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HUMAN HEALTH RISK ASSESSMENT AS A TOOL FOR IMPROVING THE NATIONAL AIR QUALITY MONITORING SYSTEM

EVALUAREA RISCULUI PENTRU SĂNĂTATEA UMANĂ CA INSTRUMENT PENTRU ÎMBUNĂTĂȚIREA SISTEMULUI NAȚIONAL DE MONITORIZARE A CALITĂȚII AERULUI

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ABSTRACT

Background. The effectiveness of an air quality monitoring network depends on its spatial and temporal representativeness and on the integration of monitoring data with exposure and health-risk assessment.

Aim. To develop a methodological approach for improving the national air quality monitoring system by integrating geospatial analysis, mathematical dispersion modelling, field measurements, and human health risk assessment.

Materials and Methods. The study was conducted in an urban agglomeration in western Ukraine. Industrial emission sources were geocoded in ArcGIS; 1-hour, 24-hour, and annual pollutant concentrations were modelled using ISC-AERMOD; health risks were assessed using standard approaches; and field measurements were performed with a mobile laboratory.

Results. Nine industrial enterprises and 283 emission sources were assessed. The modelling grid contained 1,435 receptor points. Modelled PM_{2.5} concentrations exceeded the WHO Air Quality Guidelines by 1.1-1.5 times. The total noncarcinogenic hazard index ranged from 1.0 to 1.86, indicating potential concern that requires pollutant- and target-organ-specific interpretation. Field concentrations ranged from 43.22 ± 0.74 to $98.70 \pm 0.84 \mu\text{g}/\text{m}^3$ for PM₁₀ and from 26.19 ± 0.54 to $86.38 \pm 0.61 \mu\text{g}/\text{m}^3$ for PM_{2.5}. Three reference-grade and three indicative automated monitoring stations were proposed.

Conclusions. Integrating dispersion modelling, field measurements, and health-risk assessment can support evidence-based placement of automated air quality monitoring stations and selection of priority pollutants for continuous monitoring.

Keywords: air pollution, exposure assessment, modelling, monitoring, risk assessment

REZUMAT

Introducere. Eficiența unei rețele de monitorizare a calității aerului depinde de reprezentativitatea spațială și temporală și de integrarea datelor de monitorizare cu evaluarea expunerii și a riscurilor pentru sănătate.

Scop. Elaborarea unei abordări metodologice pentru îmbunătățirea sistemului național de monitorizare a calității aerului prin integrarea analizei geospațiale, modelării matematice a dispersiei, măsurărilor de teren și evaluării riscurilor pentru sănătatea umană.

Materiale și metode. Studiul a fost realizat într-o aglomerație urbană din vestul Ucrainei. Sursele industriale de emisii au fost geocodificate în ArcGIS; concentrațiile poluanților pentru intervale de o oră, 24 de ore și un an au fost modelate cu ISC-AERMOD; riscurile pentru sănătate au fost evaluate prin metode standard; iar măsurările de teren au fost efectuate cu un laborator mobil.

Rezultate. Au fost evaluate nouă întreprinderi industriale și 283 de surse de emisii. Grila de modelare a cuprins 1.435 de puncte receptoare. Concentrațiile modelate ale PM_{2.5} au depășit valorile recomandate de OMS de 1,1-1,5 ori. Indicele total de pericol necancerigen a variat între 1,0 și 1,86, indicând un potențial motiv de îngrijorare care necesită interpretare specifică poluantului și organului țintă. Concentrațiile măsurate au variat între $43,22 \pm 0,74$ și $98,70 \pm 0,84 \mu\text{g}/\text{m}^3$ pentru PM₁₀ și între $26,19 \pm 0,54$ și $86,38 \pm 0,61 \mu\text{g}/\text{m}^3$ pentru PM_{2.5}. Au fost propuse trei stații automate de referință și trei stații indicative.

Concluzii. Integrarea modelării dispersiei, măsurărilor de teren și evaluării riscurilor pentru sănătate poate fundamenta amplasarea stațiilor automate de monitorizare și selectarea poluanților prioritari pentru monitorizarea continuă.

Cuvinte-cheie: poluarea aerului, evaluarea expunerii, modelare, monitorizare, evaluarea riscului

Introduction

Air pollution is a major environmental health problem associated with substantial morbidity and mortality. World Health Organization (WHO) estimates attribute approximately 6.7 million deaths annually to ambient and household air pollution, with noncommunicable diseases accounting for most of this burden. Globally, air pollution is estimated to contribute to approximately 29% of lung cancer deaths, 43% of deaths from chronic obstructive pulmonary disease, 24% of stroke deaths, and 25% of deaths from ischemic heart disease [1, 2].

