4PCAN

D2.8 – Military-generated pollution and cancer

February 2025

Funded by the European Union. Views and opinions expressed are however those of the author (s) only and do not necessarily reflect those of the European Union or European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

Funded by the European Union. Views and opinions expressed are however those of the author (s) only and do not necessarily reflect those of the European Union or European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

Project number: 101104432

Project name: Personalized CANcer Primary Prevention research through Citizen Participation and digitally enabled social innovation

Project acronym: 4P-CAN

Call: HORIZON-MISS-2022-CANCER-01-01

Version number	
Status	Final document
Dissemination level	Public
Due date of deliverable	20/02/2025
Actual submission date	20/02/2025
Project officer	Marianne Ines Da Silva
Work package	WP2 Multi-level Assessment of Cancer Risk Factors Preventive Legislation
Lead partner	DNIPRO&CUMO
Partner (s) contributing	FEMINA M
Authors	
Main author name	Viktor Semenov
	Liliia Kriachkova
	Nikola Milašević
	Milica Kuzmanoska
Contributing authors	Mirjana Babamova
	Serhii Zakharov
	Nataliia Onul

	Liubov Krotova
	Kyrylo Simon
	Ivana Vojvodić
	Gordana Djukanovic
	Nevenka Lukovac – Janjić
Reviewers	
Reviewer name	EUROPEAN NETWORK FOR SMOKING PREVENTION (ENSP)

Statement of originality *This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.*

Version Tracker

Date	Version number*	Change
30/04/2024	1	Final version
18/02/2025	2	Revised final version

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AAPC	–	Average annual percentage change
AirQ+	–	Software tool for health risk assessment of air pollution
AQG	–	Air quality guidelines
AQI	–	Air Quality Index
ARIMAX	–	AutoRegressive Integrated Moving Average eXtended
As	–	Arsenic
BaP	–	Benzo(a)pyrene
BMI	–	Body mass index
C_6H_6	–	Benzol
Cd	–	Cadmium
CEOBS	–	Conflict and Environment Observatory
CETI	–	Center for Ecotoxicological Testing of Montenegro
CGO	–	Central Geophysical Observatory
CI	–	Confidence interval
CO	–	Carbon oxide
DALY	–	Disabilty-adjusted life years
DCR	–	Dnipro Cancer Registry
DU	–	Depleted uranium
EAPC	–	Estimated annual percentage changes
EBRD	–	The European Bank for Reconstruction and Development
EMEP	–	European Monitoring and Evaluation Program
EIONET	–	European Environment Information and Observation Network
EPA	–	Environmental Protection Agency
EU	–	European Union
FCDO	–	Foreign Commonwealth & Development Office
GBD	–	Global Burden of Diseases
GBD MAPS	–	Global Burden of Disease from Major Air Pollution Sources
GC	–	Gastric cancer
Globocan	–	Global Cancer Observatory
HCRI	–	Humanitarian and Conflict Response Institute
HI	–	Hazard index
HL	–	Hodgkin Lymphoma
HM	–	Hematological malignances

HQ	–	Hazard quotient
HR	–	Hazard ratio
IDD	–	International Development Department
IDPS	–	Internally Displaced Persons
IDS	–	Institute Development Studies
IEA	–	International Energy Agency
IHME	–	Institute for Health Metrics and Evaluation
IPH	–	Institute for Public Health
IPHRNM	–	Institute for Public Health of the Republic of North Macedonia
IQAir	–	Swiss Air technology company
K4D	–	Knowledge Evidence and Learning for Development
KIIS	–	Kyiv International Institute of Sociology
LDL	–	Low-density lipoprotein
LSTM	–	Liverpool School of Tropical Medicine
MEPNRU	–	Ministry of Environmental Protection and Natural Resources of Ukraine
MoEPP	–	Ministry of Environmental and Physical Planning
MPC	–	Maximum permissible concentrations
NATO	–	North Atlantic Treaty Organization
NCD	–	Non-communicable diseases
NCRU	–	National Cancer Registry of Ukraine
NH_3	–	Ammonia
NHL	–	Non-Hodgkin Lymphoma
Ni	–	Nickel
NMVOC	–	Non-methane volatile organic compounds
NO	–	Nitrogen oxide
NO_2	–	Nitrogen dioxide
O_3	–	Ozone
OECD	–	The Organization for Economic Cooperation and Development
OSCE	–	Organization for Security and Co-operation in Europe
Pb	–	Lead
PM	–	Particulate matter
RCGM	–	Dnipro Regional Centre of Hydrometeorology
RR	–	Relative risk
SDG	–	Sustainable Development Goals
SO_2	–	Sulphur dioxide

TROPOMI	–	Tropospheric Monitoring Instrument
UB station	–	Urban background station
UCCK	–	University Clinical Centre of Kosovo
UI	–	Uncertanity interval
Ukrstat	–	State Statistics Service of Ukraine
UN	–	United Nations
UNDP	–	United Nations Development Programme
UNEP	–	United Nations Environment Programme
UT station	–	Urban traffic station
VOCs	–	Volatile Organic Compounds
WHO	–	World Health Organization
YLL	–	Years of lost life

Executive Summary

Military actions impose serious short and long-term environmental impact on the territories where they unfold. War influences the environment in multiple direct and indirect ways, leading to contamination of air, water and soil. Air pollution is among top-five main causes of death and it remains one of the leading threats to public health worldwide, with certain regional peculiarities. In the presented report the authors aimed to shed light on possible consequences of military actions for air pollution and cancer epidemiology, based on the current and historical data on cancer epidemiology and air pollution in European countries who went through the war in the last decades.

The investigation implied literature review of scientific and grey literature dedicated to the impact of wars on air pollution and cancer epidemiology, with attention to Yugoslavian wars and Russian-Ukrainian war. The consequences of Yugoslavian wars were investigated using literature review and analysis of air pollution and cancer epidemiology data in 1990-2022. Investigation of the consequences of Russian-Ukrainian war was performed using literature review and ecological study. Systematic review and analysis, bibliosemantic, epidemiological, expert assessment, and statistical methods were applied.

The results of the deliverable highlight the complex influence of war on air pollution and cancer epidemiology in the involved countries. Twenty-five years after the Yugoslavian wars, discussions regarding the long-term impact of war pollution on public health are ongoing. Despite it is not possible to draw definitive conclusions about the effect of wars on air pollution and population health (including cancer epidemiology), signs of negative short- and mid-term consequences of war-generated pollution on cancer epidemiology were observed. The signs of short-term negative impact of war on air pollution were identified. Reduction in survival median of patients diagnosed with cancer during the full-scale Russian military invasion to Ukraine, when compared to pre-invasion times, was revealed.

The question of military-generated pollution effect on cancer incidence requires further investigation. There is the need of longitudinal cohort studies of the involved populations during and immediately after the conflict. The impact of air pollution as an environmental risk factor intensified by war cannot be viewed in isolation from the influence of other ecological, behavioural, and socio-economic determinants. It warrants the need in development and improvement of European

policies targeted on the complex preventive influence on behavioural, ecological and socio-economic drivers of cancer.

1. Introduction

Deliverable objective and scope

Military actions impose serious short and long-term environmental impact on the territories where they unfold (1). War influences the environment in multiple direct and indirect ways, leading to contamination of air, water and soil. Since wars are frequently associated with products of burning (usage of explosives, fuel consumption, fires in industrial objects and living areas, forest fires etc), air quality decrease may be considered as an environmental consequence of the utmost importance. Air pollution is the second most important factor of non-communicable diseases, including lung cancer (2). Despite air pollution being an important risk factor of respiratory system neoplasms (3), it is also responsible for other, non-respiratory types of cancer (4).

War can influence cancer epidemiology not only via biospheric pollution. Destruction of healthcare infrastructure, problems with drug supply, termination of clinical trials, prioritizing of healthcare services provision to patients in emergency conditions, demographic shifts, behavioural changes of population, and many other factors may significantly hamper all spheres of public health of countries in war, including cancer care.

The 4P-CAN Project aims to understand and to tackle challenges of primary cancer prevention on multiple levels. In the presented report the authors aim to shed light on possible consequences of military actions for air pollution and cancer epidemiology, based on the current and historical data on cancer epidemiology and air pollution in European countries who went through the war in the last decades.

Relation to other WPs and deliverables

The present deliverable is the part of the task T2.4 Environmental and workplace pollution exposure. The deliverable is linked to the Work package WP6 – Multi-stakeholders' co-creation of CPP policy recommendations, as the conclusions made in the document will be used for policy recommendations designing.

Content of the deliverable

The presented report includes the investigation of influence of war on air pollution and cancer epidemiology based on currently available information and historical data. The document is structured into three parts for the representation of perspective of countries who were involved directly or indirectly into wars in past decades: Montenegro (by CUMO), Republic of North Macedonia (by FEMINA-M) and Ukraine (by DNIPRO). Each part comprises the literature review, description of methodology, main results and discussion, conclusion and references list.

2. Montenegro Perspective (CUMO)

Introduction

The war in the former Yugoslavia, often referred to as the Yugoslav Wars, was a series of conflicts that occurred in the 1990s following the breakup of the Socialist Federal Republic of Yugoslavia. These wars were marked by ethnic, religious, and political tensions, resulting in displacement of populations, and widespread human suffering. Twenty five years after the ending of the wars we still discuss about late consequences, caused by war pollution and its impact on the health of the population of the countries that participated in the war.

The dissolution of the Socialist Federal Republic of Yugoslavia began in the late 1980s and early 1990s amid rising nationalist sentiments and political upheaval. The republic's constituent republics, including Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia, and Slovenia, sought independence from federal control, leading to the fragmentation of Yugoslavia. This breakup consisted of different wars: Croatian and Slovenian Wars of Independence (1991), which was the first conflicts erupted in 1991 with the declarations of independence by Croatia and Slovenia. The wars resulted in significant casualties, displacement of populations, and the establishment of independent states. From 1992-1995 the most devastating conflict of the Yugoslav Wars, the Bosnian War, was characterized by large scale civil war. The Kosovo War erupted in 1998, and after that NATO intervened with airstrikes against Serbia and Montenegro (at that time SR Yugoslavia) in 1999, leading to the withdrawal of Serbian forces and the establishment of Kosovo as a United Nations protectorate.

The Yugoslav Wars resulted in a profound humanitarian crisis, with millions of people displaced, killed, or injured.

On the territory of Montenegro the most of the direct military events took place during the period of NATO bombing in 1999. However, throughout the rest of the period of the wars in the former Yugoslavia, especially when the Economic Sanctions against Serbia and Montenegro were established (1992-1995), there was a devastating impact of the wars on the demographic and economic situation in Montenegro.

In addition to the direct impact on the health of the population, there was also an indirect impact in terms of the collapse of the health system in Montenegro with acute and delayed consequences on the health of the nation, including the potential increase in the incidence of malignant neoplasms, through the non-implementation of primary and secondary prevention measures, lack of medicines, inadequate health care registers, outdated infrastructure and lack of digitization.

The war pollution resulting from the conflicts in the former Yugoslavia raised many questions concerning increase in cancer incidence and mortality among populations affected by the wars, due to the pollution from bombings, industrial destruction, and other military activities which released various carcinogens into the environment, which could have long-term health consequences, including cancer development.

This topic has been very poorly studied scientifically, and there are no examples from the literature that have proven the direct impact of wartime pollution and the long term increase in the incidence of malignancy.

The environmental pollution resulting from the wars in the former Yugoslavia significantly impacted air, water, and soil quality, exacerbating broader environmental deterioration. However, specific tracking of these types of pollution directly attributable to the 1990s wars in the Western Balkans was not identified. The data available for analysis originate from existing monitoring stations for air, water, and soil control, covering the period from 1990 to 2022. Our focus was on air pollution data for Montenegro.

Additionally, we have examined the accessible data concerning malignancy in Montenegro spanning from 1990 to 2018. In this analysis, we have assessed the quality of data and encountered challenges within the registries. Presently, Montenegro has only fully finalized data collection, cleaning and analyses on malignant neoplasms for the year 2013.

Air pollution in Montenegro

Monitoring and control of air quality in Montenegro is a legal obligation of the Environmental Protection Agency, and it is carried out for the purpose of assessment, planning and management of air quality. The analysis of the obtained results serves as a basis for proposing measures to improve air quality, as well as for numerous other analyses and the adoption of policies from other areas.

The Environmental Protection Agency was founded in 2008 and in accordance with its responsibilities, took care of the implementation of legislation in the area of air quality. During 2010, Montenegro established the National Air Quality Monitoring Network with measurements at automatic stationary stations, with improved data quality that enables better reporting on air quality, and during all the following years, with the adoption and implementation of EU standards and legislation, as well as the implementation significant projects, achieved the level of reporting and coverage with measurements that the most modern European countries have.

Monitoring of cross-border air pollution is the responsibility of the Institute for Hydrometeorology and Seismology, but the EMEP station is included in the national network, that is, it is part of the State Network for Air Quality Monitoring.

The oldest data on air quality in Montenegro that could be found for the purposes of this analysis date from the end of the 1970s, that is, the beginning of the 1980s, and were presented in the publication "Air Pollution in the SR of Montenegro". which was published in 1986 by the then Republic Hydrometeorological Institute of Montenegro (1). The publication contains data on the methods of physico-chemical analysis of air and precipitation, chemical aspects of air pollution that contain the results of SO_2 and smoke measurements, radioactivity of precipitation, measurements of the amount of sediment particles. Also, meteorological aspects of air pollution are described and an assessment of the general state of air pollution in urban-city, urban-industrial environments as well as recreational-tourist areas of Montenegro is given.

The conclusions of this study speak in favour of relatively well preserved air quality in Montenegro. "In the coastal zone, the air belongs to the category of clean air, while in the central and northern part it ranges from moderately polluted air. Air pollution in the cold part of the year in the Pljevlja area, as well as air quality in strictly industrial zones, are excluded (4).

Effect of air pollution on health in Montenegro

The first analysis of the impact of air pollution on health in Montenegro (2) was made in 2016 in cooperation with the World Health Organization (WHO). In the same year, the WHO publishes a very important publication - "Air pollution: global assessment of exposure and burden of disease" (3) in which an assessment is also given for Montenegro. According to this publication, the average concentration of suspended particles $PM_{2.5}$ was estimated at 22 µg/m^3, and the crude mortality rate at 62/100,000 inhabitants. The years of lost life (YLLs) caused by air pollution were estimated at 755/100,000 inhabitants and the number of premature deaths at 61/100,000 inhabitants.

As part of the cooperation between Montenegro and the WHO, an analysis of existing national data on air quality and health was carried out in order to evaluate and quantify the impact of air pollution on health in Montenegro. The analysis included Podgorica, Nikšić and Pljevlja, and the methods for checking health risks recommended by the WHO were used. The analysis showed that over 250 premature deaths and 140 hospital admissions per year, as well as several other health outcomes, are associated with exposure to concentrations of suspended particles that exceed the value recommended by the WHO Air Quality Guidelines. More than half of the mentioned impacts are related to the increased level of pollution during the winter months, mainly due to the burning of solid fuels for heating. The impact of air pollution on health is more common in Pljevlja than in the other two cities, but due to the larger number of inhabitants in Podgorica and Nikšić, the absolute burden of pollution on health in these cities is similar to that in Pljevlja. In order to reduce the impact of air pollution on health in cities in Montenegro, it is necessary to significantly reduce the burning of solid fuels for heating and cooking purposes in households.

Air pollution and human health: the case of the Western Balkans (5)

The report on the assessment of the impact of air pollution on human health for the area of the Western Balkans was prepared in cooperation with the WHO and the United Nations Environment Program (UNEP) with the support of the Government of Norway, whereby the previously prepared analysis for Montenegro served as a model for the region. The report provides an overview of air quality in the Western Balkans, as well as an assessment of the impact of air pollution on health in the region, with a framework of appropriate instruments to alleviate energy poverty, the key cause of air pollution in the region. The report covers Albania, Bosnia and Herzegovina, North Macedonia, Montenegro and Serbia.

The assessments of the health impacts of air pollution in the Western Balkans presented in this report focus on the population in cities for which data were available from national air quality and health monitoring systems. For Montenegro, these are: Bar, Nikšić, Pljevlja, Podgorica and Tivat. In addition, estimates for the Western Balkans at the level of the entire country are presented based on global analyses conducted by the WHO.

The results showed that air pollution causes approximately 5,000 premature deaths in certain cities of the region. On average, the inhabitants of the Western Balkan countries live 1.3 years shorter due to polluted air.

Air pollution can be attributed between 4% and 19% of total premature mortality in selected cities and shortens life expectancy by between 0.4 and 1.3 years. On average, 20% of the lost years of life due to exposure to polluted air lead to the premature death of people under the age of 65. Exposure to fine particulate matter ($PM_{2.5}$) is estimated to be responsible for 75% of all exposure-related deaths. The percentage of total mortality from natural causes that can be attributed to all considered air pollutants in cities varied from 4% in Bar and Tivat to 19% in Tetovo. For the 18 cities for which baseline mortality data were available, the attributable proportion was used to calculate the annual number of deaths attributable to air pollution. The sum of all deaths directly attributable to air pollution in the cities of the Western Balkans included in this study is almost 5,000 per year, with the largest number of deaths registered in the largest city in the region, Belgrade (1,004 deaths per year can be attributed to air pollution). Estimates of mortality attributable to $PM_{2.5}$ exposure exceeding WHO Guidelines in Bosnia and Herzegovina, Montenegro, North Macedonia and Serbia are higher than in most EU member states.

WHO/UNEP data in 2019

In support of health protection policies and measures, the WHO has developed a software tool that contains functions for assessing the health effects of exposure to air pollutants. AirQ+ can be used, with some restrictions, for cities, countries or regions worldwide. Data obtained in this way can answer the following questions:

1. How much of a certain impact on health can be attributed to certain pollutants?
2. What would be the change in health effects if air pollution levels were to change in the future?

The test results are shown in the following figures.

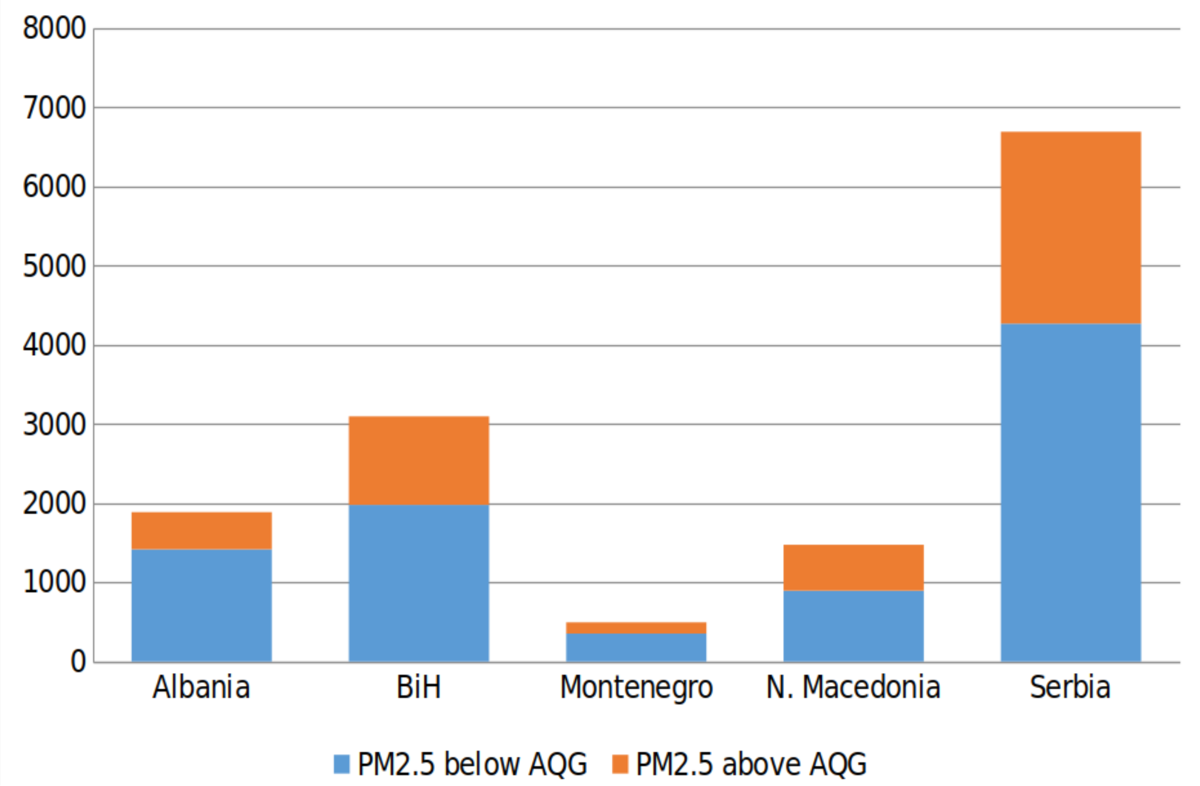


Figure 2.1. The number of premature deaths attributable to the impact of $PM_{2.5}$ – region

Legend: blue - $PM_{2.5}$ concentrations below recommended values, orange - $PM_{2.5}$ concentrations above recommended values

For all five countries considered in this study, estimates attribute approximately 13,640 deaths to $PM_{2.5}$ exposures, of which 4,733 (35%) are attributable to $PM_{2.5}$ concentrations exceeding WHO guideline levels.

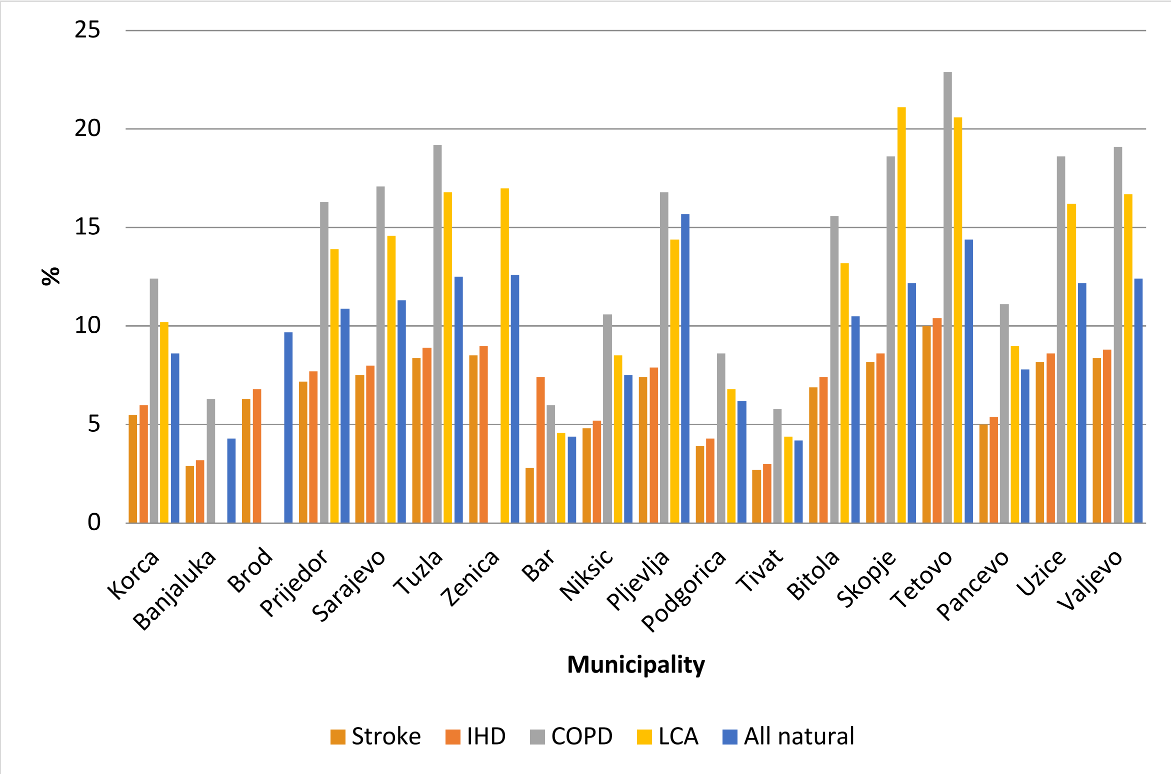


Figure 2.2. Proportion of certain causes of death in mortality attributable to exposure to concentrations of suspended particulate matter $PM_{2.5}$ exceeding levels recommended by WHO guidelines

Notes: light orange – heart attack; orange – ischemic heart diseases; gray – chronic obstructive pulmonary diseases; yellow – lung cancer; blue – all natural causes

Cause-specific mortality rates due to exposure to increased concentrations of suspended particulate matter $PM_{2.5}$ were calculated using the integrated exposure response functions available in the AirQ+ software. Estimates of the share attributable to air pollution for chronic obstructive pulmonary disease and lung cancer range between 15 and 20% in several cities. Estimates for cerebrovascular disease and ischaemic heart disease are 5 to 10 percent lower. Estimated proportions for both groups of circulatory diseases are lower than those for all-cause mortality in all cities. For cities with cause-specific mortality data, the absolute number of cause-specific deaths as well as calculated cause-specific mortality rates attributable to $PM_{2.5}$ exposures are given.

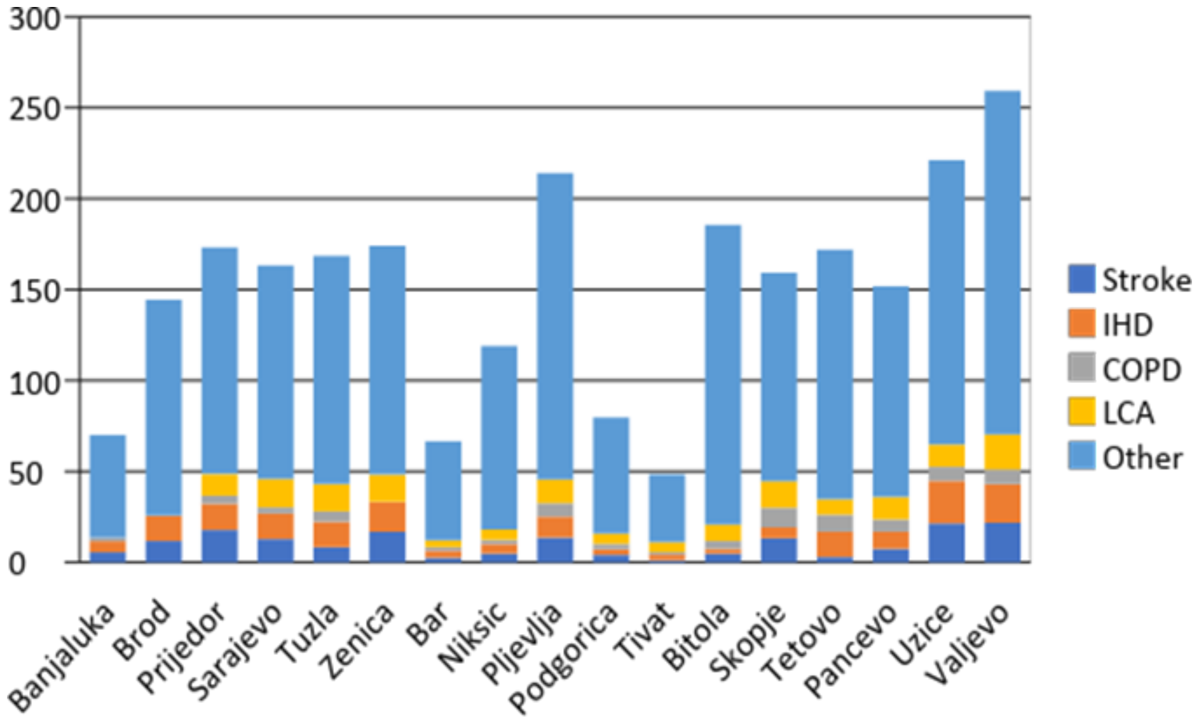


Figure 2.3. Death rate (per 100,000) attributable to $PM_{2.5}$ exposures by registered cause of death by city

State	WHO number of attributed cases		Mortality	Mortality certain causes
	Total	For $PM_{2.5}$ concentrations above the recommended values	Attributed mortality per /100,000	WHO (national assessment)
Albania	1885	469	63.4	15.8
Austria	3427	386	38.7	4.4
Belgium	4547	713	39.4	6.2
Bosnia and Herzegovina	3096	1118	86.7	31.3
Bulgaria	8751	2283	120.8	31.5
Croatia	2982	704	69.7	16.5
Cyprus	388	98	32.6	8.3
Czech Republic	6357	1363	59.0	12.7
Denmark	1767	33	30.4	0.6
Estonia	575	0	43.1	0.0
Finland	1051	0	18.7	0.0
France	16580	1705	25.2	2.6
Germany	37690	3625	45.3	4.4
Greece	7075	1662	62.2	14.6
Hungary	8184	1741	82.7	17.6
Ireland	974	41	20.2	0.8
Italy	29396	6693	48.7	11.1

Latvia	1668	210	83.2	10.5
Lithuania	2428	191	82.1	6.4
Luxembourg	133	1	22.6	0.1
Malta	190	31	43.5	7.2
Montenegro	**494**	**143**	**77.4**	**22.3**
North Macedonia	1474	580	69.7	27.5
Netherlands	5412	625	31.3	3.6
Poland	29583	9232	76.3	23.8
Portugal	3003	396	28.3	3.7
Romania	16920	2905	84.2	14.5
Serbia	6690	2423	74.7	27.1
Slovakia	3019	772	54.6	14.0
Slovenia	1009	233	47.8	11.1
Spain	12815	3020	27.1	6.4
Sweden	1859	19	18.5	0.2
Great Britain	21530	465	32.1	0.7

Table 2.1. Cause-specific mortality rate (all ages) attributable to $PM_{2.5}$ exposures: comparison with estimates for EU Member States

Estimates of mortality rates attributable to exposure to increased concentrations of $PM_{2.5}$ compared to WHO guidelines in Bosnia and Herzegovina, Montenegro, North Macedonia and Serbia are higher than in most EU member states. In some EU countries, only a small part of the population is exposed to $PM_{2.5}$ concentrations that exceed the WHO AQG level, and the impacts of such exposure are marginal. The table shows that the total mortality rate attributable to air pollution in Montenegro is 77.4/100,000 inhabitants. The situation is similar in Poland, while higher mortality rates than the EU member states were estimated for Bulgaria, Hungary, Lithuania, Latvia and Romania.

The Global Burden of Disease

The Global Burden of Disease (GBD) (6) is a survey that was first initiated by the World Bank in 1990, for the purpose of preparing the World Development Report for 1993. Then, in 1998, the WHO created a database and generated estimates for the period 2000-2002. which are published in the WHO global annual health reports. The GBD for 2010 was created with the help of the Bill Gates Foundation and included over five hundred experts, with the scope of the study being significantly expanded. The Institute for Health Metrics (IHME) (7) was established and a methodology was established for 300 diseases and 79 risk factors. The results of the GBD research for 2013 showed that air pollution represents the fifth (out of a total of 79) risk factor that contributes to the burden of disease, as well as the most important environmental risk factor at the global level. GBD 2016 is linked to the Sustainable Development Goals for the first time and includes 333 diseases, 84 risk factors and 23 age groups, and the assessment was carried out for 774 locations around the world with the participation of over two and a half thousand collaborators from 133 countries. The last global survey was conducted in 2019 and covered 990 locations in 204 countries (including state territories), 369 diseases and injuries, as well as an increased number of risk factors.

The national profile for Montenegro (8) singles out the 10 most significant risk factors that cause the most premature deaths and disabilities, where air pollution is in sixth place.

	Factor ranking 2009	Factor ranking 2019	% changes 2009 -2019
Use of tobacco products	1	1	1.1
High blood pressure	2	2	- 1.1
Risks related to nutrition	3	5 ˅	- 1.1
High body mass index	4	3 ˄	6.9
High plasma glucose level (on an empty stomach)	5	4 ˄	14.4
Air pollution	6	6	-12.9
High cholesterol (LDL)	7	7	- 2.4
Use of alcohol	8	8	- 1.3
Kidney dysfunction	9	9	3.8
Suboptimal air temperature	10	10	1.6

Table 2.2. Risk factors for health, Montenegro 2009-2019. Source: GBD 2019 – state profile of Montenegro https://www.healthdata.org/montenegro

Table 2.2 shows that in the period 2009-2019, air pollution as a risk factor for health was consistently ranked sixth, and that the impact of this risk on the number of premature deaths and endangering health was reduced by 12.9%. The total estimated number of premature deaths in Montenegro that can be attributed to air pollution in 2019 is 118.95/100,000 inhabitants.

Analysis of the legal framework for air quality monitoring

The Ministry of Tourism, Ecology, Sustainable Development and Development of the North is the primary state institution responsible for drafting legislation, monitoring its implementation and developing the national air quality policy.

A key role in the implementation of legislation is played by the Environmental Protection Agency (EPA), which is responsible for managing the network of air quality monitoring stations, creating lists of air emissions, creating reports on air quality, informing the public about air quality, and creating and submitting reports on air quality in accordance with the prescribed methodology to the European Environmental Agency through the EIONET network.

Center for ecotoxicological research - CETI implements the annual air quality monitoring program by working in the field and in the laboratory. The laboratory has accreditation for reference methods for monitoring air quality in accordance with EU directives, participates in interlaboratory tests, performs measurements, laboratory analyses, verification and confirmation of data, and conducts data quality assurance/control procedures.

The Institute for Hydrometeorology and Seismology is involved in the implementation of legislation in the area of air quality by the obligation to calculate the natural contribution to air pollution and monitor air quality at the EMEP cross-border pollution monitoring station.

Local authorities are responsible for the development and implementation of air quality plans in zones where the permitted values of polluting substances have been exceeded, in cooperation with the Ministry and the Environmental Protection Agency.

The Directorate for Inspection Affairs is the body responsible for inspection supervision over the application of legislation in the field of environmental protection, including air quality.

Air Quality Legislation

The Law on Air Protection ("Official Gazette of Montenegro", No. 25/2010, 43/15) and a large package of by-laws regulating various aspects of air protection are fully harmonized with the acquis of the EU on the environment.

Limit values and other air quality protection standards for pollutants in the air are prescribed by the Decree on determination of types of pollutants, limit values and other air quality standards ("Official Gazette of Montenegro", no. 45/08, 25/2012) and are fully harmonized with EU legislation.

The territory of Montenegro is divided into three air quality zones, as shown in table 2.3.

Air quality zone	Municipalities in the zone

Northern air quality zone	Andrijevica, Berane, Bijelo Polje, Gusinje, Pljevlja, Kolašin, Mojkovac, Petnjica, Plav, Plužine, Rožaje, Šavnik and Žabljak
Central air quality zone	Podgorica, Nikšić, Danilovgrad and Cetinje
Southern air quality zone	Bar, Budva, Kotor, Tivat, Ulcinj and Herceg Novi

Table 2.3. Air quality zones. Source: Environmental Protection Agency

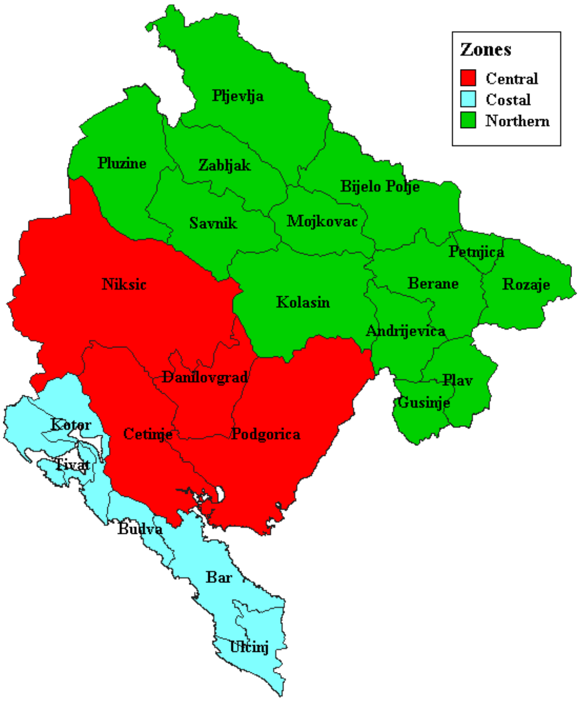


Figure 2.4 Air quality zones and network of measuring points; Source: Environmental Protection Agency

Until May 2019, the State Network for continuous monitoring of air quality consisted of seven stationary stations (table 2.4), namely:

No	Name of the Station	Type of measuring point	Pollutants that are measured
1	Podgorica 1	UT	NO, NO_2, NOx, CO, PM_{10} and Pb, BaP in PM_{10}
2	Bar 2	UB	NO, NO_2, NOx, CO, SO_2, O_3, $PM_{2.5}$, PM_{10} i Pb, As, Cd, Ni and BaP in PM_{10}
3	Nikšić 2	UB	NO, NO_2, NOx, CO, SO_2, O_3, $PM_{2.5}$, PM_{10} i Pb, As, Cd, Ni and BaP in PM_{10}
4	Pljevlja 2- Gagovića imanje	UB	NO, NO_2, NOx, SO_2, $PM_{2.5}$, PM_{10} i Pb, As, Cd, Ni and BaP in PM_{10}
5	Tivat	UB	$PM_{2.5}$

6	Gradina	SB	NO, NO_2, NOx, SO_2, O_3
7	Golubovci	SB	NO, NO_2, NOx, SO_2, O_3

Table 2.4. Measuring points within the National Air Quality Monitoring Network until May 2019. Source: Environmental Protection Agency

After the expansion of the network (2019), in addition to the number of locations where air quality is monitored, the number of parameters also increased, which is shown in table 2.5.

