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GIS-BASED ENVIRONMENTAL RISK ASSESSMENT IN INDUSTRIAL CITIES: METHODOLOGICAL FRAMEWORK AND APPLICATION TO ALMALKYK, UZBEKISTAN

Adilov Zarif Himmatovich¹, Ziad Baydoun², Oripova Sarvinoz Abduqaxor qizi³, Ubaydullakhujaev Saidazizkhuja Utkur ugli⁴, Mamazhanova Zukhra Alizhon kizi⁵

^{1,3}Department of Architecture,

**TASHKENT UNIVERSITY OF ARCHITECTURE AND CIVIL ENGINEERING,
UZBEKISTAN**

² College of Architecture, Art and Design,

AJMAN UNIVERSITY, UNITED ARAB EMIRATES

⁴Department of Architecture,

**TASHKENT INTERNATIONAL UNIVERSITY OF FINANCE
AND TECHNOLOGY, UZBEKISTAN**

⁵Higher School of Science, Basic Doctoral Student, Uzbekistan

Abstract

Industrial cities are characterized by the coexistence of intensive production, dense settlement patterns, transport infrastructure, and long-term anthropogenic pressure on environmental systems. Under such conditions, environmental risk is not confined to a single medium but emerges through the interaction of atmospheric pollution, groundwater and soil contamination, ecological degradation, and human exposure. This study develops a geoinformation-based methodological framework for assessing environmental risks in industrial urban territories and applies it to Almalyk, Uzbekistan, as a representative mining and metallurgical city. The framework integrates remote sensing, spatial interpolation, buffer analysis, thematic layer overlay, and multi-criteria evaluation within a unified GIS environment. Environmental indicators related to air quality, groundwater contamination, land use, vegetation condition, industrial proximity, and population vulnerability are standardized and combined to derive a composite environmental risk index. The results show that environmental burden in Almalyk is unevenly distributed and is concentrated in industrial zones and adjoining residential territories, especially those influenced by mining and metallurgical activity, waste disposal areas, and pollutant transport pathways. The resulting risk map provides a practical analytical basis for environmental monitoring, urban planning, zoning control, and public health protection in industrial cities.

Keywords: Geographic information systems; Environmental risk assessment; Industrial city; Almalyk; remote sensing; Spatial analysis; AHP; Environmental monitoring.

² Corresponding author. Email: z.baydoun@ajman.ac.ae

INTRODUCTION

Industrial urban systems are important for economic growth and jobs, but they also create heavy environmental pressure because industrial, residential, transport, and waste areas are often close together (Pupentsova et al., 2019). This proximity increases emissions, dust, noise, waste buildup, soil and groundwater pollution, and habitat fragmentation. Beyond environmental control, urban sustainability also depends on how public and religious spaces support social cohesion and community identity (Baydoun, Bin, et al., 2025). Traditional Uzbek Islamic architecture and calligraphy reflect sustainable design that integrates cultural and ecological contexts, offering insights for mitigating industrial impacts (Baydoun et al., 2024; Baydoun, Baydoun, et al., 2025).

Environmental risk in such territories cannot be understood adequately through isolated measurements alone (Mehta et al., 2025). Industrial cities display strong spatial heterogeneity, and the intensity of environmental pressure can vary substantially over short distances depending on source location, land-use pattern, topography, meteorological conditions, and urban morphology (He et al., 2020). Consequently, analytical approaches that can integrate multiple spatial datasets into a unified system are essential for effective environmental assessment and decision-making (Dong et al., 2025).

Geographic information systems have evolved from cartographic support tools into advanced analytical platforms that enable the collection, storage, management, analysis, modeling, and visualization of heterogeneous environmental information (Janarthanan et al., 2023). GIS is widely used to identify pollution hotspots, map exposure, integrate remote sensing with ground data, and support planning in urban and industrial areas (Mohammed Hamud et al., 2019). The literature shows that GIS-based environmental risk assessment is now standard, especially when integrated with interpolation, remote sensing, and multi-criteria analysis (Calka & Szostak, 2025).

