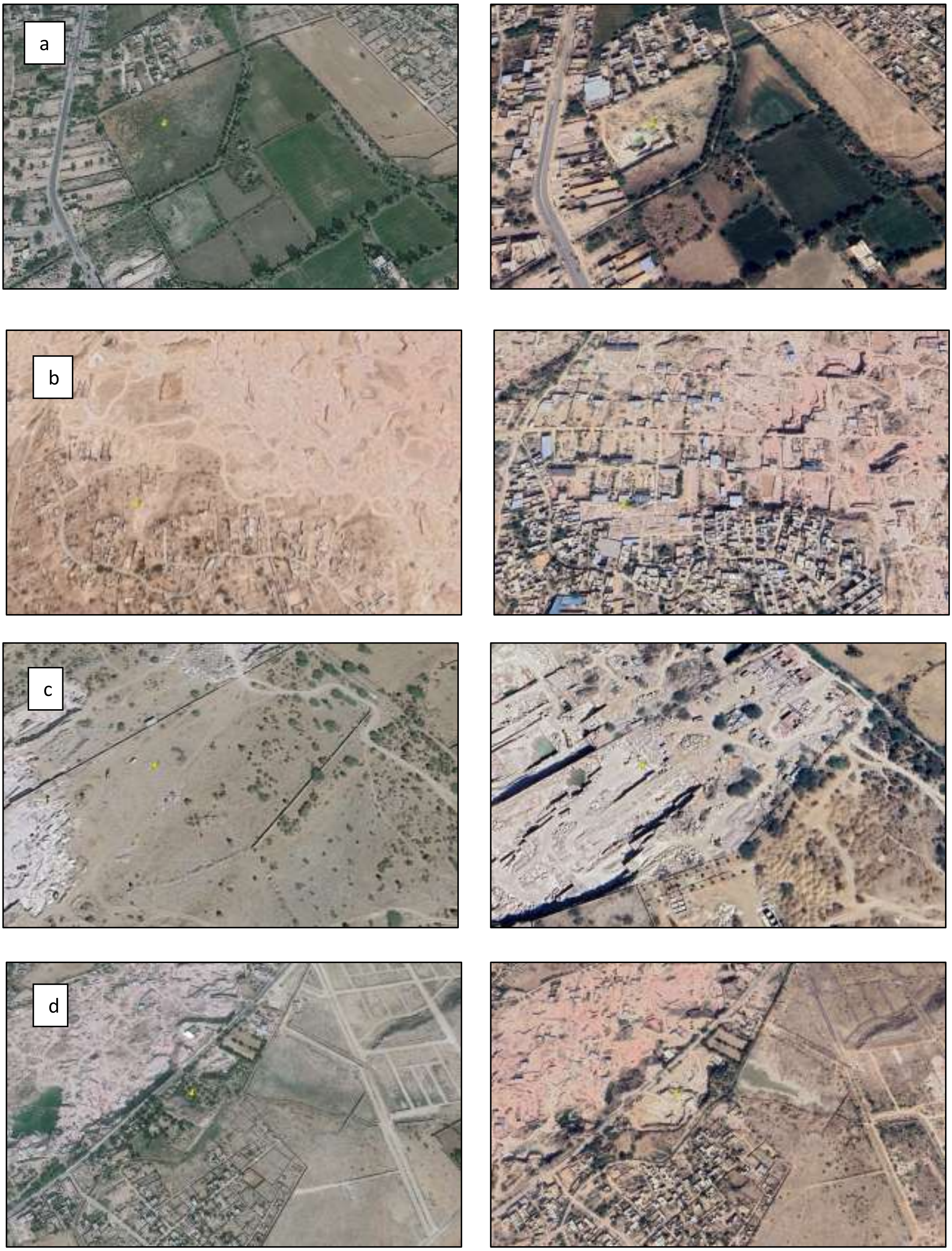
Figure (b) illustrates the outward growth of the city toward mining zones. It also shows an increase in the number of stone cutting and processing stations near urban areas. This proximity between mining-related activities and residential zones raises serious environmental and public health concerns.

Figures (c), (d), (e), and (f) further demonstrate the continuous increase in mining area over time. These images reveal not only the horizontal expansion of quarry sites but also their gradual shifting toward agricultural land. Additionally, more cutting stations are being established closer to both farming areas and urban settlements.

Figure (g) presents the overall increase in mining area between 2015 and 2025, clearly showing the large-scale expansion toward agricultural land and the relocation or establishment of cutting stations nearby.

The establishment of cutting stations close to city areas is particularly harmful, as these units release fine silica dust and particulate matter into the atmosphere. Due to prevailing wind directions, this dust can easily disperse toward residential areas, increasing the risk of respiratory and other health problems among the nearby population.