No	Name of the Station	Type of measuring point	Pollutants that are measured
1.	Pljevlja 2-Gagovića imanje	UB	NO, NO_2, NOx, SO_2, CO, $PM_{2.5}$, PM_{10} (Pb, As, Cd, Ni and BaP in PM_{10})
2.	Gradina	RB	NO, NO_2, NOx, SO_2, O_3, CH_4, THC i Hg
3.	Bijelo Polje	UB	NO, NO_2, NOx, CO, $PM_{2.5}$, PM_{10}, (Pb, As, Cd, Ni and BaP in PM_{10})
4.	Podgorica 2	UB	SO_2, $PM_{2.5}$, PM_{10}, (Pb, As, Cd, Ni and BaP in PM_{10})
5.	Podgorica 3	UT	NO, NO_2, NOx, CO, C_6H_6, PM_{10}, (Pb, As, Cd, Ni and BaP in PM_{10})
6.	Podgorica 4-Gornje Mrke	RB	NO, NO_2, NOx, O_3, CH_4 and THC
7.	Nikšić 2	UB	NO, NO_2, NOx, CO, O_3, SO_2, $PM_{2.5}$, PM_{10} (Pb, As, Cd, Ni and BaP in PM_{10})
8.	Bar 3	UB	NO, NO_2, NOx, $PM_{2.5}$, PM_{10} (Pb, As, Cd, Ni and BaP in PM_{10})
9.	Kotor	UT	NO, NO_2, NOx, CO, SO_2, C_6H_6, PM_{10}, (Pb, As, Cd, Ni and BaP in PM_{10})
10	Velimlje	EMEP	PM_{10}, $PM_{2.5}$, SO2, NOx, O3, CO

Table 2.5. Measuring points within the National Air Quality Monitoring Network, active since October 2019. Source: Environmental Protection Agency

In accordance with the Law on Air Protection, Center for Ecotoxicological Testing of Montenegro (CETI) LLC implements the Air Quality Monitoring Program of Montenegro. The program includes the systematic measurement of the emission of polluting substances in the air at automatic measuring stations. The list of polluting substances-ISO-code (ISO 7168-2:1998) is given in table 2.6.

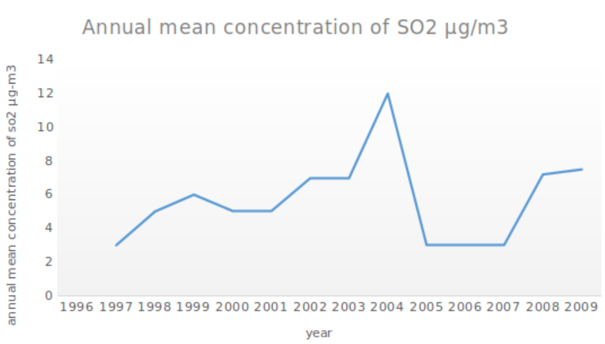
No	ISO-code	Formula	Name of polluting substance	Measuring unit	Averaging time
1.	1	SO_2	Sulphur dioxide	$\mu g/m^3$	1 hour 24 hours
2	3	NO_2	Nitrogen dioxide	$\mu g/m^3$	1 hour
3	8	O_3	Ozone	$\mu g/m^3$	8 hours
4	24	PM_{10}	Particulate matter	$\mu g/m^3$	24 hours

5		CO	Carbon monoxide	mg/m^3	8 hours
6	19	Pb	Lead	ng/m^3	Seven days
7	82	Cd	Cadmium	ng/m^3	Seven days
8	80	As	Arsenic	ng/m^3	Seven days
9	87	Ni	Nickel	ng/m^3	Seven days
10	P6	BaP	Benzo(a)pyrene	ng/m^3	Seven days
11		BbF	Benzo(b)fluoranthene	ng/m^3	Seven days
12		BjF	Benzo(j)fluoranthene	ng/m^3	Seven days
13		BkF	Benzo(k)fluoranthene	ng/m^3	Seven days
14		Ind	Ideno (1,2,3-d)pyrene	ng/m^3	Seven days
15		DahA	Dibenzo(ah)anthracene	ng/m^3	Seven days

Table 2.6. List of polluting substances - ISO code (ISO 7168-2:1998). Source: Environmental Protection Agency

Analysis of the results of air quality monitoring 1996-2009

Until the establishment of the Environmental Protection Agency (2009), air quality monitoring was carried out by the Institute for Hydrometeorology of Montenegro. Sampling was done by so-called semi-automatic methods, while the concentration of pollutants was determined by the spectrophotometric method in the laboratory. For the period from 1996 to 2009, data are available on the average annual concentrations of sulphur(IV) oxide SO_2 and smoke and soot. This analysis presents data from 4 representative measuring stations: Pljevlja, Bijelo Polje, Podgorica and Bar.



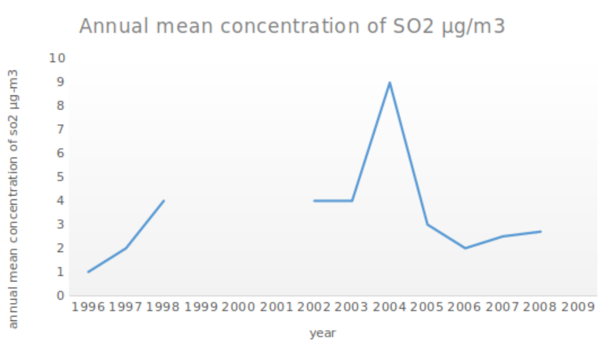
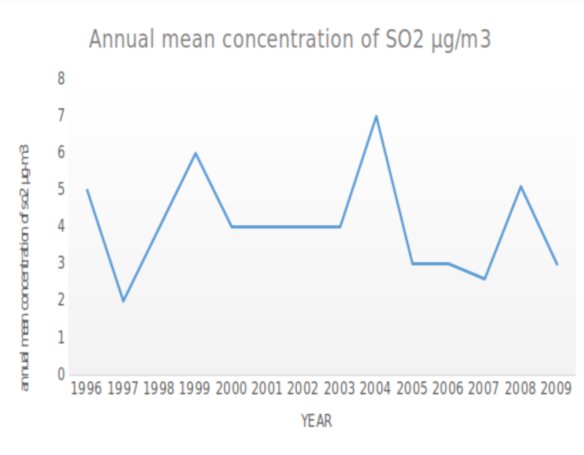


Figure 2.5. Annual mean concentration of SO_2 -Pljevlja Figure 2.6. Annual mean concentration of SO_2 -Bijelo Polje



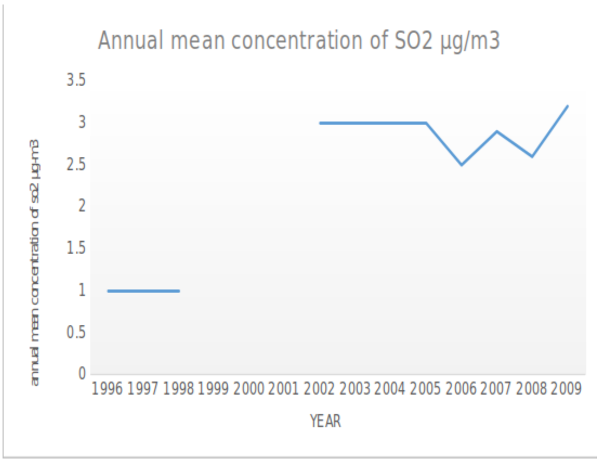
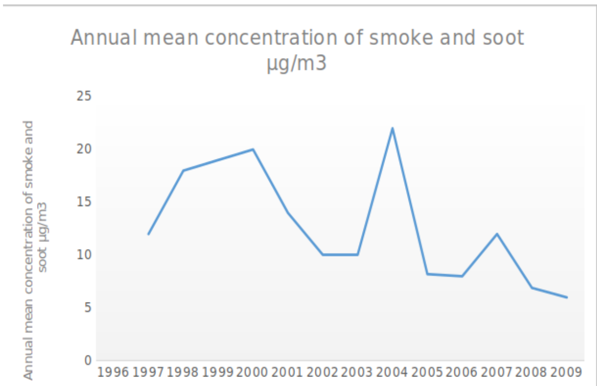


Figure 2.7. Annual mean concentration of SO_2

Figure 2.8. Annual mean concentration of SO_2 -Bar Podgorica

Source: Institute for Hydrometeorology.

The conclusion is that sulphur(IV) oxide SO_2 concentrations during the period 1996-2009 were very low. Data are missing for 1999 and 2000 at the measurement sites in Bijelo Polje and Bar due to restrictions in the implementation of air quality monitoring during the period of NATO bombing (1999) and as a consequence of the lack of measurement resources (2000).



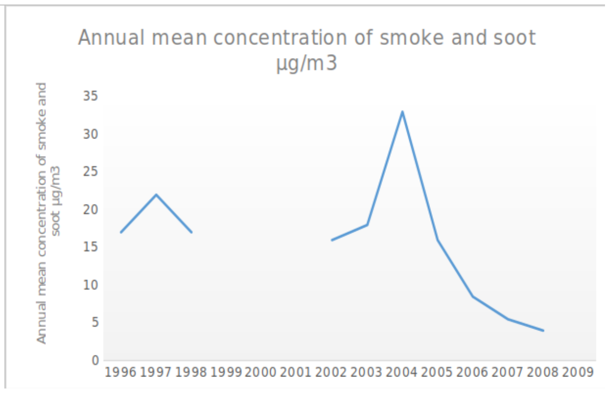


Figure 2.9. Annual mean concentration of smoke and soot - Pljevlja

Figure 2.10. Annual mean concentration of smoke and soot -Bijelo Polje

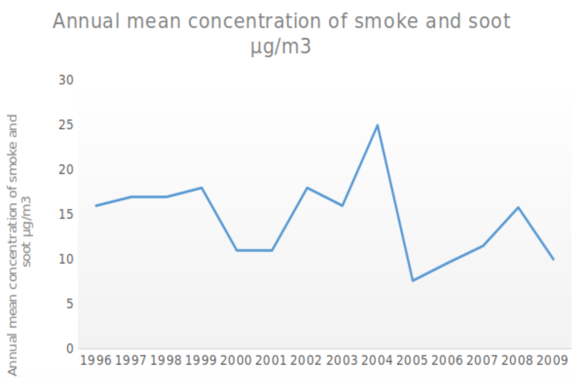


Figure 2.11. Annual mean concentration of smoke and soot -Podgorica

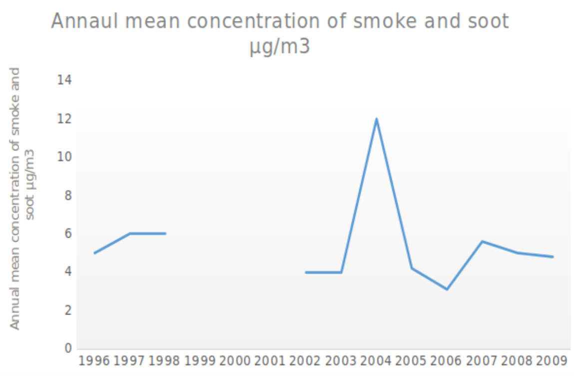


Figure 2.12. Annual mean concentration of smoke and soot -Bar

Source: Institute for Hydrometeorology

The conclusion is that smoke and soot concentrations during the period 1996-2009 were very low, as was also stated for the concentration of sulphur(IV)oxide SO_2. Data are missing for 1999 and 2000 at the measurement sites in Bijelo Polje and Bar due to restrictions in the implementation of monitoring during the period of NATO bombing (1999) and as a consequence of the lack of measurement resources (2000).

The general conclusion is that during the presented period there was no exceeding of the then valid limit values. One of the reasons is the closing of factories and large number of facilities, as a result of the economic crisis that occurred after the war (1992-1995), as well as a result of the NATO bombing in 1998.

The air quality monitoring system was significantly improved with the establishment of the Environmental Protection Agency (2009). A modern State network for air quality monitoring at automatic stationary stations has been established and the entire legislation governing the area of air quality management is harmonized with EU legislation.

Analysis of the results of air quality monitoring 2009-2022

Sulphur (IV) oxide SO_2

Anthropogenic sulphur(IV)-oxide emissions mainly originate from the burning of sulphur-containing fossil fuels (e.g. coal and fuel oil). Sulphur(IV)-oxide is a by-product of numerous industrial and traffic processes.

Natural sources of sulphur(IV)-oxide emissions are volcanoes and oceans, although they contribute only about 2% to total global emissions.

Sulphur(IV) oxide (SO2) causes irritation when inhaled, and very high concentrations can cause breathing problems. Asthmatics and chronic lung patients can be extremely sensitive to the negative effects of very high concentrations, which in extreme cases can cause asthma attacks (Report on the state of the environment in Montenegro based on indicators, Agency for Nature and Environmental Protection, 2017).

More than 67% of sulphur(IV)-oxide emissions in Montenegro originate from the burning of fossil fuels – coal and fuel oil in the energy sector. The second most significant source is combustion in non-industrial furnaces, as well as the railway, maritime, air traffic and the use of non-road machinery (construction and mining machinery), which each contribute 10% to the total emissions. The rest is due to emissions from the combustion sector in industrial furnaces and production processes. Only about 0.3% of sulphur(IV)-oxide is emitted from road traffic (National Air Quality Management Strategy with Action Plan for the period 2013-2016, 2013).

For the assessment of air quality based on the results of measurements of concentrations of sulphur (IV) oxide SO_2, the results of measurements at measuring points within the National Air Quality Monitoring Network were analysed.

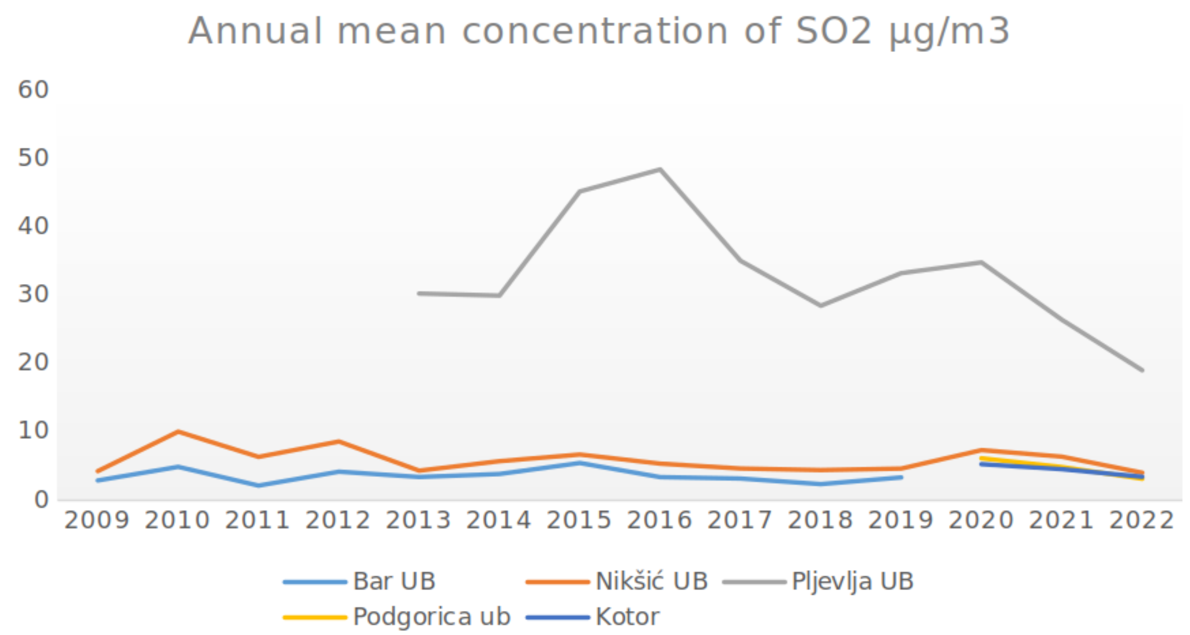


Figure 2.13. Mean annual concentrations of sulphur(IV)-oxide (µg/m^3) in the period 2009-2022; Source: Environmental Protection Agency

Except at the measuring points in the municipality of Pljevlja, at other locations during the entire measurement period there was no exceeding of the limit values, neither for the average hourly nor the average daily concentration. The number of overruns registered at the UB station in Pljevlja is shown in figure 2.14.

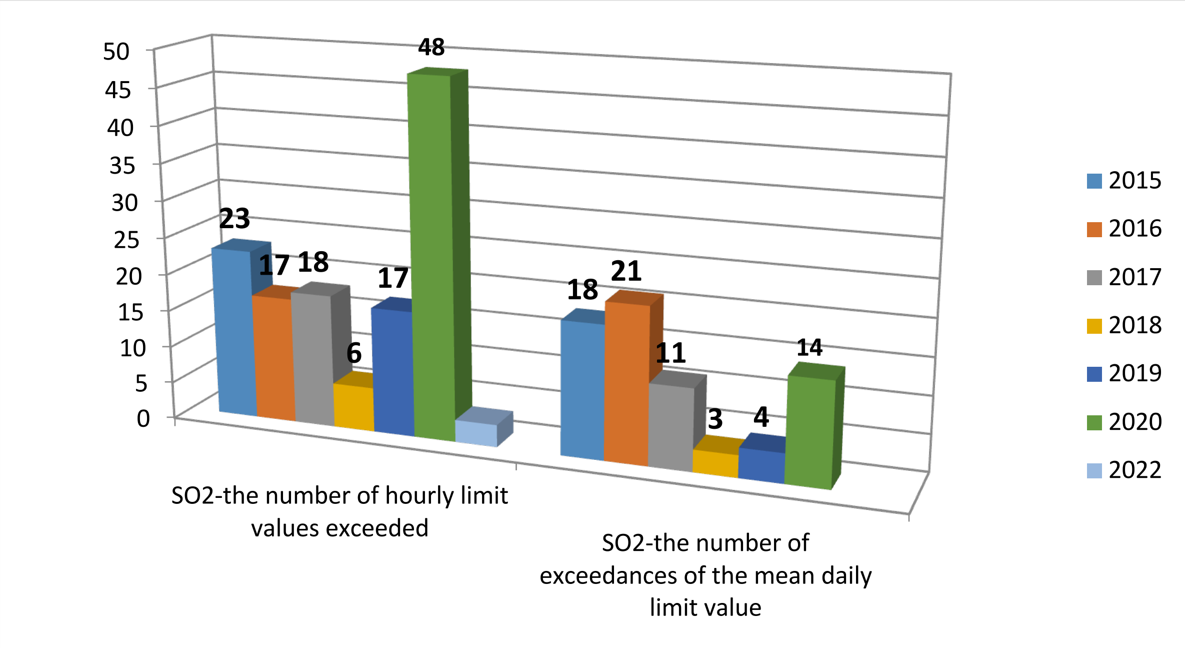


Figure 2.14. Mean annual concentrations of sulphur(IV)-oxide (µg/m^3) in the period 2009-2022; Source: Environmental Protection Agency

By analysing the results of the measurements and the factors that influenced the air quality in the period when exceedances were registered, the conclusion is that the dominant factors that caused poor air quality based on the concentration of SO_2 were emissions from small and medium-sized furnaces in which coal was used for combustion, as well as emissions from the Pljevlja Thermal Power Plant, during a period of very unfavourable meteorological conditions from the aspect of air quality, during the heating season. These factors are high atmospheric pressure, the absence of wind and precipitation and the dominant presence of temperature inversions, which, in the case when the top of the stack of the Pljevlja Thermal Power Plant is above the inversion layer, indicate the greatest influence of local small and medium-sized furnaces where coal is burned.

Figure 2.15 Temperature inversion with the appearance of thick fog in the Pljevlja basin during the winter months

Nitrogen (IV) oxide NO_2

Nitrogen compounds that are present in the atmosphere are found in oxidized and reduced form. Reduced compounds include ammonia and ammonium ion, and oxidized compounds include nitrogen(I)-oxide, nitrogen(II)-oxide, nitric acid, nitric acid, peroxyacetyl-nitrate, nitrate ion. NOx in the air is a generic term for nitrogen oxides - nitrogen (II)-oxide and nitrogen(IV)-oxide ($NO+NO_2$).

Short-term exposure to higher concentrations of nitrogen(IV)-oxide can cause lung damage. Exposure of people with chronic lung diseases, such as asthma and chronic obstructive pulmonary disease, may cause changes in lung and airway function. Based on the results of research conducted on animals, it is well-founded that nitrous oxide and ozone in combination worsen the allergic reaction to inhaled allergens.

The main sources of nitrogen oxide emissions in Montenegro are road traffic and combustion in the production and transformation of energy. Nitrogen oxide emissions from road traffic account for about 50% of total emissions in Montenegro, while the energy production and transformation sector accounts for about 25% (National Air Quality Management Strategy with Action Plan for the period 2013-2016, 2013).

Figure 16 shows the average annual concentrations of nitrogen(IV)-oxide in the period 2009-2022 at measuring points within the State Network for Air Quality Monitoring.

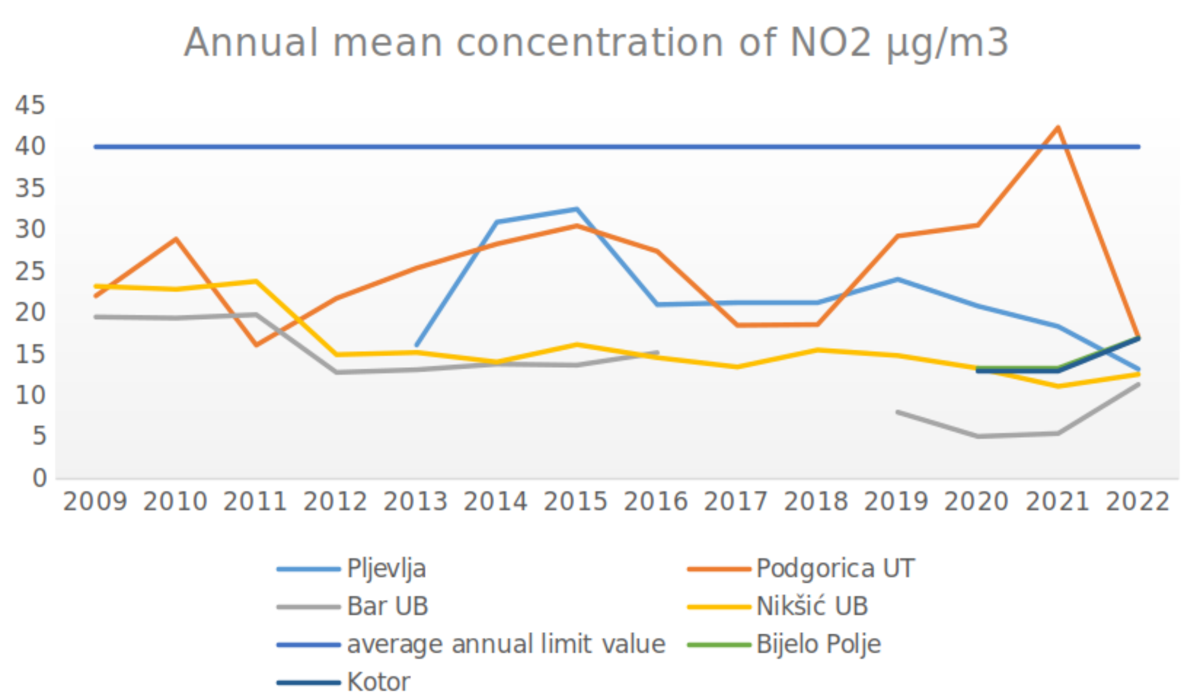


Figure 2.16. Mean annual concentrations of nitrogen(IV)-oxide (µg/m³) in the period 2009-2022; Source: Environmental Protection Agency

During the entire measurement period, limit values were not exceeded at any measuring point within the National Air Quality Monitoring Network. Based on this parameter, the air quality is satisfactory at all measuring points.

PM_{10} and $PM_{2.5}$

The origin of PM substances is diverse. They appear in both urban and rural environments. Among the main sources are: household heating, emissions from motor vehicles, dust from construction sites, landfills and landfills, dust from agricultural areas, fires, industrial plants. Combustion of fossil fuels in the energy sector and in households represent the most significant sources of particulate matter in Montenegro, with a total of 70-80% of emissions, while road traffic contributes with around 8% of total emissions. Production processes in the aluminium and iron industry account for 3.5% of the total emissions of suspended particles.

Particulate matter PM_{10}

Particulate matter with a diameter of less than 10 µm are among the most dangerous pollutants in the air. When inhaled, they affect the resistance of the respiratory system and are deposited in the deepest parts of the lungs. Health problems start when the body starts to defend itself against these foreign bodies (particles). Particles with a larger diameter, PM_{10}, can cause or worsen asthma, bronchitis and other lung diseases, thereby reducing the body's overall resistance. Although PM_{10} dust has a negative effect on the entire population, children, pregnant women, the elderly and the sick are particularly vulnerable. Although studies supported by the World Health Organization cannot show a clear cause-and-effect relationship between certain health problems and increased concentrations of particulate matter (primarily due to different chemical composition and particle diameter), they agree that there is no concentration that can be declared safe for health People.

In addition to having a negative impact on health, dusty substances also reduce visibility during the day, because they create the effects of reduced visibility characteristic of haze, which is often recognized as smog (National air quality management strategy with Action Plan for the period 2013-2016, 2013).

Figure 2.17 shows the average annual concentrations of PM_{10} particulate matter in the period 2009-2022 year at measuring points within the National Air Quality Monitoring Network.

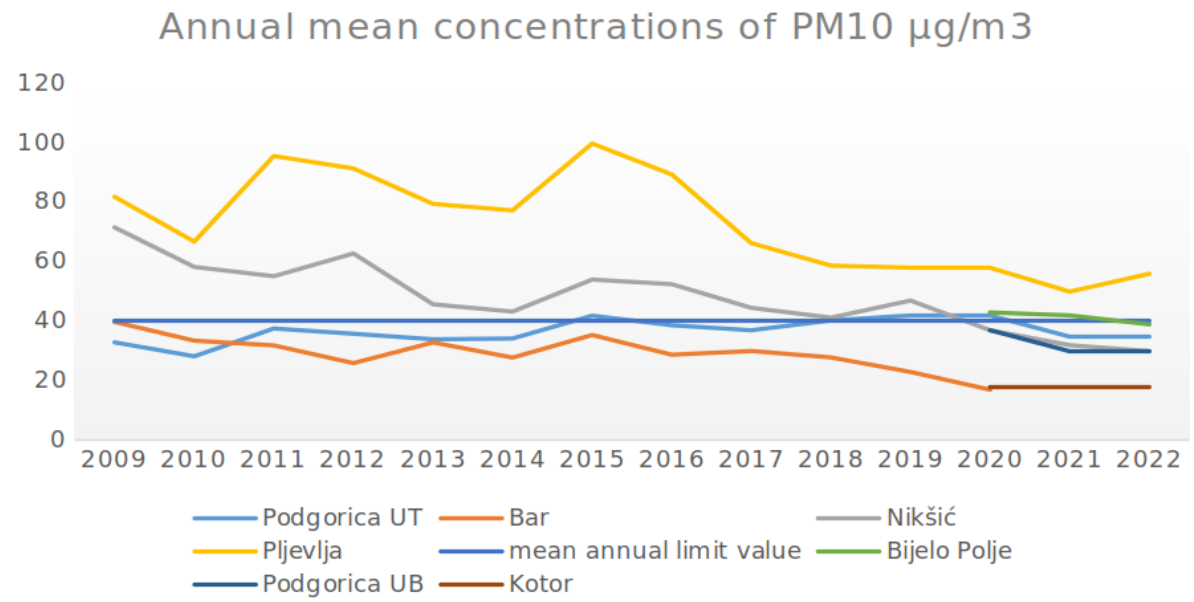


Figure 2.17. Mean annual concentrations of particulate matter PM_{10} (µg/m^3) in the period 2009-2022; Source: Environmental Protection Agency

In addition to concentration values, the number of days with exceedances of the limit value for the average daily concentration is important for air quality assessment (the limit value for the average daily concentration must not be exceeded more than 35 days during the calendar year). Except in the Southern Air Quality Zone, at all measuring points in the Northern and Central Air Quality Zones during the entire measurement period, every year the number of days with exceedances of the limit value for the average daily concentration was over 35. This problem is more pronounced in Pljevlja. Figure 2.18 show the number of days with exceedances by measurement locations.

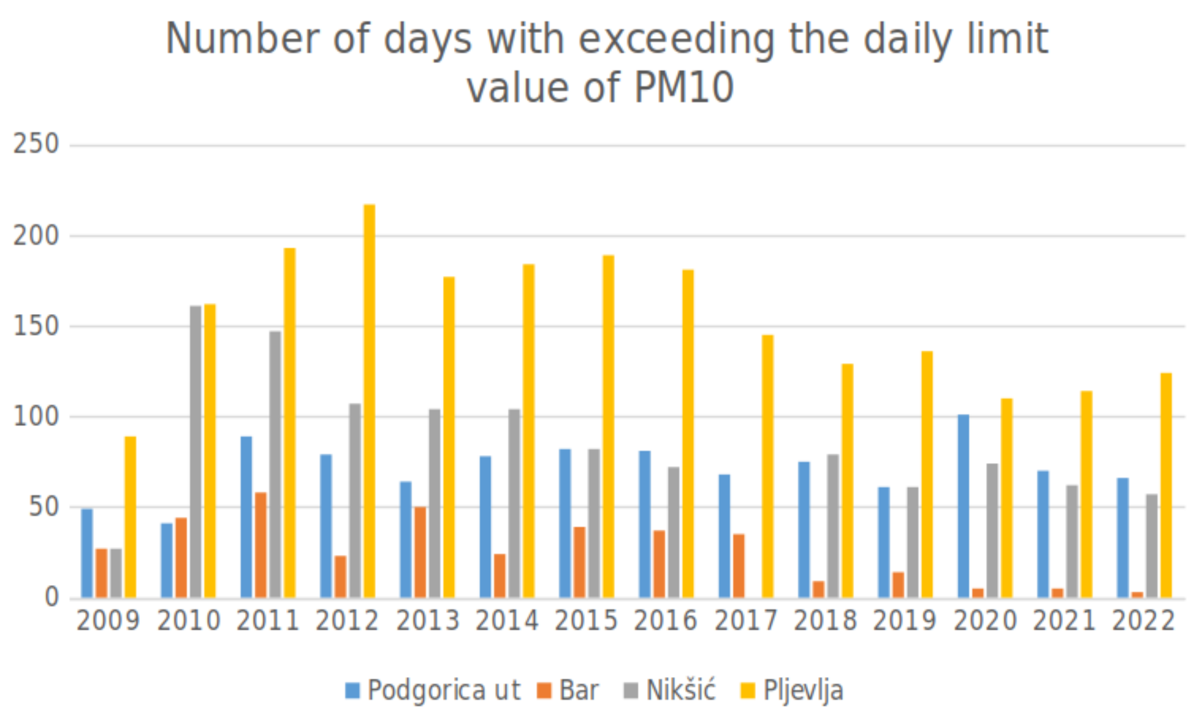


Figure 2.18. Number of days with exceedances of the limit value for the average daily concentration of PM_{10} particles; Source: Environmental Protection Agency

Particulate matter $PM_{2.5}$

During 2012, with the acquisition of new equipment for sampling $PM_{2.5}$ particles, monitoring of this pollutant was established at 4 measuring points in the urban zone: Bar, Tivat, Nikšić and Pljevlja. The results of the measurements indicate that the air is heavily loaded with this pollutant, especially during the winter months, when solid fuels are mostly used for house heating. The problem of the presence of high concentrations of $PM_{2.5}$ particles is particularly pronounced in Pljevlje, where in the period from 2012-2022 year, the limit value for the mean annual concentration was exceeded every year. Nikšić and Podgorica face increased concentrations of $PM_{2.5}$, but not to the same extent as Pljevlja. In Bar and Tivat, the state of air quality based on this pollutant is satisfactory.

More than 250 premature deaths and 140 hospital admissions per year, as well as a number of other health outcomes, are associated with exposure to particulate matter concentrations above the recommended concentration in the WHO air quality guidelines. More than half of these impacts are related to an increase in the level of pollution during the winter, caused mainly by the burning of solid fuel for heating. Further studies are needed to assess the exposure of the urban population to air pollution related to traffic emissions and their impact on health. (2)

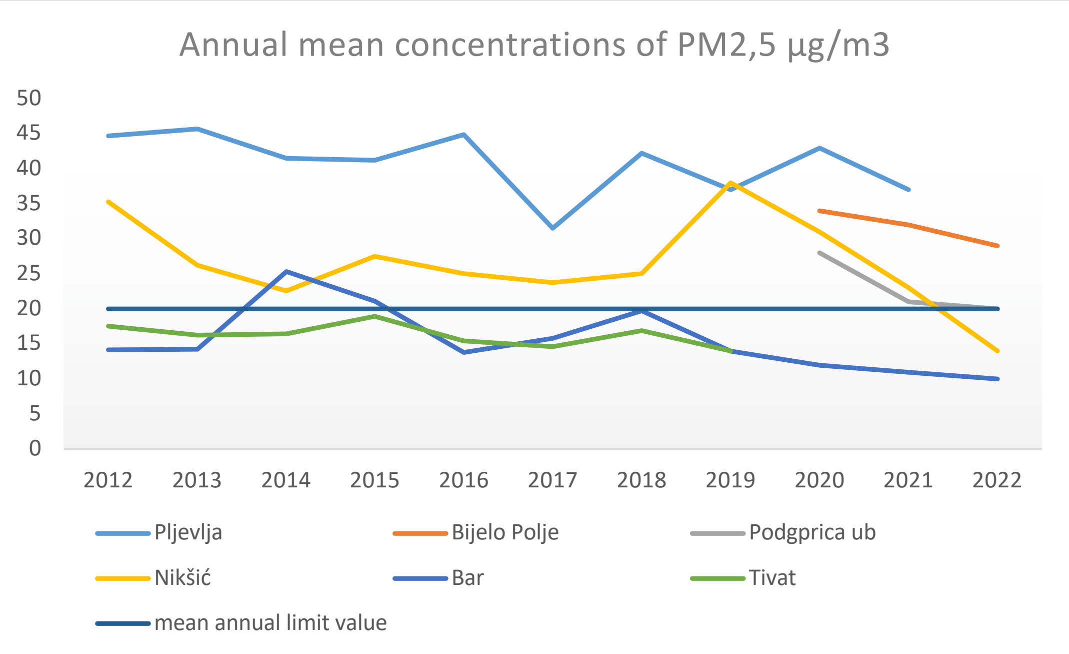


Figure 2.19. Mean annual concentrations of particulate matter $PM_{2.5}$ (µg/m^3) in the period 2012-2022; Source: Environmental Protection Agency

Carbon (II) oxide CO

The concentration of carbon(II) oxide CO after the improvement of the air quality monitoring network is monitored at locations in Podgorica (UT), Pljevlja, Bijelo Polje, Nikšić and Kotor. Maximum eight-hour average annual carbon(II) oxide concentrations, in the period 2009-2022 year at all measurement points during the entire measurement period were below the prescribed limit value of 10 mg/m^3.

Benzo(a)pyrene

The concentration of benzo (a) pyrene (and PAHs) is continuously monitored at all measuring points where the concentration of PM_{10} particles is also measured using the reference method. The average annual content of benzo (a) pyrene in PM_{10} particles indicates a significant impact of burning solid fuels (mainly wood) on air quality in Montenegro, as a high content of this pollutant was recorded only during the winter heating season. European and domestic regulations have not established a limit value for this pollutant. The average annual concentration of benzo(a)pyrene is above the prescribed target value at all measurement locations in the Northern and Central air quality zones during the entire measurement period. Figure 2.20 shows the average annual concentrations of terrestrial benzo(a)pyrene in the period 2012-2022.