Industrial cities in Uzbekistan provide a particularly important context for such work. Cities such as Almalyk, Navoi, Angren, and Fergana function as major economic centers but also experience elevated environmental stress arising from mining, metallurgy, thermal energy production, transport activity, and historical pollution legacies (Perez-Lancellotti et al., 2025). Almalyk is especially significant because of its association with large-scale mining and metallurgical operations and because residential districts occur in proximity to industrial infrastructure and waste-related facilities.

The novelty of this study is the development of an integrated GIS-based environmental risk framework for industrial cities that combines multiple hazard and vulnerability indicators in one spatial model. This goes beyond earlier GIS-AHP studies by linking remote sensing, interpolation, buffer analysis, and weighted overlay for practical urban risk mapping.

This study develops a GIS-based methodology for environmental risk assessment in industrial cities, demonstrated in Almalıy. It identifies key indicators, integrates them in a geospatial framework, classifies risk zones, and interprets results for planning and governance, offering a practical approach that combines hazard and vulnerability.

LITERATURE REVIEW

GIS in environmental assessment

Environmental risk assessment has shifted toward integrated spatial analysis, as urban-industrial degradation arises from interconnected processes. GIS supports this by combining monitoring data, satellite indicators, regulatory thresholds, infrastructure, and socio-demographic variables in a single platform (Chen et al., 2022; Mojaddadi et al., 2017). In environmental applications, GIS supports the creation of thematic maps, detection of risk concentrations, comparison of multiple indicators, and communication of results to planners and decision-makers. The reviewed material indicates that GIS is especially valuable in industrial settings where environmental hazards are spatially concentrated and where population exposure depends strongly on location. Through GIS, environmental observations can be transformed from isolated records into continuous surfaces and then interpreted in relation to land use, urban structure, and sensitive receptors (Benza et al., 2016). This makes GIS suitable not only for mapping but also for environmental diagnosis and planning support.

Weighted overlay and multi-criteria methods

One of the most common approaches in environmental GIS studies is the use of multi-criteria decision analysis, especially the Analytic Hierarchy Process (Cegan et al., 2017). AHP integrates expert judgment with quantitative environmental indicators to assign weights and build a composite index. In industrial assessments, it captures the combined effects of pollutants, ecological sensitivity, settlement patterns, and socio-economic vulnerability. Studies show that AHP-based GIS models effectively classify ecological vulnerability and pollution risk using weighted overlay (Artat et al., 2025; Wen et al., 2026). Their advantage lies in methodological transparency, since each criterion can be justified and weighted explicitly. When properly validated, this approach provides interpretable outputs that are suitable for planners and environmental managers.

Statistical integration and PCA

Another important line of research links GIS to multivariate statistical analysis, particularly principal component analysis. PCA is useful when large environmental datasets contain correlated variables that must be reduced into a smaller set of meaningful dimensions before interpretation (Gewers et al., 2022).

Studies summarized in the source text show the use of PCA in groundwater quality assessment, pollution source discrimination, and health-risk-related environmental mapping (Balamurugan et al., 2020; Ncibi et al., 2023). Principal components represent key pollution patterns mapped in GIS, reducing redundancy and highlighting the most important environmental factors across multiple pollutants and sites.

Remote sensing and interpolation

Remote sensing has become an essential companion to GIS-based environmental risk assessment because it enables regular and wide-area observation of land surface conditions, vegetation cover, water-related features, surface temperature, and atmospheric conditions. The reviewed material identifies Landsat, Sentinel, MODIS, ASTER, and other sources as suitable inputs for industrial environmental analysis (Acar & Zengin, 2023; Song et al., 2021). Remote sensing, GIS, and interpolation are effective for mapping pollution patterns in industrial cities, especially where field data are limited. They help estimate continuous contamination surfaces and capture spread along wind, terrain, drainage, and land-use gradients.

