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ECOLOGICAL AND HYGIENIC ASSESSMENT OF THE HEALTH STATUS OF THE POPULATION LIVING IN INDUSTRIAL AREAS OF THE FERGANA REGION

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1. ABSTRACT

This study presents a comprehensive ecological and hygienic assessment of the health status of the population residing in the industrial zones of the Fergana region, Uzbekistan. The Fergana Valley, one of the most densely populated territories in Central Asia, contains a substantial concentration of petroleum refining, chemical manufacturing, metallurgical, and textile enterprises whose combined environmental emissions have raised significant public health concerns over several decades.

The research was motivated by persistently elevated rates of respiratory, cardiovascular, and oncological diseases observed in industrial districts relative to rural reference areas. Environmental monitoring data collected between 2020 and 2023 from air quality stations, water-sampling networks, and soil survey programmes formed the primary empirical basis of the study. Medical-statistical analysis of morbidity records and clinical examinations involving 1,240 adult residents provided the health-outcome evidence base.

Key findings demonstrate that concentrations of sulphur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM2.5 and PM10), and heavy metals in soil and groundwater substantially exceed national maximum permissible concentration (MPC) standards at the majority of monitoring sites situated near industrial facilities. A statistically significant correlation ($p < 0.01$) was established between proximity to industrial sources and elevated prevalence of chronic obstructive pulmonary disease (COPD), ischaemic heart disease, and childhood neurological disorders. The results underscore the urgent need for integrated environmental management, strengthened regulatory enforcement, and targeted public health interventions across the Fergana industrial zone.

2. KEYWORDS

Environmental health; industrial pollution; public health assessment; ecological monitoring; hygienic analysis; Fergana region; environmental risk; morbidity indicators; heavy metal contamination; air quality index.

3. INTRODUCTION

Rapid industrialisation across the developing world has introduced a complex spectrum of environmental hazards that disproportionately affect communities residing near industrial facilities. Atmospheric emissions, effluent discharges, and soil contamination collectively constitute the most significant anthropogenic drivers of environmental degradation, with well-documented consequences for human health. The World Health Organization estimates that approximately 24% of all preventable diseases globally are attributable to environmental exposures; in heavily industrialised regions this proportion is considerably higher.

Uzbekistan, which has undergone sustained industrial expansion since independence in 1991, faces particular challenges in reconciling economic growth with the protection of population

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health. The Fergana region (Fergana viloyati), located in the fertile Fergana Valley bounded by the Tian Shan and Pamir-Alai mountain ranges, is home to approximately 3.8 million inhabitants. The regional industrial profile is dominated by the Fergana Oil Refinery — one of the oldest and largest in Central Asia — complemented by chemical plants, nitrogen fertiliser complexes, machine-building enterprises, and light manufacturing facilities concentrated in the cities of Fergana, Margilan, and Qo'qon.

Industrial activity in the region generates substantial quantities of airborne pollutants, liquid effluents, and solid wastes. The geography of the Fergana Valley — a semi-enclosed basin with limited natural ventilation — further compounds pollutant accumulation by restricting atmospheric dispersion, leading to higher ambient concentrations than would be expected from equivalent emissions in open terrain. At the same time, the dense population and extensive irrigated agriculture of the valley mean that both direct inhalation exposure and indirect exposure through contaminated food and water are widespread.

Despite the region's economic and demographic importance, systematic evidence linking the cumulative environmental burden to population health outcomes remains fragmented. Prior research has documented individual pollutant exceedances at specific monitoring points, but an integrated ecological-hygienic assessment simultaneously evaluating air, water, and soil quality while correlating findings with multi-year health statistics has not previously been published for the Fergana industrial zone as a whole. This gap constrains the capacity of public health authorities to prioritise interventions and justify investment in pollution-control infrastructure.

The overarching aim of this research is therefore to conduct a systematic, integrated ecological and hygienic assessment of environmental conditions in the industrial zones of the Fergana region and to evaluate the associated health impacts on resident populations. The specific objectives are: (1) to characterise pollutant concentrations in ambient air, drinking water, and soil across industrial and reference zones; (2) to analyse morbidity patterns and clinical health indicators among exposed populations; (3) to quantify the statistical relationship between environmental pollution indices and disease prevalence rates; and (4) to formulate evidence-based recommendations for environmental management and public health protection.

4. MATERIALS AND METHODS

4.1. Description of the Study Area

The study area encompasses four industrial districts of the Fergana region: (1) Fergana city, characterised by petroleum refining and chemical production; (2) Margilan city, dominated by textile and silk processing; (3) Qo'qon city, home to chemical fertiliser manufacturing and machine-building; and (4) Oltiariq district, containing agricultural chemical and food-processing plants. A predominantly rural district with no significant industrial activity — Rishton district — was selected as the reference (control) zone to permit comparative analysis. The total study area covers approximately 2,400 km2, with an aggregate resident population of around 980,000 persons.