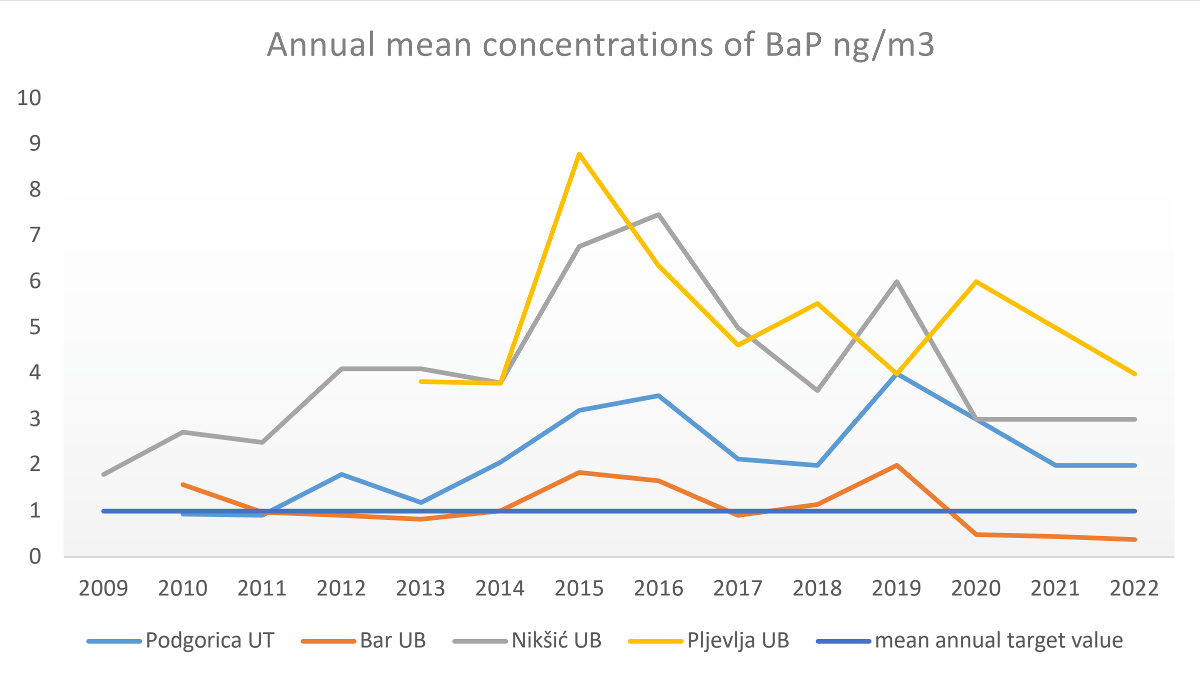


Figure 2.20. Mean annual concentrations of benzo(a)pyrene (ng/m^3) in the period 2009-2022; Source: Environmental Protection Agency

The highest average annual concentrations of benzo(a)pyrene were registered in parallel with the highest average annual concentrations of PM_{10} particles, during the winter months in the Northern and Central air quality zones.

Content of heavy metals (Pb, Cd, As and Ni) in suspended PM_{10} particles

The average annual values of the content of lead, cadmium, arsenic and nickel in suspended PM_{10} particles at the measuring points where the concentration of PM_{10} particles in the air was monitored using the reference method during the measurement period (2009-2022) were below the prescribed limit and target values.

Gaseous mercury

For gaseous mercury that has been monitored at the Gradina station (Pljevlja municipality) since October 2019, no limit values have been prescribed, but only control measures. Monitoring of this pollutant was established for the first time with the aim of monitoring the impact of emissions from the Pljevlja Thermal Power Plant on the air quality of suburban and rural areas, because the location of the Gradina measuring station meets the meteorological and other criteria for detecting the direct impact of pollutants emitted from the Pljevlja Thermal Power Plant. In addition, by establishing monitoring of gaseous mercury, Montenegro fulfilled one of the obligations stipulated by the EU Mercury Regulation 2017/852 and the obligation stipulated by the Minamata Convention.

Oncological statistics

The studies reveal alarming statistics regarding cancer burden in Europe. In 2020, over 4 million new cancer cases (excluding non-melanoma skin cancers) and close to 2 million deaths from cancer were estimated (20). The incidence and mortality rates vary considerably among European countries, reflecting differences in risk factors, national cancer control plans, and screening programs. Notably, breast, colorectal, prostate, and lung cancers account for half of the overall cancer burden, both in terms of incidence and mortality.(23)

Prostate cancer ranked as the most commonly diagnosed cancer among men in nearly all northern and western European nations, while lung cancer predominated in the majority of Eastern European countries. (23) Conversely, breast cancer emerged as the primary diagnosis for women across all European regions. (23) These specific cancers also stood as the foremost causes of cancer-related deaths on the continent: lung (resulting in 388,000 deaths, accounting for 20%), colorectal (242,000 deaths, 13%), female breast (138,000 deaths, 7%), and pancreatic cancer (128,000 deaths, 7%). (23)

Significant disparities in both incidence and mortality rates are evident at the national level, showcasing the varying landscape of cancer burden across Europe. Incidence rates among males range from 430 per 100,000 in Ireland to 239 in Montenegro, reflecting a notable contrast in the likelihood of cancer diagnosis. .(23) Similarly, the lifetime risk of receiving a cancer diagnosis spans from 35% in Ireland to 25% in Montenegro, highlighting the divergent experiences across these nations. (23)

Breast cancer stands out as the most prevalent cancer among women across all European countries, with estimates indicating its status as the primary cause of female cancer mortality in most European countries (20). The cumulative risk of being diagnosed with breast cancer before the age of 75 is 8%, translating to approximately 1 in 12 women, while the risk of death from breast cancer before the age of 75 is 1.6%, or 1 in 61 women, across Europe. Breast cancer reigns as the most commonly diagnosed malignant neoplasm, comprising 27.8% of all cases of cancer among female in Europe. It is followed by colorectal cancer, with 12.4% of cases, lung cancer with 8.5%, and corpus uteri cancer with 6.8%. (20)

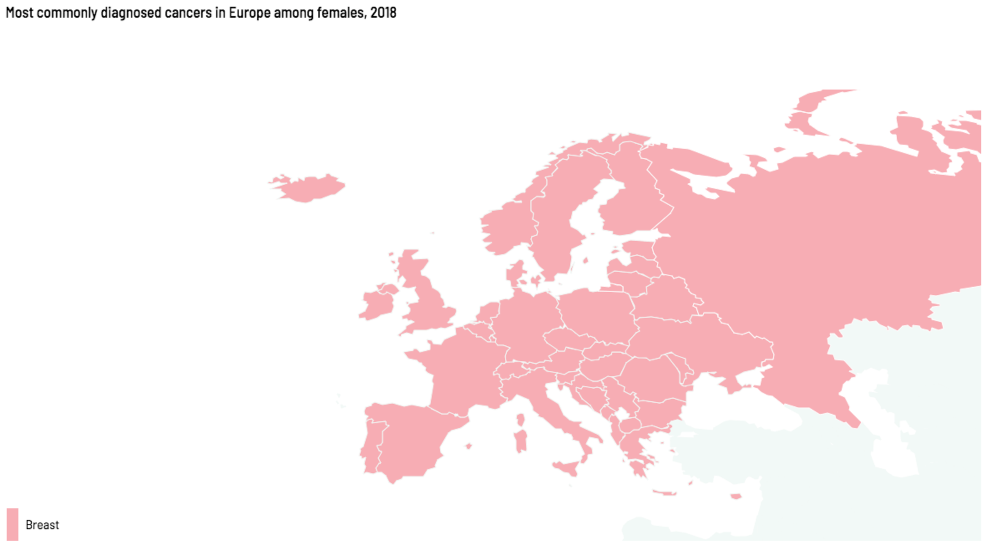


Figure 2.21 Most commonly diagnosed cancers in Europe among females, 2018. Source: The Cancer Atlas (23)

The leading cancers among males include prostate cancer, constituting 22.2% of all cases, followed by lung cancer with 14.8%, colorectal cancer with 13.2%, and bladder cancer with 7.3%. (20)

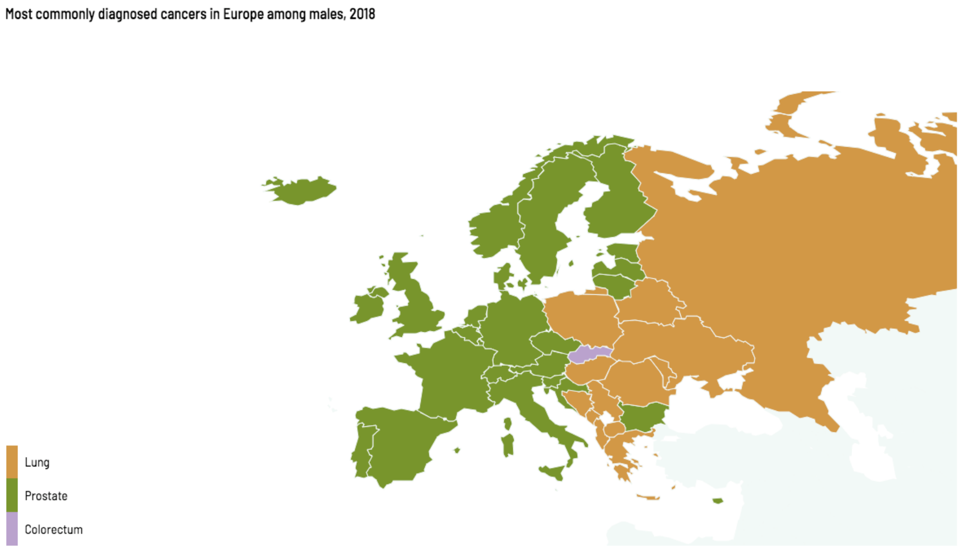


Figure 2.22 Most commonly diagnosed cancers in Europe among males, 2018. Source: The Cancer Atlas (23)

Registries for malignancies in Montenegro

The Registry of Malignant Neoplasms in Montenegro was established in 2013 following the adoption of the Law on Health Data Collections in 2008, which laid the groundwork for disease registers. (19) The aim was to provide quality data on cancer incidence and mortality. Registration is a legal requirement for all healthcare providers, and the registry collects data on malignant neoplasms as well as a certain number of benign or undefined neoplasms. The annual report of the registry provides information on the burden of cancer across the country and in individual regions, which is crucial for planning prevention, diagnosis, treatment, and rehabilitation efforts. Data from the registry are vital for comparing with the situation in other countries, tracking trends over time, and conducting research in oncology. By the end of the first quarter of the year 2024, only data for 2013 are publicly available. However, setting up this registry necessitates adequately trained personnel, appropriate facilities, and equipment. Moreover, the development of a national data system for monitoring program implementation and reporting is indispensable. (19)

In addition to the data from the National registry, there are four malignant diseases whose mortality data were analysed in Montenegro in the period from 1990 to 2015 and from 1990 to 2018. These are: Lung cancer, breast cancer, stomach cancer and liver cancer.

Lung cancer

Research done by Mirjana Nedović-Vuković1, Dragan Laušević et al (2019) revealed that in 2015, lung cancer accounted for 5.44% of all deaths and 22.92% of all cancer deaths in Montenegro. It was the leading cause of all cancer deaths and the third-leading cause of all deaths (16). Research has pointed out that a join point was observed in 2004 in women and in the entire population, and in 2005 in men (16). The overall mortality rates increased from 1990 to 2004 by an average of 3.91% per year and decreased from 2004 to 2015 by an average of 1.95%; which in the entire observed period resulted in an average increase of 1.3% per year (16). A particularly strong growth rate was observed in women, even 7.14% in the period from 1990 to 2004. (16)

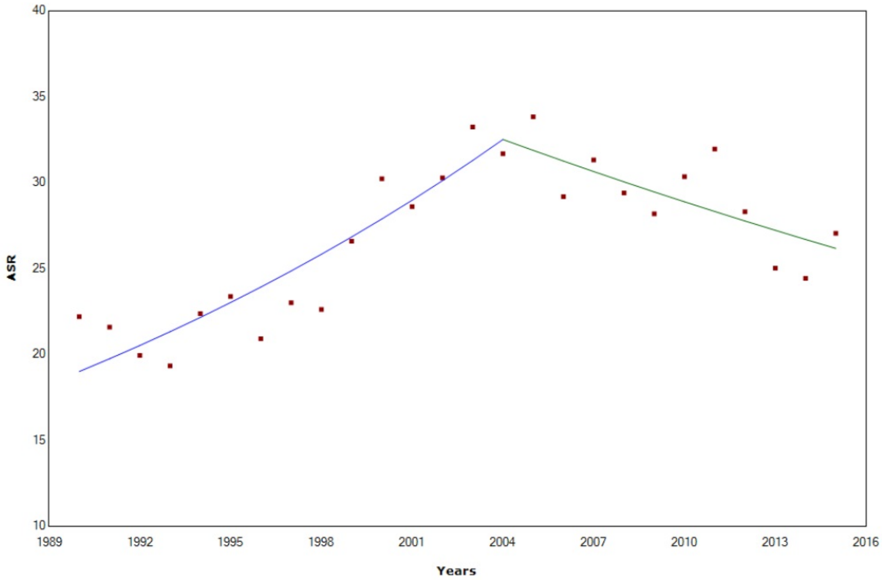


FIGURE 1. Joinpoint regression analysis of overall lung cancer mortality in Montenegro from 1990 to 2015. ASR – rate per 100 000 age-standardized to World Standard Population. Red square – observed; blue line – 1990-2004 annual percent change (APC) = 3.91*; green line – 2004-2015 APC = -1.95*. Asterisk indicates APC that is significantly different from zero at alpha = 0.05.

Figure 2.23 Jointpoint regression analyses of overall lung cancer mortality in Montenegro from 1990 - 2015. Source: Nedović-Vuković, Mirjana et al. (2019) (16)

Breast cancer

According to the M.M.N. Vuković et al (2022) in 2018 in Montenegro, breast cancer accounted for 4.64% of all deaths in women and for 19.78% of all cancer deaths in women (17). In terms of total cancer mortality, it ranked first among women (17). Age-standardized rates ranged from 11.41/100,000 in 1990 to 20.46/100,000 in 2016 (17). In the observed period, breast cancer mortality rates significantly increased in the women in Montenegro (average annual percentage change (AAPC) = 1.44%) (17). The most affected age group was 55-64 years (17). There is a growing breast cancer mortality trend in Montenegro. (17)

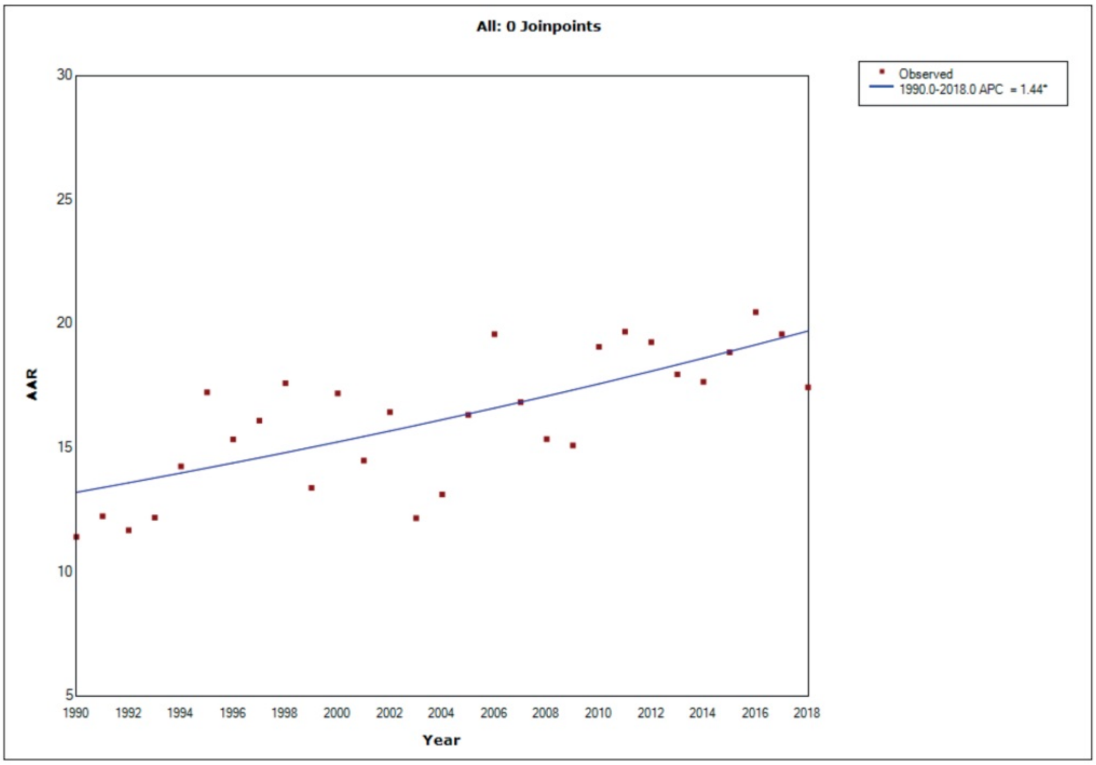


Figure 1. Joinpoint regression analysis of overall women breast cancer mortality in Montenegro from 1990 to 2018. AAR-age adjusted rate standardized to World Standard Population. APC-Annual Percentage Change, *APC was significantly different from zero $p < 0.001$.

Figure 2.24 Jointpoint regression analyses of overall woman breast cancer mortality in Montenegro from 1990 – 2018. Source: Nedović-Vuković, Mirjana et al. (2022) (17)

Gastric cancer

Gastric cancer (GC) remains a significant global public health problem, despite the decreasing trends in GC mortality rates in the last 5 decades. The study done by Mirjana Nedović Vuković et al. (2024), aimed to examine the pattern of GC mortality in Montenegro between 1990 and 2018. Joinpoint regression implemented within this study (15) reveals a statistically significant decrease in the age standardized rate for the overall level, on average by 1.4% per year, which was due to a decrease in the age-standardized rate in men with an average annual change of -1.8%, while in women the rates were stable. Findings (15) indicate a noteworthy decline in age-standardized overall GC mortality rates among men in Montenegro, while rates for women have remained constant.

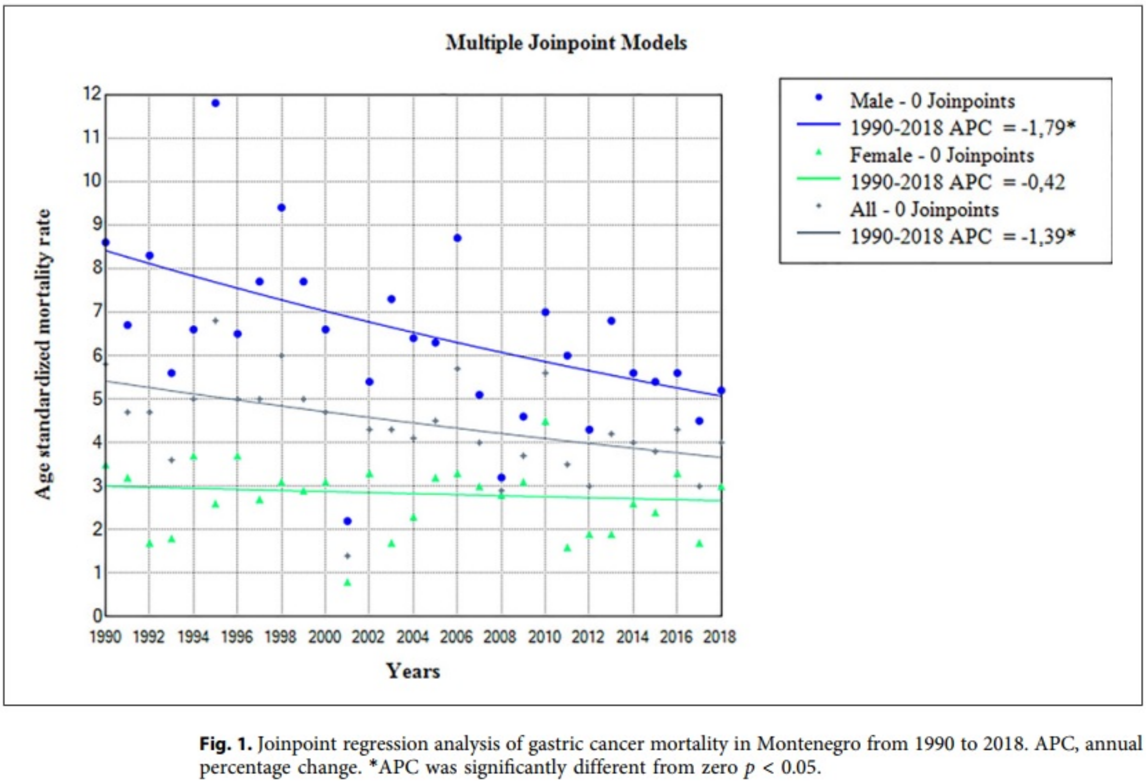


Figure 2.25 Jointpoint regression analyses of overall gastric cancer mortality in Montenegro from 1990 - 2018. Source: Nedović-Vuković, Mirjana et al. (2019) (15)

The highest average annual percentage decrease was registered in the age group 55–64 for both men and the overall level. In contrast, a drop in mortality rates is registered in both genders and all age groups at the global level for a similar period (1990–2019). At the global level, the average annual decline in men aged between 50 and 69 is about 2.2% (15) Additionally, in Montenegro, the death rates are significantly higher in men, with the highest death rates registered in the age groups 55–64 and 65–74. (15)

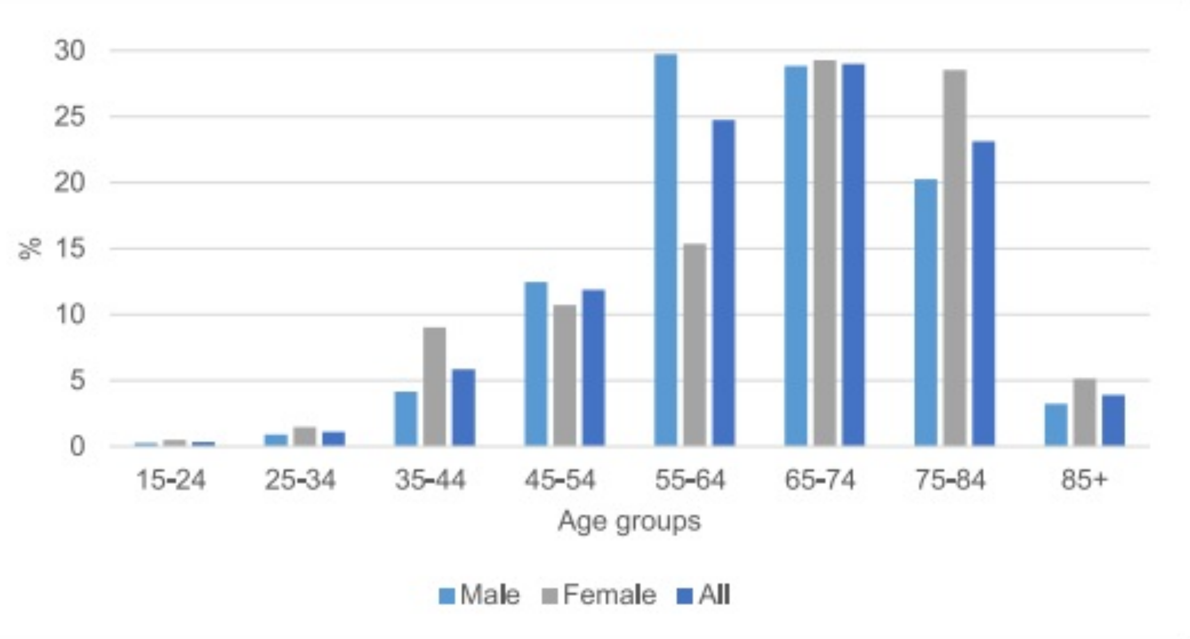


Figure 2.26. Distribution of the gastric cancer mortality by age groups in Montenegro, 1990-2018, Source: M.M.N. Vuković et al (2019) (15)

Liver cancer

Liver cancer mortality data in Montenegro from 1990 to 2018 were collected and analysed by Mirjana Nedović-Vuković (2024), Within this study mortality rates were age standardized to the World Standard Population. Study (18) indicated that the mortality trend was constant, with no significant increase or decrease in mortality rates both at the overall level and by gender. Further analysis has shown that the number of cases, however, increases significantly at the overall level by an average of 1.4% per year (average annual percentage change (AAPC) and in women by 1.9% per year. (18) In men, there was no change in the number of cases. The three age groups most burdened by mortality from liver cancer were 65–74 (34.9%), 75–84 (26.6%) and 55–64 (25.8%) (18). The consistent implementation of prevention measures and hepatitis virus infection treatment has played a role in partially favourable liver cancer mortality trends in Montenegro. (18)

Data from Registry for malignant neoplasm from 2013

Montenegro has finalized the compilation, analysis, and publication of data solely for the Registry of Malignant Neoplasms for the year 2013. Meanwhile, publications for subsequent years are anticipated. According to the data from 2013, in different age groups, the leading locations of malignant diseases vary. In the youngest group (0-19 years), leukaemia is most common in boys, while in girls, leukaemia and brain neoplasms prevail (19). Young adults (20-34 years) are more likely to develop testicular neoplasms (males) and breast/cervical neoplasms (females) (19). In the 35-49 age group, men are most likely to develop lung neoplasms, while breast and cervical neoplasms are more common in women. (19) In the 50-64 age group, both genders are most affected by malignant neoplasms, with lung neoplasms being most common in men and breast neoplasms in women (19). A similar situation occurs in the 65-74 age group. In individuals over 75 years old, the highest number of cases is of neoplasms of unknown primary localization, with lung and prostate neoplasms being common in men, and breast, colorectal, and lung neoplasms in women (19). Nearly half of all cases of malignant neoplasms are registered in individuals over 65 years old (19). The cumulative risk of developing malignant neoplasms before the age of 75 is approximately 1 in 3 for men and 1 in 4 for women (19). In 2013, malignant neoplasms accounted for a quarter of deaths in Montenegro, with over half of deaths from them occurring due to neoplasms of the five leading locations, including the lungs, colorectum, breast, pancreas, and prostate. (19) Nearly a quarter of deaths from malignant neoplasms were due to lung cancer. (19)

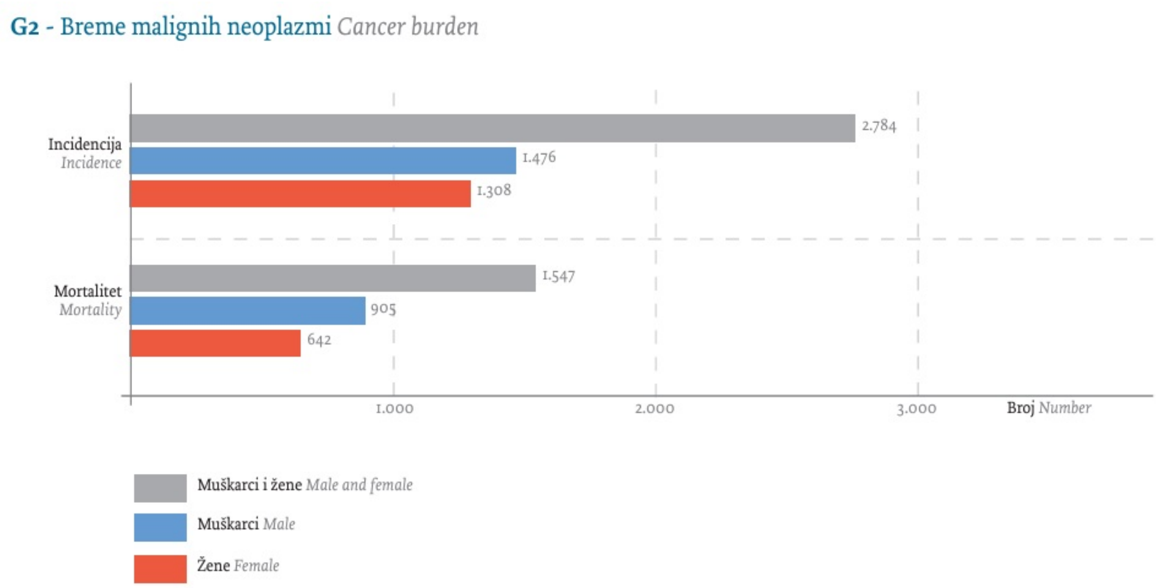


Figure 2.27: Cancer burden, Source: Data from Registry for malignant neoplasm from 2013, updated 2018. (19)

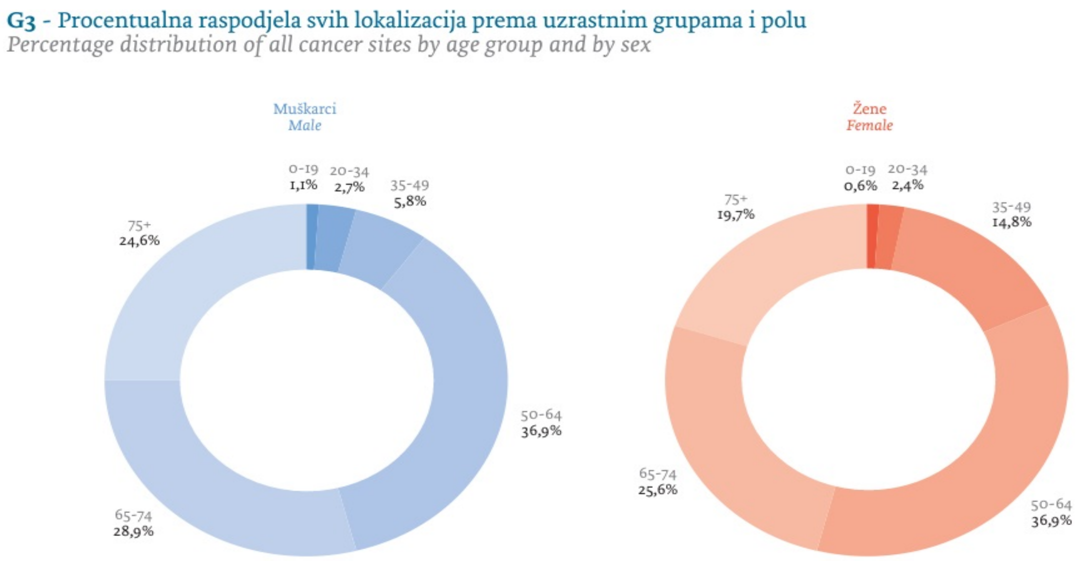


Figure 2.28. Percentage distribution of all cancer by age group by sex, Source: Data from Registry for malignant neoplasm from 2013, updated 2018. (19)

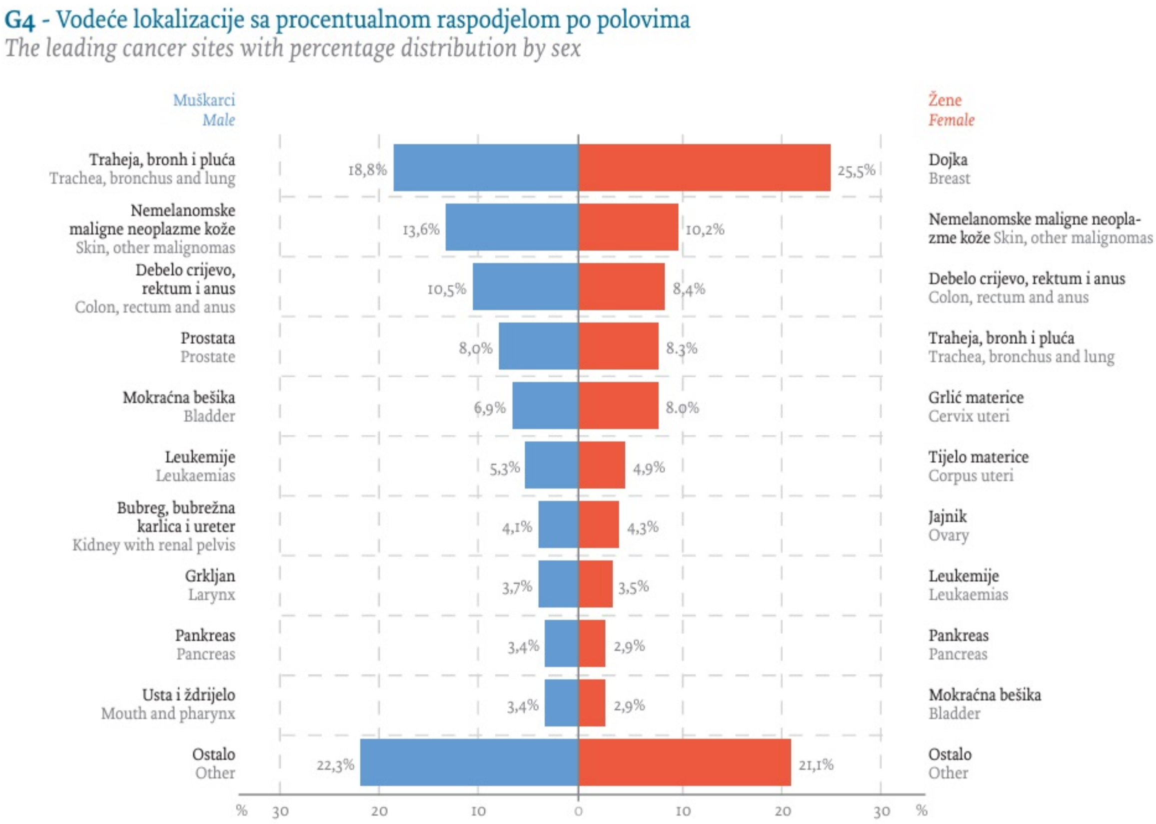


Figure 2.29. The leading cancer sites with percentage distribution by sex. Source: Data from Registry for malignant neoplasm from 2013, updated 2018. (19)

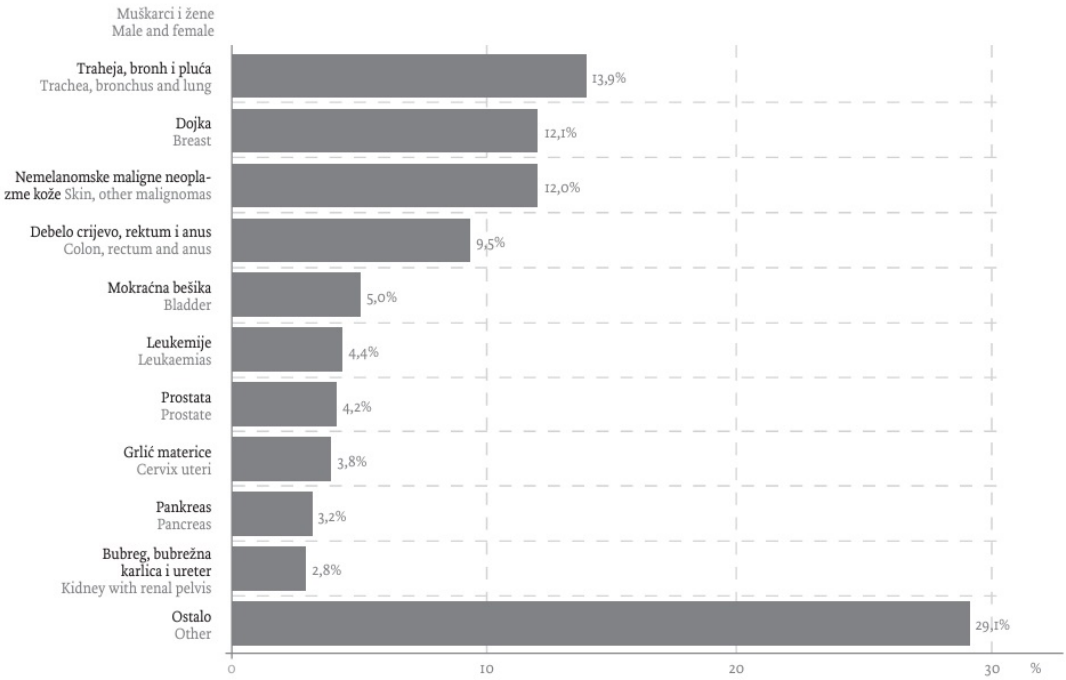


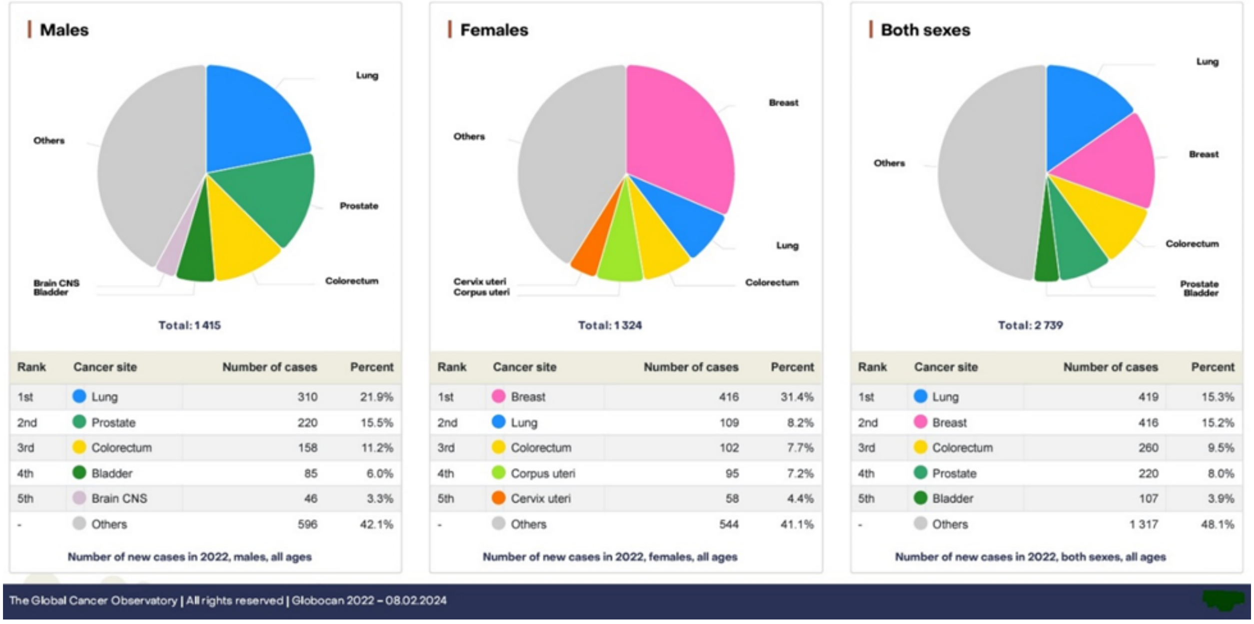
Figure 2.30. The leading cancer sites with percentage distribution, Source: Data from Registry for malignant neoplasm from 2013, updated 2018. (19)

Globocan data

Another source of data is Globocan. According to new data from Globocan, the number of new cases in Montenegro in 2022 was 2739, number of deaths was 1535, number of prevalent cases (5-year) was 7847. (22)

Top leading cancer by incidence in males were lung, prostate and colorectum, and in females: breast, lung colorectum. (22)

Top leading cancer (ranked by deaths) in males were lung, colorectum and prostate, and in females breast lung colorectum, which makes lung cancer the first cause of death in both sexes, on the second place colorectum, and on the third place breast. (22)



Rank	Cancer site	Number of cases	Percent
1st	Lung	310	21.9%
2nd	Prostate	220	15.5%
3rd	Colorectum	158	11.2%
4th	Bladder	85	6.0%
5th	Brain CNS	46	3.3%
-	Others	596	42.1%

Number of new cases in 2022, males, all ages

Rank	Cancer site	Number of cases	Percent
1st	Breast	416	31.4%
2nd	Lung	109	8.2%
3rd	Colorectum	102	7.7%
4th	Corpus uteri	95	7.2%
5th	Cervix uteri	58	4.4%
-	Others	544	41.1%

Number of new cases in 2022, females, all ages

Rank	Cancer site	Number of cases	Percent
1st	Lung	419	15.3%
2nd	Breast	416	15.2%
3rd	Colorectum	260	9.5%
4th	Prostate	220	8.0%
5th	Bladder	107	3.9%
-	Others	1 317	48.1%

Number of new cases in 2022, both sexes, all ages

Figure 2.31. Top leading cancer (ranked by deaths). Source: Globocan, (22)

Conclusions

Studies analysing national mortality registries from 1990 to 2018 reveal complex changes in cancer mortality. However, due to limited data availability, particularly with only the 2013 National Data Registry completed, there is a need for updated epidemiological national registries. These would provide more precise data with standardized methodologies for case entry and follow-up.