Research Gap

Existing studies provide valuable methodological components, but many remain fragmented by focusing either on a single pollutant, a single analytical technique, or a single environmental medium. There is a continuing need for a coherent GIS-based framework that can integrate atmospheric, hydrological, ecological, and socio-demographic dimensions of risk in industrial cities and translate them into planning-relevant outputs. This study addresses that need by presenting an integrated methodological structure and illustrating its application to Almalyk.

STUDY AREA

Almalyk, in Uzbekistan's Tashkent region, is a major industrial city shaped by mining and metallurgical activities, transport systems, waste facilities, and nearby residential areas. These factors create a complex environment with risks from emissions, dust, heavy metals, blasting, and groundwater contamination. Its overlapping industrial and residential pressures make it a representative case for environmental risk assessment.

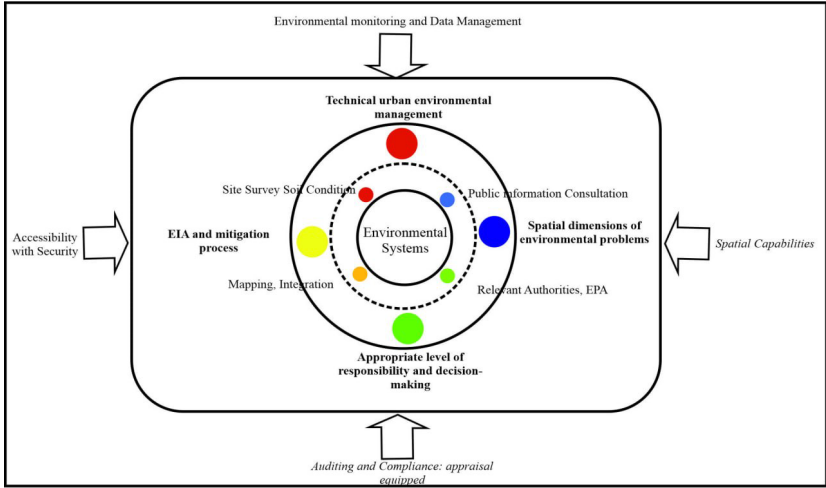


Fig. 1: GIS as a vital tool for environmental impact assessment and mitigation.

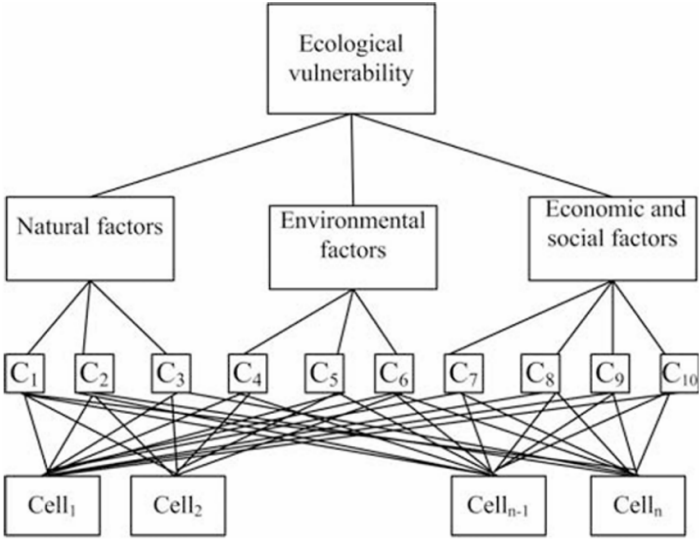


Fig. 2: Integrated evaluation criteria system used in GIS-based ecological vulnerability assessment.