Overall, the temporal comparison between 2015 and 2025 confirms significant mining expansion, agricultural land loss, peri-urban encroachment, and increasing environmental and health risks within the study region.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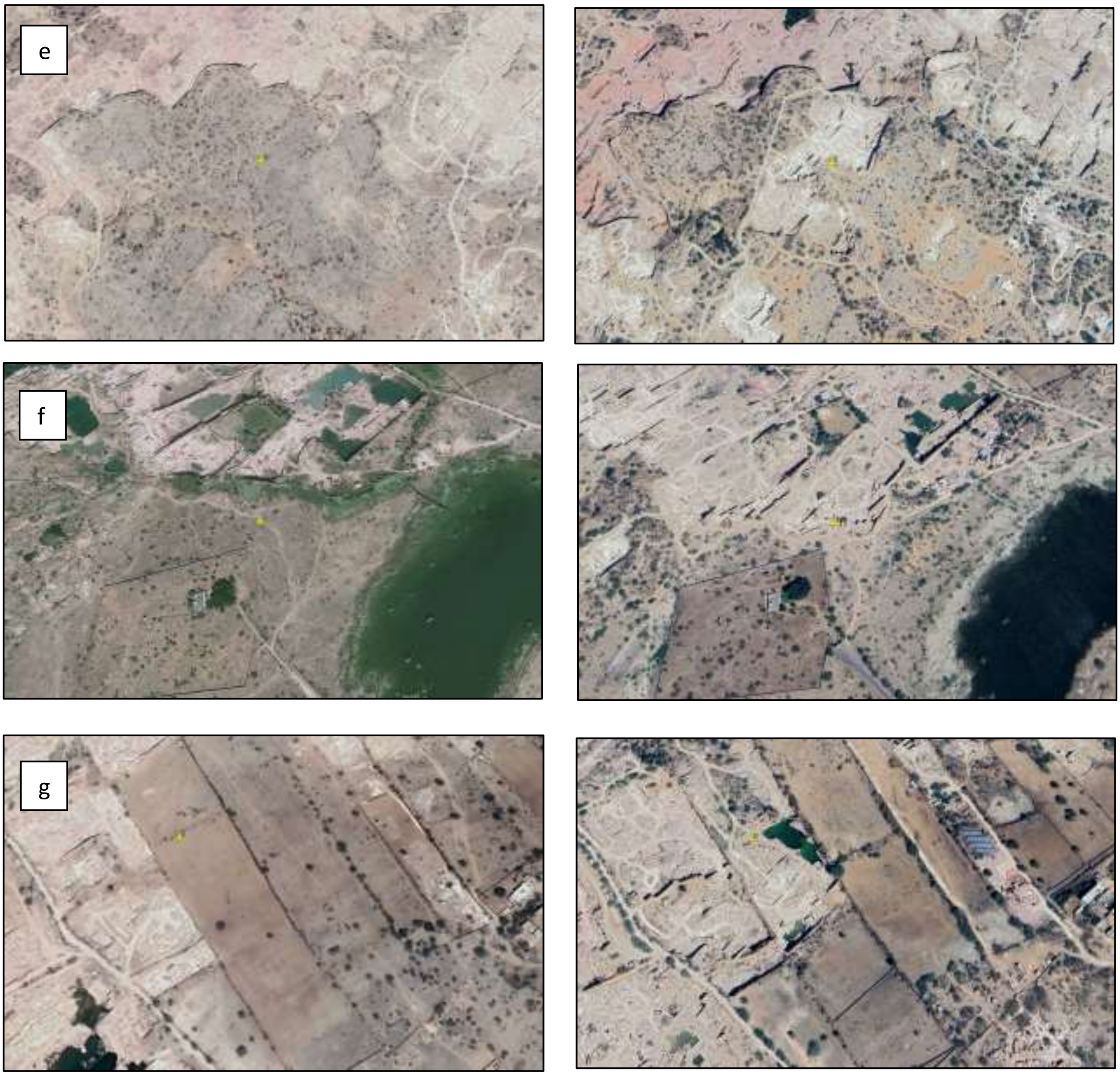

Figure 3 Multi-temporal analysis (2015–2025) showing land transformation and spatial expansion: (a) agricultural land conversion into quarry areas; (b) urban growth toward mining zones with increased cutting stations; (c–f) progressive horizontal expansion and shifting of mining toward agricultural land; (g) overall increase in mining extent and relocation of cutting units near settlements.

3.2 Air Quality Assessment

Table 3 Air pollutant concentrations at selected monitoring stations in the mining area.

AIR QUALITY						
Locations	**PM2.5**	**PM10**	**NO2**	**NH3**	**SO2**	**CO**
A1	119.129	109.3226	38.22581	4.032258	6.225806	39.58065
A2	126.7419	91.67742	27.09677	4.451613	6.032258	29.87097
A3	119.129	109.3226	38.22581	4.032258	6.225806	39.58065

As stated in **Table 3 and Figure 4**, the spatial distribution of air quality parameters within the 10 km mining buffer of Jodhpur shows noticeable variation, particularly in particulate matter concentrations. The monitoring stations (A1, A2, and A3), selected from the CPCB database, indicate that PM2.5 ranges from 119.12–126.74 µg/m³ and PM10 from 91.67–109.32 µg/m³. The highest PM2.5 concentrations is recorded at A2 (126.74 µg/m³), which is located near active mining areas, while A1 and A3 show elevated PM10 and similar pollutant trends. The spatial interpolation maps clearly highlight higher particulate concentrations around mining-dominated zones, reflecting intense dust emissions from drilling, blasting, crushing, transportation of sandstone, and movement of heavy vehicles.

Gaseous pollutants show comparatively moderate variation, with NO_2 ranging from 27.09–38.22 µg/m³, NH_3 from 4.03–4.45 µg/m³, SO_2 from 6.03–6.22 µg/m³, and CO from 29.87–39.58 µg/m³. Higher NO_2 and CO levels at A1 and A3 correspond to vehicular activity and machinery operation, whereas A2—being closer to quarrying sites—reflects a stronger influence of dust and mining-related emissions. Overall, the figure suggests that particulate pollution is the dominant air quality concern in the sandstone mining belt, posing potential respiratory health risks to nearby communities and emphasising the need for effective dust suppression and emission control measures.