The Yugoslav Wars of the 1990s, characterized by ethnic and political tensions following Yugoslavia's breakup, led to widespread suffering and displacement. Twenty-five years later, discussions continue regarding the long-term impact of war pollution on public health. Despite millions being displaced, killed, or injured during the wars, the direct impact on cancer incidence remains uncertain.

Montenegro, heavily affected during the NATO bombing in 1999 and economic sanctions from 1992 to 1995, suffered demographic and economic repercussions. The collapse of the health system likely contributed to potential increases in malignant neoplasm incidence due to inadequate prevention measures and healthcare infrastructure.

Although war pollution from bombings and military activities released carcinogens into the environment, causing concerns about long-term health effects like cancer development, scientific evidence on this remains limited. Environmental pollution did impact air, water, and soil quality, but more specific data on pollution during the 1990s Balkan wars is lacking.

Available data on air pollution during the Balkan wars suggest that monitoring stations detected less pollution due to industrial collapse, resulting in improved overall air quality. However, with the current limitations, a direct connection between war pollution in Montenegro and increased malignant neoplasm incidence cannot be conclusively proven for the specified period.

References

1. Air pollution in SR Montenegro, Republic of Montenegro Hydrometeorological Institute, Titograd 1986.
2. Michal Krzyzanowski. Health impacts of air pollution in Montenegro. Copenhagen: World Health Organization Europe. 2016
3. WHO. Ambient air pollution: A global assessment of exposure and burden of disease [Internet]. www.who.int. 2016. Available from: https://www.who.int/publications/i/item/9789241511353
4. ANALYSIS OF AVAILABLE DATA ON THE INFLUENCE OF AIR POLLUTION ON HUMAN HEALTH, Olivera Prodanović, PhD, 2023
5. Air pollution and human health: the case of the Western Balkans", M. Colovic Daul, Prof. M. Kryzanowski, O. Kujundzic, UNEP 2019
6. GBD History [Internet]. Institute for Health Metrics and Evaluation. 2014. Available from: https://www.healthdata.org/gbd/about/history
7. IHME. Institute for Health Metrics and Evaluation [Internet]. Institute for Health Metrics and Evaluation. 2019. Available from: https://www.healthdata.org/
8. Montenegro | Institute for Health Metrics and Evaluation [Internet]. www.healthdata.org. [cited 2024 Apr 22]. Available from: https://www.healthdata.org/montenegro
9. Banja Manjola, Đukanović Gordana, Claudio B. Status of air pollutants and greenhouse gases in the Western Balkans: Benchmarking the accession process progress on environment. 2020 Jan 1;
10. Informacije o stanju životne sredine [Internet]. Agencija za zaštitu životne sredine. [cited 2024 Apr 22]. Available from: https://epa.org.me/informacije-o-stanju-zivotne-sredine/
11. Government of Montenegro. National air quality management strategy with Action Plan for the period 2013-2016. Podgorica. 2013
12. Agency for Nature and Environmental Protection. Impact of meteorological factors on air quality in Pljevlja during 2015. Podgorica. 2016
13. Short-term action plan for the Municipality of Pljevlja, Agency for Nature and Environmental Protection, 2017
14. Fourth report on the implementation of the National Air Quality Management Strategy with the Action Plan for the period 2017-2020.
15. Mirjana Nedović Vuković, Jakšić M, Brigita Smolović, Miloš Lukić, Zoran Bukumirić. Trends in Gastric Cancer Mortality in Montenegro, 1990–2018:

Joinpoint Regression. Oncology. 2024 Feb 19;1–9.

16. Nedović-Vuković M, Laušević D, Ljaljević A, Golubović M, Trajković G. Lung cancer mortality in Montenegro, 1990 to 2015. Croatian Medical Journal [Internet]. 2019 Feb 1 [cited 2022 Apr 20];60(1):26–32. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6406062/
17. M M N Vuković, Laušević DB, Vućković LM, Bukumirić ZM. Trend of breast cancer mortality in Montenegro, 1990-2018 - Joinpoint regression. DOAJ (DOAJ: Directory of Open Access Journals). 2022 Jun 1;26(11):3849–57.
18. Mirjana Nedović Vuković, Jakšić M, Danijela Stojanović, Brigita Smolović. Time trends in liver cancer mortality rates in Montenegro from 1990 to 2018. European journal of gastroenterology & hepatology. 2024 Mar 4;
19. Malignant neoplasms in Montenegro 2013. Podgorica: Insitute of Public Health of Montenegro, Center for Control and Prevention of Non-communicable Diseases, Registry of Malignant Neoplasms of Montenegro, 2018
20. Dyba T, Randi G, Bray F, Martos C, Giusti F, Nicholson N, et al. The European cancer burden in 2020: Incidence and mortality estimates for 40 countries and 25 major cancers. European Journal of Cancer. 2021 Nov;157:308–47.
21. Cancer (IARC) TIA for R on. Global Cancer Observatory [Internet]. gco.iarc.fr. 2022. Available from: https://gco.iarc.who.int/en
22. Statistics at a glance, 2022 Top 5 most frequent cancers Number of new cases 2 739 [Internet]. [cited 2024 Apr 22]. Available from: https://gco.iarc.who.int/media/globocan/factsheets/populations/499-montenegro-fact-sheet.pdf
23. Europe [Internet]. The Cancer Atlas. Available from: https://canceratlas.cancer.org/the-burden/europe/

3. Republic of North Macedonia Perspective (FEMINA M)

Introduction. North Macedonia's involvement

The Republic of North Macedonia (here after North Macedonia), formerly part of the Socialist Federal Republic of Yugoslavia, notably remained uninvolved in direct military conflict during the Yugoslav Wars and NATO's bombardment campaign in the 1990s. Despite the regional turmoil and ethnic tensions that characterized the era, North Macedonia pursued a policy of non-alignment, opting to prioritize diplomatic efforts and maintain neutrality, thereby avoiding entanglement in the violent conflicts that plagued neighbouring regions.

Our country, North Macedonia itself did not directly participated in the armed conflict, as it was mentioned before (except for the civil conflict in 2001 in some parts of the country) it was situated in close proximity to the conflict zones and was affected by the broader regional instability. The influx of refugees, displacement of populations, and disruptions to trade and transportation routes had profound socio-economic and environmental implications for North Macedonia.

North Macedonia, experienced significant upheaval during the Yugoslav Wars of the 1990s. The conflicts, particularly the Kosovo War in 1999, and subsequent NATO bombardment had profound effects on the region, including complete degradation on the environment and air quality and presumed enlarged cancer cases in the population living on this area, consequently on the population in North Macedonia. Also, the civil war in North Macedonia which was fought in certain parts of the country, had a significant impact in the overall picture. The country, underwent substantial turmoil during the Yugoslav Wars of the 1990s. The conflicts, notably the Kosovo War in 1999, and the subsequent NATO bombardment, left enduring imprints on the region's socio-political landscape, infrastructure, and environment. Among the various repercussions, the impact on air quality stands out as critical concern. The Kosovo War, marked by ethnic tensions and armed conflict, unfolded in close proximity to North Macedonia, affecting its environment profoundly. The subsequent NATO intervention, aimed at halting the conflict and mitigating humanitarian crises, further altered the dynamics of the region. However, the consequences of military actions extended beyond immediate combat zones, permeating neighbouring territories like North Macedonia.

This report endeavours to delve into the intricate relationship between air pollution in North Macedonia from longer period of time and the confluence of factors arising from the Yugoslav War and NATO bombardment. By scrutinizing historical events, analysing environmental data, and exploring socio-economic contexts, it seeks to unravel the complex interplay between conflict dynamics and environmental degradation, air pollution and incidence of enlarged number of cancer cases. Through this analysis, the report aims to offer insights into the long-term ramifications of armed conflicts on air quality and environmental and overall health of the population, with North Macedonia as a focal point of examination.

This report will be divided on two parts as a review, at the same time aims to analyse the connection between air pollution in North Macedonia from the years of military action until now and as an equally important part of the report is incidence of cancer cases on which an effort will be put in investigation, explanation and in some way to try to find connection on increased cases of cancer in the Macedonian population. The incidence of cancer cases in North Macedonia is not straightforward and direct. However, there are potential indirect links that can be considered. It's important to note that while these are plausible connections, they are speculative, and any direct correlation between the Yugoslav Wars/NATO bombing and cancer incidence in North Macedonia would require thorough epidemiological studies and data analysis to establish causality. Cancer is a complex disease with multifactorial causes, including genetic predisposition, lifestyle factors, environmental exposures, and healthcare access, among others. Therefore, attributing cancer cases solely to specific historical events or interventions would be challenging without comprehensive research and evidence. There hasn't been a specific studies or comprehensive documentation directly linking the Yugoslav Wars and cancer incidence in North Macedonia. However, we can provide insights into potential ways, generally based on gray literature documentation and states in which the military actions and their aftermath could indirectly influence cancer rates in the region, particularly in North Macedonia as a neighbouring country in the region where the military actions were taken.

Based on our competitivity as a Patients Organization, as much as possible, we will put a strong effort to provide a link between military actions taken in the region and environmental degradation presented by air pollution and enlarged incidence of cancer cases through years after military operations which had have been overflowed in North Macedonia.

Impact on air quality in North Macedonia

In North Macedonia, air quality in the last decade has been a significant concern, particularly in urban areas. The country faces challenges related to industrial emissions, traffic pollution, and reliance on coal for energy production. These factors contribute to high levels of particulate matter and other pollutants, impacting public health and the environment. Efforts to address air quality issues include regulatory measures, technological advancements, and international cooperation aimed at improving monitoring and reducing pollution levels. Some of the factors which have significant impact and consequences on air quality are as follows:

- Industrial disruption: The Yugoslav Wars disrupted industrial activities and infrastructure in North Macedonia. Factories and power plants suffered from lack of maintenance, leading to increased emissions of pollutants. Industrial facilities such as factories, power plants, and refineries suffered from damage, reduced maintenance, and interrupted operations. This disruption likely led to increased emissions of air pollutants such as sulphur dioxide ($SO2$), nitrogen oxides (NOx), and particulate matter (PM), contributing to air pollution.
- Energy sector: The conflicts disrupted energy production and distribution systems, leading to shortages and inefficiencies in power generation. In North Macedonia, the energy sector relied heavily on coal-fired power plants, which can be significant sources of air pollution. Disruptions in coal supply chains and maintenance of power plants may have exacerbated emissions of pollutants, further deteriorating air quality.
- Transportation and mobility: The conflicts disrupted transportation networks and infrastructure, impacting road, rail, and maritime routes. In North Macedonia, increased military convoys, refugee movements, and disruptions in trade routes could have led to higher vehicular traffic and emissions of air pollutants from diesel and gasoline engines. Additionally, damaged infrastructure may have contributed to dust emissions from unpaved roads and construction activities.

- Agricultural burning and deforestation: The Yugoslav Wars led to widespread displacement of populations and economic disruptions, including in agriculture. Displaced populations may have resorted to traditional agricultural practices such as slash-and-burn farming, leading to increased emissions of air pollutants from biomass burning. Deforestation, driven by resource scarcity and population displacement, could have also contributed to higher levels of air pollution due to reduced carbon sequestration and increased soil erosion.
- Urbanization and population displacement: The conflicts led to significant population movements, including internally displaced persons (IDPs) and refugees. In North Macedonia, influxes of refugees from neighbouring conflict zones placed additional pressure on urban infrastructure and services. Overcrowding, inadequate housing, and limited access to sanitation facilities in refugee camps may have contributed to localized air pollution, including indoor air pollution from biomass fuel use for cooking and heating
- Health impacts: The combination of increased air pollution and population displacement during the Yugoslav Wars likely had adverse health effects on the population of North Macedonia and the broader region. Exposure to air pollutants such as PM, NOx, and volatile organic compounds (VOCs) can exacerbate respiratory diseases, cardiovascular disorders, and other health conditions. Vulnerable populations, including children, the elderly, and individuals with pre-existing health conditions, may have been particularly susceptible to these health impacts.
- Post-War recovery challenges: The environmental consequences of the Yugoslav Wars persisted beyond the cessation of hostilities, posing challenges to post-war reconstruction and sustainable development efforts. North Macedonia, like other countries in the region, faced the daunting task of rebuilding infrastructure, restoring ecosystems, and addressing environmental pollution while simultaneously addressing socio-economic challenges and political transitions.
- Refugee crisis: The influx of refugees during the Kosovo War strained North Macedonia's resources, including energy and transportation. Increased vehicular traffic and makeshift settlements likely contributed to air pollution.

- Military activity and bombardment: Although North Macedonia was not directly targeted by NATO airstrikes, the regional conflict and military activities likely led to heightened air pollution due to fuel combustion, explosions, and industrial damage.

This rapid literature review collates available evidence on the causes and consequences of air pollution in North Macedonia. It draws on a diverse range of sources from multiple academic disciplines and grey literature. The literature highlights that North Macedonia is considered to have some of the worst air quality in the West Balkans, and consequently some of the worst globally. Air pollution is a significant problem in North Macedonian cities and urban centres with exposure to high levels of particulate matter (PM) a particular issue. The $PM_{2.5}$ size fraction is the focus of many air pollution studies because it is associated with a range of adverse health outcomes, it is also the focus of this review. This review identifies a limited but expanding evidence base discussing air pollution in North Macedonia. Studies are principally focused on the capital city Skopje and ambient (outdoor)air pollution. There is a limited literature that discusses air quality issues outside of the capital and a dearth of evidence on household (indoor) air pollution.

Air pollution in North Macedonia

Due to lack of sufficient evidence based on scientific and professional studies, links between air pollution and cancer incidence, will be request in reports created by other sources.

According to K4D, Knowledge, evidence and learning for development the Western Balkans is considered to be Europe's most polluted area in terms of a range of air pollutants with levels of air pollution influenced by a complex mix of anthropogenic and meteorological factors. The K4D research helpdesk provides rapid syntheses of a selection of recent relevant literature and international expert thinking in response to specific questions relating to international development (helpdesk@k4d.info).
K4D services are provided by a consortium of leading organizations working in international development, led by the Institute of Development Studies (IDS), with the Education Development Trust, Itad, University of Leeds Nuffield Centre for International Health and Development, Liverpool School of Tropical Medicine (LSTM), University of Birmingham International Development Department (IDD) and the University of Manchester Humanitarian and Conflict Response Institute

(HCRI). This report was prepared for the UK Government's Foreign, Commonwealth & Development Office (FCDO) and its partners in support of pro-poor programs.

For example, estimates suggest that the region's sixteen power plants produce more air pollution than the 250 power plants of the EU combined. Further to this, during winter months, the region's larger cities report air pollution levels that are the highest in Europe and some of the highest globally (Civil Society Forum, 2021). More broadly, efforts to manage air quality issues (and indeed environmental governance) in the region are challenged by corruption, ineffective law enforcement mechanisms, and the lack of reliable data on the state of the environment (Civil Society Forum, 2021).

More specifically, North Macedonia is considered to have some of the worst air quality in the region, and consequently some of the worst globally (see, for example Table 3.1).

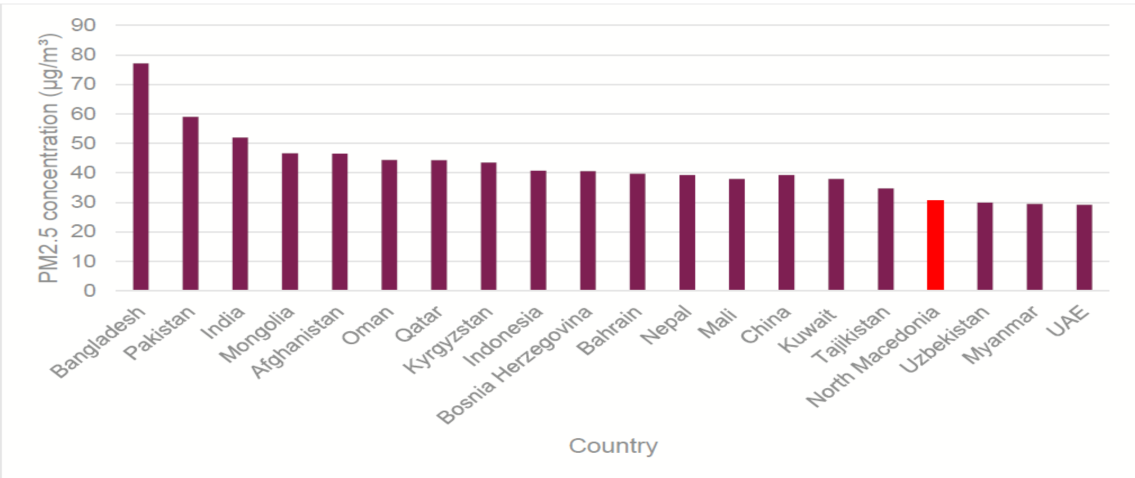
In particular, air pollution is a significant problem in North Macedonian cities and urban centres (World Bank, 2019). In the context of North Macedonia, exposure to high levels of particulate matter (PM) is a particular concern. PM or atmospheric aerosols is the term used to indicate any solid or liquid particle suspended in the atmosphere. Atmospheric particles vary widely in their physical parameters such as size and chemical composition. PM of small size fractions are considered to be particularly detrimental to public health as they can enter the respiratory system and lead to respiratory disease, asthma, strokes, cancer and heart disease (Thurston et al., 2016). Other health-effects of exposure to PM air pollution include dermal absorption and ocular exposure which may result in eye or skin irritation. The smaller the size of PM particle and the specific nature of its composition, the more impact they are considered to have on health. $PM_{2.5}$ and PM_{10} are particulate matter with aerodynamic diameters less than 2.5 and 10 µm, respectively (Seinfeld & Pandis, 2016). The $PM_{2.5}$ size fraction is the focus of many air pollution studies because it is associated with adverse health outcomes, it is also the focus of this review.

Pollutant		WHO air quality guidelines	EU air quality guidelines	North Macedonia air quality limits
$PM_{2,5}$ (µg/m^3)	Annual mean	10	25	25
	24-hour mean	25		

Table 3.7 Air quality limit values in North Macedonia compared to the WHO guidelines and EU standards.

Source: Authors own collation

Figure 3.1 provides an overview of annual average $PM_{2.5}$ concentration (µg/m³), weighted by population in the twenty countries with the worst air quality globally. According to IQ Air (2021: 11), North Macedonia ranked seventeenth internationally for air quality in 2021.



Source: Author's Own created using data from ***IQ Air, 2021: 11*** ***https://www.iqair.com/world-most-polluted-cities/world-air-quality-report-2021-en.pdf***

Figure 3.32 2021 World country/region ranking (top 20) arranged by annual average $PM_{2.5}$ concentration (µg/m³), weighted by population based on the available data

Exposure to high levels of air pollution is considered to be a major cause of premature death and disease and is the single largest environmental health risk in Europe, causing around 400,000 premature deaths per year (UNDP Website). According to a report produced by the UN Environment Programme (UNEP) and World Health Organization (WHO), three North Macedonian cities – Skopje, Bitola, and Tetovo – were ranked in 2017 as among the top ten most-polluted in Europe with conditions worsening tangibly and measurably over the past five years (UNEP & WHO, 2019). In North Macedonia, average annual population weighted $PM_{2.5}$ concentration is estimated to be 37 µg/m³ in highly polluted areas and 14 µg/m³ in cleaner, rural areas (World Bank, 2019: 34).

Antilla et al. (2016: 134) reported that $PM_{2.5}$ concentration levels are particular high in the nation's capital, Skopje. Annual means for $PM_{2.5}$ were 56 µg/m³ at Centar and

55 µg/m^3 at Karposh monitoring stations in Skopje. Antilla et al. (2016) highlighted that the extremely high concentrations in early winter are the main reason that air pollutant concentrations did not comply with European air quality standards in Skopje during their study period. Continuous monitoring in selected North Macedonian cities found $PM_{2.5}$ hourly concentrations of up to 800 µg/m^3, more than 30 times higher than the 24-hour mean set by the WHO guidelines (at 25 µg/m^3) to protect human health (Anttila et al. 2016). In 2016, annual average $PM_{2.5}$ concentration in Tetovo reached six times the WHO health-based guidelines. In the capital city Skopje, annual average concentrations of ambient $PM_{2.5}$ were four times higher than the WHO air quality guideline values (World Bank, 2019: 18). Air pollution has thus reached levels considered health threatening in most urban locations across North Macedonia, particularly during winter months (FMI & MoEPP, 2017).

- North Macedonia ranked seventeenth internationally in 2021 in terms of annual average $PM_{2.5}$ concentration (µg/m^3), weighted by population according to IQ Air (2021: 11)
- Three North Macedonian cities – Skopje, Bitola, and Tetovo – were ranked in 2017 as among the top ten most-polluted in Europe with conditions worsening tangibly and measurably over the past five years (UNEP & WHO, 2019). Other studies suggest that air quality in North Macedonia is improving slowly.
- According to Balkan barometer data, reported by the OECD (2022), in 2019 in response to the question "Do you consider pollution to be a problem in your place of living?", 45% of respondents in North Macedonia considered it a "very serious problem".

Various commentators have reflected that PM concentrations have remained at a broadly similar level during periods of analysis, exceeding limit values significantly in urban locations (see, for Example Figure 3.2). These high PM concentrations are considered to pose a serious risk to the health of the population.

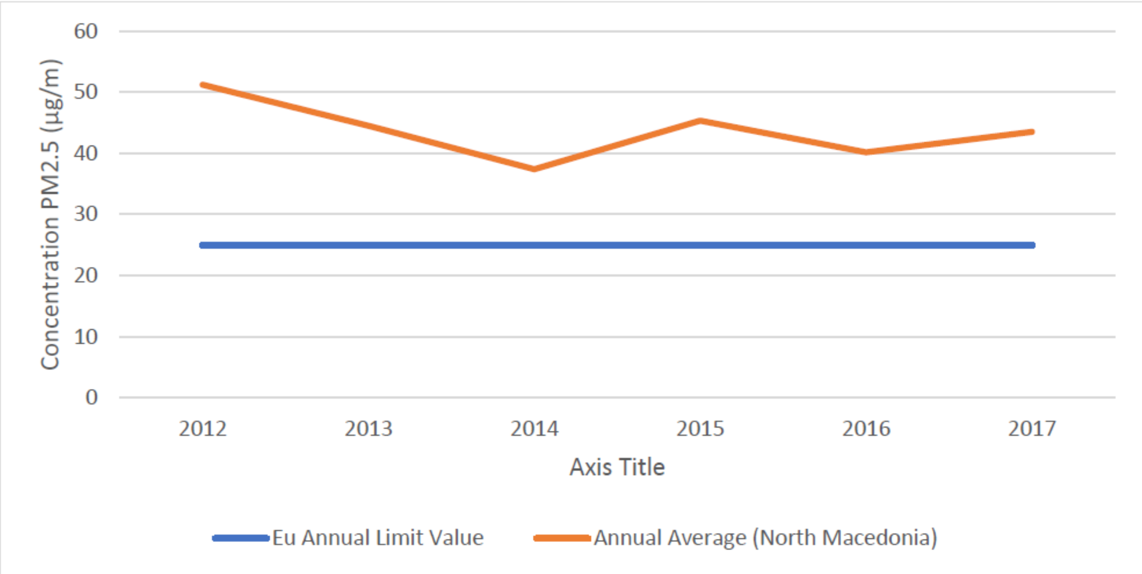


Figure 3.33 Trend in annual mean concentration across all stations (North Macedonia) against the EU standard $PM_{2.5}$ (µg/m^3 for the years 2012-2017). Source: EEA, 2021 reproduced under CC BY 2.5 DK

More recent studies have reported that North Macedonia's annual exposure to $PM_{2.5}$ air pollution decreased from 39.1 µg/m^3 in 2005 to 33 µg/m^3 in 2017 (OECD, 2022). Despite this decline, it remains the highest level in the Western Balkans (average for the West Balkans 25.77 µg/m^3), more than double the EU and OECD averages (13.1 µg/m^3 and 12.5 µg/m^3, respectively) and far above the WHO recommended maximum (annually) of 10 µg/m^3. In terms of public perception, air pollution issues have assumed increased prominence as a social and political issue in recent years. According to Balkan barometer data in 2019, reported in OECD (2022), in response to the question "Do you consider pollution to be a problem in your place of living?", respondents in North Macedonia reported the following:

- Very serious problem 45%
- Somewhat serious problem 37%
- Not too serious problem 11
- Not a problem at all 5%
- I don't know/I refuse to answer 2%

$PM_{2.5}$ emissions are not expected to decline markedly under existing policies due to the combustion of fuelwood in household stoves and boilers with current energy projections do not foresee major shifts away from fuelwood burning in households (World Bank, 2019). To make effective emission reduction measures, not only the pollution levels but also the relationship between emissions, atmospheric conditions and local source contributions needs to be understood. In North Macedonia there is an expanding, though limited, systematic and reliable data on air pollutant emissions as well as their formation and concentrations (Antilla et al., 2016).

Causes of air pollution

Whilst the causes or sources of poor air quality can be identified, these causes and underlying processes may vary within and between cities (MoEPP, 2017). Natural sources of PM include dust storms, ocean/sea spray (sea salt), dust erosion due to wind, forest fires, volcanic eruptions, and the release of biogenic PM (e.g., pollen and spores). Man-made sources include traffic, non-combustion and combustion industrial processes, power plants, construction activities, agricultural activities (including agricultural waste burning) (Haq & Schwela, 2008: 6). A key contributor to heightened levels of PM in urban settings is the combustion of solid and liquid fuels for power generation, domestic heating, cooking or lighting and in vehicle engines. PM can also be formed in the atmosphere through chemical processing of its gaseous precursors. Source Apportionment is an approach used for the identification of ambient air pollution sources and the quantification of their contribution to pollution levels. This task can be accomplished using different methods: emission inventories, source-oriented models and receptor-oriented models. A number of source apportionment studies have been undertaken in North Macedonia, at both national and local levels. At the national level, the dominant share of $PM_{2.5}$ pollution originates within the geographical boundaries of North Macedonia. The contribution of transboundary sources (about 30%) to ambient air pollution in the country is considerably less than domestic sources (World Bank, 2019). The main sources of ambient PM air pollution in North Macedonia in 2014 were identified as: residential heating (36% of total primary emissions), industrial processes (33%) and energy production (20%). Traffic contributed 2% of the total emissions of PM particles (World Bank, 2019). A PM source apportionment study for the City of Skopje conducted in 2015/16 identified similar sources originating from household heating (32-36%), traffic (16-19%), road dust (19-20%), and industry (18% of the total particulate matter concentrations) (Dimovska & Gjorjev, 2018). According to a 2017 report from North Macedonia's MoEPP, the main emission sources for $PM_{2.5}$

in 2016 in North Macedonia were residential heating with a share of 58%, industrial processes and product use (mainly ferroalloys production) with 20%, and energy industries with 6%. Fugitive emissions, agriculture, and waste are reported to be minor sources of $PM_{2.5}$ emissions in 2016 (World Bank, 2019: 40).

- At the national level, the dominant share of $PM_{2.5}$ pollution originates within the geographical boundaries of North Macedonia. The contribution of transboundary sources (about 30%) to ambient air pollution in the country is considerably less than domestic sources (World Bank, 2019).
- The main sources of ambient PM air pollution in North Macedonia in 2014 were identified as; residential heating (36% of total primary emissions), industrial processes (33%) and energy production (20%). Traffic contributed with 2% of the total emissions of PM particles (World Bank, 2019).
- A PM source apportionment study for the City of Skopje conducted in 2015/16 similarly identified sources as originating from household heating (32-36%), traffic (16-19%), road dust 19-20%, and industry (18% of the total PM concentrations) (Dimovska &, Gjorgjev, 2018).
- Household fuel use: Household fuel use is consistently identified as the predominant source of PM emissions in North Macedonia. In particular, the use of polluting fuels (e.g., firewood) for heating of households in the winter period causes serious problems with air quality in densely populated residential areas.
- Energy: According to the International Energy Agency (IEA), North Macedonia remains reliant on fossil fuels. The majority of its total energy mix, both on supply and demand side, falls under the category of fossil fuels mostly due to the usage of coal and oil.
- Industry: In North Macedonia, industrial activities can have a detrimental effect on air quality at the local level due to the prevalence of old industrial plants that lack modern emission reduction systems (MoEPP 2017). According to information provided by the Ministry of Environment and Physical Planning (MoEPP), major sources of pollution include ferroalloy production facilities and power plants.
- Transport: Vehicular emissions are a significant source of pollution in many urban areas. The MoEPP (2017) report that at the national level, circa half of the nation's passenger cars and buses are old, belonging to the high-emission

vehicle categories. Although transport may not appear to be a significant source of emission at the national level, its impact on air quality and population exposure to $PM_{2.5}$ may be more important at the local level.

Legislation and enforcement

The Government of North Macedonia has made significant efforts to develop a comprehensive legal framework for ambient air quality management that is harmonized with European legislation (World Bank, 2019). Achieving sustained reductions in air pollution, however, requires further government commitment, dedicating significantly higher resources, and building capacity at different levels to both monitor air quality and to enforce that legislation that exists. In particular, World Bank (2019) highlight that agencies responsible for air quality management tasks need to be adequately staffed with people having the requisite technical skills and adequate budgets allocated not only for sustained operation and maintenance of the air quality monitoring network but other critical aspects including data analysis, reporting and management, chemical analyses, atmospheric modelling, and health impact assessment (World Bank, 2019). Strengthening institutional capacity to enforce existing air pollution limits is another pressing priority. As of 2015, a total of nineteen inspectors were responsible for enforcing all environmental laws at the national level. Resource constraints are also evident at the municipal level, leading to individuals being responsible for inspections, issuance of permits, and other documentation. Sustained, higher resource allocation for enforcement and strong political will are key to improve enforcement of existing air quality laws and regulations (World Bank, 2019).

Covid-19 impact

The impact of the COVID-19 pandemic on air pollution was multifaceted. Studies in North Macedonia have highlighted a decrease in the levels of all pollutants measured during the COVID-19 period in 2020 compared to those reported between 2017 and 2019 (Dimovska & Gjorgjev, 2020: 355). The first movement restrictions in the country were introduced in March 2020, followed by stricter movement restrictions in April 2020. Dimovska and Gjorgjev (2020: 357) identified a substantial decrease in PM concentrations in all cities observed in the study (15–48% for $PM_{2.5}$ during the strictest COVID restrictions). They assert that this was likely attributable to the significant reduction of vehicular traffic and transport, and to the reduction or complete stop of industrial activities given restrictions imposed by the authorities (Dimovska & Gjorgjev, 2020: 357).

Consequences of air pollution

A significant proportion of Europe's urban population lives in cities where EU air quality standards for the protection of human health are regularly exceeded, with North Macedonian cities ranking as some of the worst for air quality. Air pollution continues to have significant impacts on the health of Europeans, particularly in urban areas. These health impacts have economic costs, cutting short lives, increasing medical costs and reducing productivity through lost working days. The pollutants with the most serious impacts on human health are PM, nitrogen dioxide and ground-level ozone (EBRD, 2019). Alongside these health costs, air quality exerts a significant economic impact (associated with health-related costs) and is an issue of political concern. Whilst various estimates exist, the EBRD estimate that approximately 1,350 lives are lost annually due exposure to PM, costing the North Macedonian economy EUR 253 million, or 3.2% of GDP (EBRD, 2019: 17).

When examining the relationship between cancer and air pollution, researchers typically conduct epidemiological studies to analyse patterns and trends. These studies often involve large populations over extended periods. They assess various factors, including exposure to different pollutants, geographical locations, demographic information, and health outcomes such as cancer incidence rates.

If there is no established connection between cancer and air pollution in North Macedonia, it might mean that:

1. Existing Studies: Existing epidemiological studies in North Macedonia might not have found a significant correlation between cancer rates and air pollution levels. This could be due to various reasons such as limited data, methodological constraints, or other confounding factors.
2. Data Quality: The available data on cancer incidence and air pollution levels might not be comprehensive or reliable enough to establish a clear link.
3. Other Factors: Other factors such as lifestyle choices, genetic predispositions, occupational exposures, and access to healthcare services could be more

significant contributors to cancer incidence rates in North Macedonia than air pollution.

4. Local Context: The specific composition and sources of air pollution in North Macedonia might not be strongly associated with cancer development
compared to other regions.

It's essential to note that the absence of evidence does not necessarily imply evidence of absence. In other words, just because a connection between cancer and air pollution hasn't been firmly established in North Macedonia doesn't mean that it doesn't exist.

Further research, including more comprehensive studies and data collection efforts, may be necessary to fully understand the relationship between air quality and cancer in the region. The most extreme estimates suggest that in selected North Macedonian cities 1,903 human lives (excess deaths) are lost annually due to $PM_{2.5}$ exposures (22.3% of total all-cause mortality). The mortality rate attributable to $PM_{2.5}$ exposures (per 100,000 populations) is highest in the city of Tetovo (301); Bitola (234); and Skopje (208) (Dimovska & Gjorgjev, 2018). The World Bank (2019) estimated the economic cost associated with mortality from exposure to air pollution in North Macedonia is in the range of US$500–900 million annually, equivalent to 5.2–8.5% of GDP in 2016 (World Bank, 2019: iv-v). This valuation only quantifies economic impacts from premature mortality associated with specific diseases. Whilst the political consequences of air pollution are multifaceted and can be difficult to identify, it is important to acknowledge the potential impact of poor air quality. For example, North Macedonia's accession to the European Union is dependent on it meeting obligations, including those around air
quality.

The incidence of cancer in North Macedonia has been linked to various factors, including air pollution. Air pollution refers to the presence of harmful substances in the air, such as particulate matter, nitrogen dioxide, sulphur dioxide, and volatile organic compounds, emitted from sources like industrial activities, vehicle emissions, and household heating, also emphasizing the pollution as the consequence of military actions due to Yugoslav war and NATO bombardment which caused long-term damage to the entire environment. Prolonged exposure to these pollutants has been associated with respiratory problems, cardiovascular

diseases, and an increased risk of cancer. In North Macedonia, where urban areas often experience high levels of air pollution due to industrial activities and heavy traffic, the correlation between air pollution and cancer incidence is a growing concern. Studies have shown associations between certain air pollutants and cancers such as lung cancer, bladder cancer, and leukaemia. Additionally, pollutants can exacerbate existing health conditions, potentially leading to a higher cancer risk over time.
Efforts to mitigate air pollution in North Macedonia include implementing stricter regulations on emissions, promoting cleaner technologies, improving public transportation systems, and increasing public awareness about the health risks associated with poor air quality. By addressing air pollution comprehensively, North Macedonia aims to reduce the incidence of cancer and improve overall public health.

Cancer related to military actions

While the Yugoslav Wars and NATO bombing campaigns did not directly cause cancer in North Macedonia, the conflict and associated environmental damage may have indirectly contributed to health issues, including cancer, in the region. During the conflicts of the 1990s, industrial facilities, infrastructure, and hazardous materials were targeted, leading to environmental contamination and pollution. Additionally, the use of depleted uranium ammunition by NATO forces in neighbouring regions raised concerns about potential environmental and health impacts due to radioactive contamination. The long-term effects of environmental damage and exposure to pollutants from the conflicts have been a subject of ongoing research and debate. While there is no direct evidence linking cancer cases in North Macedonia solely to the Yugoslav Wars and NATO bombing, the disruption caused by the conflicts and their environmental aftermath may have contributed to health challenges faced by the population, including an increased risk of certain cancers. It's essential for authorities to continue monitoring and addressing environmental health concerns to safeguard the well-being of the population.