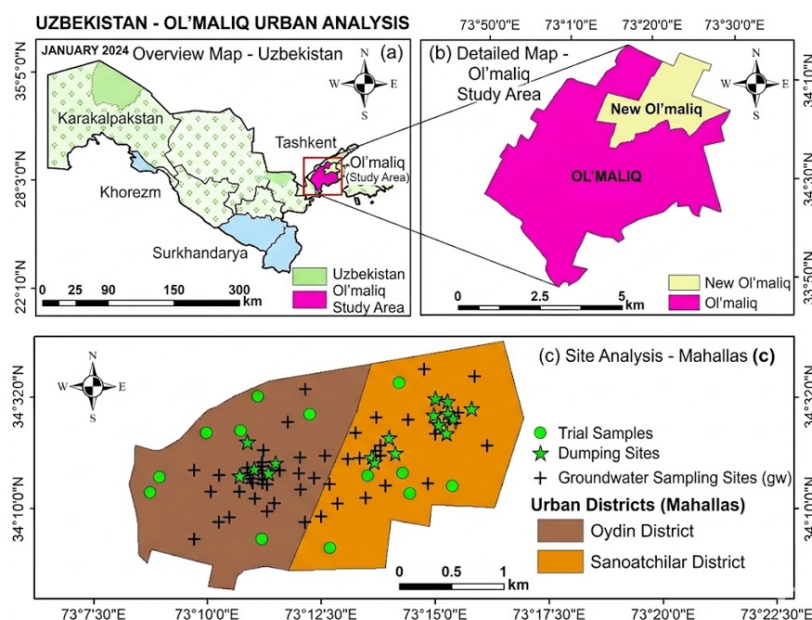


Fig. 3: Location of Almalyk city, industrial zones, and groundwater sampling sites.

RESEARCH METHODOLOGY

Conceptual basis of the model

The study conceptualizes environmental risk as the interaction between environmental hazard and territorial vulnerability. Hazard is the intensity and extent of industrial environmental pressure, while vulnerability is the exposure and sensitivity of people, infrastructure, and ecosystems. This distinction matters because pollution alone does not define risk; it becomes critical where it overlaps with vulnerable or sensitive areas.

Data Categories

A comprehensive environmental risk assessment in an industrial city requires integrating several data groups. The study uses atmospheric pollution, water and groundwater quality, soil contamination, meteorological, land-use/land-cover, and socio-economic or demographic data to build hazard and vulnerability layers in GIS. Atmospheric indicators include PM_{2.5}, PM₁₀, NO₂, and SO₂; water and groundwater indicators include heavy metals and related quality parameters; soil contamination is assessed through heavy metals and residual pollutants. Ecological indicators include NDVI, NDWI, land cover classes, and landscape fragmentation, while vulnerability is represented by population density, proximity to industrial objects, and the location of critical urban facilities.

Geospatial data sources

The framework is compatible with open-access geospatial data such as Landsat 8/9, Sentinel-2, Sentinel-5P, MODIS, and SRTM, which provide multispectral, atmospheric, topographic, and land-surface information. Additional layers can come from OpenStreetMap and official databases for roads, boundaries, built-up areas, industrial facilities, and infrastructure. In GIS, raster data represent continuous features and vector data capture discrete elements; formats are converted as needed for overlay and mapping.

Preprocessing and quality control

All input data must be standardized before analysis. Satellite imagery is atmospherically corrected, geometrically rectified, and reprojected to a common coordinate system, while spatial layers are clipped, checked for consistency, and matched in scale and resolution. Monitoring data are checked for missing values, outliers, and coordinate errors, and interpolation is used where observations are incomplete. This is necessary because monitoring often provides point data, while risk modeling needs continuous territory-wide surfaces.

Technical parameters used in GIS and AHP analysis

Table 1 summarizes the key technical parameters used in the GIS and AHP workflow to improve methodological transparency and reproducibility.

Table 1: Methodological matrix of GIS-based environmental risk assessment approaches, data sources, and indicators

Technical parameter	Value/specification
GIS software	QGIS 3.34 (LTS, Prizren) with GDAL 3.8.4; secondary verification in ArcGIS Pro 3.2
Coordinate reference system	WGS 1984 UTM Zone 41N (EPSG:32641)
Spatial resolution	30 × 30 m
Raster cell size	30 × 30 m
Buffer distances	0–500 m, 500–1,000 m, 1,000–3,000 m, 3,000–5,000 m
Interpolation method	IDW (power = 2) for air/water; ordinary kriging with spherical variogram for soil
Expert respondents (AHP)	N = 18
AHP consistency ratio	CR = 0.047
Study period	Environmental data: 2018–2023; satellite imagery: 2021–2023

Spatial interpolation and environmental surfaces

Interpolation methods turn sampled values into continuous environmental surfaces for joint analysis with other spatial variables. In this framework, inverse distance weighting is preferred for its simplicity and interpretability, while kriging may be used when observations are denser and geostatistical assumptions

are stronger. These interpolated surfaces are applied to air pollution, groundwater contamination, and other sampled parameters to reveal hotspots, gradients, and likely exceedance zones. They are then reclassified and integrated into the composite risk model.