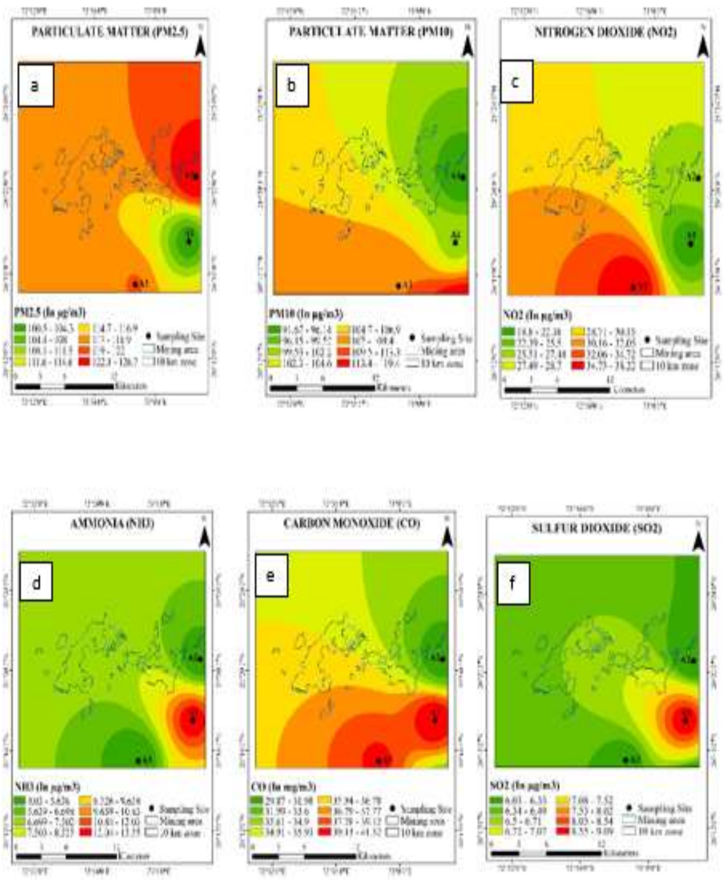

Figure 4 Spatial distribution maps of major air pollutants within the 10 km mining zone. (a) $PM_{2.5}$ concentration surface; (b) PM_{10} concentration surface; (c) NO_2 distribution; (d) NH_3 distribution; (e) CO distribution; (f) SO_2 distribution.

3.3 Soil Quality Assessment

Table 4 Soil quality parameters at selected sampling locations

SOIL QUALITY									
Locations	**PH**	**Electrical conductivity**	**Calcium**	**Magnesium**	**Sodium**	**Potassium**	**Nitrogen**	**Phosphorous**	**Organic matter**
S1	7.58	1.48	28	39	20	42	33	38	9
S2	7.55	1.42	22	33	13	34	52	24	21
S3	7.56	1.45	23	35	15	38	50	32	16
S4	7.52	1.4	20	32	8	30	68	31	54

As stated in **Table 4 and Figure 5**, the spatial distribution maps of soil parameters within the 10 km mining zone of Jodhpur show clear variations linked to proximity to sandstone quarrying activities. Soil pH remains slightly alkaline and stable across all locations (7.52–7.58), indicating no significant acidification. However, higher concentrations of sodium (20 mg/kg), potassium (42 mg/kg), calcium (28 mg/kg), magnesium (39 mg/kg), and electrical conductivity (1.48 dS/m) are prominently observed at S1, which lies close to the active mining belt. The interpolation maps reflect a concentration gradient radiating from S1 toward comparatively lower values at S4, suggesting localised mineral enrichment and salt accumulation due to mining disturbance and dust deposition.

In contrast, S4—located relatively away from the core mining zone—shows lower salinity (EC: 1.4 dS/m; Na: 8 mg/kg; K: 30 mg/kg; Ca: 20 mg/kg; Mg: 32 mg/kg) but records higher nitrogen (68 mg/kg) and organic matter (54%), indicating better soil fertility conditions. Nitrogen and phosphorus display moderate spatial variability, with S2 and S3 showing balanced nutrient levels. Overall, the figure suggests that soils nearer to intensive mining areas exhibit increased salt and base cation accumulation, whereas peripheral zones retain comparatively higher organic content and nutrient balance. This spatial contrast reflects localized soil quality alteration due to sandstone mining and highlights emerging risks of soil salinization and fertility decline in mining-dominated sectors.