The connection between the Yugoslav Wars and NATO's intervention, particularly the bombing campaign in 1999, and the incidence of cancer cases in North Macedonia is not straightforward and direct. However, there are potential indirect links that can be considered:

1. Environmental impact: During the NATO bombing campaign in 1999, North Macedonia, then part of the Federal Republic of Yugoslavia, was not directly targeted but still experienced some environmental consequences due to fallout and pollution from nearby areas that were bombed. Although North Macedonia wasn't directly targeted, there could have been fallout affecting air, water, and soil quality due to the proximity to bombed areas. Depending on factors such as wind patterns and geographic proximity, there could have been contamination of air, water, and soil in parts of North Macedonia, potentially affecting public health in the long term. Contaminants such as heavy metals, particulate matter, and toxins from destroyed infrastructure and military activities can pose long-term health risks, potentially contributing to cancer development.
2. Disruption of healthcare services: The Yugoslav Wars and subsequent political instability in the region could have disrupted healthcare systems and infrastructure in North Macedonia. This disruption might have affected healthcare access, including cancer screening, diagnosis, and treatment, potentially leading to underreporting or inadequate management of cancer cases. Armed conflicts can disrupt healthcare services and infrastructure, including cancer screening, diagnosis, and treatment. Displacement of populations, damage to healthcare facilities, shortages of medical supplies, and disruptions in transportation networks can hinder access to essential healthcare services. Delayed diagnosis and treatment of cancer can lead to advanced disease stages and poorer outcomes.
3. Stress and psychological impact: Wars and armed conflicts can have profound psychological effects on populations, leading to increased stress, anxiety, and mental health issues. Chronic stress and trauma have been linked to negative health outcomes, including a potential impact on the immune system and increased susceptibility to diseases like cancer. The Yugoslav Wars subjected populations in the region, including North Macedonia, to significant psychosocial stress and trauma. Displacement, violence, loss of loved ones, and economic hardship can have profound psychological impacts on individuals and communities. Chronic stress and trauma have been associated with adverse health outcomes, including immune system dysregulation and increased vulnerability to diseases such as cancer. However, direct causality between

psychological stress and cancer remains a subject of ongoing research.

4. Economic consequences: The economic consequences of the Yugoslav Wars and subsequent political instability could have indirect effects on cancer incidence in North Macedonia. Economic downturns, poverty, and unemployment can influence lifestyle factors such as diet, physical activity, and access to healthcare, which are known determinants of cancer risk.

It's important to note that while these are plausible connections, they are speculative, and any direct correlation between the Yugoslav Wars/NATO bombing and cancer incidence in North Macedonia would require thorough epidemiological studies and data analysis to establish causality. There is poor data on this topic in North Macedonia, mostly based on data from the Institute for Public Health of the Republic of North Macedonia (IPHRNM) in collaboration with Centers of Public Health in The Republic of North Macedonia, which integrates all data from the University Clinics in North Macedonia as University Clinic for Radiotherapy and Oncology; University Clinic for Haematology; University Clinic for Gynaecology and Obstetrics and others and gray literature- presented as materials and research produced by organizations outside of the traditional commercial or academic publishing and distribution channels (reports, working papers, government documents, newsletters, and evaluations. Cancer is a complex disease with multifactorial causes, including genetic predisposition, lifestyle factors, environmental exposures, and healthcare access, among others. Therefore, attributing cancer cases solely to specific historical events or interventions would be challenging without comprehensive research and evidence.

From the health map of North Macedonia

The Health map of the Republic of North Macedonia represents the status of the health protection and health condition in the Republic in general and separately for each health region in 2021, in terms of the organizational structure, health services, health personnel, morbidity and mortality. The aim of this publication is to provide contribution in preparation of the health development strategy in our Republic, as well as the use of information by the health workers and coworkers and all the interested subjects. The preparation of the health map is based on official data, collected and processed by the Department for health statistics and informatics of the Center for statistical processing health data, publication and education provided by the Institute for public health in Republic of North Macedonia and the State Statistical Office. The Health map of the Republic of North Macedonia for 2021 is the twenty-third publication in a row that as a form of continuous annual publishing of actual data, will go on in the future.

The Cancer Registry of the Republic of Northern Macedonia is managed by the Institute of Public Health of the Republic of North Macedonia (IPH). Since 1995, the Register has been kept in electronic form. It registers more than 165,000 individuals by 31 December 2021.

Cancer in North Macedonia 2010-2019 and Cancer in The Republic of North Macedonia 2012-2021 documents are created by the Health Data Department which is a part of The Institute of Public Health of The Republic of North Macedonia. Those two documents from the IPH will be compared in terms of incidence of cancer cases in these years. The main point is to establish if there is real number of enlarged incidence of cancers.

The aim of this reports is to provide information on new cases of cancer at the level of diagnoses, gender and adult groups of patients for ten years. The report also provides information on the distribution of cases by geographically defined health regions. Statistically processed data for ten years presented in the report provide more accurate information on the condition, trends and other relevant parameters of the disease.

The ten-year report on cancer in the Republic of North Macedonia for 2010-2019 was prepared in the Department of Health Data, part of the IPH, based on data from the Cancer Registry of the Republic of Northern Macedonia. The analyses in the Report were made from data contained in the application form 3-35-86 according the Law on Records of the Republic of North Macedonia. In the period from 2010 to 2019, the Register included 66,941 patients. On average in the Republic of Northern Macedonia in the period 2010-2019 there are 6694 new cases per year, there are 323 cases per 100,000 population, 55% of the cases are males while 45% are females. Up to the age of 50, females are represented by 59%, and males by 41%. Above the age of 50, males are represented by 57%, unlike females are covered by 43%. The data show that about 87% of cancer cases are among the population over the age of 50, , of which 20% are between the ages of 50 and 60. About 0.4% of cancer cases occur in children and adolescents under the age of 15.

The most common diagnoses in the ten years on the entire population are malignant neoplasms of the bronchi and lungs with 12.16% of the total reported cases, followed by malignant neoplasms of the breast, other malignant neoplasms of the skin, stomach, etc. The most common diagnoses in the ten years on the male population are malignant neoplasms of the bronchi and lungs with 18.6% of the total reported cases, followed by malignant neoplasms of the prostate, other malignant neoplasms of the skin, stomach, etc. The most common diagnoses in the ten years on the female population are malignant neoplasms of the Breast with 23.21% of the total reported cases, followed by malignant neoplasms of corpus uteri, other malignant neoplasms of the skin, bronchi and lung, etc.

Analysed according to the health regions of the malignant neoplasm bronchi and lung are most common in Skopje, with an average of 288 cases per year in 10 years, 46 cases per 100,000 population. Demir Hisar and Sveti Nikole have the highest rate per 100 000 population with 60 cases followed by Gevgelija with 59 cases.

Breast cancer is the most common in Skopje, with an average of 271 cases per year in 10 years, 85 cases per 100,000 population. The highest rate per 100,000 inhabitants has Sveti Nikola with 93 and Kratovo and Berovo with 91 cases.

On average for 10 years, at the level of one year, the number of patients with malignant diseases treated in the hospital-inpatient health care system is 30923, which represents 11.43% of the average number of all patients treated annually.

In the processed ten-year period, the length of stay of patients with malignant diseases at the annual level in average is 299,858 days, which represents 14.44% of the length of stay of all patients.

The analysis shows an increase in patients with malignant neoplasms who are treated in the hospital-stationary part of the health system. In 2019, 12.98% of the total treated patients had malignant diseases, while the length of stay was 20.53% of the total length of stay of all patients. The previously given analyses do not show the health services that are provided in the day hospitals. The processing of data from the Cancer Registry can significantly contribute to the development of appropriate policies with which health systems deal with this disease.

In the tables bellow new cancer cases average value distribution among male and female are presented between 2010-2019:

Key facts most common cancers (average for ten years) 2010-2019						
ALL	**MKB 10 ICD10**	**Cases per year**	**% of all cancers**	**Incidence rate per 100 00**	**Death per year**	**Mortality rate per year**
All		6694	100	322,6	3720	179,3
Bronchus and lung	C34	863	12,9	41,6	801	38,6
Breast	C50	752	11,2	72,6	296	28,6
Other of skin	C44	504	7,5	24,3	61	3,0
Stomach	C16	425	6,4	20,5	307	14,8
Colon	C18	390	5,8	18,8	208	10,0
Prostate	C61	347	5,2	33,4	176	17,0
Liver and intrahepatic bile ducts	C22	300	4,5	14,4	184	8,9
Rectum	C20	264	3,9	12,7	172	8,3
Bladder	C67	255	3,8	12,3	115	5,5
Corpus uteri	C54	211	3,2	20,4	56	5,4
Pancreas	C25	204	3,1	9,8	189	9,1
Larynx	C32	169	2,5	8,1	85	4,1
Brain	C71	158	2,4	7,6	147	7,1
Cervix uteri	C53	151	1,3	14,6	50	4,9
Ovary	C56	112	1,7	10,8	76	7,3
Melanoma of skin	C43	110	1,6	5,3	55	2,7
Diffuse non-Hodgkin lymphoma	C83	90	1.3	4,4	24	1,1
Kidney except renal pelvis	C64	81	1,2	3,9	44	2,1
Myeloid leukaemia	C92	80	1,2	3,9	44	2,1
Trachea	C33	78	1,2	3,8	7	0,3
Other		115,0	17,2	55,4	628	30,3

Table 3.8 Key facts most common cancers (average for ten years)

Notes: (*) CR per 100 000 for female population; (*) CR per 100 000 for male population

Key facts most common cancers in female (average for ten years) 2010-2019					
Female	**MKB10 ICD10**	**Cases per year**	**% of all cancers**	**Incidence rate per 100 000**	**Death per year**
All		3009	100	290.33	1499
Breast	C50	738	24,52	71,19	290
Corpus uteri	C54	211	7,02	20,38	56
Other of skin	C44	204	6,77	19,65	23
Bronchus ang lung	C34	178	5,90	17,13	162
Colon	C18	161	5,36	15,57	86

Cervix uteri	C53	151	5,02	14,59	50
Stomach	C16	136	4,52	13,11	101
Ovary	C56	112	3,71	10,78	76
Rectum	C20	106	3,53	10,25	72
Liver and intrahepatic bile	C22	97	3,23	9,37	70
Pancreas	C25	89	2,96	8,61	81
Brain	C71	67	2,22	6,45	62
Bladder	C67	52	1,72	5,00	22
Thyroid gland	C73	48	1,60	4,65	7
Melanoma of skin	C43	47	1,55	4,51	20
Diffuse non-Hodgkin lymphoma	C83	42	1.40	4,06	11
Uterus part unspecified	C55	37	1,22	3,53	33
Myeloid leukaemia	C92	36	1.20	3,48	0
Lymphoid leuk.	C91	30	0,99	2,89	12
Kidney except renal pelvis	C64	29	0,96	2,79	15
Other		439	14,59	42,37	250

Table 3.9 Key facts most common cancers in female (average for ten years) 2010-2019

Key facts most common cancer in male (average for ten years) 2010-2019					
Male	**MKB10 ICD10**	**Cases per year**	**% of all cancers**	**Incidence rate per 100 000**	**Death per year**
All		3685	100	354.7	2221
Breast	C34	685	18,6	65,9	639
Corpus uteri	C61	347	9.4	33.4	176
Other of skin	C44	301	8.2	28.9	39
Bronchus ang lung	C16	290	7.9	27.9	206
Colon	C18	228	6.2	22.0	123
Cervix uteri	C67	203	5,5	19.6	93
Liver and intrahepatic bile duct	C22	203	5.5	19.5	114
Rectum	C20	158	4.3	15.2	100
Larynx	C32	151	4.1	14.6	77
Pancreas	C25	115	3.1	11.1	107
Brain	C71	91	2,5	8.8	84
Melanoma of skin	C43	63	1.7	6,1	35
Trachea	C33	60	1,6	5,8	7

Kidney except renal pelvis	C64	52	1,4	5.0	29
Diffuse non-Hodgkin lymphoma	C83	48	1.3	4,6	0
Lymphoid leukemia	C91	46	1,3	4.4	21
Myeloid leukemia	C92	44	1.2	4.2	21
Testis	C62	36	1.0	3.5	0
Rectosigmoid junction	C19	36	1.0	3,5	19
Other		496	13.4	47,7	303

Table 3.10 Key facts most common cancers in male (average for ten years) 2010-2019

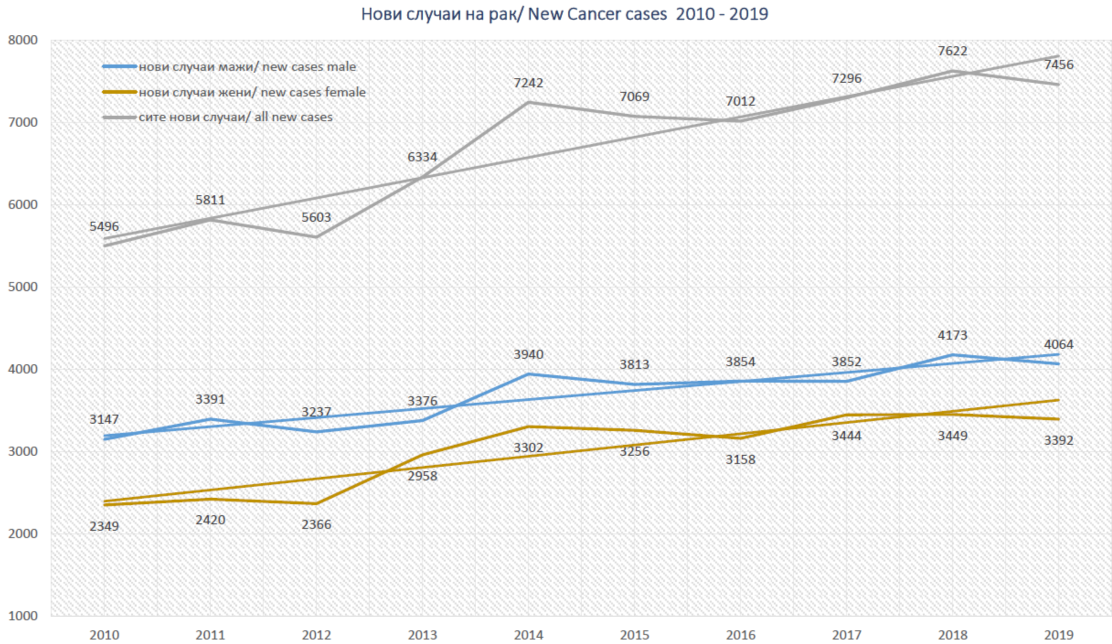


Figure 3.34 New cancer cases in North Macedonia 2010-2019

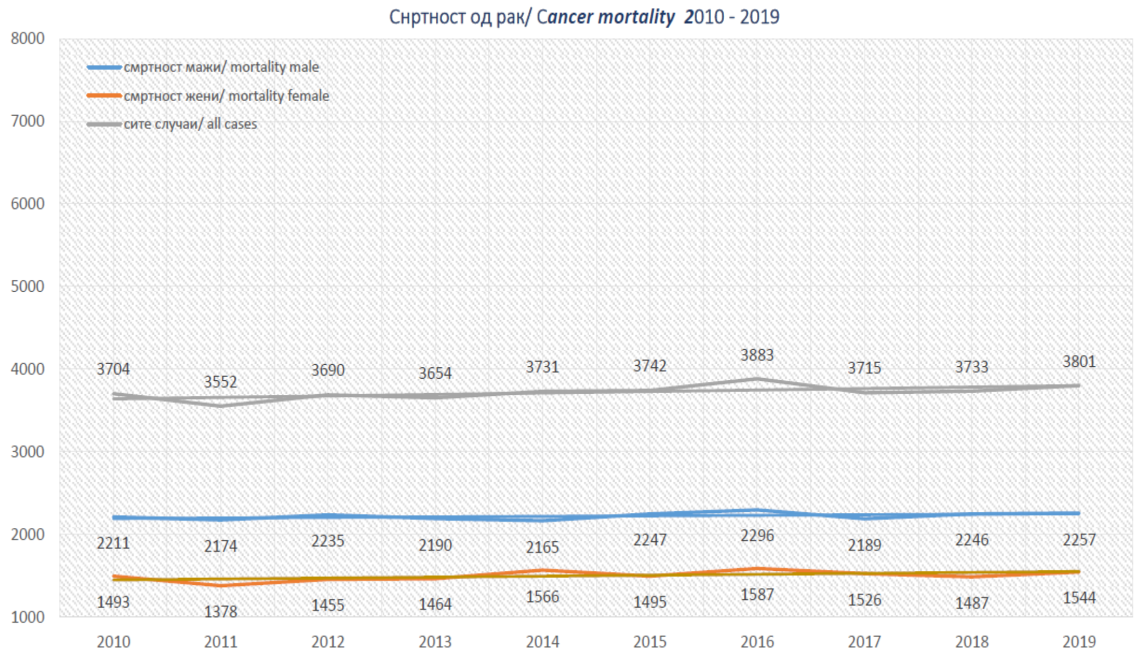


Figure 3.35 Cancer mortality in North Macedonia 2010-2019

The ten-year report on cancer in the Republic of North Macedonia for 2012-2021 was prepared in the Department of Health Data, part of the IPH, based on data from the Cancer Registry of the Republic of North Macedonia. The analyses in the Report were made from data contained in the application form 3-35-86 according the Law on medical Records - North Macedonia. In the period from 2012 to 2021, the Register included 69.088 patients.

On average in the North Macedonia in the period 2012-2021 there are 6908 new cases per year, I.e. there are 333 cases per 100,000 population, 54.2% of the cases are males while 45.8% are females. Up to the age of 50, females are represented by 60.80%, and males by 39.20%. Above the age of 50, males are represented by 56.24%, unlike females are covered

by 43.76%. The data show that about 87.92% of cancer cases are among the population over the age of 50, of which 18.64% are between the ages of 50 and 60. About 0.35% of cancer cases occur in children and adolescents under the age of 15.The most common diagnoses in the ten years on the entire population are malignant neoplasms of the bronchi and lungs with 12.56% of the total reported cases, followed by malignant neoplasms of the breast, other malignant neoplasms of the skin, stomach, etc.

The most common diagnoses in the ten years on the male population are malignant neoplasms of the bronchi and lungs with 18.90% of the total reported cases, followed by malignant neoplasms of the prostate, other malignant neoplasms of the skin, stomach, etc.

The most common diagnoses in the ten years on the female population are malignant neoplasms of the Breast with 24.87% of the total reported cases, followed by malignant neoplasms of corpus uteri, other malignant neoplasms of the skin, bronchi and lung etc.

Analysed according to the health regions of the malignant neoplasm bronchi and lung are most common in Skopje, with an average of 273 cases per year in 10 years, 45 cases per 100,000 population. Demir Hisar have the highest rate per 100 000 population with 57 cases.

Breast cancer is the most common in Skopje, with an average of 303 cases per year in 10 years, 98 cases per 100,000 population. The highest rate per 100,000 inhabitants has Kratovo with 128 and Sveti Nikole with 117 cases.

On average for ten years, at the level of the year, the number of patients with malignant diseases treated in the hospital-inpatient health care system is 29,648 which represents 11.91% of the average number of all patients treated annually. In the analysed ten-year period, the length of stay of patients with malignant diseases at the annual level in average is 339,323 days, which represents 17.06% of the length of stay of all patients.

The analysis shows an increase number of patients with malignant neoplasms who are treated in the hospital-stationary part of the health system. In 2021, 13.34% of the total number of patients were treated for malignant diseases, while their length of stay in hospital was 21.07% of the length of stay of all patients.

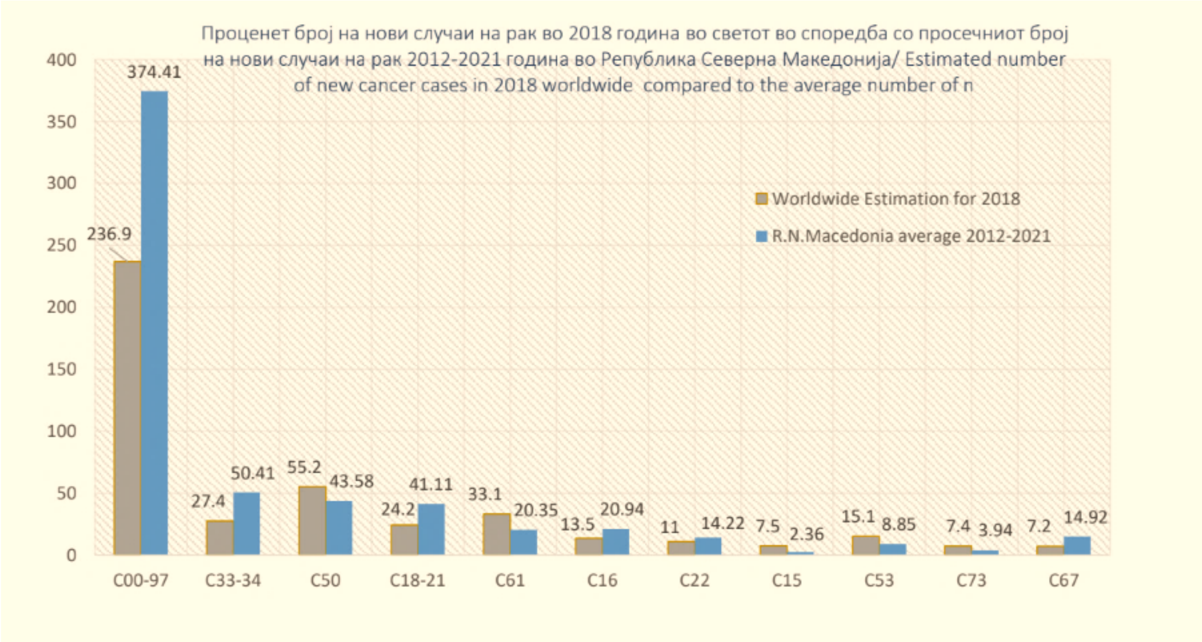


Figure 3.36 Estimated number of new cancer cases in 2018 worldwide compared to average number of new cancer cases in North Macedonia

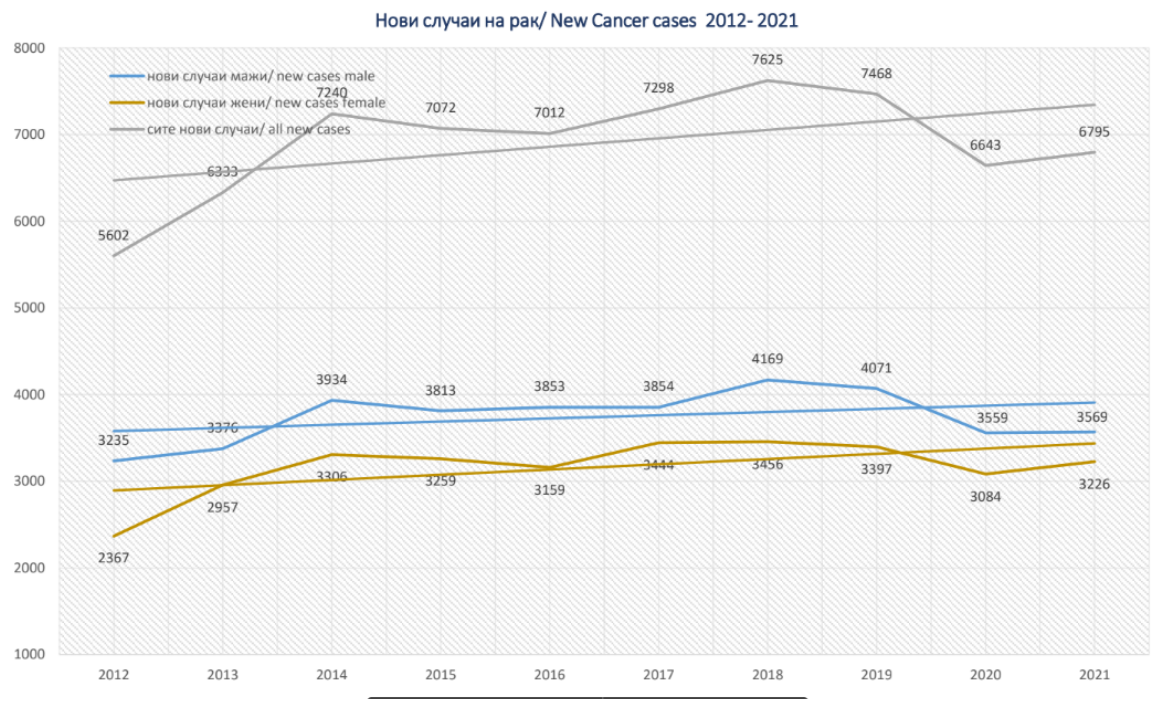


Figure 3.37 New cancer cases 2012-2021

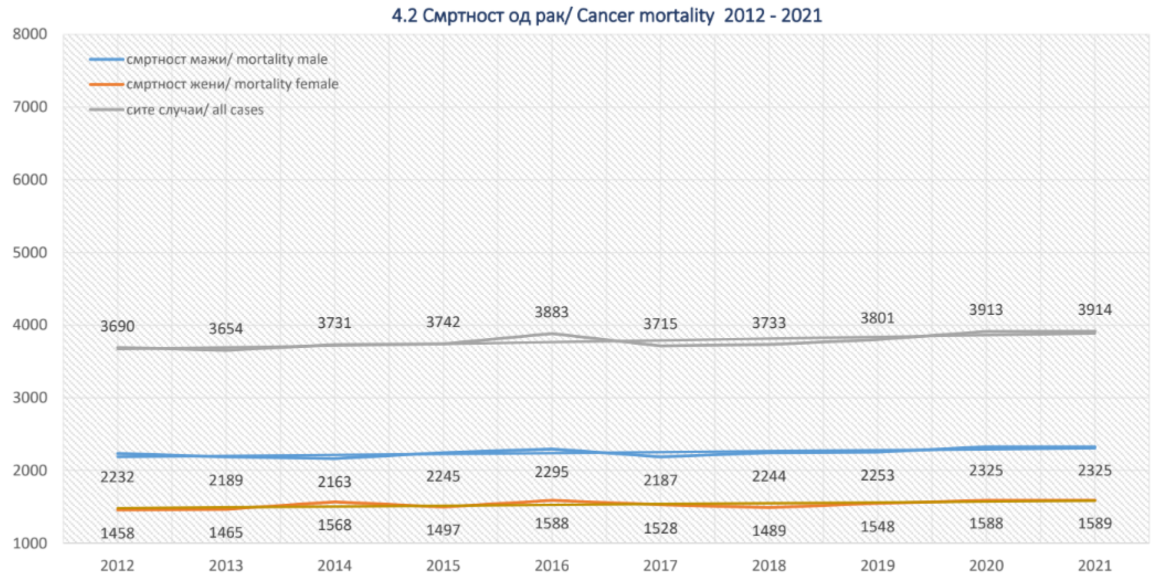


Figure 3.38 Cancer mortality 2012-2021

Comparing new cancer cases for period of these two ten-year reports 2010-2019 to 2011-2021, there are 6694 new cases per year, on average 55% of the cases were male, while 45% female population. Up to the age of 50, females are represented by 59% and males by 41%. Above the age of 50, males are represented by 57% and females are covered by 43%. The Register included 66,941 patients.

For the period of 2011-2021, there are 69,088 new cases per year, on average 54,2 % are males while, 45,8% are females. Up to the age of 50, females are represented by 60,80% and males by 39,20% Above the age of 50, males are represented 56,24% unlike females are covered by 43,76%.

Taking into account these statistics data, we can conclude that there is not much difference in both two-year reports created by the Institute of Public Health in North Macedonia.

To make comparison for cancer incidence with neighbouring countries which were directly involved in military conflicts, the following is summary of retrospective-registered study in Kosovo published on National Library of Medicine (PubMed Central).

Kosovo example: Incidence of haematological malignancies in Kosovo—A post "uranium war" concern

During the Kosovo War (1998–99) approximately 31,000 rounds with Depleted Uranium (DU) were fired on 85 targets in Kosovo. The number of haematological malignancies (HM) increased after the war and the concern was the use of DU during the war. The aim of this study was to analyse the incidence rates of HM in Kosovo throughout a 20-year that includes pre- and post- war period (1995–2015); and to examine if there is any association between the use of DU rounds and incidence rates of HM in different regions of Kosovo.

In this retrospective register-based study, 1,798 new patients diagnosed with leukaemia, Hodgkin lymphoma, non-Hodgkin lymphoma and Multiple myeloma were analysed over a 20-year period. Incidence rates were calculated focusing on specific time periods, regions and age-groups. In addition, the correlation between the use of DU in different regions and their incidence of HM was analysed.

The average annual crude rate of all HM in Kosovo was 5.02 cases per 100,000 persons. Incidence rates of HM in first post-war period (2000–2003) increased by 0.37 cases/100,000 persons (9.51%) compared to the pre-war period (1995–1998) whereas in the last post-war period (2012–2015), incidence of HM increased by 3.19/100,000 persons (82%). Gjakova and Peja, the first and third most exposed regions to DU ordnance ranked first and second in difference in HM. Prishtina, Gjilan and Ferizaj, regions with the least number of rounds/km2, were characterized by a decline of incidence rates.

After the war, the increase in incidence rate of HM was higher in two regions with most DU rounds/km^2 expended Despite these findings, this study warrants further investigation and does not lead us to a conclusive finding on the existence of a causal relationship between the use of DU during the war and the rise in incidence of HM in Kosovo.

The use of depleted uranium in military actions raised concern after reported increases in incidence of leukaemia and lymphoma and other cancers among soldiers involved in the Balkan and the Gulf war (24,25). In a cancer surveillance study in Italian soldiers deployed in Bosnia and Kosovo, increased incidence of Hodgkin's lymphoma (HL) was reported, although this was considered as a sporadic event, unlikely related to DU exposure(26). In contrast, a study carried out in three Iraqi provinces exposed to intensive military activities during the 1991 and 2003 wars, found higher uranium serum levels in leukaemia patients compared to control group (27). However, epidemiological studies which compared the risk of all cancers including leukaemia between Balkan veterans and general population in Norway, Sweden, Netherlands and Denmark, failed to demonstrate a higher incidence among Balkan veterans (28–32).

There have been indications that the numbers of HM cases in Kosovo post-war have increased and the concern was it was due to the use of DU during the war (33). The purpose of this study was twofold: 1) to analyse the incidence rates of HM in Kosovo throughout a 20-year pre- and post- war period (1995–2015); and 2) to examine if there is any association between the use of DU rounds and incidence rates of HM in different regions of Kosovo.

In this retrospective register-based study, were identified all HM newly diagnosed patients in two haematology departments (Clinic of Internal Medicine; January 1995–2015 and the Pediatric Clinic; January 2000–2015) at University Clinical Centre of Kosovo (UCCK)—the only healthcare institution in the country that diagnoses and treats malignancies. In some cases, patients may have sought treatment in institutions outside Kosovo, bypassing the UCCK. This particularly applies to four municipalities located in the northern part of the country: Mitrovica North, Leposavic, Zubin Potok and Zveçhan.

Nevertheless, we estimate that UCCK covered the vast majority of newly diagnosed patients with haematopoietic and lymphoid malignancies; therefore, the data collected are representative for Kosovo. Due to deficiencies in the Kosovo Health Reporting System, patients' data were collected from the primary sources—patient registries and records from the two abovementioned clinics. Patient data (age, sex, residence and diagnosis) were cross-checked several times for duplication and inaccurate entries and in dozens of cases were verified via phone calls.

In this study were identified 1989 new patients diagnosed with HM over 20 years in UCCK, of them 1,696 adult patients and 293 pediatric patients. Patients diagnosed with leukaemia, HL, NHL and Multiple Myeloma (MM) were the subject of the study. As a result, from the total of 1,989 HM we excluded 129 cases of Myelodysplastic syndrome, 23 cases of Myeloproliferative neoplasms, 12 cases of non-Kosovar patients, 22 cases with largely incomplete data, as well as five cases from two municipalities in the northern part of Kosovo, yielding a total of 1,798 patients analysed.

Statistical analysis

Descriptive findings are presented for 1,798 patients diagnosed with leukaemia, HL, NHL and MM during the period 1995–2015. Annual incidence crude rates per 100,000 persons/year were calculated for each disease separately, as well as for HM combined. For the sake of accuracy, annual incidence rates at Kosovo level were calculated by using population data estimates for respective years, whereas calculation of annual incidence rates for the 7 Kosovo regions is based on the 2011 census data. 'Age Specific Incidence Rate' was calculated only for the period 2011–2015 using population projections (38) based on the 2011 census, because of missing age-specific data for the period 1995–2010. In this study the age distribution of the population is given in five-year age groups extending to 75 years and over. For the same reason (missing age-specific data for the period 1995–2010), 'Age-Standardized Rates' (ASR) according to European Standard Population are presented only for the period 2011–2015, for the sake of comparison of incidence rates with different countries.

In order to compare different findings over time, we defined five time periods: 1995–1998, 2000–2003, 2004–2007, 2008–2011, 2012–2015. The year 1999, when the 11-weeks NATO air-campaign effectively ended the war in Kosovo, was excluded from those time periods due to huge displacements of population and considerable disruption in provision of health care services in Kosovo.

The distribution of 1,798 patients diagnosed with leukaemia, HL, NHL and MM in Kosovo for the period 1995–2015 is presented in (Table 3.4) along with median age at the time of diagnosis, sex-rate ratio (male rate/female rate), average annual incidence CR/100,000 and annual average ASR only for the period 2011–2015. The most frequent type of HM was leukaemia with 49.5%. HM were more frequent in males than in females (sex-rate ratio 1.32) with difference being more evident for HL (sex-rate ratio 1.54). The median age at diagnosis of HM combined was 50 years. The average annual CR of all HM in Kosovo was 5.02 cases per 100,000 persons, whereas the average annual ASR for period 2011–2015 for HM combined was 8.33.

Characteristics of HM in Kosovo for a 20 year period (1995-2015)									
Diagnosis	Frequency, N (%)	Median age at diagnosis (years)	Sex-rate ratio (m/f)	Average Annual CR rate per 100 000, 1995-2015			Average Annual ASR 2011-2015		
				M	F	T	M	F	T
Leukemia	890 (49,5 %)	43 (16-62)	1.30	2.81	2.16	2.49	4.52	2.71	3.57
HL	251 (14,0 %)	44 (27-60)	1.54	0.85	0.55	0.70	1.32	0.81	1.06
NHL	468 (26 %)	54 (41-65)	1.27	1.45	1.15	1.30	2.94	2.23	2.56
MM	189 (10,5 %)	61 (51-67)	1.32	0.60	0.45	0.52	1.55	0.76	1.13
Total HM	1,798 (100 %)	50 (25-64)	1.32	5.71	4.32	5.2	10.33	6.51	8.33

Table 3.11 Characteristics of HM in Kosovo for 20 year period (1995-2015)

Leukaemia was the most common malignancy among children and adults till the age of 30, but the majority of cases occurred in older people (Fig 3.7). NHL exceeded leukaemia at ages 30–34, 50–54 and 65–69. The decline in incidence of NHL and MM occurred at ages 65–69 whereas the decline in incidence of leukaemia and HL occurred at ages 70–74.

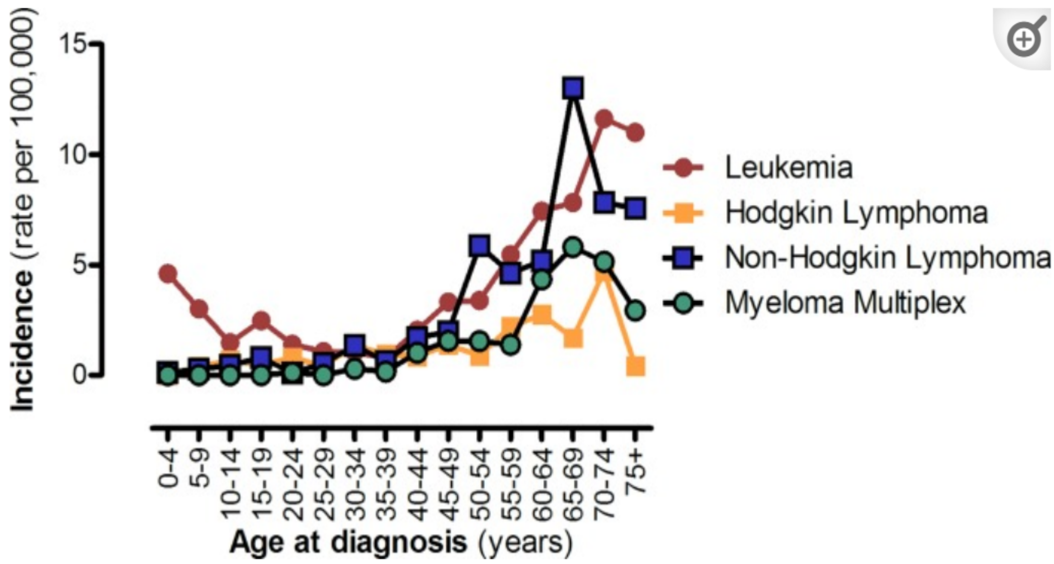


Figure 3.39 Average annual age-specific rates for HM in Kosovo for the period 2011-2015

Regional variations in incidence of HM during five four-year periods: In the pre-war period, the incidence rates of HM malignancies combined were higher in Prishtina, Mitrovica and Ferizaj with increased prevalence of leukaemia (3.23) and HL (0.92) in Prishtina, MM (0.65) in Mitrovica and NHL (1.12) in Ferizaj. In this period the lowest incidence of HM combined was in Gjakova and Peja. In the last post-war period (2012–2015), Mitrovica was still the region with the highest incidence of HM (9.34), followed by Ferizaj (8.11), Peja (8.06) and Prishtina (7.87). Incidences for each malignancy for the same time periods were also calculated.