Remote sensing indicators

Remote sensing provides an important source of information for environmental conditions and land-surface characteristics. The Normalized Difference Vegetation Index is used to assess vegetation status and green cover conditions, while the Normalized Difference Water Index supports the interpretation of surface moisture and water-related features. Land use and land cover classification derived from satellite imagery is further used to distinguish industrial land, residential areas, open land, green spaces, and water-related surfaces. The standard expression for NDVI is given by:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

This indicator is particularly useful in industrial cities because vegetation conditions may reflect ecological stress and may also influence dust retention and microclimatic regulation. Remote sensing, therefore, supplements field monitoring with territorial continuity and repeated observation capacity.

Indicator standardization

Because the environmental indicators used in the study differ in scale, unit, and interpretation, standardization is required before weighted integration. A common min-max normalization procedure is applied to convert all indicators to a comparable dimensionless scale. For direct risk indicators, the normalization can be expressed as:

$$X'_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

For inverse indicators, where higher values correspond to lower environmental stress, the transformation direction is reversed. Standardization ensures that heterogeneous data can be integrated meaningfully in subsequent multi-criteria analysis.

AHP-based weighting

The Analytic Hierarchy Process assigns weights to risk criteria through pairwise comparison of expert judgments. It is useful because it transparently combines

scientific and local knowledge, with matrix normalization, priority vectors, and a consistency check to ensure logical judgments. Indicators with the strongest expected impact, such as air pollution, groundwater contamination, and proximity to industrial sources, can therefore receive higher weights than secondary factors. Table 2 presents the AHP pairwise comparison results, final criterion weights, eigenvector priorities, and overall consistency ratio used in the analysis.

Table 2: The AHP pairwise comparison results.

Criteria	Weight	Eigenvector	CR value
Air Quality (AQ)	0.282	0.291	0.047
Water Quality (WQ)	0.201	0.208	0.047
Soil Contamination (SC)	0.148	0.153	0.047
Noise Pollution (NP)	0.102	0.105	0.047
Health Risk Index (HR)	0.074	0.076	0.047
Proximity Buffers (PB)	0.110	0.113	0.047
Land Use Compatibility (LU)	0.083	0.054	0.047

Composite environmental risk index

After indicator standardization and weighting, the final environmental risk index is computed using weighted overlay analysis. The general form of the model is:

$$ERI = \sum_{i=1}^n w_i x_i$$

where w_i represents the weight assigned to the i -th criterion and x_i represents its standardized spatial value. This procedure produces a composite index surface that can be classified into environmental risk categories. In conceptual terms, the index integrates hazard and vulnerability, allowing the analyst to identify places where environmental pressure and human exposure overlap most strongly. The classified output can then be represented using a low-medium-high risk scheme and visualized through thematic GIS mapping.

Buffer and overlay analysis

Buffer analysis defines influence zones around industrial facilities, waste sites, mines, and other major sources, helping identify direct exposure and priority management areas. In blasting and vibration zones, concentric buffers help distinguish levels of disturbance. Overlay analysis then combines the reclassified

hazard and vulnerability layers in GIS to produce final risk zones. This is the key step that turns separate datasets into an integrated territorial risk model.

Example of integrated indicator structure

The study framework may be summarized through a methodological matrix linking approach, data sources, and principal indicators as shown in Table 3.

Table 3: Methodological matrix of GIS-based environmental risk assessment approaches, data sources, and indicators.