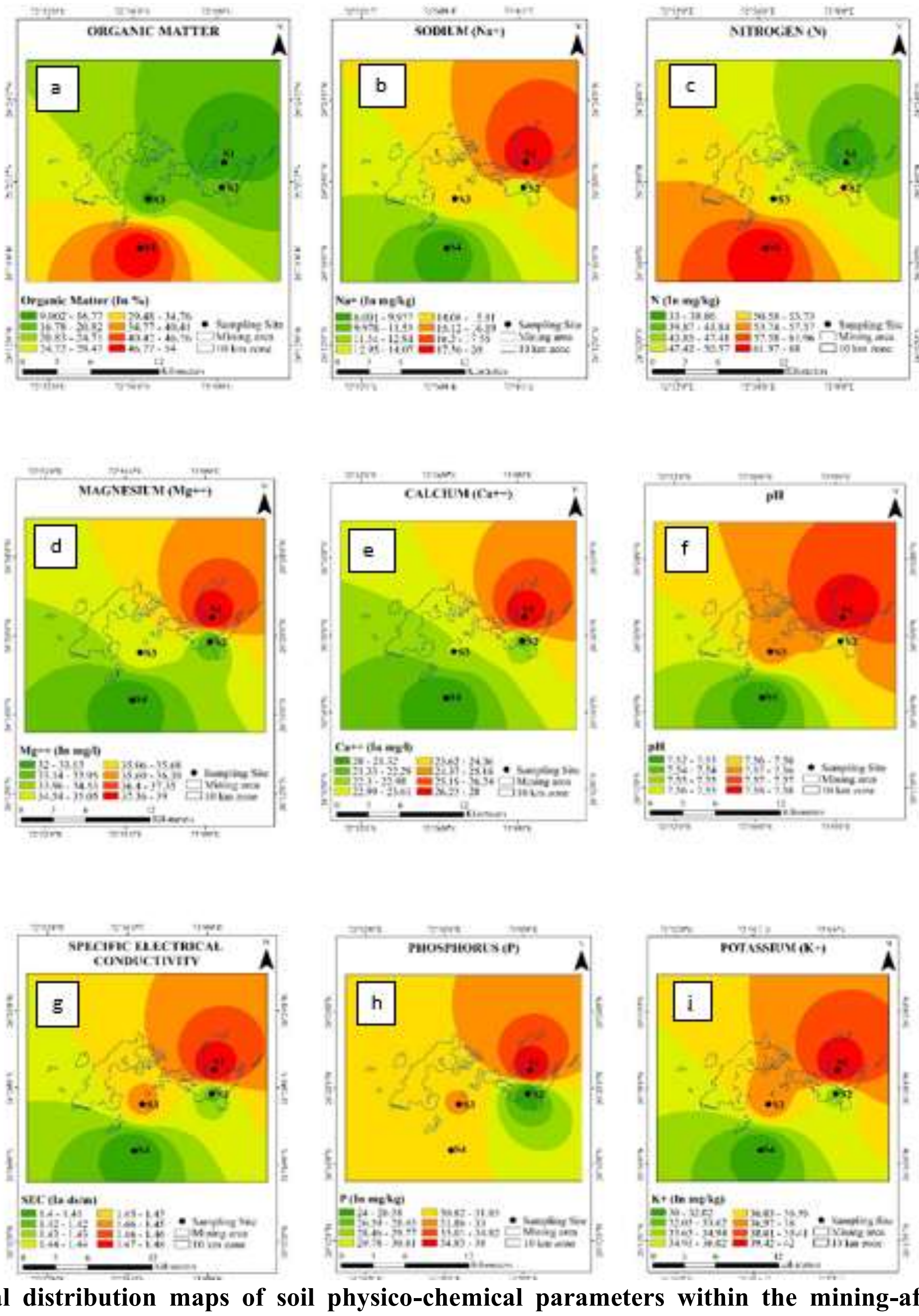

Figure 5 Spatial distribution maps of soil physico-chemical parameters within the mining-affected area. (a) Organic matter; (b) Sodium (Na^+); (c) Nitrogen (N); (d) Magnesium (Mg^{2+}); (e) Calcium (Ca^{2+}); (f) pH; (g) Specific electrical conductivity; (h) Phosphorus (P); (i) Potassium (K^+).

3.4 Water quality Assessment

Table 5 Physico-chemical characteristics of Waterbodies samples from selected locations in the study area.

WATER QUALITY							
Name of Sampling Location	**PH**	**TDS**	**TOTAL HARD NESS**	**CALCIU M**	**MAGN ESIUM**	**FLUO RIDE**	**NITRAT E**
W1	7.42	271	162	39	16	0.92	6.4
W2	7.43	260	156	38	15	0.93	6.3
W3	7.44	580	348	84	33	0.94	6.2
W4	7.39	104	62	15	6	0.93	6.8

W5	8.34	107	69	13	7	0.93	6.9
W6	7.38	168	101	24	10	0.94	6.7
W7	7.4	610	366	88	35	0.91	6.7
W8	7.41	137	82	20	8	0.92	6.48
W9	7.44	181	108	26	10	0.92	6.42
W10	7.44	1707	1024	246	98	0.96	6.53
W11	7.38	822	493	118	47	0.86	6.32
W12	7.39	136	82	18	8	0.92	6.48
W13	7.42	256	154	37	15	0.95	6.51

As stated in **Table 5 and Figure 6,** the spatial maps clearly highlight noticeable variations in groundwater quality within the 10 km mining zone of Jodhpur. While pH (7.38–8.34), fluoride (0.86–0.96 mg/L), and nitrate (6.2–6.9 mg/L) remain within acceptable limits across all sampling sites, distinct hotspots of Total Dissolved Solids (104–1707 mg/L) and Total Hardness (62–1024 mg/L) are visible. The highest concentrations are observed at W10, followed by W11, W7, and W3, all located near active sandstone mining areas.

The figure further shows that these zones of elevated TDS and hardness correspond with higher calcium and magnesium levels, indicating increased mineral dissolution due to quarrying activities. In simple terms, the groundwater near intensive mining sites is becoming more mineralized compared to peripheral locations. Although most parameters do not exceed drinking water standards, the consistent pattern of higher mineral content in mining-dominated areas suggests gradual environmental stress and raises concerns about long-term community health if such trends continue without proper monitoring and management.