After the war, incidence rates of HM combined increased continuously throughout the five-year time periods. The post-war changes can be summarized as follows; the first post-war period and third post-war period (2000–2003 and 2008–2011) were characterized by sharp increases in leukaemia and NHL in the majority of regions of Kosovo, the second post-war period (2004–2007) with increases in HL and MM in the majority of regions, whereas the fourth post-war period (2012–2015) with increases of all malignancies in the majority of regions of Kosovo (Fig 3.8).

Fig 2

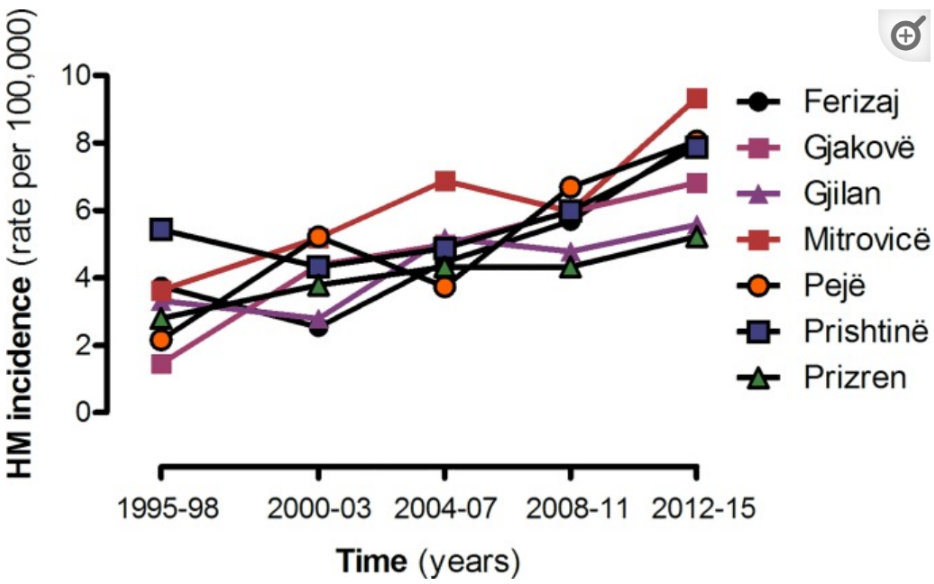


Figure 3.40 Difference in incidence of HM between pre-war period and the two post-war periods and DU exposure by regions

Table 3.5. presents incidence rates by seven Kosovo regions in the pre-war (1995–1998), as well as the first and the last post-war period (2000–2003 and 2012–2015). In the pre-war period the lowest incidence rates of HM combined were in the two regions most exposed to DU ordnance (Gjakova and Peja), whereas the highest incidence rates were encountered in the regions with lower exposure to DU ordnance (Prishtina and Mitrovica). Whereas, in the first post-war period (2000–2003) Gjakova and Peja, the first and the third most exposed regions to DU ordnance show proportionally higher increase in incidence compared to the pre-war period (1995–1998) than it is the case with the regions least exposed to DU ordnance—Prishtina, Gjilan and Ferizaj which were characterized by declining in incidence compared to the pre-war situation. The increase in incidence of HM combined also was shown in Prizren region which ranked second by exposure to DU and Mitrovica which ranked fourth. Similar trends can be observed in increase of incidence rates of Leukaemia in the respective regions.

Regional variations of rounds/km^2 and incidence in the pre-war period (1995-1998) and two post-war periods (2000-2003 and 2012-2015)													
Region	Rounds/ km^2	Leukemia			Hodgkin Lymphoma			Non-Hodgkin Lymphoma			Myeloma Multiplex		
		1995 1998	2000 2003	2012 2015	1995 1998	2000 2003	2012 2015	1995 1998	2000 2003	2012 2015	1995 1998	2000 2003	2012 2015
Ferizai	1.58	1.72	1.01	3.55	0.51	0.61	1.62	1.12	0.71	1.93	0.41	0.20	1.01
Gjakova	7.73	0.49	2.80	3.53	0.49	0.12	0.85	0.24	0.97	1.46	0.24	0.49	0.97
Gjilan	0.73	1.46	1.46	2.92	0.40	0.27	0.27	1.06	0.93	1.99	0.40	0.13	0.40
Mitrovica	1.85	1.43	2.98	3.63	0.52	0.38	0.78	1.04	1.56	2.47	0.65	0.26	2.47
Peja	4.78	0.68	1.82	3.74	0.57	1.02	1.13	0.68	2.04	2.50	0.23	0.34	0.68
Prishtina	1.17	3.23	2.07	3.78	0.92	0.67	0.85	0.79	1.22	2.38	0.49	0.37	0.85
Prizren	5.42	1.44	2.17	1.90	0.27	0.45	1.26	0.99	0.99	1.26	0.09	0.18	0.81

Table 3.12 Regional variations of rounds/km^2 and incidence in the pre-war period (1995-1998) and the two post-war periods (2000-2003 and 2012-2015)

Increase in HM continued over the 15 post-war years. This was reflected in big differences seen in incidence rates between the pre-war (1995–1998) and the last post-war period (2012–2015). Throughout the Kosovo region, HM combined increased by 3.19 cases/100,00 persons (82%). When analysed by regions, we found that the largest increase of incidence of HM combined occurred in Gjakova and Peja, with the largest difference seen in leukaemia and NHL. Prizren was the region with the largest increased incidence of HL and MM. The smallest increase of incidence of HM combined was found in Prishtina and Gjilan.

To date, this is the first study which analyses incidence of four broad categories of HM—leukaemia, NHL, HL and MM in Kosovo for a period of twenty years (1995–2015). In Kosovo the most frequent type of HM was leukaemia, which was similar to that seen in most other SEE countries—Albania, Greece, BiH, Macedonia, Serbia and Montenegro, excluding Slovenia and Croatia where the most frequent type of HM was NHL (39).

Similar to other SEE countries and estimates for Albania, Greece, Macedonia and Montenegro(39), incidence of all HM in Kosovo were higher in males than in females. Age of diagnosis of HM varies across different world regions. In western countries HM usually affects older people, whereas in Asia it is diagnosed at younger ages (40–42). The decline in incidence rates of HM in Kosovo occurred earlier than in other SEE countries, presumably as a result of shorter longevity (life expectancy 71.65 years) (43).

Incidence rates of HM vary widely by geographic location suggesting different etiological factors, and, in general, are higher in more developed countries (39,44). Compared to other SEE countries (39), Kosovo had the lowest ASR of all HM, except for NHL and MM which were higher only compared to Albania. It is known that higher national income and healthcare budgets are associated with the higher cancer incidences (45). From that perspective, low incidence rates of HM in Kosovo may be explained by the fact that it is lower-middle-income country (46) with a poor healthcare system and variations in malignancy detection. Whereas, a possible explanation for the low incidence of lymphomas can be the low incidence of HIV infection in this country (47) which is known as a risk factor for lymphomas (48–51).

Although the results of the present study demonstrate that the incidence of all HM in Kosovo was lower than in other countries, in the 20-year period, the incidence rate increased more compared to other countries. Also, in general, in Western countries the overall incidence of HM appears to be rising (52). In SEE countries some HM showed increase in incidence rates and others decrease in incidence. For example, in Slovenia, the CR of leukaemia increased by 28.1% in 2012 compared to annual average CR in period 1995–1998, NHL by 78.2%, MM by 94.5% whereas HL decreased by 19.5%. In Croatia, the annual crude rate of NHL increased by 29.3% in 2012 relative to average annual CR in period 2001–2004, MM by 5.9% whereas leukaemia and HL decreased by 8.1% and 11.5% respectively (44). The larger increase in incidence of HM in Kosovo may partly be due to improvements in diagnostic procedures and the increase in longevity, but also may reflect a true increase in disease occurrence. Due to the fact that Kosovo is the most heavily afflicted region by DU pollution in the Balkans (15), possibility of DU toxicity and radiation effects on inhabitants cannot be ruled out, although it is far from being proven.

Analysis of pre-war incidence rates show that the lowest incidence rates of HM combined were in the two regions most exposed to DU ordnance (Gjakova and Peja), whereas highest incidence rates were encountered in the regions with low exposure to DU ordnance (Prishtina and Mitrovica). Prishtina and Mitrovica are considered to be the most polluted regions in Kosovo, due to the presence of polluting industries which is one of the factors explaining the pre-war difference in incidence of HM between regions. The Mitrovica region is known as one of the most polluted areas in Europe by several toxic heavy elements such as Pb, Zn, As and Cd, as a consequence of a lead processing industry which operated until the year 2000 (53–55). Also, a study by Di Lella et al. in 2001 showed that levels of uranium analysed in lichens from Mitrovica were higher than in other regions of Kosovo, suggesting contamination of thalli by terrigenous material and not by DU contamination of the environment (55). On the other hand, in the region of Prishtina there are coal power plants which are the largest point source of air pollution in Europe (56). In a study by Kittner et al. significant trace metal content—Ni, Cr, Hg, As was found in lignite coal from Obiliq municipality (12 km far from Prishtina) (56). Knowing that high exposure to methylmercury is associated with leukaemia (57,58) and that there were suggestions that Ni would be an etiological factor for leukaemia (59), it is possible that higher incidence rates of leukaemia in pre-war and post-war period in Prishtina, could be partially attributed to environmental pollution by these heavy metals. Despite the fact that before and after the war Mitrovica and Prishtina were regions with the highest incidence of HM, the differences in incidence between the pre-war period and the first and last post-war period, were highest in the two least polluted regions of Kosovo, but with most DU ordnance expended per km^2—in Gjakova and Peja. On the other hand, two regions with the least number of rounds/km2, Prishtina and Gjilan, in the first and last post-war period had a decrease in incidence of HM.

If we take into account that DU can enter the body by ingestion (food and water), increased levels of uranium into the water could pose risk for population. After the war in Kosovo, several research groups analysed uranium water concentration. In a study done in the Region of Gjakova in 2001 by Mellini and Riccobono, uranium levels analysed in 247 wells showed normal values(60). On the other hand, in a study done in 2014 by Berisha et al. which analysed 951 water samples, mainly in central and eastern part of Kosovo, only 2.6% of samples exceeded the World Health Organization maximum acceptable concentration of 30 µgL/1, and 44.2% of the samples exceeded the 2 µgL/1. German maximum acceptable concentrations recommended for infant food preparations (61). Whereas immediately after the war levels of uranium in water were within normal values, high contamination of soil samples taken in battlefield areas in southwest Kosovo(6,7,13,62) was found, which could enter the food chain. However, it is not possible to conclusively attribute this findings because we have assessed the exposure to DU at the municipality level and not individual level, and due to the fact that DU is not considered as a human carcinogen(63). Namely, uranium is not very radioactive (having such a long half-life of billions of years, 238U decays very slowly), and its chemical properties are often such that any inhaled or ingested uranium is excreted rather quickly from the body(64).

Nonetheless, there are several contradictory studies about DU effect on the risk of occurrence of cancers among them leukaemia and lymphomas. A small number of studies show the increased risk (25, 26), whereas a huge number of epidemiological studies provide no consistent evidence that uranium causes leukaemia or lymphoma such are occupational studies of workers exposed to uranium for many years, studies of cancer mortality and cancer incidence among people who have lived near uranium mills, mines and processing facilities and studies of military participants and peacekeepers (64,65–68).

Whilst this study is the first of its kind in Kosovo, there are several limitations. Firstly, there were no cancer registry data in Kosovo for the period analysed, so data were collected from patient registries and records. Secondly, deficiencies in demographic data required us to resort to estimates of resident populations for the period 1995–2010 which may not always be accurate. Since it was not possible to estimate data by age groups for this period, the crude rates were used instead of age-standardized rates. Thirdly, four Kosovo municipalities constituting around 9% of the territory were excluded from this study due to the fact that populations living in those areas do not seek medical treatment at UCCK.

Taking into account information from another source (Kosovo-Online.com), every year, the number of cancer patients in Kosovo increases by 10 to 15 percent. The director of the Oncology Clinic at the University Clinical Center of Kosovo in Pristina Ilir Kurtishi, said for Kosovo Online (6 November, 2023, source: Kosovo online), warning that the number of cancer patients this year could reach up to 2,500. Dr. Kurtishi also says that the Oncology Clinic in Pristina sees around 450 to 500 patients per day, with about 300 people currently receiving chemotherapy and over 170 individuals undergoing radiotherapy. Citation: "In Kosovo, breast cancer is the most dominant cancer among women. More than 400 women are diagnosed annually, and there are four to five cases in men. In men, lung cancer is the most prevalent. In the second position, we have colon cancer in both men and women, followed by tumours in the genital organs - uterus, ovaries, and cervix", Kurtishi explains. When asked whether the number of cancer patients had increased after the 1999 bombing, Kurtishi emphasized that the Oncology Clinic had been opened in 2010, and they did not have data from before that time. Head of the Department of Radiotherapy at the Clinical Hospital Center's Oncology Clinic in Pristina, points out that over 20 years have passed since the bombing, and no direct impact on the occurrence of malignant diseases has been proven.

Citation: "It is certain that the bombing had an impact on the increased incidence, but it has been more than 20 years since 1999. There are many other external factors that affect us and our health, such as pollution, water, soil, and the use of chemicals in agriculture. I think those are more significant reasons for the occurrence of malignant diseases than the bombing, which has never been proven. It is certainly not good, but it has not been proven whether it directly causes a higher number of malignant diseases now, many years have passed, so I would not connect it with that, we attribute all of this to the time of COVID. We had two years when patients did not come for check-ups, so I think there are a few more now accordingly", Blakaj said and claims, that the number of cancer patients has been increasing in the last two years.

The director of the "Donja Gusterica" Health Center, confirms that the number of cancer patients in Serbian communities in Kosovo is also on the rise and simply by working in primary healthcare, the doctors communicate with the Republic Health Insurance Fund, and based on the number of patients they refer to institutions in central Serbia where they receive treatment, notice that this number is increasing, larger than before. not want to speculate whether the increase in the number of cancer patients in Kosovo is related to the 1999 bombing, explaining that this is a matter for experts.

Citation: "There are studies that suggest the increase in cancer patients occurred after the bombing, i.e., after the high concentration of uranium in the air. We know that radiation is one of the risk factors for cancer development. So, there may be some correlation regarding the increase in the number of patients", Dr. Mladenovic points out and provides similar data as the Albanian experts.

The incidence of cancer in Kosovo following the Yugoslav Wars and NATO bombing campaigns has been a subject of concern and ongoing study. While direct causality between the conflicts and cancer rates is difficult to establish conclusively, there are several notable observations and conclusions:

1. Environmental contamination: The use of depleted uranium ammunition by NATO forces during the bombing campaigns raised significant concerns about environmental contamination in Kosovo. Depleted uranium is radioactive and has the potential to cause long-term health effects, including cancer, through exposure to radioactive particles.
2. Health impacts: Studies have indicated a potential correlation between the use of depleted uranium and an increase in cancer rates and other health problems among populations exposed to the aftermath of the conflict. However, establishing a direct causal link remains challenging due to various confounding factors and limitations in data collection and analysis.
3. Complexity of factors: Cancer incidence is influenced by multiple factors, including genetics, lifestyle, environmental exposure, and healthcare infrastructure. While the conflicts and bombing campaigns may have contributed to environmental contamination and stressors on healthcare systems, other factors also play significant roles in cancer development and prevalence.
4. Public health concerns: Regardless of direct causality, the potential health impacts of environmental contamination and exposure to hazardous materials in post-conflict regions like Kosovo underscore the importance of ongoing monitoring, research, and public health interventions to mitigate risks and support affected populations.

To date, the pioneering study of HM incidence analysis in Kosovo showed an increase by 3.19 cases/100,000 persons (82%) between the 20 years period of 1995–2015. The differences of HM incidence between pre and post war periods were higher in two regions with most DU rounds/km^2 expended. Despite these findings, this does not lead us to conclusive findings on the existence of causal relationship between the use of DU during the war and the rise in incidence of HM in Kosovo. So, further studies need to take place in specific regions of Kosovo to come to conclusive findings.

Conclusion

While the exact relationship between pre and post-war period and cancer incidence in Kosovo as directly involved and North Macedonia as neighbouring country, remains complex and multifaceted, there are legitimate concerns regarding environmental contamination and potential health effects. Continued research, monitoring, and support for affected communities are essential to address these challenges and safeguard public health in post-conflict regions. By prioritizing research, monitoring, and support for affected communities, policymakers, healthcare professionals, and international organizations can work together to address the complex health challenges faced by populations in post-conflict regions like Kosovo and neighbouring country North Macedonia, including concerns about cancer incidence following conflicts and bombing campaigns.

The purported link between the Yugoslav Wars and NATO bombings and cancer rates in North Macedonia and Kosovo is a complex and contentious issue. While some individuals and groups have suggested a correlation between the use of depleted uranium munitions during the NATO bombings in 1999 and subsequent health issues, including cancer, there is no definitive scientific consensus confirming a causal relationship. Factors such as limited data availability, methodological challenges, and confounding variables make it challenging to establish a direct link between the bombings and increased cancer rates. Furthermore, cancer is a multifactorial disease influenced by various genetic, environmental, and lifestyle factors. Therefore, attributing cancer cases solely to military actions or environmental contamination is often difficult without rigorous epidemiological evidence. In conclusion, while concerns about the health impact of the Yugoslav Wars and NATO bombings on the populations of North Macedonia and Kosovo are understandable, conclusive evidence establishing a causal link between these events and increased cancer rates remains lacking. Further research and comprehensive studies are necessary to fully understand the potential health consequences of past conflicts in the region.

References:

1. Avis R, Causes and consequences of air pollution in North Macedonia. K4D Helpdesk Report. Institute of Development Studies. DOI:10.19088/K4D.1395. 2022.
2. Anttila P, Characterization of extreme air pollution episodes in an urban valley in the Balkan Peninsula. Air Qual Atmos Health. 2016. Available from: https://link.springer.com/article/10.1007/s11869-015-0326-7
3. Civil Society Forum. Green Agenda: Air Pollution. 2020. Available from: https://wb-csf.eu/docs/CSF_Paper_WG-F.pdf.pdf
4. Dimovska M, Gjorgjev D, Assessing Health Impact of Air Pollution in Macedonian Cities. Biomedical Journal of Scientific and Technical Research, 10 (1). 2018. Available from: http://dx.doi.org/10.26717/BJSTR.2018.10.001887
5. Dimovska M, & Gjorgjev D, (2020). The Effects of COVID-19 Lockdown on Air Quality in Macedonia. Open Access Maced J Med Sci. 2020 Oct 26; 8(T1):353-362. Available from https://doi.org/10.3889/oamjms.2020.5455
6. EBRD. North Macedonian Diagnostic. EBRD. 2019 Available from: https://www.ebrd.com/documents/north-macedonia-country-diagnostic.pdf
7. EC. Status of air pollutants and greenhouse gases in the Western Balkans Benchmarking the accession process progress on environment. EC. 2020 Available from: https://publications.jrc.ec.europa.eu/repository/handle/JRC11867920
8. EEA (2021) North Macedonia – air pollution country fact sheet. EEA. Available from : https://www.eea.europa.eu/themes/air/country-fact-sheets/2021-country-fact-sheets/north-macedonia-air-pollution-country
9. Haq G, & Schwela D, (2008). Foundation Course on Air Quality Management in Asia. Asia Foundation. Available from : https://www.sei.org/publications/foundation-course-air-quality-management-asia/
10. IQ Air (2021). World Air Quality Report. IQ Air. Available from :https://www.iqair.com/world-most-polluted-cities/world-air-quality-report-2021-en.pdf
11. Landrigan PJ, et al. (2017). The Lancet Commission on Pollution and Health. Lancet. 391:10119. Available from : https://doi.org/10.1016/S0140-6736(17)32345-0
12. Martinez G, et al. (2018). Health Impacts and Economic Costs of Air Pollution

in the Metropolitan Area of Skopje. International Journal of Environmental Research and Public Health. 15 (4). Available from https://doi.org/10.3390/ijerph15040626
13. Meisner C, et al. (2015). Estimating health impacts and economic costs of air pollution in the Republic of Macedonia. SEEJPH. Available from: https://d-nb.info/1212967860/34
14. Ministry of Environment and Physical Planning (MoEPP) (2017). Macedonian Air Aq
uality Assessment Report for the Period 2005-2015. MoEPP. Available from: https://air.moepp.gov.mk/wp-content/uploads/2017/07/AirQualityReport_EN.pdf
15. OECD (2022). Multi-dimensional review of the West Balkans: Assessing Opportunities and Constraints. OECD. Available from: https://www.oecd-ilibrary.org/sites/e232493b-en/index.html?itemId=/content/component/e232493b-en
16. Seinfeld J, & Pandis, S. (2016). Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, 3rd Edition. Wiley
17. Spiridonov V,.et al. (2021). Improvement of chemical initialization in the air quality forecast system in North Macedonia, based on WRF-Chem model. Air Quality, Atmosphere & Health volume 14. Available from:https://doi.org/10.1007/s11869-020-00933-4
18. State Statistical Office (2015). Energy Consumption in Households. State Statistical Office. Available from: https://www.stat.gov.mk/Publikacii/6.4.15.03.pdf
19. Thurston G, et al., (2016). Ambient Particulate Matter Air Pollution Exposure and Mortality in the NIH-AARP Diet and Health Cohort. Environ Health Perspect. 124. 484-490. Available from: https://ehp.niehs.nih.gov/wp-content/uploads/124/4/ehp.1509676.alt.pdf
20. Vidoeski S, (2021). North Macedonia: Energy Transition and Democracy. Heinrich Böll Stiftung. Available from: https://ba.boell.org/sites/default/files/2021-03/RESEARCH%20PAPER_North%20Macedonia%20-%20Energy%20Transition%20and%20Democracy.pdf
21. World Bank (2019). Western Balkans Regional AQM - Western Balkans Report – AQM in North Macedonia. World Bank. Available from :https://openknowledge.worldbank.org/bitstream/handle/10986/33042/Air-Quality-Management-in-North-Macedonia.pdf?sequence=5&isAllowed=y

22. Cancer in The Republic of North Macedonia. Msc. d-r Rechica.V - Head of the Health Data Department 2010-2019, IPH 2020, Health Data Department, Institute for Public Health of The Republic of North Macedonia, Available from :www.iph.mk
23. Health Map of The Republic of North Macedonia, 2021, I Part, Status in republic of North Macedonia, PHO Institute for Public Health of The RNM – SKOPJE Director Doc. d-r Shaban MEMETI .Department of Health Data and publication M-r d-r Recica V, , Available from :www.iph.mk
24. Department part of Institute of Public Health of the Republic of Macedonia from data obtained from the Cancer of the Republic of North Macedonia. Available from: www.iph.mk
25. Bleise A, Danesi PR, Burkart W, Properties, use and health effects of depleted uranium (DU): A general overview. J Environ Radioact. 2003;64(2–3):93–112. 10.1016/s0265-931x(02)00041-3
26. International physicians for the prevention of nuclear war—physicians for social responsibility and International Coalition to Ban Uranium Weapons Report: The health effects of nuclear weapons—The social debate on the use of a controversial weapon. 2014 August.
27. Data concerning the locations of depleted uranium ordnance expended during Operation Allied Force (grid co-ordinates) [Internet]. Available from :https://www.nato.int/du/docu/d010124a.htm
28. Nato confirms to United Nations use of Depleted Uranium during Kosovo conflict | Meetings Coverage and Press Releases [Internet]. 2001. Available from :https://www.un.org/press/en/2000/20000322.hab163.doc.html
29. Depleted Uranium in Kosovo. Post-Conflict Environmental Assessment. UNEP [Internet]. 2001. Available from :https://postconflict.unep.ch/publications/uranium.pdf
30. Carvalho FP, Oliveira JM, Uranium isotopes in the Balkan's environment and foods following the use of depleted uranium in the war. Environ Int. 2010;36(4):352–60. 10.1016/j.envint.2010.02.003
31. Danesi PR, Bleise A, Burkart W, Cabianca T, Campbell MJ, Makarewicz M, et al. Isotopic composition and origin of uranium and plutonium in selected soil samples collected in Kosovo. J Environ Radioact. 2003;64(2–3):121–31. 10.1016/s0265-931x(02)00043-7
32. Danesi PR, Markowicz A, Chinea-Cano E, Burkart W, Salbu B, Donohue D, et al. Depleted uranium particles in selected Kosovo samples. J Environ Radioact. 2003;64(2–3):143–54. 10.1016/s0265-931x(02)00045-0

33. Di Lella LA, Nannoni F, Protano G, Riccobono F. Uranium contents and 235U/238U atom ratios in soil and earthworms in western Kosovo after the 1999 war. Sci Total Environ. 2005;337(1–3):109–18. 10.1016/j.scitotenv.2004.07.001
34. Di Lella LA, Frati L, Loppi S, Protano G, Riccobono F. Lichens, as biomonitors of uranium and other trace elements in an area of Kosovo heavily shelled with depleted uranium rounds. Atmos Environ. 2003;37(38):5445–9.
35. Jia G, Belli M, Sansone U, Rosamilia S, Gaudino S. Concentration, distribution and characteristics of depleted uranium (DU) in the Kosovo ecosystem: A comparison with the uranium behavior in the environment uncontaminated by DU. J Radioanal Nucl Chem. 2004;260(3):481–94.
36. Sansone U, Stellato L, Jia G, Rosamilia S, Gaudino S, Barbizzi S, et al. Levels of depleted uranium in Kosovo soils. Radiat Prot Dosimetry. 2001;97(4):317–20. 10.1093/oxfordjournals.rpd.a006679
37. Sansone U, Roberto Danesi P, Barbizzi S, Belli M, Campbell M, Gaudino S, et al. Radioecological survey at selected sites hit by depleted uranium ammunitions during the 1999 Kosovo conflict. Sci Total Environ. 2001;281(1–3):23–35. 10.1016/s0048-9697(01)01034-8
38. Uyttenhove J, Lemmens M, Zizi M. Depleted Uranium in Kosovo: Results of a Survey By Gamma Spectrometry on Soil Samples. Health Phys. 2002;83(4):543–8. 10.1097/00004032-200210000-00014
39. Besic L, Muhovic I, Asic A, Kurtovic-Kozaric A. Meta-analysis of depleted uranium levels in the Balkan region. J Environ Radioact. 2017;172:207–17. 10.1016/j.jenvrad.2017.03.013
40. Burkart W, Danesi PR, Hendry JH, Properties, use and health effects of depleted uranium. Int Congr Ser. 2005;1276:133–6.
41. Faa A, Gerosa C, Fanni D, Floris G, Eyken PV, Lachowicz JI, N V. Depleted Uranium and Human Health. Curr Med Chem. 2016;25(25):49–64.
42. 44. Hao Y, Ren J, Liu J, Yang Z, Liu C, Li R, et al. Immunological changes of chronic oral exposure to depleted uranium in mice. Toxicology. 2013;309:81–90. 10.1016/j.tox.2013.04.013
43. Asic A, Kurtovic-Kozaric A, Besic L, Mehinovic L, Hasic A, Kozaric M. Chemical toxicity and radioactivity of depleted uranium: The evidence from in vivo and in vitro studies. Environ Res. 2017;156(May):665–73.
44. Miller AC, Stewart M, Rivas R. DNA methylation during depleted uranium-induced leukemia. Biochimie. 2009;91(10):1328–30. 10.1016/j.biochi.2009.03.010

45. Miller AC, McClain D. A review of depleted uranium biological effects: in vitro and in vivo studies. Rev Environ Health. 2007;22(1):75–89. 10.1515/reveh.2007.
46. Al-dujaily EA, Al-janabi AA, Pierscionek T, Yasseen AA. High prevalence of HER-2 / neu overexpression in female breast cancer among an Iraqi population exposed to depleted uranium. J Carcinog. 2008;7:8 10.4103/1477-3163.44026
47. Krunić A, Haverić S, Ibrulj S. Micronuclei frequencies in peripheral blood lymphocytes of individuals exposed to depleted uranium. 2019;56(3):16180607.
48. Shelleh HH, Depleted Uranium. Is it potentially involved in the recent upsurge of malignancies in populations exposed to war dust? 2012;33(5): 483–8.
49. Busby C, Hamdan M, Ariabi E. Cancer, infant mortality and birth sex-ratio in Fallujah, Iraq 2005–2009. Int J Environ Res Public Health. 2010;7(7):2828–37. 10.3390/ijerph7072828
50. Peragallo MS, Lista F, Sarnicola G, Marmo F, Vecchione A. Cancer surveillance in Italian army peacekeeping troops deployed in Bosnia and Kosovo, 1996–2007: Preliminary results. Cancer Epidemiol. 2010;34(1):47–54. 10.1016/j.canep.2009.12.014
51. Al-Hamzawi AA, Jaafar MS, Tawfiq NF. Uranium concentration in blood samples of Southern Iraqi leukemia patients using CR-39 track detector. J Radioanal Nucl Chem. 2014;299(3):1267–72. 10.1007/s10967-013-2808-0
52. Strand LA, Martinsen JI, Borud EK. Cancer risk and all-cause mortality among Norwegian military United Nations peacekeepers deployed to Kosovo between 1999 and 2011. Cancer Epidemiol. 2014;38(4):364–8. 10.1016/j.canep.2014.04.003 Avaialable from:
53. Gustavsson P, Talbäck M, Lundin A, Lagercrantz B, Gyllestad P-E, Fornell L. Incidence of cancer among Swedish military and civil personnel involved in UN missions in the Balkans 1989–99. Occup Environ Med. 2004;61(2):171–3. 10.1136/oem.2002.005538
54. Oeh U, Priest ND, Roth P, Ragnarsdottir K V., Li WB, H??llriegl V, et al. Measurements of daily urinary uranium excretion in German peacekeeping personnel and residents of the Kosovo region to assess potential intakes of depleted uranium (DU). Sci Total Environ. 2007;381(1–3):77–87. 10.1016/j.scitotenv.2007.03.024
55. Storm HH, Jorgensen HO, Kejs AMT, Engholm G. Depleted uranium and

cancer in Danish Balkan veterans deployed 1992–2001. Eur J Cancer. 2006;42(14):2355–8. 10.1016/j.ejca.2006.01.064
56. Bogers RP, van Leeuwen FE, Grievink L, Schouten LJ, Kiemeney LALM, Schram-Bijkerk D. Cancer incidence in Dutch Balkan veterans. Cancer Epidemiol. 2013;37(5):550–5. 10.1016/j.canep.2013.04.005
57. IWPR Balkans. Global voices Balkan. Frikë nga Uraniumi i Varfëruar në Kosovë. 2001; Februar. [Internet] Available from: https://iwpr.net/sq/global-voices/frikë_nga_uraniumi_i_varfëruar_në_Kosovë.
58. Administrative Instruction No.05/2012 Supervision of professional ethics [Internet]. Available from: https://msh.rks-gov.net/wp-content/uploads/2013/11/Udhezim-Administrativ-05-2012.pdf
59. Kosovo RK. Law No. 03/L-172 on Protection of the Personal Data. (03):1–44.
60. Kosovo Agency of Statistics Database, Census 2011 [Internet]. http://askdata.rks-gov.net/PXWeb/pxweb/en/askdata/?rxid=dad1d6c2-3144-40cb-b853-14c152c52bbc
61. Depleted Uranium Engagement Points 6 Apr 99–10 Jun 99 [Internet].Available from: https://www.nato.int/du/home.htm
62. Kosovo Agency of Statistics. Kosovo Population Projection 2011–2061 [Internet]. 2013. Available from:https://ask.rks-gov.net/rekos2011/repository/docs/KOSOVO_POPULATION_PROJECTION_2011-2061.pdf
63. EUCAN, Cancer factsheets, 2012 [Internet]. Availble from:http://eco.iarc.fr/eucan
64. Smith A, Howell D, Patmore R, Jack A, Roman E. Incidence of haematological malignancy by sub-type: a report from the Haematological Malignancy Research Network. Br J Cancer. 2011;105(11):1684–92. 10.1038/bjc.2011.450
65. Hossain MS, Iqbal MS, Khan MA, Rabbani MG, Khatun H, Munira S, et al. Diagnosed hematological malignancies in Bangladesh—A retrospective analysis of over 5000 cases from 10 specialized hospitals. BMC Cancer. 2014;14(1).
66. Elidrissi Errahhali M, Elidrissi Errahhali M, Boulouiz R, Ouarzane M, Bellaoui M. Distribution and features of hematological malignancies in Eastern Morocco: A retrospective multicenter study over 5 years. BMC Cancer. 2016;16(1):1–10.
67. The World Bank. Life expectancy at birth, total (years) | Data [Internet].Available

from: https://data.worldbank.org/indicator/SP.DYN.LE00.IN?view=chart
68. ECIS—European Cancer Information System [Internet]. https://ecis.jrc.ec.europa.eu
69. Ades F, Senterre C, de Azambuja E, Sullivan R, Popescu R, Parent F, et al. Discrepancies in cancer incidence and mortality and its relationship to health expenditure in the 27 European Union member states. Ann Oncol. 2013;24(11):2897–902. 10.1093/annonc/mdt352
70. World Bank list of economies [Internet]. 2014.Available from: http://www.iawp.org/joiniawp/countrylist.htm
71. Kosovo Agency of Statistics—KAS. Seria 5: Statistikat Sociale Statistikat e Arsimit 2012–2013; Available from : http://ask.rks-gov.net/arsimi/publikimet/doc_view/1120-statistikat-e-arsimit-2012-2013?tmpl=component&format=raw
72. Shiels MS, Cole SR, Kirk GD, P C. A meta-analysis of the incidence of non-AIDS cancers in HIV-infected individuals. J Acquir Immune Defic Syndr. 2010;52:(5):611–22.
73. Shiels MS, Pfeiffer RM, Gail MH, Hall HI, Li J, Chaturvedi AK. Cancer Burden in the HIV-Infected Population in the United States. J Natl Cancer Inst. 2011;103(9):753–62. 10.1093/jnci/djr076
74. Grulich AE, van Leeuwen MT, Falster MD, V C. Incidence of cancers in people with HIV/AIDS compared with immunosuppressed transplant recipients: a meta-analysis. Lancet. 2007;370(958):59–67.
75. Schneider E, Whitmore S, Glynn KM, Dominguez K, Mitsch A MMC for DC and P (CDC). Revised surveillance case definitions for HIV infection among adults, adolescents, and children aged < 18 months and for HIV infection and AIDS among children aged 18 months to < 13 years—United States, 2008. MMWR Recomm Rep. 2008. December 5;57(RR-10):1–12.
76. Rodriguez-Abreu D, Bordoni A, Zucca E. Epidemiology of hematological malignancies. Ann Oncol. 2007;18 Suppl 1:i3–i8.
77. Borgna L, Di Lella LA, Nannoni F, Pisani A, Pizzetti E, Protano G, et al. The high contents of lead in soils of northern Kosovo. J Geochemical Explor. 2009;101(2):137–80.
78. Brown MJ, McWeeney G, Kim R, Tahirukaj A, Bulat P, Syla S, et al. Lead poisoning among internally displaced Roma, Ashkali and Egyptian children in the United Nations-Administered Province of Kosovo. Eur J Public Health. 2010;20(3):288–92. 10.1093/eurpub/ckp164
79. Di Lella LA, Frati L, Loppi S, Protano G, Riccobono F. Environmental

distribution of uranium and other trace elements at selected Kosovo sites. Chemosphere. 2004;56(9):861–5. 10.1016/j.chemosphere.2004.04.036
80. Kittner N, Fadadu RP, Buckley HL, Schwarzman MR, Kammen DM. Trace Metal Content of Coal Exacerbates Air-Pollution-Related Health Risks: The Case of Lignite Coal in Kosovo. Enviormental Sci Technol. 2018;52(4):2359–67.
81. U.S. Environmental Protection Agency NC for EA. Methylmercury (MeHg); CASRN 22967-92-6 [Internet]. Available from: https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0073_summary.pdf
82. Yorifuji T, Tsuda T, Kawakami N. Age standardized cancer mortality ratios in areas heavily exposed to methyl mercury. Int Arch Occup Env Heal. 2007;80(8):679–88.
83. Yang Y, Jin X, Yan C, Tian Y, Tang J, Shen X. Urinary level of nickel and acute leukaemia in Chinese children. Toxicol Ind Heal. 2008;24(9):603–10.
84. Mellini M, Riccobono F. Chemical and mineralogical transformations caused by weathering in anti-tank du penetrators ("the silver bullets") discharged during the Kosovo war. Chemosphere. 2005;60(9):1246–52. 10.1016/j.chemosphere.2005.02.005
85. Berisha F, Goessler W. Uranium in Kosovo ' s drinking water. Chemosphere. 2013;93(9):2165–70. 10.1016/j.chemosphere.2013.07.078
86. Schimmack W, Gerstmann U, Schultz W, Geipel G. Long-term corrosion and leaching of depleted uranium (DU) in soil. Radiat Environ Biophys. 2007;46(3):221–7. 10.1007/s00411-007-0114-3
87. International Agency for Rsearch on Cancer. Agents Classified by the IARC Monographs, Volumes 1–123 2016. p. 1–37.
88. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Effects of Ionizing Radiation. UNSCEAR 2006 Report to the General Assembly with Scientific Annex A. Epidemiological studies of radiation and cancer. New York, United Nation; 2008;
89. Boice JD, Cohen SS, Mumma MT, Chadda B, Blot WJ. A cohort study of uranium millers and miners of Grants, New Mexico, 1979–2005. J Radiol Prot. 2008;28(3):303–25. 10.1088/0952-4746/28/3/002
90. Institute of Medicine (IOM). Committee on Gulf War and Health: Updated Literature Review of Depleted Uranium Gulf War and Health: Updated Literature Review of Depleted Uranium. Washington, DC: National Academy Press; 2008.

91. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources, Effects and Risks of Ionizing Radiation. UNSCEAR 2016. Report to the General Assembly Volume 1 Scientific Annex D. Biological Effects of Selected Internal Emitters—Uranium. Publ E.17.IX.1. New York, United Nations; 2017.
92. Strand LA, Martinsen JI, Borud EK. Cancer risk and all-cause mortality among Norwegian military United Nations peacekeepers deployed to Kosovo between 1999 and 2011. Cancer Epidemiol. 2014;38(4):364–8. 10.1016/j.canep.2014.04.003

4. Ukrainian Perspective (DNIPRO)

Literature review of evidence from military conflicts' impact on pollution and cancer epidemiology

Introduction

The relevance of the problem of air pollution's negative impact on health in Ukraine compared to other countries before the onset of full-scale invasion

Even though over almost 30 years (from 1990 to 2019), air pollution has shifted from the second to the fourth position in the ranking of risk factors - the main causes of death, it remains one of the leading threats to public health worldwide, with certain regional peculiarities. The regions most affected by air pollution are South Asia, Africa, and the Middle East, while the European region experiences a more favorable situation (5).

According to The State of Global Air report 2020 (6), prepared by the Health Effects Institute and the IHME's GBD project, the mortality rate from air pollution decreased by 29% from 1990 to 2019. However, mortality caused by ambient particulate matter increased by 40%.

$PM_{2.5}$ accounted for 4.14 million deaths (118 million years of healthy life lost); household air pollution accounted for 2.31 million deaths (91.5 million years of healthy life lost), and ozone accounted for about 365,000 early deaths (6.21 million years of healthy life lost).

The total GBD from air pollution in Ukraine in 2019 amounted to 2,322.66 disabilty-adjusted life years (DALYs) per 100,000 population (95% UI 1,451.7 - 3,279.68), which was higher compared to Figure 4.1. In comparison with neighbouring Moldova, the GBD from air pollution in Ukraine was higher by 52.9% ($p > 0.05$), compared to Romania, it was higher by 22.8% ($p > 0.05$). However, the GBD indicator from air pollution did not exceed global average values and did not fall into the zone of special attention, unlike the mortality rate from all causes associated with this risk factor, which in 2019 amounted to 104.74 (95% UI 65.99 - 148.56) per 100,000 population, exceeding the values in Moldova and Romania by 59.7% and 17.6%, respectively ($p>0.05$).

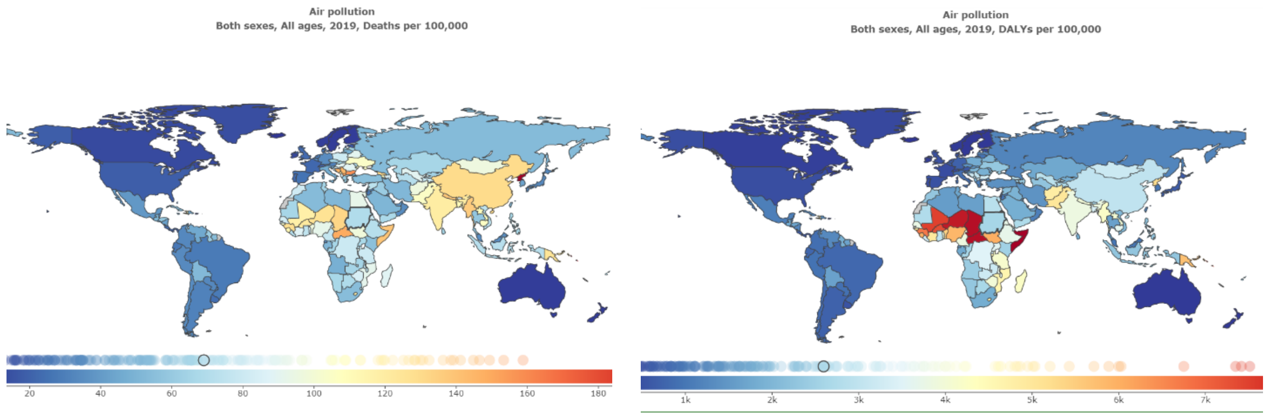


Figure 4.41 Air pollution is a significant cause of death and DALYs worldwide among the entire population of both genders for 2019, according to IHME data (7)

The health conditions most commonly affected by poor air quality are cardiovascular diseases (ischemic heart disease, stroke), respiratory diseases (lower respiratory infections, chronic obstructive pulmonary disorder), tracheal, bronchus and lung cancer, and type 2 diabetes mellitus (8).

The impact of polluted air is associated with the recurrence of many diseases, including cardiovascular, respiratory, digestive, musculoskeletal, and genitourinary disorders, as well as cancer (9).

The proportion of deaths from tracheal, bronchial, and lung cancer associated with outdoor air pollution by fine particles in 2019 worldwide was 15%, trailing behind chronic obstructive pulmonary disease (21%) and strokes (17%) (10). In Ukraine, neoplasms were the second leading cause of death, and despite overall downward trends, they accounted for 14.1% of the total number of deaths in 2019 (Figure 4.2).

In the structure of causes of death from tracheal, bronchial, and lung cancer, among men, it ranked first, and among women, it ranked fourth. Approximately one-third of cancer deaths were attributed to five main risk factors: body mass index, low consumption of fruits and vegetables, lack of physical activity, tobacco use, and alcohol consumption. Polluted air ranked eighth in the rating (11). The main source of pollution leading to increased mortality was indoor air pollution from coal combustion in stoves (10).

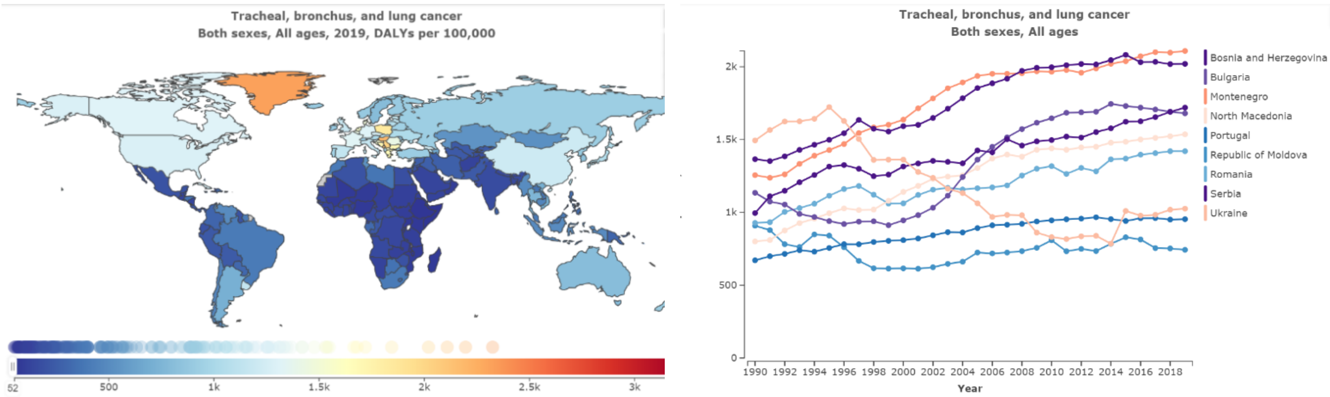


Figure 4.42 DALYs of the trachea, bronchus, and lung cancer worldwide in the total population of both sexes in 2019 according to IHME (7)

The highest mortality rates and GBD from tracheal, bronchial, and lung cancer associated with air pollution in 2019 were observed in Eastern Europe, particularly in Bosnia and Herzegovina, Serbia, and Montenegro (tab. 1). In Ukraine, the mortality rates and GBD were lower than global values by 18.0% and 5.8% respectively ($p > 0.05$), but exceeded the average values for Eastern Europe by 26.9% and 33.2% respectively ($p > 0.05$).

The Global Burden of Disease from Major Air Pollution Sources (GBD MAPS) project determined that 27.3% of the total mortality associated with $PM_{2.5}$ could be avoided by discontinuing the burning of fossil fuels, primarily coal (8,12).

The project State of Global Air, 2020 (https://www.stateofglobalair.org/) acknowledges the severity of the air pollution problem in Southeastern Europe due to high concentrations of $PM_{2.5}$, which significantly exceed regulations by the WHO limits (5 μg/m^3) (Figure 4.3), the mortality rate due to air pollution. The mortality rate due to air pollution in Southeastern Europe is nearly four times higher than in Western Europe, primarily due to energy poverty and the burning of fossil fuels (13–15). Air pollution was the 7th leading cause of death in Serbia in 2019; 10,500 deaths were linked to exposure to ambient $PM_{2.5}$. Of these, 27% or 2,841 deaths were linked to fossil fuel combustion (13).

Location	Deaths (Tracheal, bronchus, and lung cancer)		DALYs (Disability-Adjusted Life Years)	
	Rate	95% CI	Rate	95% CI
Albania	7.32	4.66 – 10.62	162.77	103.12 – 236.46
Belarus	4.4	2.73 – 6.56	111.16	68.29 – 165.89
Bosnia and Herzegovina	16.06	11.09 – 21.81	380.64	258.5 – 520.25
Bulgaria	10.41	7.09 – 14.42	262.81	178.44 – 363.65
Croatia	9.25	6.15 – 13.2	208.77	136.67 – 298.23
Czechia	7.1	4.85 – 9.96	151.91	103.24 – 213.72
Estonia	1.83	0.56 – 3.65	38.5	11.76 – 78.2
Hungary	12.72	8.59 – 17.71	300.94	202.34 – 418.31
Latvia	4.41	2.66 – 6.79	98.35	58.62 – 152.28
Lithuania	3.33	1.92 – 5.23	74.81	43.07 – 118.95
Montenegro	15.38	10.52 – 21.34	378.26	258.64 – 523.59
North Macedonia	12.86	8.84 – 17.81	331.63	225.92 – 462.09
Poland	13.57	9.56 – 18.37	308.12	217.02 – 419.12
Republic of Moldova	2.97	1.59 – 4.55	78.71	42.01 – 120.04
Romania	7.25	4.76 – 10.3	179.48	117.55 – 257.43
Russian Federation	2.91	1.51 – 4.52	72.11	37.08 – 112.53
Serbia	15.96	10.98 – 21.83	388.22	264.96 – 539.2
Slovakia	6.2	4.12 – 8.89	145.4	95.96 – 208.35
Slovenia	7.95	5.17 – 11.51	173.18	111.34 – 253.19
Ukraine	4.11	2.32 – 6.35	108.94	60.97 – 167.89
Eastern Europe	3.24	1.87 – 4.83	81.78	47.18 – 122.67
Global	5.01	3.72 – 6.33	115.7	86.34 – 146.59

Table 4.13 The frequency of deaths and GBD from tracheal, bronchial, and lung cancer associated with air pollution in 2019 in Eastern European countries per 100,000 population (7)

Despite a slow and decade-long decline in use, as of 2020, some 70.5% of Ukraine's energy needs were still met by fossil fuels. The war had a major negative impact on the production, processing, storage, and transit of fossil fuels (16).

It should be noted that the issue of active use of fossil fuels, particularly coal burning, is also acute in Ukraine. However, at present, it is difficult to trace it precisely because it is primarily characteristic of the occupied Donetsk and Luhansk regions, where there is extraction of these natural resources.

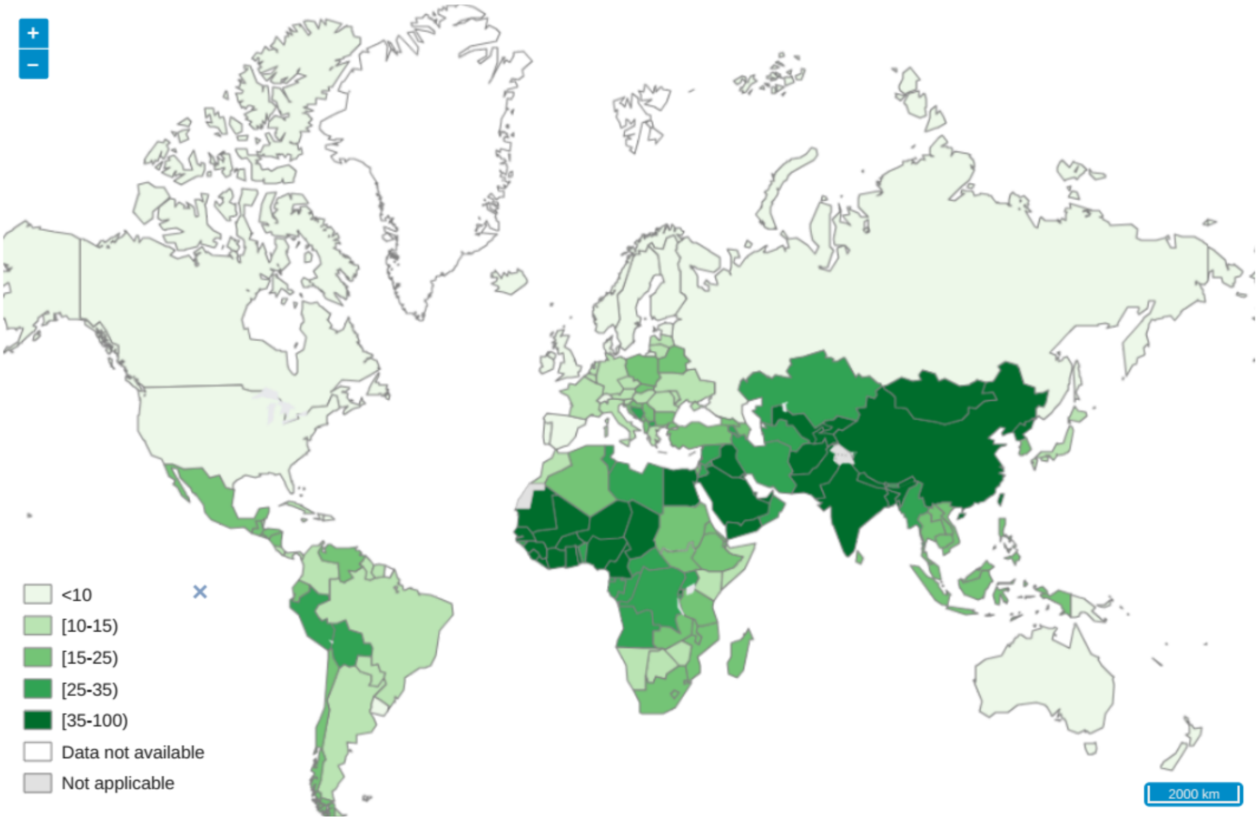


Figure 4.43 Concentrations of fine particulate matter ($PM_{2.5}$), 2019 (WHO 2024) (17)

The highest annual average of $PM_{2.5}$ exposures in 2019 was observed in North Macedonia at 30.3 (95 % CI 27.4 – 33.1) μg/m³, while Romania had the lowest exposure at 15.7 (95 % CI 12.7 – 16.9) μg/m³. In Ukraine, the indicator was lower, at 14.5 (95% CI 10.8 - 19.4) μg/m³, but still exceeded the recommended values by the WHO (6).

The standardized age-specific death rate per 100,000 population associated with $PM_{2.5}$ (Figure 4.4) In 2019, in Ukraine, the standardized age-specific death rate per 100,000 population associated with [the specific cause] was 56.7 (95% CI 34.9 - 82.4), which practically matched the global average. It was lower by 42.4% compared to North Macedonia and higher by 53.2% compared to Romania ($p>0.05$).

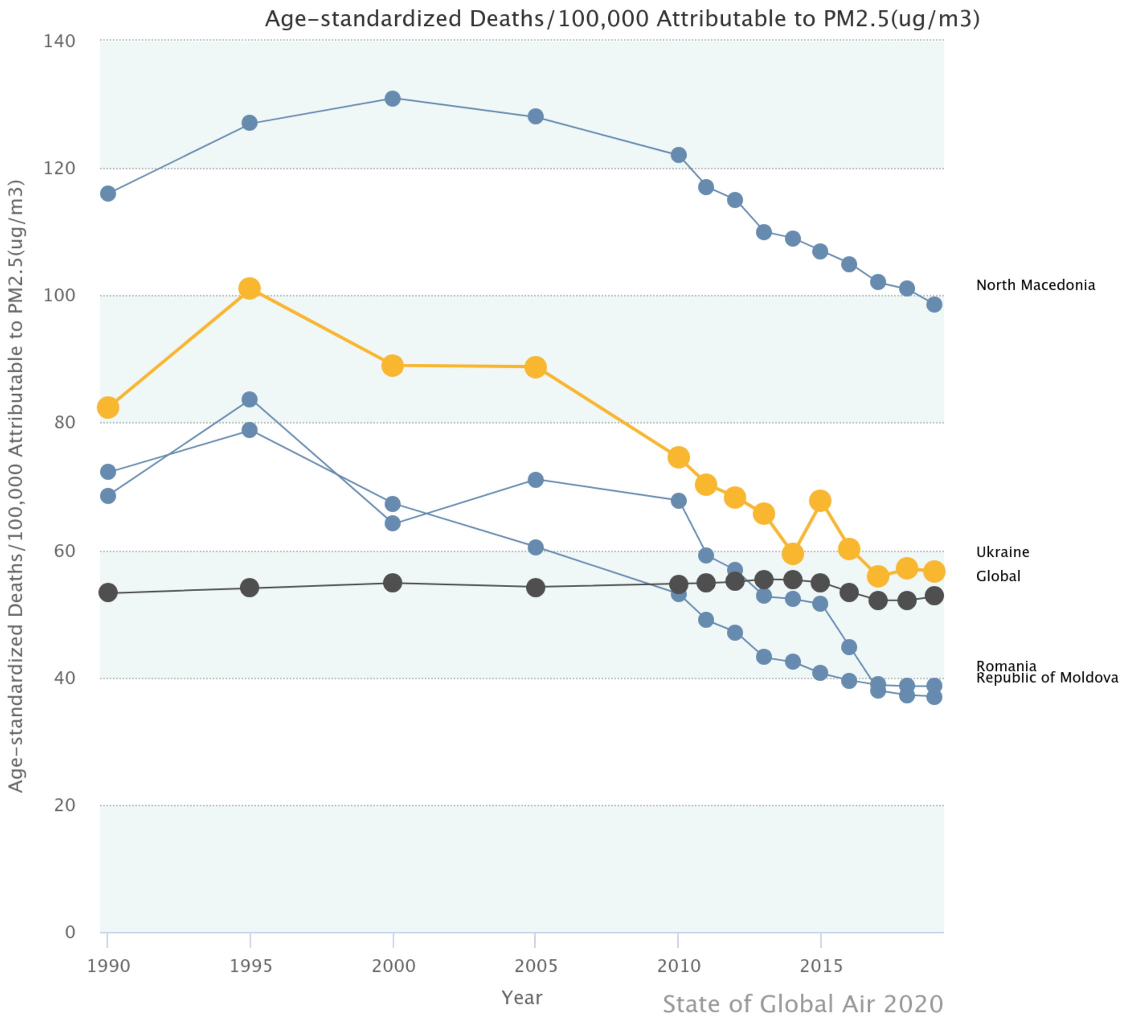


Figure 4.44 Standardized age-specific death rate per 100,000 population associated with $PM_{2.5}$ in Ukraine and specific European countries (7)

According to data from the Swiss technology company IQAir, which aggregates air quality data, Ukraine did not belong to the countries with high levels of air pollution (based on the indicator PPM). In 2022, however, there was an observed exceedance of 1 to 3 times the WHO recommended level of $PM_{2.5}$ at stations installed by the project in a limited number of cities (18).

According to the World Air Quality Index (AQI) Ranking, among the most polluted cities in Ukraine based on AQI, Kyiv ranks number 104, followed by Lutsk - 80, Ternopil - 74, Ivano-Frankivsk - 67, Khmelnytskyi - 67, Lviv - 64, Uzhgorod - 64, Chernivtsi - 60, Vinnytsia - 56, and Odesa - 46 (19). It should be noted that the ranking does not include large industrial cities in the eastern region, which may be explained by the small number of stations in these areas and the active burning of coal and wood for household purposes in the western regions of the country.

According to the Ambient Air Quality Database (WHO, April 2022), based on data from the O.M. Marzeiev Institute for Public Health of the National Academy of Medical Science of Ukraine, the annual average indicators in Kyiv were in 2018 - $PM_{2.5}$ 22.82 μg/m^3, PM_{10} 37.84 μg/m^3, and in 2019 - 23.36 and 31.19 μg/m^3, respectively (20).

The reasons for air pollution in Ukraine before active military actions

Residential (19.2%), industrial (11.7%), and energy production (10.2%) sectors are among the dominant global sources of emissions worldwide (8). Residential, agricultural, and ground transport emissions are calculated to be the largest three sectoral sources of $PM_{2.5}$-related health risks, accounting for 23.5%, 23.0%, and 19.4%, respectively, of total anthropogenic contributions within Europe (21).

In Ukraine, sources of air pollution and emissions of greenhouse gases include transportation, heat and power generation plants, mining, and processing industries, as well as coke chemical plants (22).

Electricity generation and industry, including coal mining, metallurgy, engineering, and chemical processing, have historically been the leading sources of emissions in Ukraine. In large cities, pre-war sources of pollutants included transportation, construction, and industrial activities (23). The occupied eastern region of Ukraine is a mining hub of the country. Before the war, eastern cities such as Donetsk and Mariupol were the most polluted in the country due to coal usage, power plants, mining, and metallurgical activities (24).

Emissions from Ukrainian coal power plants were associated with an estimated 5,000 (95% confidence interval: 3,200–6,700) deaths in 2019. In 2019, 2,700 (1,700–3,600) of the associated deaths occurred in Ukraine, 1,300 (850–1,700) in the EU, and 1,000 (660-1,400) in other countries. The most affected regions in Ukraine were Donetsk, Kyiv, Dnipropetrovsk, and Lviv. Coal-fired power plants in Ukraine are responsible for 80% of the total emissions of sulphur dioxide in Ukraine and 25% of nitrogen oxide (25).

In the available literature, there are certain discrepancies regarding the identification of the leading sources of pollution in Ukraine, which are associated with different approaches in the existing statistical reporting on the environmental situation. Taking this into account, we conducted independent calculations based on the data from the State Statistics Service of Ukraine (Table 4.2).

In 2021, transportation accounted for almost all emissions into the atmosphere due to household activities (93.7%). In the breakdown of "Total air emissions account (economic activity plus households)," the share of transportation was 68.9%. When analysing economic activity excluding households and considering greenhouse gas emissions, Manufacturing (42.2%) and Electricity, gas, steam, and air conditioning supply (32.2%) ranked first and second in the structure of polluters, together contributing to almost three-quarters of emissions. The share of Transport, warehousing, postal, and courier activities was 6.9%, Mining, and quarrying - 4.9%, Agriculture, forestry, and fishing - 4.9%, while the rest of economic activities accounted for less than 3%.

Electricity, gas, steam, and air conditioning supply ranked first among other types of economic activities in terms of air pollution with NO_2, SO_2, PM_{10}, and $PM_{2.5}$; Manufacturing ranked first in pollution with NH3, NMVOC, and CO. Regarding pollutants, the most significant issue for households, excluding greenhouse gas emissions, was CO (constituting 77.7% in the household pollutant structure) and NO_2 (9.0%). In the emissions structure due to economic activity, CO (48.1%), SO_2 (29.1%), and NO_2 (12.5%) predominated.

Sources of pollutant emissions	Emissions of pollutants													
	NO_2		SO_2		NH_3		NMVOC		CO		PM_{10}		$PM_{2,5}$	
	t	%	t	%	t	%	t	%	t	%	t	%	t	%
Household consumption expenditure														
Transport	96701,8	83,1	9186	96,9	6,4	100	118505,7	81,8	901349,1	90,1	10467,4	62,3	–	–
Heating	19612	16,9	296,6	3,1	0	0	26373,6	18,2	99009,2	9,9	6324,3	37,7	–	–
Other	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Households – total	116313,8	100	9482,6	100	6,4	100	144879,3	100	1000358,3	100	16791,7	100	–	–
Economic activity by CTEA-2010														
Agriculture, forestry, and fishing	14347,38	5,7	2452,231	0,4	10151,93	57,5	7993,3	10,5	52492,84	5,4	8288,04	9,6	2246,2	9,2
Mining and quarrying	17530,35	7	10659,45	1,8	25,80768	0,1	7074,283	9,3	47900,01	4,9	15224,96	17,7	1118,8	4,6
Manufacturing	67627,87	26,8	52542,23	9	6929,482	39,3	27599,01	36,2	670120,4	69,2	19891,61	23,1	3482,9	14,3
Electricity, gas, steam, and air conditioning supply	96022,82	38,1	480604	82	37,6982	0,2	5947,57	7,8	28017,18	2,9	22587,1	26,3	14725,2	60,3
Water supply; sewerage, waste management, and remediation activities	1881,729	0,7	805,5471	0,1	343,0225	1,9	927,1372	1,2	7800,122	0,8	397,1499	0,5	332,9	1,4
Construction	5440,261	2,2	860,6256	0,1	0,069169	0	2196,632	2,9	15874,98	1,6	1449,48	1,7	34	0,1
Wholesale and retail trade; repair of motor vehicles and motorcycles	6709,471	2,7	871,484	0,1	20,06365	0,1	5190,492	6,8	29859,78	3,1	2404,821	2,8	995,1	4,1
Transport, warehousing, postal and courier activities	34068,49	13,5	4728,475	0,8	73,54494	0,4	12570,92	16,5	76249,49	7,9	9422,531	11	807	3,3
Accommodation and food service activities	107,9748	0	33,01793	0	0,046325	0	368,5361	0,5	481,6002	0	7,536689	0	4,3	0
Information and telecommunications	258,5447	0,1	30,65714	0	0,020272	0	278,7164	0,4	1938,369	0,2	39,22967	0	0,1	0
Financial and insurance activities	333,4414	0,1	47,33471	0	0,015241	0	236,0893	0,3	1602,985	0,2	59,55697	0,1	0,2	0
Real estate activities	3406,36	1,4	29060,19	5	33,81735	0,2	1068,309	1,4	2790,448	0,3	5195,735	6	14,2	0,1
Professional, scientific, and technical activities	534,0648	0,2	198,3795	0	6,286359	0	582,695	0,8	3799,231	0,4	89,3982	0,1	20,2	0,1
Administrative and support service activities	970,5238	0,4	132,9371	0	8,250892	0	804,3751	1,1	5873,04	0,6	169,5212	0,2	26,8	0,1
Public administration and defense; compulsory social security	1409,571	0,6	1706,03	0,3	0,493009	0	1926,443	2,5	12783,08	1,3	401,9605	0,5	216,7	0,9
Education	403,0538	0,2	706,2452	0,1	4,007498	0	364,0454	0,5	3022,439	0,3	133,8658	0,2	153,4	0,6
Human health activities, residential care activities, and social work	906,6248	0,4	796,7304	0,1	4,81355	0	1024,753	1,3	7523,815	0,8	270,0701	0,3	211,2	0,9
Arts, entertainment, and recreation	61,72986	0	31,59721	0	1,979616	0	60,4339	0,1	404,067	0	6,646251	0	10,2	0
Other service activities	5,377	0	1,703	0	0,044	0	1,329	0	46,858	0	1,15	0	1,9	0
Economic activity – total	252025,6	100	586268,9	100	17641,39	100	76215,07	100	968580,8	100	86040,37	100	24401,3	100

Table 4.14 The distribution of sources emitting pollutants into the atmosphere in Ukraine excluding greenhouse gas emissions for 2021 (own calculations based on data (26)))

Notes: t – tonnes; NMVOC – non-methane volatile organic compounds.

The air quality monitoring system in Ukraine

Since Ukraine gained independence, there has been legislative regulation regarding air quality control. Currently, the main regulatory document in this regard is the Law of Ukraine "On the Protection of Atmospheric Air" (Official Bulletin of the Verkhovna Rada of Ukraine, 1992, No. 50, p. 678; revised as of 01.10.2023, based on 2573-IX) (27); the Law of Ukraine "On Environmental Protection" (Official Bulletin of the Verkhovna Rada of Ukraine, 1991, No. 41, p. 546; revised as of 08.10.2023, based on 2614-IX) is another important legislative document related to environmental conservation in Ukraine) (28) and the Law of Ukraine "On the Public Health System" (As amended by Laws No. 3039-IX of 11.04.2023 and No. 3302-IX of 09.08.2023) (29). Ukraine has a fairly extensive system of environmental monitoring (Figure 4.5).

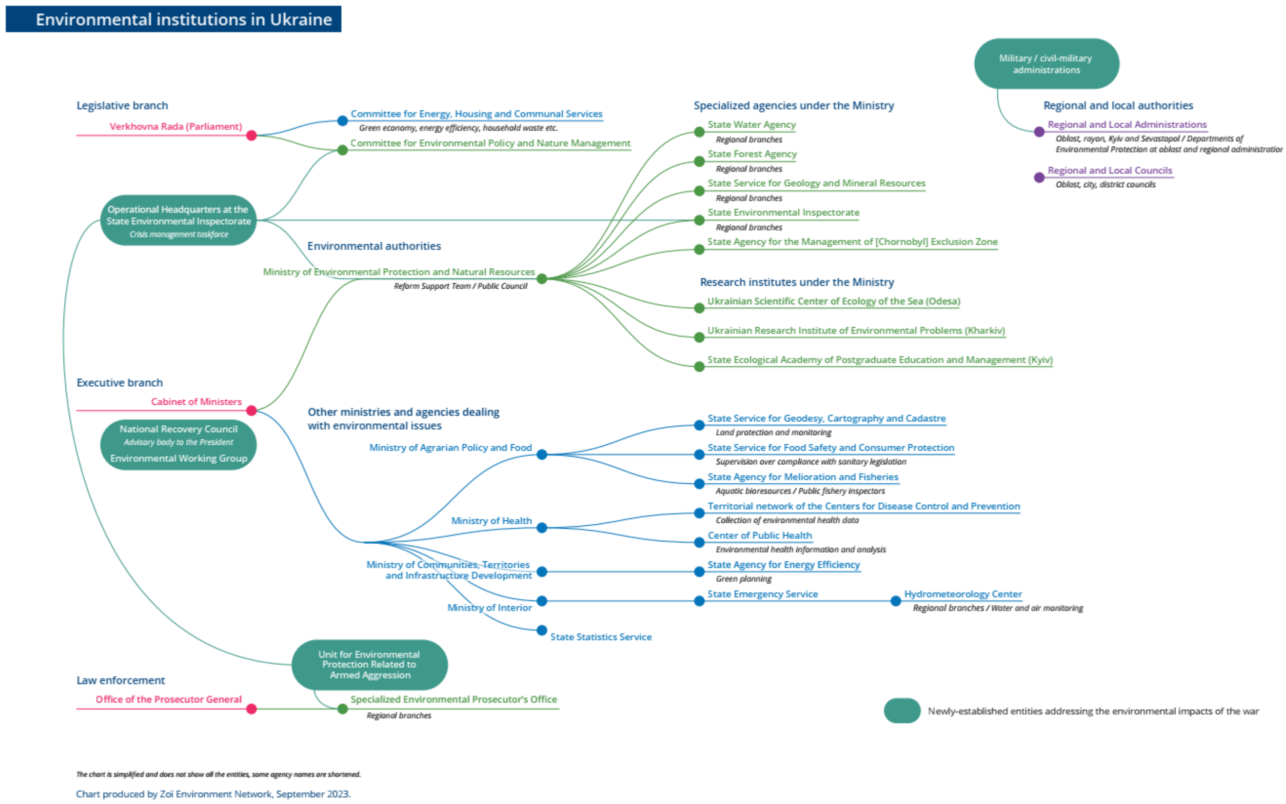


Figure 4.45 Environmental institutions in Ukraine (30)

The Ministry of Environmental Protection and Natural Resources of Ukraine (31) shapes and implements state policy in the sphere of environmental protection, including the protection of ambient air. Under the ministry's guidance, platforms such as EcoSystem operate - a national online platform providing up-to-date information on the environment (32), incorporating the e-Air network (33), which offers current registries and administrative services, and the EcoThreat platform

(34), which provides real-time information on air quality. Additionally, there is a corresponding mobile application available for smartphones.

The Ecodozor platform was developed by the Zoï Environment Network in collaboration with the United Nations Environment Programme, the Organization for Security and Co-operation in Europe, and the REACH Humanitarian Initiative,(35) it provides timely mapping of the consequences of warfare against populated areas, industrial sites, and infrastructure, as well as fires, floods, and locations threatened by air, water, and soil pollution (36).

Observing the levels of pollutants in the air of Ukrainian cities is the responsibility of the Ukrainian Hydrometeorological Center, which is a subdivision of the State Emergency Service under the Ministry of Internal Affairs (37). Reports on emissions of pollutants and greenhouse gases into the atmosphere from stationary and mobile sources can be obtained from the State Statistics Service of Ukraine (38). At present, Ukraine has a wide network of civil society organizations dedicated to monitoring air quality. Civil society platforms include EcoCity (39), LUN City AIR (40), SaveEcoBot (41), Ecoaction (42), Environment People Law (43), and others.

Comparing data obtained from various sources of statistical information regarding air pollution unfortunately shows discrepancies in the available data (44). The air quality monitoring system in Ukraine faces certain problems related to the outdated norms for assessing pollution and air quality (45), a large number of information sources that often lack integration (36,46), and the complexity of the data collection and monitoring system (30).

Data collection on air pollution is overloaded with a large amount of information from civil society and non-governmental organizations (EcoCity (39), LUN City AIR (40) and others) on one hand, and on the other hand, it is complicated by certain discrepancies with international standards. International comparisons of air pollution in global systems such as the WHO Global Health Observatory Air Pollution Data Portal (47), and Environment and Health Information System (ENHIS) (48), which use data from the AirBase of the European Environment Agency (44), European Environmental Agency (EEA) (49) are challenging because they operate with limited information, such as data from the O.M. Marzeiev Institute for Public Health of the National Academy of Medical Science of Ukraine for 2018 (20).

The country is continually undergoing a process of aligning Ukraine's environmental legislation with the legal framework regulating this issue in EU countries (50). State control in the field of air quality protection is carried out by the specially authorized central executive body responsible for ecology and natural resources, its territorial bodies, as well as other specially authorized executive bodies. Public oversight in the field of air quality protection is conducted by public environmental inspectors by the Law of Ukraine "On Environmental Protection" (51,52).

Since 2014, Ukraine's environmental policy has been significantly influenced by the Association Agreement between Ukraine and the EU. Despite progress in some areas, gaps remain in the environmental sector due to expanded obligations under the European Green Deal. Problems with collecting environmental data arose after the events in Crimea and Donbas in 2014 when significant challenges emerged regarding data collection in these territories. With the onset of full-scale invasion in February 2022, the data collection ecosystem faced new challenges due to the need to respond to the war's impacts. In many parts of the country, elements of previously existing monitoring systems were disrupted or altered due to access denials, equipment loss, internal or international displacements, and other factors (30,53,54).

Among the 17 United Nations Sustainable Development Goals (SDGs), ensuring clean air is addressed in several goals related to the environment and health. In SDG 3 "Good Health and Well-being," is presented as a risk factor for population health and is represented by specific targets and indicators. Target 3.9 aims to reduce illnesses and deaths from hazardous chemicals and pollution, with Indicator 3.9.1 focusing on the mortality rate attributed to household (indoor) and ambient (outdoor) air pollution (55). Within the framework of achieving the SDG, the objective is to substantially reduce, by 2030, the number of deaths and illnesses caused by hazardous chemicals and air, water, and soil pollution and contamination (56).

In Ukraine, out of the 183 national SDG indicators approved by the Cabinet of Ministers of Ukraine under Resolution No. 686-r dated August 21, 2019, "Issues of data collection for monitoring the implementation of sustainable development goals," data collection was conducted for 116 indicators as of 2021 (57).