Approach/method	Primary data sources	Indicators
GIS + AHP (MCDA)	Industrial facilities, road maps, population density, climate, and landscape data	Air quality, water pollution, socio-economic indices, population, and health-related exposure.
PCA + GIS	Multidimensional pollution data in air and water samples, demographic indicators	Principal pollution components and dominant contamination structures.
GIS interpolation (IDW, Kriging)	Monitoring stations for air, water, soil, and meteorological data	Continuous pollution maps, pollutant concentration gradients, and hotspot zones.
Remote sensing	Landsat 8/9, Sentinel-2/5P, MODIS, ASTER, GEE platform	NDVI, NDWI, surface temperature, land cover, dust-related or atmospheric indicators.
Machine learning	Large environmental databases, sensor outputs, social and spatial datasets	Risk classes, prediction outputs, feature importance, and uncertainty estimates.

Illustrative environmental risk index example

An example of normalized territorial values and resulting risk indices is presented below as part of the integrated assessment frameworks in Table 4.

Table 4: Illustrative example of normalized territorial values and environmental risk index calculation.

Territory	Air value	Water value	Population	Normalized air	Normalized water	Normalized population	Risk index
A	80	50	100	1.00	0.625	1.00	0.85
B	30	80	80	0.375	1.00	0.80	0.69
C	50	30	60	0.625	0.375	0.60	0.52

The illustrative values indicate that Territory A has the highest environmental risk, followed by Territory B, whereas Territory C has comparatively lower risk. In operational environmental zoning, values above 0.80 may be interpreted as high-risk conditions requiring priority intervention.

Validation of the environmental risk map

Validation was performed by comparing the GIS-derived risk map with existing monitoring and documentary data available for Almalyk. Specifically, high-risk zones were checked for spatial coincidence with groundwater and soil monitoring points reporting elevated heavy-metal concentrations and with mapped industrial sites, waste areas, and known pollutant sources. No new field campaign was conducted for this study; therefore, the validation is qualitative and limited to these available measurements and official records.

RESULT AND ANALYSIS

General spatial pattern of environmental risk

The GIS-based analysis of Almalyk indicates that environmental burden is spatially uneven and is concentrated in zones directly or indirectly affected by industrial activity. The source material identifies elevated air pollution and heavy metal contamination in areas adjacent to industrial enterprises and mining-related facilities. This concentration pattern confirms that environmental pressure follows the geography of industrial infrastructure and associated transport and waste systems. Table 5 summarizes the quantitative distribution of environmental risk classes, including area, percentage of land, exposed population, and affected neighbourhoods in Almalyk city.

Table 5: Illustrative example of normalized territorial values and environmental risk index calculation

Risk Class	Color	Area (km ²)	Area (%)	Population Exposed	Neighborhoods
Very High Risk	Red	47.3	12.4	~145,000	18
High Risk	Orange	89.6	23.5	~210,000	27
Moderate Risk	Yellow	124.8	32.7	~180,000	23
Low Risk	Green	98.2	25.7	~85,000	11
Very Low Risk	Light Green	22.1	5.7	~15,000	3
TOTAL	—	382.0	100.0	~635,000	82

The quantitative summary shows that 35.9% of the study area falls within the Very High- and High-Risk categories, affecting approximately 355,000 residents and 45 neighbourhoods. The highest-risk zones are concentrated near the AGMK smelter complex, cement manufacturing areas, and associated industrial corridors, indicating strong overlap between environmental pressure and population exposure.

Air pollution and industrial influence

The analysis suggests that particulate pollution and related atmospheric stress are highest near industrial production zones and along areas influenced by transport activity. Spatial mapping of air-quality-related indicators shows that pollutant load does not remain confined to the industrial core but extends toward inhabited urban territories. This is particularly important because exposure risk increases when polluted zones overlap with residential and service functions. The source material further indicates that prevailing winds and the structural configuration of the city influence the direction and reach of pollutant transport. As a result, districts beyond the immediate industrial footprint may also experience elevated environmental burden. This demonstrates the value of spatial modeling in identifying indirect impact zones that conventional site-based assessment may underestimate.