WHO estimates indicate that 99% of the world's population lives in areas where air pollution levels exceed WHO guideline values [2]. In Ukraine, the cited burden estimates include approximately 43,000 premature deaths and nearly 1 million disability-adjusted life years annually [3]. These estimates are model-based and should be interpreted in light of the limited availability of automated, long-term, reference-grade air quality measurements at the national level. Public monitoring stations equipped with low-cost sensors may provide useful indicative data but do not necessarily meet the methodological requirements for reference measurements.

The organization and improvement of Ukraine's national air quality monitoring system therefore remain highly relevant. Directive (EU) 2024/2881 establishes European requirements relevant to air quality assessment and monitoring [4]. In existing monitoring systems, reliance on discrete laboratory chemical analyses may limit spatial representativeness and long-term temporal assessment. Fixed measurements and air quality modelling remain insufficiently implemented, and the spatial distribution of stations in relation to residential and industrial areas requires review in light of current urban development.

The placement of automated air quality monitoring stations (AQMS) can be supported by mathematical modelling of pollutant dispersion in the atmospheric boundary layer [4]. This approach allows inhalation risks from industrial facilities and road transport to be assessed across the urban territory and may support the harmonization of monitoring networks and evidence-based air quality decisions.

Objectives. To develop a methodological approach for organizing and improving the national air quality monitoring system by integrating geospatial analysis, mathematical modelling of air pollutant dispersion, field investigations, and human health risk assessment.

The study area was an urban agglomeration in western Ukraine characterized by residential, industrial, and transport infrastructure and complex anthropogenic pressure on air quality.

The study examined the spatiotemporal formation of air pollution associated with major industrial and road-transport emission sources. Particular attention was given to integrating modelling results and field measurements to improve the existing urban network of fixed-measurement sampling points and AQMS.

The assessment was limited to outdoor ambient air and did not include indoor air in residential or industrial buildings. The temporal scope was determined by the availability of the meteorological, emission, and monitoring data required for modelling and health-risk assessment.

Materials and methods

Due to security considerations associated with the ongoing war in Ukraine, the specific name of the study city is not disclosed in this manuscript. Cartographic methods were used to analyze the physical and geographical characteristics of the study area. Environmental and hygienic methods were used to determine the spatial distribution and location of industrial emission sources. Cartographic processing and spatial analysis were performed in ArcGIS 10.2.1 using ArcMap and high-resolution satellite imagery.

Average pollutant concentrations in the atmospheric boundary layer were calculated using ISC-AERMOD View v12.0.0 (license ISCAY0002896). Model inputs included terrain, meteorological conditions for the defined period, land use, and emission-source parameters. Average 1-hour, 24-hour, and annual concentrations were calculated at each receptor point for the selected industrial emission sources. Emission inventory: 2023-2024, meteorological data: 2024.

Health risks associated with industrial emissions were assessed using standard human health risk assessment approaches developed and recommended by the US Environmental Protection Agency and WHO [5, 6]. Hazard index (HI) was calculated as follows: $HI = \sum_{i=1}^n HQ_i$, where $HQ = AC/RfC$, AC is the average pollutant concentration (mg/m^3), and RfC is the reference concentration (mg/m^3). Individual mortality risk associated with particulate matter smaller than $10 \mu\text{m}$ was calculated as follows: $IRM = LADD \times SF$, where LADD is the lifetime average daily inhaled dose of the pollutant, expressed in $\text{mg}/(\text{kg} \times \text{day})$, and SF is the individual risk coefficient for particulate matter with an aerodynamic diameter of less than $10 \mu\text{m}$ (PM_{10}) [7].

Field measurements of pollutant mass concentrations were conducted 26-29 November 2024 using a mobile medical and environmental laboratory equipped with HORIBA gas analyzers and portable instruments [8]. Concentrations of pollutants were recorded in real time at 1-minute intervals, with the measurement duration at each monitoring point ranging from 40 to 90 minutes. The instruments underwent regular metrological verification and calibration in accordance with the requirements of the State Enterprise "Ukrmetrteststandart" (Ukraine), certificate No.143/25 (valid until 11 May 2027). Data were processed using Microsoft Excel and STATISTICA 10.0. Descriptive statistics included minimum and maximum values, means (M), standard deviations (SD), and standard errors of the mean (SE).