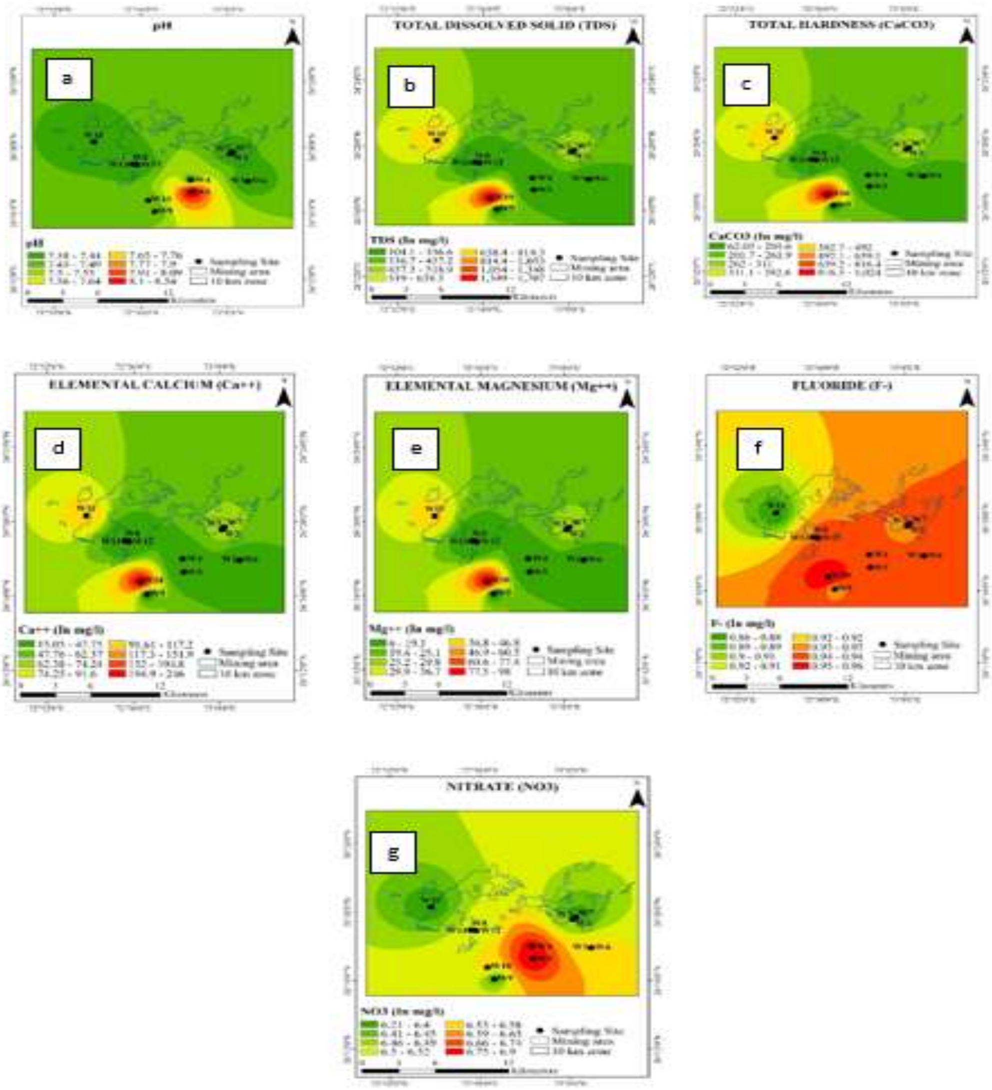

Figure 6 Spatial distribution of groundwater quality parameters within the mining-affected 10 km zone. (a) pH distribution; (b) Total Dissolved Solids (TDS); (c) Total Hardness ($CaCO_3$); (d) Calcium (Ca^{2+}); (e) Magnesium (Mg^{2+}); (f) Fluoride (F^-); (g) Nitrate (NO_3^-).

3.5 Health Impact Assessment

Sandstone mining in the Jodhpur mining areas has become a serious concern for the health of local communities. Continuous exposure to dust, noise, and frequent blasting has led to visible physical health problems such as breathing difficulties, persistent cough, and general weakness among residents. Along with physical illness, people living near mining sites increasingly report mental health issues, including stress, disturbed sleep, anxiety, and panic attacks. The constant fear of falling sick, damage to homes, and uncertainty about the future adds to psychological pressure. Field observations clearly show that the overall health of people in these areas is gradually deteriorating. This situation highlights the urgent need to assess health impacts and improve protective and support measures for affected communities.

3.5.1 Physical Health

Table 6 Distribution of reported Physical health problems among quarry workers

Health Issue	Number of Respondents	Percentage (%)
Chronic Cough	90	22.5
Shortness of Breath	98	24.5
Skin Rashes	187	46.8
Frequent Fever	52	13.0
Headache	61	15.2
Tuberculosis	43	10.8
Cancer	6	1.5
Silicosis	52	13.0
Other	49	12.2
Total	400	

Table 6 and Figure 7 present the percentage distribution of major physical health problems reported by 400 respondents residing in and around the sandstone mining areas. The data clearly indicate a high prevalence of dust-related and respiratory illnesses among the study population.

Skin rashes emerged as the most commonly reported health problem, affecting 187 respondents (46.8%), suggesting prolonged exposure to dust, heat, and unhygienic working conditions. Shortness of breath was reported by 98 respondents (24.5%), while chronic cough affected 90 respondents (22.5%), reflecting continuous exposure to airborne particulate matter generated from quarrying and stone processing activities.

Headache was reported by 61 respondents (15.2%), indicating general physical stress and possible dehydration or dust exposure. Frequent fever and silicosis were each reported by 52 respondents (13.0%). The presence of silicosis cases highlights the occupational health risks associated with long-term inhalation of silica dust. Tuberculosis was reported by 43 respondents (10.8%), further emphasizing the burden of respiratory illnesses in mining-affected communities.

Additionally, 49 respondents (12.2%) reported other miscellaneous health problems. Cancer cases were reported by 6 respondents (1.5%). Although the percentage is relatively low, the severity and long-term implications of such illnesses remain significant.