Groundwater and heavy-metal contamination

Groundwater quality constitutes a major component of environmental risk in Almalyk. The study area includes groundwater monitoring points and waste-related locations that allow contamination to be interpreted spatially in relation to industrial influence. According to the source material, elevated concentrations of copper, zinc, lead, cadmium, and arsenic are associated with industrially affected zones. To support the interpretation of groundwater contamination, the following exceedance relationship may be used:

$$Excess_{GW} = Measured$$

This expression quantifies the degree to which observed groundwater values exceed accepted regulatory or health-based standards. In the source material, arsenic contamination is interpreted using a WHO-based threshold of 0.01 mg/L. The supporting conceptual structure is presented below in Table 6.

Table 6: Conceptual framework for groundwater exceedance assessment and comparison with WHO standards.

Concept	Definition
Excess (GW)	Portion of groundwater quality indicators exceeding the normative value
Measured values (GW)	Laboratory results obtained from Almalyk and its industrial zones
WHO standards (GW)	Maximum permissible concentrations recommended for groundwater interpretation

Population exposure and urban vulnerability

Environmental risk in Almalyk is shaped not only by pollutant concentration but also by the distribution of people and urban functions. Population density and proximity to industry help identify areas of higher human exposure, with nearby residential zones facing greater environmental pressure. Particular attention is drawn to populated sectors located close to the industrial perimeter and central urban areas influenced by pollution transport pathways. In such areas, environmental vulnerability is increased by the overlap of exposure, settlement concentration, and infrastructure use. This reinforces the need for risk zoning that incorporates both source intensity and territorial sensitivity.

Buffer zones, blasting effects, and disturbance corridors

Industrial and mining activities in the study area generate disturbances beyond chemical contamination, including blasting vibrations, noise, and dust transport affecting nearby residential areas. Analysis identifies concentric buffer zones around mining sites, with the innermost 500–1 km zone showing the strongest impact and requiring strict geodynamic regulation for safe construction. Including these stressors broadens environmental assessment beyond air and water pollution metrics.

Spatial extension of risk beyond the industrial core

The mapped risk structure indicates that elevated environmental pressure extends from the central industrial sectors of Almalyk toward adjacent districts. This pattern is associated with the interaction of stationary industrial emissions, transport activity, and regional wind regimes. It shows that environmental management in industrial cities must be planned at the metropolitan or city-region scale rather than only within fenced industrial parcels.

Development indicators and planning context

The planning relevance of environmental risk assessment becomes clearer when interpreted alongside the broader development trajectory of the city. The source material provides the following urban development indicators for Almalyk as shown in Table 7.

Table 7: Current and projected urban development indicators for Almalyk city.

Indicator name	Unit of measurement	Current status (estimated)	Plan / Prospect
Population	Thousand people	190.5	215.0
Volume of industrial output	Trillion soums	35.0+	50.0+
Export potential	Million USD	900+	1,200+
Share of green areas	%	8.5	15.0
New jobs	Number	4,500	12,000

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Indicator name	Unit of measurement	Current status (estimated)	Plan / Prospect
Housing stock (new)	m ²	120,000	250,000

These indicators show that environmental risk assessment is directly relevant to ongoing and future urban development. As industrial output, employment, housing, and population continue to increase, the need for environmental zoning and exposure-sensitive planning becomes more urgent.