Results and discussion

A physical-geographical and environmental-hygienic assessment was performed using land-use characteristics, a digital elevation model, meteorological parameters, stationary-source characteristics, and emission-toxicity data (Figure 1). These data supported hazard identification, characterization of spatial pollutant dispersion, and quantitative assessment of inhalation exposure from local industrial sources.

Nine industrial enterprises comprising 283 emission sources were analyzed, geocoded, and spatially referenced in ArcGIS. Eight priority pollutants were identified: nitrogen dioxide, saturated hydrocarbons C12-C19, carbon monoxide, sulfur dioxide, total suspended particulate matter, PM10, PM2.5, and benzene, the latter being carcinogenic.

Using meteorological observations, topographical data, and land-use characteristics, average 1-hour, 24-hour, and annual concentrations were modelled for the eight priority pollutants with ISC-AERMOD v12.0.0. The computational grid covered 8.5×10 km and included 1,435 receptor points across the urban territory.

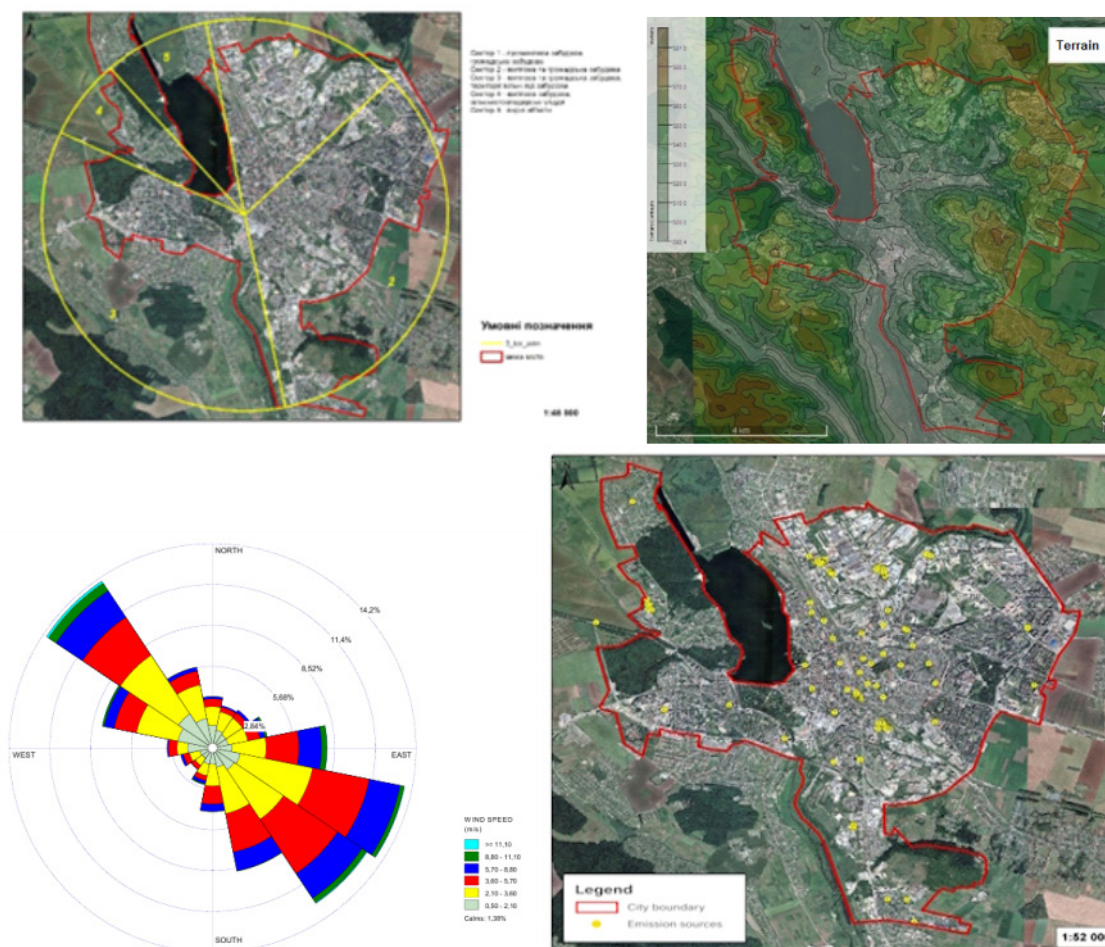
The modelled average concentrations were compared with national air quality standards and WHO Air Quality Guidelines under acute and chronic inhalation scenarios. No exceedances were identified at receptor-grid nodes for the

assessed pollutants, except for PM2.5, which exceeded WHO guideline values by 1.1-1.5 times (Figure 2).