Overall, Table 6 and Figure 7 clearly demonstrate the dominance of respiratory and dust-induced health issues among respondents, strongly indicating a linkage between sandstone mining activities, airborne particulate pollution, and adverse health outcomes in both workers and nearby residents.

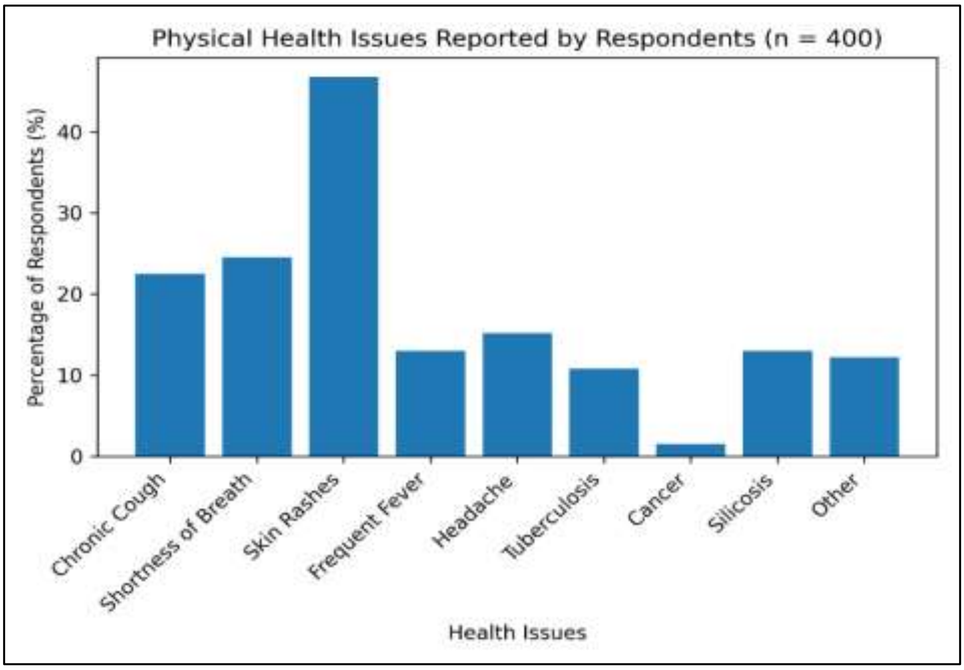

Figure 7 Percentage distribution of reported physical health issues among quarry workers

3.5.2 Panic attacks

Table 7 Distribution of respondents reporting panic attacks

Response	Number of Respondents	Percentage (%)
Yes	196	49.0
No	66	16.5
Unaware	138	34.5
total	400	

The **Table 7 and Figure 8** shows that out of 400 respondents from the sandstone mining areas of Jodhpur, **196 individuals (49.0%)** reported experiencing panic attacks. In contrast, **66 respondents (16.5%)** reported no such symptoms, while **138 respondents (34.5%)** were unaware of whether they had experienced panic attacks. The high proportion of reported cases indicates a considerable burden of anxiety-related symptoms within the mining-affected population.
The findings in Table 7 and Figure 8 indicate that nearly half of the respondents acknowledge experiencing panic-related symptoms, reflecting a substantial mental health concern within the mining-affected population. The relatively high proportion of respondents who are unaware (34.5%) suggests limited awareness and understanding of psychological conditions in these communities.
This elevated prevalence may be linked to the stressful living and working conditions associated with sandstone mining in Jodhpur, where prolonged exposure to silica dust, respiratory illnesses such as silicosis and tuberculosis, and occupational insecurity are common (Yadav et al., 2022; National Institute of Occupational Health studies in Jodhpur mines). Chronic physical illness, environmental degradation, and economic vulnerability often contribute to psychological distress, which may manifest as panic attacks and anxiety symptoms. The findings therefore suggest that alongside physical health monitoring, greater attention to mental health awareness and support is needed in mining-dominated communities.