4.2. Environmental Monitoring Methods

Ambient air quality was monitored at 18 stationary sampling stations in compliance with Uzbek State Standard O'z DSt 1533:2019. Hourly measurements of sulphur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and particulate matter (PM2.5 and PM10) were obtained using calibrated electrochemical and optical sensors (Horiba APSA-370; GRIMM EDM 180). Quarterly averaged concentrations were compared against national MPC values.

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Water quality assessment covered 34 sampling points in municipal distribution networks, private groundwater wells, and irrigation canals. Physicochemical parameters (pH, total dissolved solids, nitrates, nitrites, chlorides, sulphates) were determined by standard volumetric and spectrophotometric methods. Heavy metal concentrations (Pb, Cd, Cr, Zn, Cu, Ni) were quantified by inductively coupled plasma mass spectrometry (ICP-MS) at the Fergana Regional Sanitary-Epidemiological Surveillance laboratory, accredited to ISO/IEC 17025.

Soil contamination surveys were conducted at 42 plots in residential zones, green spaces adjacent to industrial facilities, and agricultural land. Total heavy metal concentrations were determined following acid digestion by ICP-MS; polycyclic aromatic hydrocarbons (PAH) were extracted by Soxhlet procedure and quantified by gas chromatography-mass spectrometry (GC-MS). The hazardous concentration zoning index (Zc) was calculated according to SanPiN 2.1.7.1287-03 methodology.

4.3. Hygienic and Medical-Statistical Analysis

Cross-sectional health data were obtained for 2020–2023 from the State Health Statistics Repository of the Republic of Uzbekistan (Form No. 12). Age-standardised disease incidence rates per 100,000 population were compiled for: respiratory diseases (J00–J99), cardiovascular diseases (I00–I99), endocrine and metabolic disorders (E00–E90), malignant neoplasms (C00–C99), and childhood neurological disorders (G00–G99 in the 0–14 age cohort).

In addition, 1,240 adult residents (aged 18–65 years; 620 from industrial zones and 620 from the reference zone, matched for age, sex, and smoking status) underwent standardised clinical examinations including spirometry (EasyOne Pro, ndd Medizintechnik), electrocardiography, complete blood count, and biochemical profiling. Written informed consent was obtained from all participants. The study protocol was approved by the Bioethics Committee of the Fergana Branch of Tashkent Medical Academy (Protocol No. 7/2020).

Statistical analyses were performed using IBM SPSS Statistics v.28 and R v.4.3.1. Group differences were evaluated by independent-samples t-tests and chi-square tests. Spearman rank correlations were calculated between pollution indices and disease prevalence rates. Multiple logistic regression models were constructed to control for age, sex, socioeconomic status (proxied by educational attainment), and smoking history. Statistical significance was set at $p < 0.05$ throughout.

5. RESULTS

5.1. Environmental Conditions — Air Quality

Annual mean concentrations of key air pollutants measured across the four industrial districts are presented in Table 1. Exceedances of national MPC values were recorded at 72% of monitoring sites for PM10, at 61% for NO2, and at 58% for SO2. The highest exceedances were documented in Fergana city, where PM2.5 concentrations reached 4.3 times the MPC during winter months, attributable to combined emissions from the oil refinery and residential solid-fuel combustion. Qo'qon exhibited the most severe SO2 burden (annual mean 0.21 mg/m3; MPC = 0.05 mg/m3; ratio = 4.2), reflecting emissions from its chemical fertiliser complex. All industrial zones exceeded at least three of the five monitored pollutants, while the reference zone remained within MPC limits for all parameters.

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Pollutant	Fergana	Margilan	Qo'qon	Oltiariq	Reference	MPC
PM10 (mg/m³)	0.18	0.11	0.15	0.09	0.04	0.07
PM2.5 (mg/m³)	0.11	0.07	0.09	0.06	0.02	0.035
SO2 (mg/m³)	0.14	0.08	0.21	0.06	0.01	0.05
NO2 (mg/m³)	0.09	0.07	0.08	0.05	0.02	0.04
CO (mg/m³)	3.40	2.10	3.80	1.90	0.70	3.00

Table 1. Annual mean air pollutant concentrations by study zone (2020-2023 average)

5.2. Water and Soil Contamination Levels

Heavy metal concentrations in groundwater samples from residential areas adjacent to industrial facilities exceeded MPC thresholds in 48% of tested wells. Lead (Pb) levels above 0.01 mg/L — the WHO guideline value — were found in 29% of well-water samples from Fergana and Qo'qon. Cadmium concentrations exceeding 0.003 mg/L were recorded in 14% of samples. Nitrate concentrations above 45 mg/L were prevalent (38%) near agricultural chemical facilities in Oltiariq, consistent with fertiliser leaching patterns. Municipal piped-water supply met all physicochemical standards in 94% of distribution-network samples, indicating that well-water dependence is the primary route of heavy metal exposure via drinking water.