The total noncarcinogenic HI associated with all prioritized pollutants ranged from 1.0 to 1.86 at the receptor-grid nodes. An HI above 1 indicates the potential for adverse noncancer effects but does not predict their probability or severity and requires pollutant- and target-organ-specific interpretation. The estimated individual mortality risk associated with particulate matter smaller than $10 \mu\text{m}$ ranged from 3.1×10^{-6} to 1.3×10^{-4} and reached approximately 10^{-4} at several receptor nodes near industrial areas; the acceptability of these values must be interpreted using the risk-management framework specified by the authors.

The results identified areas with the highest estimated health risks and provided a preliminary basis for selecting zones for automated AQMS placement.

To account for road-transport emissions and unaccounted industrial emissions, additional field measurements were performed for nitrogen dioxide, nitrogen monoxide, sulfur dioxide, carbon monoxide, ozone, total suspended particulate matter (including PM10 and PM2.5), total hydrocarbons, and formaldehyde. Sampling locations were selected using the zones of elevated estimated exposure risk identified by modelling. Meteorological and topographical conditions and high-intensity traffic areas were also considered. The findings



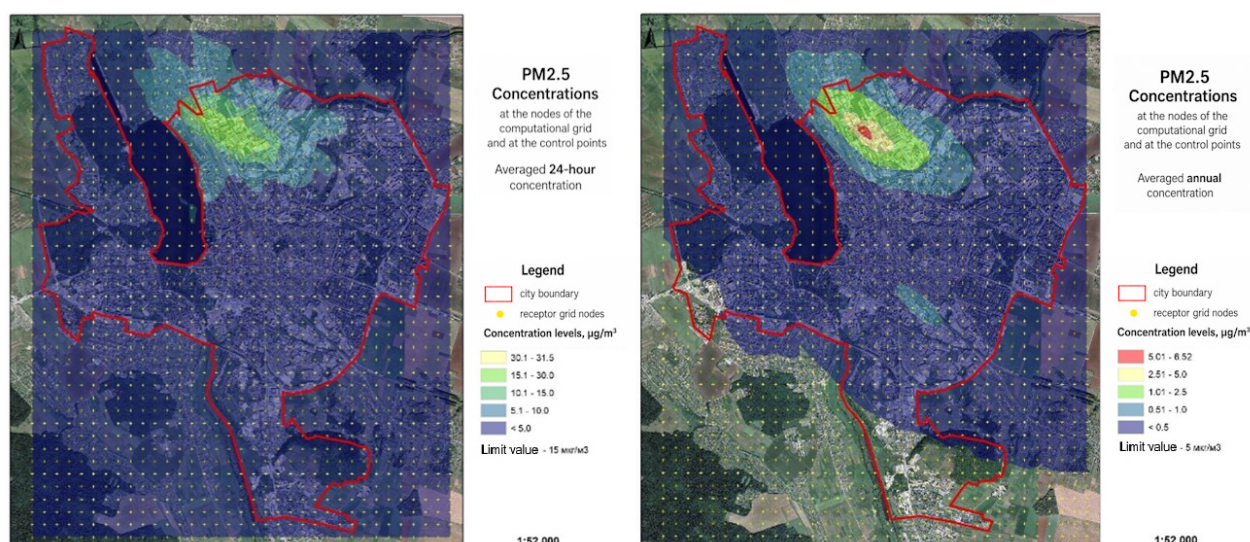


Figure 2. Dispersion-modelling results for average daily and annual PM_{2.5} concentrations at receptor-grid nodes.