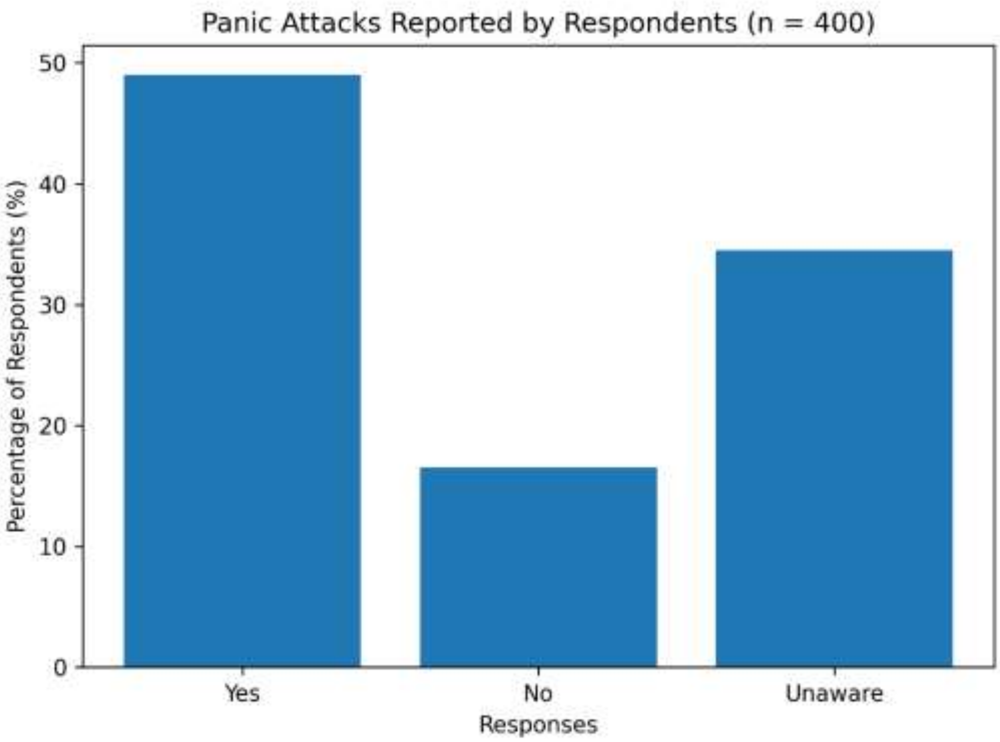

Figure 8 Distribution of respondents reporting panic attacks among quarry workers

3.5.3 Sleeping Trouble

Table 8 Distribution of respondents reporting sleeping problems

Response	Number of Respondents	Percentage (%)
Yes	156	39.0
No	56	14.0
Unaware	188	47.0
Total	400	

Table 8 and Figure 9 illustrate the prevalence of sleeping disturbances among the study population. Out of 400 respondents, **156 individuals (39%)** reported experiencing sleeping trouble. In contrast, **56 respondents (14%)** reported no sleeping-related issues, while a substantial proportion, **188 respondents (47%)**, were unaware of having any sleep-

related problems. This distribution indicates that sleep disturbances are common, while awareness regarding sleep health remains notably low among the respondents.
Many participants attributed their sleep difficulties to extreme physical fatigue resulting from prolonged and strenuous mining activities, as well as the use of alcohol as a sleep aid. Although alcohol may initially induce sleep, it is known to disrupt normal sleep patterns over time, leading to poor sleep quality. The high proportion of respondents unaware of sleep problems reflects limited health awareness within the community. Overall, occupational stress, substance use, and prolonged exposure to silica dust collectively contribute to disturbed sleep patterns and declining health conditions among populations residing in mining-affected areas.

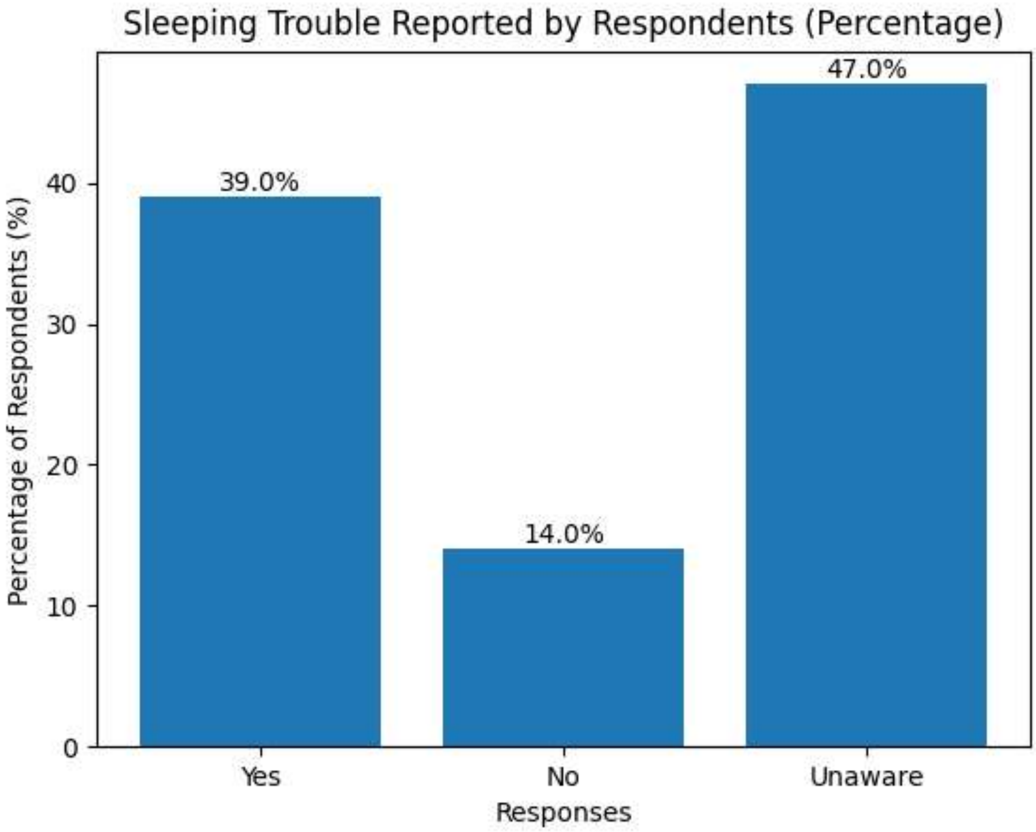

Figure 9 Percentage distribution of respondents reporting sleeping problems

3.5.4 Drug Abuse

Table 9 Distribution of respondents reporting drug abuse

Type of Substance	Number of Respondents	Percentage (%)
Alcohol	240	60.0
Tobacco	211	52.8
Smoking	89	22.3
Total	400	

Table 9 and Figure 10 present the distribution of substance use among respondents residing in and around the mining areas. Alcohol consumption was reported by **240 respondents (60%)**, making it the most commonly used substance. This was followed by **tobacco use among 211 respondents (52.8%)** and **smoking among 89 respondents (22.3%)**. The high prevalence of substance use highlights its widespread acceptance and routine use among the mining population.
Many respondents reported consuming alcohol—often locally available brands—because they believe it helps them fall asleep more easily after long and physically exhausting workdays. Tobacco use was commonly justified as a means to maintain focus during work and to avoid the discomfort of working on an empty stomach. However, the combined effects of persistent substance use and prolonged exposure to silica dust appear to have significantly deteriorated their overall health, particularly affecting respiratory functions and general physical well-being.