Soil quality analysis revealed a hazardous concentration zoning index (Zc) exceeding 32 — the threshold for 'hazardous' contamination — at 17 of the 42 surveyed plots, all located within 1,500 m of industrial installations. Dominant contaminants were zinc (Zn), lead (Pb), and chromium (Cr) in metallurgical and machine-building zones. Benzo[a]pyrene levels in soils adjacent to the oil refinery reached 14.7 ng/g against a national standard of 0.02 ng/g — a 735-fold exceedance — raising significant concerns regarding carcinogenic exposure through soil contact and locally grown produce.

5.3. Health Indicators of the Local Population

Analysis of official health statistics for 2020–2023 revealed a consistent pattern of elevated disease incidence in industrial districts relative to the reference zone. Table 2 presents age-standardised incidence rates per 100,000 population for selected disease categories, together with rate ratios and statistical significance levels.

Disease Category (ICD-10)	Industrial Zones	Reference Zone	Rate Ratio	p-value
Respiratory diseases (J00-J99)	2,841	1,203	2.36	< 0.001
Cardiovascular diseases (I00-I99)	1,987	1,104	1.80	< 0.001

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Disease Category (ICD-10)	Industrial Zones	Reference Zone	Rate Ratio	p-value
Malignant neoplasms (C00-C99)	312	189	1.65	0.003
Endocrine/metabolic disorders (E00-E90)	876	541	1.62	0.007
Childhood CNS disorders (G, age 0-14)	189	74	2.55	< 0.001

Table 2. Age-standardised morbidity rates per 100,000 population (2020-2023); incidence rates in industrial vs. reference zones

Clinical spirometry confirmed subclinical lung function impairment among industrial-zone residents. Mean FEV1/FVC ratio was 72.4% (SD 8.1%) in exposed participants versus 81.6% (SD 5.9%) in the reference group ($t = 14.3$; $p < 0.001$). An obstructive pattern consistent with early COPD (FEV1/FVC < 0.70) was found in 29.5% of industrial-zone participants aged 40 years or older, compared with 9.8% in the reference group. Blood biomarker analysis showed significantly elevated serum lead levels (mean 8.3 vs. 2.1 ug/dL; $p < 0.001$) and urinary cadmium (mean 2.7 vs. 0.6 ug/g creatinine; $p < 0.001$) in exposed participants.

5.4. Relationship Between Environmental Factors and Disease Prevalence

Spearman rank correlation analysis demonstrated strong positive associations between the composite air pollution index and respiratory disease incidence ($r_s = 0.81$; $p < 0.001$), cardiovascular disease incidence ($r_s = 0.73$; $p < 0.001$), and childhood neurological disorder rates ($r_s = 0.69$; $p < 0.001$). Soil heavy metal contamination index (Zc) correlated significantly with malignant neoplasm rates ($r_s = 0.67$; $p = 0.002$) and endocrine disorder incidence ($r_s = 0.61$; $p = 0.008$).

Multiple logistic regression models — adjusted for age, sex, smoking status, and educational attainment — confirmed that residence in an industrial zone remained a statistically significant independent predictor of chronic respiratory disease (adjusted OR 2.14; 95% CI 1.78-2.57), hypertension (adjusted OR 1.69; 95% CI 1.42-2.01), and self-reported neurological symptoms (adjusted OR 2.31; 95% CI 1.87-2.86). These associations persisted after stratification by smoking status, confirming that air pollution exposure contributes to disease burden independently of tobacco use.

6. CONCLUSION

This study provides robust, integrated evidence that industrial activity in the Fergana region is generating multi-media environmental pollution — in ambient air, drinking water, and soil simultaneously — at levels that substantially and consistently exceed national and international health-protective standards. The convergence of environmental monitoring data with clinical and epidemiological health outcomes constitutes compelling evidence of a causal pathway from industrial emissions to measurable deterioration in population health across the region.

The most pronounced health burdens are borne by communities residing within 1,500-2,000 metres of major industrial installations. Rates of chronic respiratory disease among these

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populations are more than double those of reference populations living in non-industrial areas of the same region. Childhood neurological disorder rates are 2.55 times higher, and malignant neoplasm incidence is 65% elevated — findings that are consistent with the broader international literature on industrial pollution health effects and extend those findings to the specific Central Asian context of the semi-enclosed Fergana Valley.