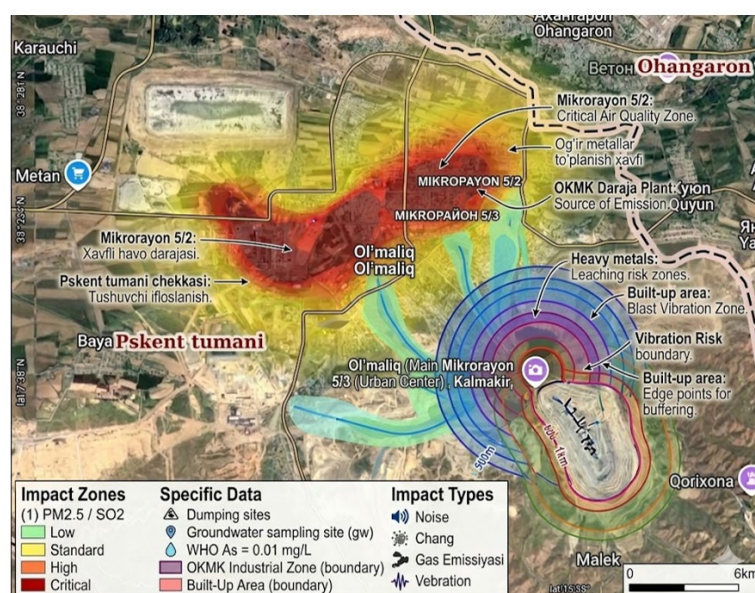


Fig. 4: Impact of the industrial zone in Almalyk on the population.

DISCUSSION

The results confirm that environmental risk in industrial cities is a cumulative and spatially differentiated phenomenon. In Almalyk, environmental pressure peaks where industry, waste, and population intersect, highlighting the need for integrated territorial assessment rather than isolated pollutant control. The GIS-based framework used in this study provides several advantages for such assessment. First, it enables the integration of diverse environmental datasets that would otherwise remain analytically separate. Second, it converts point-level observations and remote-sensing indicators into interpretable territorial patterns. Third, it supports prioritization by showing where environmental burden is greatest and where human exposure is most significant.

From a planning perspective, the identification of high-risk zones near industrial-residential interfaces is especially important. These areas should receive priority attention in the form of stronger monitoring systems, stricter land-use regulations, green-buffer development, and public health safeguards. Groundwater-sensitive zones and areas influenced by waste disposal should also be monitored more intensively because contamination in these areas may persist and spread through subsurface pathways.

The study also demonstrates the value of remote sensing as a complement to field-based environmental monitoring. Vegetation condition, land cover, terrain, and atmospheric indicators improve the interpretation of ecological stress and help explain the territorial differentiation of risk. In rapidly transforming industrial cities, such tools can support repeated observation and long-term environmental management at relatively low cost. At the same time, the effectiveness of the framework depends on the quality and completeness of input data. A robust implementation requires a reliable sampling design, accurate spatial coordinates, justified weighting, clear classification rules, and validation against observed environmental patterns. Continued refinement may include stronger use of PCA, fuzzy approaches, uncertainty analysis, and machine-learning-based prediction where sufficient data are available.

The results support spatial planning in industrial cities through industrial buffer zoning, environmental protection corridors, targeted green infrastructure, and stricter development control near high-risk areas. The risk map can also guide environmental monitoring priorities and be integrated into local structure plans to support land-use regulation, pollution mitigation, and public health protection. This study is limited by the availability and completeness of environmental and spatial data, and the analysis reflects the specific time period for which those data were collected. Some uncertainty remains in the AHP weighting process because expert judgments are inherently subjective. In addition, while the framework is transferable in principle, its application to other industrial cities will require local data and context-specific adjustment.

CONCLUSION

This study presents a GIS-based methodological framework for environmental risk assessment in industrial cities and demonstrates its application to Almalyk, Uzbekistan. By integrating environmental hazard indicators and vulnerability indicators within a unified geospatial environment, the framework provides a practical basis for identifying high-risk zones and supporting spatially informed environmental governance. The results indicate that environmental risk in Almalyk is not distributed evenly across the urban territory. The most significant pressures are concentrated in industrial zones, nearby residential sectors,

groundwater-sensitive areas, and corridors influenced by pollutant transport and mining-related disturbance. These findings confirm the need for environmental management strategies that are spatially targeted and linked directly to urban planning and public health protection. The methodological structure developed in this study is applicable beyond the specific case of Almalyk. With appropriate local data, it can be adapted to other industrial cities experiencing overlapping environmental pressures from production, urban growth, and ecological degradation. The integration of GIS, remote sensing, spatial interpolation, and multi-criteria analysis, therefore, offers a strong foundation for sustainable urban environmental assessment in an industrial region.

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