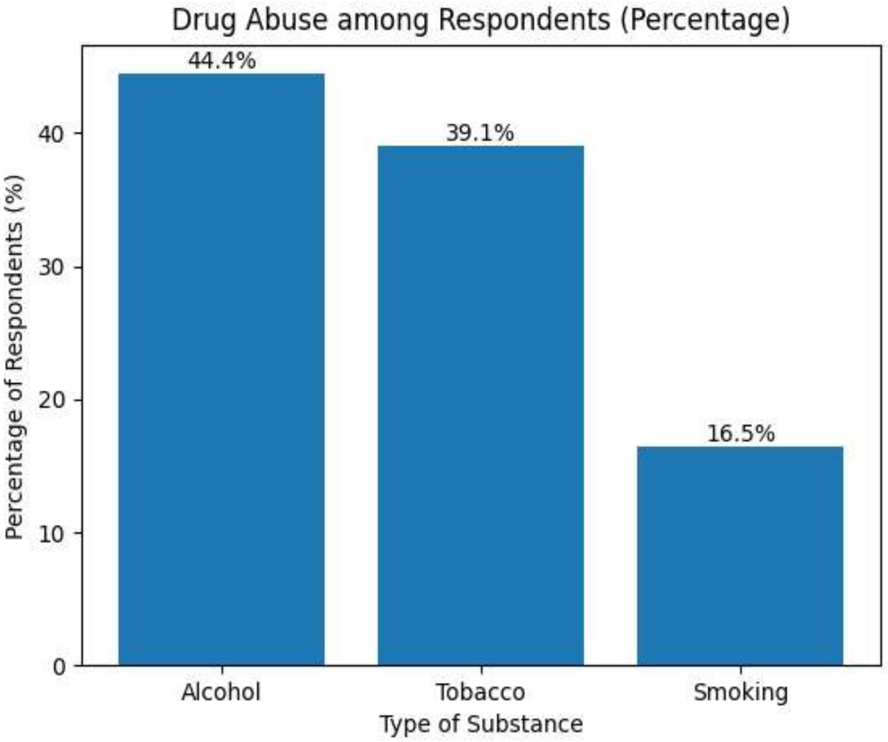

Figure 10 Percentage distribution of substance abuse (alcohol, tobacco, and smoking) among respondents

DISCUSSION

The GIS-based integration of environmental quality parameters, land conversion data (2015–2025), and health survey responses revealed a clear spatial overlap between environmental stress and declining community health in the sandstone mining belt of Jodhpur. Areas that have rapidly transitioned from agricultural land to quarry sites and stone-cutting units showed markedly higher levels of air and water pollution. Fine particulate matter concentrations were substantially elevated ($PM_{2.5}$ up to 126.74 µg/m³), while groundwater samples reflected increasing mineralization, with total dissolved solids reaching 1707 mg/L and total hardness up to 1024 mg/L. Soil samples collected closer to active mining zones also showed higher electrical conductivity and accumulation of base cations, suggesting localized salinization and mineral enrichment (CPCB, 2018; MoEFCC, 2020).

When these environmentally stressed zones were spatially compared with health survey responses, a strong alignment emerged with increased reports of respiratory illness, skin disorders, silicosis, and psychological distress. Nearly half of the respondents reported anxiety-related symptoms, including panic attacks, highlighting the less visible but equally serious mental health burden associated with living in degraded environments. Such outcomes are consistent with evidence showing that prolonged exposure to mining-related dust and polluted water significantly affects both physical and mental well-being in nearby communities (WHO, 2016; ICMR, 2021).

Communities residing closer to mining sites experienced a stronger overlap between high dust exposure and respiratory morbidity, indicating that the health risks extend beyond mine workers to the surrounding population. Long-term inhalation of silica-rich dust has been widely linked to chronic lung damage and silicosis, even among non-occupationally exposed residents, particularly in arid mining regions (Rosenman et al., 2015).

Overall, the integrated GIS-based analysis identified distinct high-risk zones where environmental degradation and health burdens coexist. These findings demonstrate the value of spatial overlay techniques in revealing mining-induced vulnerability hotspots and underline the urgent need for targeted environmental management and public health interventions in sandstone mining regions.

CONCLUSION

The integrated geospatial assessment demonstrates a clear spatial linkage between sandstone mining expansion and environmental as well as health degradation in Jodhpur. Multi-temporal land analysis confirms accelerated quarry growth, agricultural land loss, and peri-urban encroachment. Elevated particulate matter, groundwater mineralization, and localized soil salinization were concentrated near active mining zones. Spatial overlay further revealed that these environmentally stressed areas coincide with higher prevalence of respiratory illnesses, silicosis, skin disorders, and anxiety-related symptoms among both mining workers and nearby residents. The findings highlight distinct vulnerability hotspots and underscore the urgent need for strengthened environmental regulation, dust control measures, and integrated public health interventions in mining-dominated regions.

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- **Author information**

Ethics declarations

Ethical approval

This is not applicable. All participants took part in the study voluntarily after being clearly informed about its purpose. Their identities were kept confidential, and no personal information was recorded at any stage. The research involved non-invasive surveys and environmental sampling, conducted with respect for participant dignity and well-being.

Consent to participate

This is not applicable.

Consent to publish

This is not applicable.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

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