The study also reveals critical deficiencies in the current environmental monitoring infrastructure. Only 18 air quality stations serve a population of nearly one million within the study area; monitoring frequency is insufficient to capture peak industrial emission episodes; and water and soil surveillance programmes lack the analytical breadth to characterise the full contaminant mixture to which populations are exposed. These infrastructure gaps impede timely regulatory response and undermine the evidence base required for effective health protection policy.

In broader perspective, the ecological and hygienic situation in the industrial zones of the Fergana region constitutes a significant and ongoing public health challenge that demands coordinated, multi-sectoral responses from environmental regulators, health ministries, industrial operators, local government, and international development partners. The evidence generated by this research provides a scientifically grounded and policy-relevant foundation for the design and prioritisation of targeted intervention programmes.

7. RECOMMENDATIONS

Based on the findings of the present study, the following evidence-based recommendations are advanced for consideration by policy-makers, environmental regulators, public health professionals, and industrial managers:

7.1. Measures to Reduce Environmental Pollution in Industrial Areas

- Mandate the installation and operation of state-of-the-art stack emission abatement systems — including electrostatic precipitators, wet scrubbers, and catalytic converters — at all heavy industrial facilities in the Fergana region, with legally binding compliance timelines not exceeding 36 months from the date of regulatory enactment.
- Establish and enforce a minimum industrial exclusion buffer zone of 1,500 metres between major emission sources and the nearest residential development, implemented through revision of the Fergana Regional Land-Use and Spatial Planning Ordinance.
- Require all industrial enterprises operating within the region to adopt a certified environmental management system conforming to ISO 14001, with mandatory annual third-party verification and results published in a publicly accessible registry.
- Progressively phase out the combustion of high-sulphur fuel oil in industrial boilers and replace with low-sulphur alternatives or natural gas, targeting full compliance across the industrial sector within five years.
- Introduce stricter effluent discharge standards for wastewater from chemical and metallurgical plants discharging into the Syr Darya tributaries and irrigation canal networks, with continuous automated effluent monitoring at all major outfall points.

7.2. Improvement of Environmental Monitoring Systems

- Expand the ambient air quality monitoring network from the current 18 stations to a minimum of 42 stations, ensuring spatial coverage within 500 metres of each major industrial source and real-time public data dissemination through an open online platform accessible to citizens and researchers.

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• Establish a comprehensive soil and groundwater surveillance programme with standardised annual sampling at no fewer than 80 fixed sentinel points, complemented by targeted emergency surveys following any reportable industrial incident or accidental release.

• Integrate satellite remote-sensing products — including Copernicus Sentinel-5P tropospheric NO2 columns and MODIS aerosol optical depth — with ground-level monitoring networks to improve the temporal and spatial resolution of regional exposure assessments.

• Develop a unified Regional Environmental Health Information System linking pollution monitoring databases with electronic health records and disease surveillance data, enabling near-real-time ecological-epidemiological analysis and early warning of emerging health risks.

7.3. Implementation of Preventive Health Programmes

• Introduce mandatory annual health screening — encompassing spirometry, cardiovascular risk assessment, and heavy metal biomonitoring (blood lead, urinary cadmium) — for all residents living within 2,000 metres of major industrial facilities, with priority given to children, pregnant women, and the elderly.

• Develop and fund a targeted COPD and chronic respiratory disease management programme across primary healthcare facilities in industrial districts, including subsidised access to bronchodilator therapy, pulmonary rehabilitation, and integrated smoking cessation support.

• Launch sustained community health-literacy campaigns informing residents of environmental risks, recommended protective behaviours (use of air filtration devices during pollution episodes, avoidance of produce grown on contaminated land), and the location and availability of relevant health services.

• Establish occupational health surveillance programmes within industrial enterprises, with periodic biological monitoring of workers for heavy metal body burden and lung function, linked to a centralised national occupational disease registry to enable trend analysis and regulatory benchmarking.

7.4. Strengthening Public Health Protection in Industrial Regions

• Revise national maximum permissible concentration standards for PM2.5, benzo[a]pyrene in soil, and cadmium in groundwater to align with current WHO Air Quality Guidelines (2021 revision) and WHO Guidelines for Drinking-water Quality (4th edition), which are significantly more stringent than existing Uzbek norms.

• Strengthen the operational independence and technical capacity of the State Ecological Inspectorate through increased staffing, modern analytical equipment, transparent administrative procedures, and penalty structures that eliminate conflicts of interest between regulatory enforcement and industrial revenue generation.

• Establish a multi-stakeholder Regional Environmental Health Council — comprising representatives of the health ministry, environmental agency, industrial operators, district government, academic institutions, and civil society organisations — to coordinate policy responses, monitor progress against defined environmental health targets, and report publicly on outcomes on a biannual basis.

• Engage international organisations — including WHO, UNEP, and the World Bank — as technical and financial partners to support the implementation of pollution-control investments, capacity-building programmes, and long-term epidemiological research in the Fergana region.

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