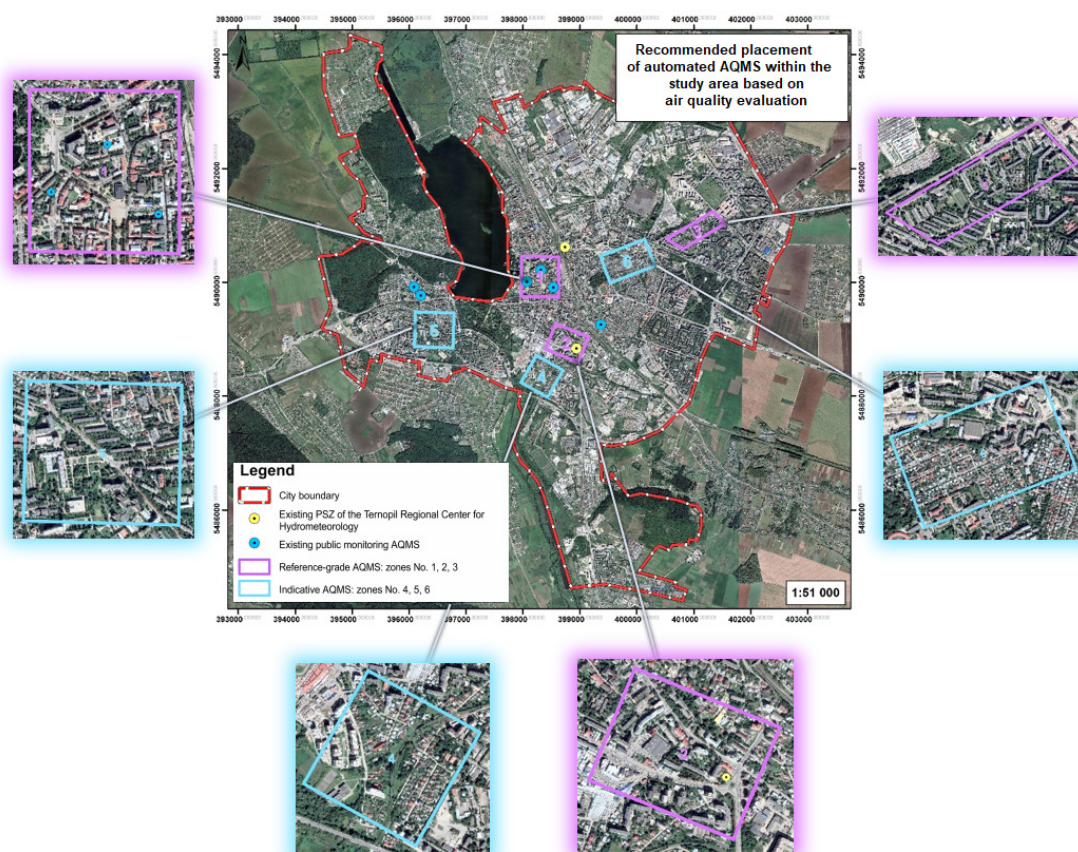


Figure 3. Recommended placement of automated AQMS within the study area based on air quality evaluation.

were used to evaluate potential AQMS locations and the pollutants requiring continuous monitoring, with attention to densely populated residential areas.

Five control sampling locations were established near residential buildings, urban infrastructure, and major roads with intensive traffic. Existing monitoring data from governmental agencies and public environmental organizations and available public complaints were also considered. Mean PM₁₀ concentrations ranged from $43.22 \pm$

0.74 to $98.70 \pm 0.84 \mu\text{g}/\text{m}^3$, and mean PM_{2.5} concentrations ranged from 26.19 ± 0.54 to $86.38 \pm 0.61 \mu\text{g}/\text{m}^3$. The highest concentrations were observed in traffic-affected areas, with lower concentrations associated with industrial emissions and residential solid-fuel heating. Ozone concentrations ranged from 0.028 ± 0.001 to $0.048 \pm 0.001 \text{ mg}/\text{m}^3$. Other measured pollutants remained within the applicable standards.

Based on the integrated assessment and the existing monitoring network, three additional reference-grade AQMS

and three indicative AQMS were proposed, together with a priority list of pollutants for monitoring (Figure 3).

The proposed six-station network comprises three fixed measurement stations and three indicative measurement stations. Its configuration was determined using the spatial analysis and air-pollution modelling results, considering major industrial emission sources, road traffic, population exposure, and the spatial variability of pollutant concentrations. This site-specific, risk-oriented network is consistent with the general principles of Directive (EU) 2024/2881 and is intended to provide representative coverage of the principal anthropogenic sources and areas of potentially elevated population exposure.

Conclusions

The findings support the establishment and expansion of an air quality monitoring network capable of informing

quantitative health-risk assessment, public communication, environmental protection, and preventive health measures.

The integrated modelling, health-risk assessment, and instrumental measurements identified zones suitable for automated AQMS placement. Reference-grade AQMS should monitor total suspended particulate matter, including PM₁₀ and PM_{2.5} separately, ozone, nitrogen oxides, carbon monoxide, sulfur dioxide, total hydrocarbons, and formaldehyde. Indicative AQMS should, at minimum, monitor particulate matter and ozone. Monitoring requirements for arsenic, cadmium, mercury, nickel, and polycyclic aromatic hydrocarbons should be aligned with the applicable European legal framework [4].

The approach supported the scientific selection of AQMS locations, the proposed number of stations, and the list of pollutants for continuous monitoring in the study area. It also provided evidence-based recommendations for authorities developing an air quality monitoring program.

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