Indicators related to air pollution were calculated within the framework of achieving Goal 11 "Sustainable cities and communities," specifically analyzing indicators 11.5.1: "Volume of emissions of air pollutants from stationary sources (percentage change from the 2015 level)" and 11.5.2: "Number of cities where the annual mean concentrations of air pollutants exceed the WHO guidelines for air quality (units by pollutant: suspended particles (dust), sulphur dioxide, carbon monoxide, nitrogen dioxide, nitrogen oxides, phenol, soot, hydrogen fluoride, ammonia, formaldehyde)." Indicator 11.5.1, according to comparative estimates by the State Statistics Service for 2020-2021, shows positive dynamics, while 11.5.2 demonstrates negative trends (58).

The Voluntary National Review on Sustainable Development Goals in Ukraine conducted in 2021 showed that the reduction of emissions of air pollutants from stationary sources to 86.1% in 2019 compared to the 2015 level was, in part, a result of the implementation of the Association Agreement between Ukraine and the EU. However, the number of cities where the annual mean concentrations of key air pollutants (including carbon monoxide, nitrogen dioxide, phenol, and formaldehyde) exceeded the daily permissible concentrations increased from 34 in 2015 to 36 in 2019 (according to the Ministry of Environmental Protection and Natural Resources) (59).

Despite the ongoing military actions in the country, the process of optimizing the legislative framework and regulating the control of air quality continues. In March 2023, the Cabinet of Ministers of Ukraine adopted Resolution No. 272 dated March 28, 2023, "On the Approval of the Procedure for the Introduction of Mandatory Automated Systems for Monitoring Emissions of Polluting Substances" (60). Even though the country's industry is currently operating at a quarter of its pre-war level (61), the resolution requires enterprises to install automated monitoring and control systems for emissions of pollutants within 5 years after the cessation or cancellation of the state of war in Ukraine. Enterprises are required to conduct relevant measurements and transmit the data on emissions from their equipment to the Ministry of Ecology (60,61).

According to the recommendations of international experts such as the Conflict and Environment Observatory and Zoï Environment Network, with contributions from the OSCE's expert network (39), as well as national experts expressed in an analytical note on the state and prospects of development of the state environmental monitoring system by the Ministry of Ecology and Natural Resources of Ukraine (31), and reports from civil society organizations like SaveDnipro (46) measures are being taken to standardize the air quality monitoring system.

The recently adopted Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Regarding the State Environmental Monitoring System, Environmental

Information (Ecological Information), and Information Support for Environmental Management" (Official Bulletin of the Verkhovna Rada of Ukraine, 2023, No. 63, p. 208) (62), which will come into effect soon, aims to improve the State Environmental Monitoring System, including the subsystem for monitoring air quality. The law provides for the standardization of pollution information through the automation of information systems and the informational interaction of automated information systems in the field of air quality protection with the nationwide ecological automated information and analytical system for decision-making and access to environmental information and its network (62).

The impact of war on air pollution in Ukraine and its consequences for public health, including its effect on oncological diseases

Review of studies analysing the consequences of armed conflicts (air pollution and health) in other countries

War impacts health through physical violence and wider socioeconomic consequences. Health effects of military conflict include direct trauma, mental health issues, non-communicable diseases (NCDs), child health, sexual, reproductive, and maternal health, infectious diseases, etc. Direct health effects involve trauma-related morbidity and mortality. Indirect effects are excess morbidity and mortality due to conflict, beyond what would occur without it. Estimating indirect mortality is challenging and often under-reported. The commonly cited 9:1 ratio of indirect to direct deaths lacks strong evidence and varies between conflicts. Indirect health effects are influenced by population health, nutrition, public health system resilience, and healthcare access. Mental health issues can be direct from traumatic events or indirect from displacement and loss of livelihoods (63).

In addition to the direct impact of war on the health of the population, there is also an indirect impact on various risk factors - environmental, social, etc (64,65). One of the leading risk factors affected by war which in turn affects the health of the population is atmospheric air pollution (66,67).

The issue of the impact of war on air pollution, which in turn poses a risk factor for human health, was not actively researched before the onset of large-scale warfare in Europe. Studies were typically divided into two categories: those dedicated to the impact of military actions and disasters on air pollution (68–74) and a separate, more substantially researched segment, which found its reflection in the WHO report and corresponding recommendations (75–77), about the impact of air pollution on the health of the population in general, including oncological diseases and mortality in particular (66,78–89).

There are studies available on the impact of pollution on air quality and environmental damage resulting from wars in Vietnam (90), Afghanistan (91), Serbia, Kosovo (70–73,92), the Middle East (74,93), and North Africa (94). Additionally, there are works on the indirect impact of industrial armament production on air pollution in the United Kingdom and the United States (95). There are studies available on the impact of air pollution following the war in the Persian Gulf on premature mortality in the population (96), and the development of asthma as a result of oil fires (97).

Very few studies investigate air quality changes during a war according to Zalakeviciute R. et al. (thirteen at the beginning of 2022), in addition, they focus on a single pollutant, mostly PM (98). The research often addresses specific links in the chain of the "war - air pollution - oncological diseases" impact, particularly focusing on the influence of pollution on the development of oncological and other illnesses due to the necessity of regulating pollutant concentrations in the air.

An interesting approach involves the aggregation of available information from conducted studies into a graphical analytical tool of the probable causal impact of air pollution on public health using the Swiss literature database (99). The interactive tool involves predicting both short-term and long-term consequences of various pollutants, highlighting potential problem areas on a schematic representation of the human body.

WHO global air quality guidelines (75) for determining recommended concentrations of air pollutants and the consequences of their exceedance on health relied on several qualitative systematic reviews and meta-analyses (100–105), from which we obtained information regarding the impact on oncological diseases, mortality, and other health indicators in the population.

We obtained compelling evidence that $PM_{2.5}$ and PM_{10} are associated with increased mortality from all causes, cardiovascular diseases, respiratory diseases, and lung cancer. The pooled relative risks (RR) for lung cancer mortality are 1.12 (95% CI 1.07 - 1.16) for a 10 μg/m^3 increase in $PM_{2.5}$ and 1.08 (95% CI 1.04 - 1.13) for a corresponding increase in PM_{10} (100).

Huangfu P. & Atkinson R. (2020) did not investigate the impact of NO_2 and O_3 pollution on the incidence and mortality of oncological diseases. However, they obtained evidence of increased risk of all-cause mortality associated with NO_2 and information about weak associations with O_3 (101). Other researchers have also gathered evidence regarding the associations between elevated levels of PM_{10}, $PM_{2.5}$, NO_2, O_3, and SO_2 and mortality from all causes (102,103,106–109).

The connection between long-term exposure to $PM_{2.5}$, PM_{10}, NO_2, and SO_2 and lung cancer has been established, with the relative risk being relatively small (109–114).

Lipfert F.W &. Wyzga R.E. (2019), who investigated the longitudinal associations between lung cancer mortality, smoking, and air quality, found risks for lung cancer development associated with $PM_{2,5}$, PM_{10}, EC, NO_2, SO_2, SO_{2-4} and O_3 exposure, as well as minimal risks for benzo(alpha)pyrene and traces of metals. The authors note that the combined effects of air pollution and smoking remain insufficiently defined, and a reduction in risk estimates can be expected when assessing the cumulative impact of common air pollutants (111).

In China, a study was conducted to investigate the impact of short-term air pollution exposure to various pollutants on indicators of sudden mortality from different causes, including oncological diseases, based on the analysis of emergency department visits. Research on the short-term impact of $PM_{2,5}$, PM_{10}, SO_2, NO_2, $O_{3,}$ and CO on non-accidental mortality showed that the short-term effects of NO_2, $SO_{2,}$ and O_3 increased the risk of mortality from cardiovascular diseases. Regarding mortality from neoplasms, researchers found an impact from $PM_{2.5}$ and CO only when using a model with a 3-day lag (115).

The short-term impact of polluted air on public health has been studied using indicators such as hospitalization of young children due to acute lower respiratory infections (116,117), clinic visits by youth for upper respiratory infections (118), and outpatient visits for acute exacerbations of chronic obstructive pulmonary disease (119). Additionally, short-term effects of air pollution on days of restricted activity (measured as work-loss days, school-loss days, or both) have been investigated, as such limitations often occur due to the influence of specific pollutants (120).

The long-term consequences vary significantly. Even in countries with relatively low levels of air pollutants compared to others, such as Canada, air pollution continues to affect public health and cause a wide range of adverse health outcomes, from respiratory symptoms to the development of diseases and premature death (121).

For assessing the impact of pollution on cancer development, researchers typically rely on long-term cohort studies, which can last for 12 years as in the case of China (122), where the independent influence of PM_{10} and SO_2 levels on lung cancer mortality was demonstrated, or even 19-22 years as in Australia, where lung cancer was associated with elevated levels of $PM_{2.5}$ and black carbon in cities with low air pollution levels (123).

Short-term health effects of air pollution are often assessed through daily analyses of mortality, outpatient visits, or hospitalizations (80,116–119). Researchers often focus on respiratory and cardiovascular diseases (124–126), which are associated with the short-term effects of air pollution.

Air pollutants have a lag effect on the incidence and mortality of lung cancer for 2-3 years (110). The latency period of the disease is also significant, ranging from 10 to 30 years for lung cancer. Additionally, the duration of exposure to pollutants is crucial, as they exhibit accumulative and cumulative effects (111).

There are studies available on the impact of military conflicts on the development of oncological diseases, primarily in the long term following armed conflicts such as World War II (127,128), Siege of Leningrad (1941–1944) (129,130), Vietnam War (1955 – 1975) (131,132), Sri Lankan Civil War (1983 – 2009) (133), Gulf War (1990 - 1991) (134), Croatian War of Independence (1991 – 1995) (135–139), Bosnian War (1992 – 1995) (140,141), NATO bombing of Yugoslavia (1999) (142,143), non-specific conflicts following the breakup up Yugoslavia (144). Studies have investigated various types of cancer, including cervical cancer, cancers of the central nervous system, colon cancer, hematological cancers, lung cancer, prostate cancer, liver cancer, oropharyngeal cancer, ovarian cancer, pancreatic cancer, stomach cancer, and testicular cancer. It should be noted that many authors have highlighted the significant role of stress during the war in the development of oncopathology. It is noted that the long-term impact of armed conflicts on cancer incidence may result from toxic contamination of the entire environment, not just the air (145).

In the systematic review by Jawad M. et al. (2020) titled "The impact of armed conflict on cancer among civilian populations in low- and middle-income countries," out of 1543 selected sources, only 20 studies were included in the analysis, assessing 8 armed conflicts and 13 oncological diseases, two-thirds of which had low methodological quality and conflicting conclusions. Evidence was obtained that armed conflict was associated with increased incidence and mortality from nonspecific types of cancer, breast cancer, and cervical cancer, with some information about a certain link between war and stomach and testicular cancer incidence. However, there were also publications reporting studies with conflicting results (145). It's interesting to note the average time interval between wartime activities and observation (recording changes in cancer epidemiology), ranging from 3 to 64 years, with an average of 16.8 years (145).

It should be noted that the majority of evidence regarding the impact of air pollutants on health outcomes over different timeframes (short-term, medium-term, and long-term) is derived from large cohort studies. Most systematic reviews and meta-analyses focus on studying the effects of mortality indicators as the ultimate outcomes.

Therefore, only after 3 years from the onset of the conflict can we obtain some evidence of the impact of wartime activities on oncopathology. Such a significant time lag complicates the search for associations with air pollution during wartime in the current stage of the ongoing conflict in Ukraine.

Early effects of air pollution on health are measured by researchers primarily through daily analysis of deaths, outpatient visits, or hospitalizations, which requires the implementation of a study with the appropriate design.

Research conducted in Ukraine before the full-scale invasion

Research conducted in Ukraine before the full-scale invasion largely focused on the epidemiology of various types of cancer at both the national and regional levels, as well as identifying factors influencing the situation (146–157).

According to the National Cancer Registry of Ukraine (NCRU), there was a stable situation regarding cancer incidence over the decade leading up to 2020. However, following the onset of the pandemic, like in the rest of the world, cancer incidence rates began to decrease (158) Ukraine. Despite the trend of decreasing incidence and mortality rates, neoplasms continue to hold the second most significant position in the structure of mortality among the population (except for 2021, when they were surpassed by COVID-19, and in recent years, shifting to the third position) (158,159).

The study by Ryngach N. (Ptoukha Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine, 2022) (159) highlights several factors associated with the pandemic that can lead to an increase in cancer-related mortality over time. These factors include delays in seeking help due to fear of infection, reduced population mobility and access to medical care (including specialized and screening programs and diagnostics), postponement of necessary treatment, the concentration of healthcare resources on combating the pandemic leading to the overload of medical personnel, and a lack of funds for high-cost specific examinations and treatments. These challenges may contribute to delays in cancer diagnosis and treatment, ultimately resulting in higher mortality rates associated with neoplasms (159).

According to data from the National Cancer Registry of Ukraine, the sharp drop in the cancer incidence rates registered in Ukraine in 2020 is the result of the limited access to healthcare facilities as well as the reduced oncological alertness of the population due to the predominant focus on COVID-19 during the pandemic. However, it is not a manifestation of a decrease in cancer incidence as such. In the following years, this may increase the proportion of advanced-stage diagnoses, the load on the cancer care system, and cancer mortality in the Ukrainian population (158,160).

A Significant factor «beyond the COVID-19 pandemic» that determines the probable increase in the mortality rate and the share in the structure of neoplasms is the progressive ageing of the population of Ukraine. Factors that lead to a decrease in the level of neoplasm-caused mortality and its share in mortality structure may include the death from COVID-19, which «precedes» the existing oncological disease; a deterioration in the quality of determining the cause of death, especially for the elderly and the rural population; as well as the practice of assigning all those who died from COVID-19 to Class XXII according to ICD-10 (159).

Most researchers worldwide agree that the COVID-19 pandemic has significantly impacted the epidemiology of cancer due to various factors, ranging from biological to healthcare organization and reporting (161–163).

Most studies on air pollution in Ukraine before the war period were focused on the impact of chemical carcinogens on the development of oncological diseases and mainly concentrated on pollution in large cities (23,164–170).

The existence of a latent period of exposure to airborne carcinogens in the development of oncopathology has indeed been established. The maximum period for the manifestation of the influence of atmospheric carcinogens on the incidence of thyroid cancer was estimated to be approximately 10 years (164).

There have been scientific studies of the atmosphere that have taken into account the environmental risks to public health (23). The analysis showed that the majority of Kyiv territory (Popov O. et al., 2020) is characterized by 15 - 17% Risk of chronic intoxication values, 30 - 50% Risk of immediate toxic effects values, a hazard index value of 4 - 6, a hazard coefficient value (for nitrogen dioxide) from 2-2.5, and a carcinogenic risk (for formaldehyde) from 2×10^{-5} – 5×10^{-5} (23).

The analysis of field and analytical studies over the past 20-25 years reveals a significant increase in the use of plant protection products and agricultural chemicals. This has led to a notable rise in the rates of cancer affecting endocrine organs (such as breast, thyroid, and prostate glands), as well as the uterus and ovaries. Examining risk indicators for various carcinogenic substances within domestic regulatory frameworks, it was found that only 26% of substances in atmospheric air and 45% in workplace air meet acceptable risk levels according to international standards (1×10^{-4}) (169).

The total carcinogenic risk from exposure to carcinogenic substances in the atmospheric air for the population of Dnipro during the period from 2000 to 2018 ranges from 2.5 to 3.9 cases of cancer per 1000 population. This is considered high according to international classification standards, necessitating the development and implementation of precautionary measures (168).

In the large industrial cities of the Dnipro region, such as Dnipro, Kamyanske, and Kryvyi Rih, significant pollution of the atmosphere with formaldehyde and phenol has been observed over the past decade, before the pandemic-related quarantine restrictions (170).

COVID-19 pandemic policies triggered a decrease in emissions from human activities, which led to lower levels of nitrogen dioxide in industrialized regions. However, the increase in the use of fossil fuels for heating during the lockdown period resulted in a rise in sulphur dioxide levels in densely populated areas of Ukraine (171).

Study of the impact of war on air pollution in Ukraine and its influence on the oncological situation

Search strategy, selection criteria, and data analysis

A literature review was conducted, aiming to adhere to the fundamental principles of systematic reviews and meta-analyses (172), albeit with certain modifications in reporting to address the specific objectives. In the reporting, we included references not only to experimental studies but also to reports from international and environmental organizations, analyses of available statistical data, and review publications.

We conducted searches in electronic databases including PubMed, Scopus, Web of Science, ResearchGate, Embase, Global Health, Ludok, and Google Scholar, seeking relevant publications in both English and Ukrainian languages. We utilized synonyms for armed conflicts, air pollution, and oncological diseases. Additionally, we performed manual searches in the reference lists of included studies to identify additional relevant articles.

The publication search covered 10 years from 2014 - the year the military conflict with Russia began. If relevant publications from earlier periods were available, they were also included in the analysis. Regarding recent information related to the full-scale invasion, sources published primarily after 2022 were utilized for up-to-date data.

The inclusion criteria encompassed the civilian population, including children, internally displaced persons, and refugees diagnosed with any type of cancer residing anywhere in Ukraine. We excluded studies focusing on military veterans, combatants, or research related to weapon testing. For example, a study by Sasmoko, et al. (173), which examined the impact of arms export on the ecosystem, was excluded from the analysis.

We did not exclude studies based on design. Meta-analysis was not feasible due to the degree of heterogeneity among studies in terms of design. Given these limitations, a quantitative analysis of study quality was not conducted; instead, a qualitative characterization of publications was provided based on the consensus of two researchers. In cases where consensus was lacking, a third expert was consulted to formulate a consolidated final judgment.

The literature review took into account that publications may be politically biased, which could lead to the risk of bias in individual studies. Therefore, information about the country (organization) of origin of the study was included in the table and analysis.

The results of the literature review regarding the impact of the war in Ukraine on the oncological situation due to air pollution were obtained

Overall, for detailed analysis, 14 publications were selected (the rest of the literature sources were used to refine existing information, conduct additional analysis, etc.), placed in Table 4.3 in chronological order of data analysis. This selection includes 2 review articles that include an analysis of available statistical official information, 5 reports on research projects from various organizations, and 5 articles with original scientific research, 2 of which were authored by Ukrainian researchers (Table 4.3).

Part of the studies (4 publications) compare data obtained after the full-scale invasion with the pre-war situation, one focuses on the consequences after the start of hostilities in 2014, and 2 includes in the comparative analysis a separate period, the time of quarantine measures during the COVID-19 pandemic. Researchers used open data sources for the analysis of air pollution, including air quality indices (3 studies), satellite image results (4 studies), and others. The studies primarily focused on pollutants such as $PM_{2,5}$, SO_2, and NO_2.

Regarding health indicators, data from the Global Burden of Diseases were applied, as well as indicators from national or international reporting.

Currently, there are no international standards for measuring the impact on the environment during wartime. However, several countries and international organizations, including Ukraine, the European Union, the United States, and the UN Development Programme, have developed monitoring and documentation strategies to assess the impact of armed conflicts on the environment. A comprehensive assessment of the environmental impact will only be possible after the war ends (36).

Many authors note that our current knowledge about the impact of war on air quality is limited. Further research is necessary to understand the long-term implications of these events on air pollution and their impact on human health and the environment (174).

№	Bibliography	Type of publication	Country/organization of study origin	Study period	Research materials and methods	Main Findings	Assessment of the impact of air pollution on ecology	Assessment of the impact of air pollution on health (oncological diseases)	Conclusion of the authors
1	Malarvizhi AS, Liu Q, Trefonides TS, Hasheminassab S, Smith J, Huang T, et al. The spatial dynamics of Ukraine's air quality impacted by the war and pandemic. International Journal of Digital Earth. 2023;16(1):3680–705. doi: 10.1080/17538947.2023.2239762 (171)	Original research article	Department of Geography and GeoInformation Science, George Mason University, Fairfax, VA, USA Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration	2010 – 2022 The data collected on the progression of the war in Ukraine from 18 February to 3 November 2022	Analyzing NO_2, SO_2, and O3 data from Ozone Monitoring Instrument (OMI) and TROPOspheric Monitoring Instrument (TROPOMI) sensors European Space Agency (ESA). The air quality data is processed using up-scaling and aggregation techniques to remove cloud contamination and subsequently ingested into a Science Data Analytics Platform (SDAP) platform to visualize trends.	During the COVID-19 pandemic, strict quarantine policies in Ukraine led to a 2% reduction in tropospheric NO_2 concentration before the lockdown and 4% during the lockdown period. Cities like Kyiv, Donetsk, and Dnipro exhibited reductions of 5%, 11%, and 16%, respectively. Total SO_2 column concentration decreased by 6% before the lockdown and 2.5% during the lockdown period, except in high population density areas. Kyiv showed the highest reduction of 17% in SO_2 concentration, while Donetsk and Dnipro exhibited an 11% reduction. During the Russian invasion, the tropospheric NO_2 concentration between 25 February and 17 March is considerably reduced, with most of the eastern regions of the country showing a reduction in NO_2 concentration because of reduced human activities. Kharkiv, a major target for the Russian invasion and a heavily destroyed region had a considerably increased NO_2 concentration because of the war activities. The total SO_2 column before the war is 48% higher than the historical mean. However, after the war, the total SO_2 column was reduced throughout the	The war in Ukraine also impacted air quality, as there was a decrease in both nitrogen dioxide and sulphur dioxide levels.	In the analysis of the results, it is indicated that lower levels of NO_2 and SO_2 can result in better air quality and fewer respiratory issues, while elevated levels of these pollutants can have the opposite impact.	The authors' conclusions are well-founded, but comparing the long-term dynamics pre-war (since 2010 for some pollutants) to the short period post-active war phase reduces the value of the scientific findings obtained.

						country except for Kyiv and a few central regions of Ukraine.			
2	Lisova NO. Influence of military actions in Ukraine on the ecological state of the country. The scientific issues of Ternopil Volodymyr Hnatiuk National Pedagogical University. series: geography. 2017;43(2):165-173 (In Ukrainian) (175)	Review article with data synthesis	The results of the research of the International Charitable Organization "Ecology - Law - Man" and the East Ukrainian Ecological Institute are analyzed	2014	Literature review and statistical analysis	Exceeding the permissible levels of SO_2, NO_2, and CO in the air immediately after shelling was observed. The concentration of SO_2 exceeded the permissible limit by 5 times after the first shelling and by 8 times after the second shelling.	Military actions in the east of Ukraine have damaged all the objects of the environment without any exception.	An empirical conclusion is drawn about the increased risk of developing respiratory organ diseases in the conflict zone.	The article lacks convincing evidence regarding the impact of military operations on air pollution in the occupied region. However, it offers insight into the environmental consequences of the initial stage of the Russian invasion
3	Meng X, Lu B, Liu C, Zhang Z, Chen J, Herrmann H, et al. Abrupt exacerbation in air quality over Europe after the outbreak of the Russia-Ukraine war. Environment International. 2023 Aug 1;178:108120. doi: 10.1016/j.envint.2023.108120 (176)	Original research article	Department of Environmental Science & Engineering, Fudan University, Shanghai, China. Leibniz-Institut für Troposphärenforschung (IfT), Leipzig, Germany	2016 – 2022	From the World Air Quality Index project (https://aqicn.org/map/europe/cn/) Thirty European countries, 176 cities Extended unweathered-detrended model, meteorological normalization model	The war led to an average increase of 9.78% in $PM_{2.5}$, an average increase of 10.07% in NO_2, and an average decrease of 7.93% in O_3 in areas less than 1000 km from the center of Ukraine. Regional air pollution exacerbated by the war activities has offset the improvements in air quality observed during the COVID-19 pandemic	Warfare activities offset lockdown-caused air quality improvements in Europe	It was not held	The use of average data across Europe (AQI average without analyzing the reliability of differences) without indicators of air pollution in Ukraine makes the conclusions of this study questionable.
4	Zalakeviciute R, Mejia D, Alvarez H, Bermeo X, Bonilla-Bedoya S, Rybarczyk Y, et al. War Impact on Air Quality in Ukraine. Sustainability. 2022 Jan;14(21):13832. https://doi.org/10.3390/su142113832 (98)	Original research article	Grupo CATOx, CEA de la Universidad de Cuenca, Ecuador; Faculty of Data and Information Sciences, Sweden; Laboratory for Atmospheric Research, Washington State University, USA	2019–2021	Satellite images of NO_2, CO, O_3, SO_2, and $PM_{2.5}$ over Ukrainian territory and $PM_{2.5}$ land monitoring data for Kyiv were analyzed. The Google Engine (GGE) platform was used. Some additional analyses were performed using Empirical Bayesian kriging. A t-test and one-way ANOVA was performed.	Statistical analyses showed a significant difference ($p<0.05$) between all the studied periods for all criteria pollutants. An overall reduction of 24.1% in NO_2 concentrations can be seen for Ukraine and 40.42% for Kyiv. The same high reduction was registered for $PM_{2.5}$ of 38.33% (Ukraine) and 30.82% (Kyiv), and a much lower reduction for CO: -3.83% (Ukraine) and 2.73 (Kyiv). The analysis of the evolution of war shows a continuous reduction in peak NO_2 concentrations; however, the	The results showed that NO_2 and $PM_{2.5}$ correlated the most with war activities. CO and O_3 levels increased, while SO_2 concentrations reduced four-fold as the war intensified.	Drastic increases in pollution (especially $PM_{2.5}$) from bombing and structural fires raise additional health concerns.	The authors' conclusions regarding the environmental impact look reasonable, but they only concern the first 2 weeks of the war. The authors' conclusions regarding changes in the health of the population are empirical and not supported by statistical analysis

						average levels slightly increase on the 3–4th week of war (9–22 March 2022). Overall higher O_3 (2.45% for Ukraine and 3.38% for Kyiv) and SO_2 (38.06% for Ukraine and 10% for Kyiv) levels were reported during the first two weeks.			
5	Grynchyshyn N. Atmospheric air quality by the content of solid microparticles (pm 2.5) in the cities of Ukraine in the conditions of quarantine and martial state. Bulletin of Lviv State University of Life Safety. 2023;27:6-5. (In Ukrainian). https://doi.org/10.32447/20784643.27.2023.01 (177)	Article with data synthesis	Lviv State University of Life Safety, Lviv, Ukraine	2020-2022	Atmospheric air quality indices (AQI) for PM 2.5 were used in the study, calculated based on measurements of solid microparticles by public air monitoring posts in cities of Ukraine.	The quarantine had a positive impact on air quality during the summer of 2020 in large cities such as Kamianske, Dnipro, Kryvyi Rih, Odesa, and Kyiv, with a reduction in the air quality index for $PM_{2.5}$ observed. Rocket shelling of cities did not have a significant impact on increasing the levels of the air quality index for $PM_{2.5}$.	Air pollution by small PM 2.5 microparticles in the cities of Ukraine has seasonal dynamics. The highest values of air pollution indices for PM 2.5 are observed in the cold season due to emissions from the burning of fossil fuels for space heating.	An empirical conclusion is that air quality on certain days during the cold period poses a danger to human health.	The article provides insufficient evidence to support the relationship between military operations and air pollution. Nevertheless, it presents various impacts of war on atmospheric air quality, including $PM_{2.5}$ content.
6	Skok A, Khrutba V, Rak O. Air Quality in Ukraine Before and During Full-Scale Invasion. Report on the study. SaveDnipro; 2023. 67 p. (In Ukrainian) (46)	Research project report	SaveDnipro; International Renaissance Foundation, Ukraine	2021-2022	Analysis of data from the Ukrainian Hydrometeorological Center, SaveEcoBot, and other open data sources on cities with a population of over 25,000 and stations that operated more than 50% of the time	A significant reduction in emissions of polluting substances is observed in the South and East of Ukraine due to the suspension or closure of a large number of industrial enterprises, which were the main sources of atmospheric pollution. Irregularity of pollutant concentration measurements creates a methodological problem in the interpretation of the obtained results. Local air pollution after bombing lasts for 48 hours before dissipating.	Russia's invasion of Ukraine notably affected air quality, with pollution levels recorded by monitoring stations during the environmental crime showing significant local pollution from decay and burning products, directly	It was not held	A significant portion of the report compares data from various sources. The methodology for determining the impact of explosions based on the exceedance of the standard deviation of annual average indicators in 2021 and the root mean square value raises questions, therefore, the authors' conclusions appear insufficiently substantiated.

							impacting people.		
7	Zhang C, Hu Q, Su W, Xing C, Liu C. Satellite spectroscopy reveals the atmospheric consequences of the 2022 Russia-Ukraine war. Sci Total Environ. 2023 Apr 15;869:161759. doi: 10.1016/j.scitotenv.2023.161759 (178)	Original research article	Department of Precision Machinery and Precision Instrumentation, University of Science and Technology of China, Hefei, China	From February 24 to July 31, 2022	Observing atmospheric nitrogen dioxide (NO_2) using high-resolution satellite spectroscopy	Tropospheric NO_2 decreased by 10.7–27.3 % in most Ukrainian cities at the beginning of the war. Machine learning indicates that war-induced changes in anthropogenic emissions account for ~40% of NO_2 declines in Kyiv. Dramatic changes in NO_2 were found in Russian border cities and transportation hubs.	Changes in trace gas concentrations over cities and transportation hubs showed a strong correlation with the course of the war.	It was not held	The authors' conclusions based on satellite imagery appear convincing.
8	Turos OI, Petrosian AA, Maremukha TP, Morhulova VV, Brezitska NV, Kobzarenko IV, et al. Assessment of ambient air pollution by particulate matter (PM_{10}, $PM_{2.5}$) and risk for human health caused by war actions. Wiad Lek. 2023;76(4):738–44. doi: 10.36740/WLek202304106 (174)	Original research article	State institution «O.M. Marzieiev Institute for Public Health» NAMSU, Kyiv, Ukraine	From February to August 2022	Instrumental measurements of PM 10 and $PM_{2.5}$ concentration levels were made using gas analyzers APDA-371 and APDA-372 (Air Pollution Dust Analyzer, Horiba) in the surface layer of the atmosphere were conducted in mode (round the clock, continuously) at three air quality monitoring stations in Kyiv city. At the same time, an analysis of mass concentrations of particulate matter was carried out, obtained during the entire study period, and averaged over Kyiv city (according to three AQMS) Calculations of risk levels (individual risks of mortality – IRM) for the health of the exposed population were carried out using the general procedure of the human health risk assessment methodology (HHRA),	It was determined that the average daily mass concentrations (according to three AQMS data) in 2022 vary in the range for PM10 (from 1.3 $\mu g/m^3$ to 125.5 $\mu g/m^3$) and PM2.5 (from 1.7 $\mu g/m^3$ to 108.2 $\mu g/m^3$). Uncharacteristically high average daily levels of ambient air pollution with particulate matter were revealed: PM10 – March (125.5 $\mu g/m^3$) and August (99.3 $\mu g/m^3$); PM2.5 – March (108.2 $\mu g/m^3$), May (23.3 $\mu g/m^3$), June (24.6 $\mu g/m^3$), and August (27.1 $\mu g/m^3$), which were primarily caused by the conduct of active war actions and their consequences (fires, rocket attacks), intensified in the spring-summer period by unfavorable meteorological conditions.	Exceeding the average daily concentrations, according to the recommended air quality standards, was established for PM 10 in March and August 2022, by WHO recommendations (2.8 and 2.3) times and Directive 2008/50/EC (2,5-2,1) times; PM 2.5 (1.1-7.2) times during almost the entire observation period (except of July), according to WHO recommendations.	Levels of individual risk of mortality (IRM) during the studied period can vary for PM_{10} within $IRM=7.9\times10^{-6} \div 7.7\times10^{-4}$. At the same time, in March and August, the risk values were observed at the level (ICR total ≥ 10^{-4}), which is unacceptable for the population according to WHO recommendations, and possible social losses of the population in the form of additional deaths, can be up to eight cases per 10,000 people. As for PM2.5,	The use of data from only 3 stations of one large city for 7 months does not give reason to consider the authors' generalizations convincing. When comparing the data with the pre-war period, no information was provided about the existence of statistically significant differences. The approach used by the authors with the assessment of population risks from air pollution during the war is successful and makes it possible to obtain convincing results by increasing the scope and coverage of the study.

					developed and recommended by the US Environmental Protection Agency and WHO.			the risk levels ranged from – IRM=1.2×10^{-3} ÷7.3×$10^{-2,}$ and in March, June, and August could lead from 1 to 7 additional deaths per 100 people.	
9	Angurets O, Khazan P, Kolesnikova K, Kushch M, Černochova M, Havránek M. Environmental consequences of the Russian war in Ukraine. Ukraine: NGO «Green World – Friends of the Earth»; 2023. 80 p. (1)	Research project report	NGO «Green World – Friends of the Earth», Ukraine; Arnika, Czech Republic; Clean air for Ukraine, Ukraine	between February and Novembe r 2022	Descriptive research	Direct mass exposure to toxic chemicals released to the environment by the use of military equipment, ammunition components, explosives, and rocket fuel. Environmental devastation is caused by the physical impact of fires, explosions, soil damage, etc. Destruction of the environment by man-made disasters caused by the shelling of industrial enterprises (mass emissions of ammonia, chlorine, nitric acid, etc.).	Russia's invasion of Ukraine vividly showed the significant risks of large-scale man-made disasters for the environment.	It was not held	Descriptive research. Historical examples of how the environment has been affected by the wars
10	Bohovic R, Hrnčiar M, Muroň M, Chytrý J, Skalský M, Černochová M, et al. O'Campo P, Bočková S, editors. Air Pollution in Ukraine as seen from Space: The Effects of the War. World from Space: Arnika; 2023. 28 p. (179)	Research project report	Clean air for Ukraine, Ukraine (cleanair.org.ua); Arnika, Czech Republic (https://arnika.org/); World from Space, Czech	2022	Study based on the Copernicus Sentinel 5p satellite imagery. The measurement of NO_2 using the TROPOMI sensor of the Sentinel-5P satellite	Overall, there was a 9.4% reduction in NO_2 levels across Ukraine during the war compared to the pre-war period. The most significant decreases, exceeding 30%, occurred in major urban and industrial areas like Kyiv, Kryvyi Rih, and Zaporizhzhia, as well as in areas where cities were destroyed and populations relocated. There were no sustained increases in NO_2 concentrations observed at sites affected by explosions or military activities.	This study confirms that the key influence on air pollution in Ukraine is, or was, caused primarily by the outdated heavy industry based on coal combustion. The effect of war on NO_2 pollution should, however, not be underestimated .	It was not held	The report provides meaningful substantiated information regarding air pollution without considering its impact on public health.

11	Savenets M, Osadchyi V, Komisar K, Zhemera N, Oreshchenko A. Remotely visible impacts on air quality after a year-round full-scale Russian invasion of Ukraine. Atmospheric Pollution Research. 2023 Nov 1;14(11):101912. doi: 10.1016/j.apr.2023.101912 (24)	Original research article	Ukrainian Hydrometeorological Institute, Kyiv, Ukraine	From January 2019 to January 2023: pre-war (January 2019–December 2021) and war (February 2022–January 2023) periods	The study is based on NO_2 tropospheric and CO total column number density derived from the TROPOMI onboard Sentinel-5P satellite (downloaded from the Sentinel-5P Pre-Operations Data Hub: https://s5phub.copernicus.eu/dhus/#/home	NO_2 drop in big cities (up to -35%) as a result of industry damages and a decrease in mobile source emissions; NO_2 increase (up to 25%) in the eastern and northeastern parts of Ukraine (including the adjacent neighboring territories) at the beginning of the war, indicating the possible impact of emissions from military equipment; CO elevated content and releases (increase up to 8%) as a result of wildfires near the front-line after artillery shelling. Consequences differ in cities depending on their distance to the front line, "occupied – non-occupied" status, and the number of objects that can be considered critical infrastructure.	The impact of war in Ukraine on air quality is multidirectional: relatively short-term (day-to-week) events (such as missile hits, wildfires near the borderline, etc.) provoke elevated pollution episodes, while a general picture over relatively long periods and specific campaigns showed air pollution reduction.	It was not held	Using the TROPOMI approach for remote sensing of NO_2 and CO content, conducting a comparative analysis of pre-war and post-war periods during different stages of military actions and in cities at varying distances from the front line, allows us to consider the authors' conclusions convincing.
12	Estill J. Health impacts and social costs associated with air pollution in larger urban areas of Ukraine. Final report. Switzerland: United Nations Development Programme; 2022. 32 p. (180)	Research project report	United Nations Development Programme	2022	The analysis was conducted based on open data sources: The Global Burden of Disease (GBD) database of the Institute for Health Metrics and Evaluation (IHME); air quality data from SaveEcoBot and other open sources; population data accessed through the Spectrum/DemProj software interface. Linear and logistic regression models were used for forecasting.	Reducing the $PM_{2.5}$ level to less than 12.0 μg/ m^3 in large cities of Ukraine can be expected to reduce the incidence of trachea, bronchus, and lung cancer by 1.6% to 2.6%. Constant gradual improvement in the air quality, aiming at the WHO recommended level by 2030, would bring about 100,000 additional person-years of the labor force by 2035. This would correspond with an almost 3.5 billion USD increase in the economic output in one year by 2035/	It was not held	In the large cities of Ukraine where the air quality is suboptimal, improving the quality of air to a level considered «good» could prevent up to a third of all strokes and cases of chronic obstructive pulmonary disorder	The author's conclusions are convincing and sufficiently justified. In developed predictive models of disease progression, including oncological ones, the impact of other behavioral risk factors is taken into account under the influence of air pollution; however, the impact of a variable such as war has not been considered in them.
13	Hryhorczuk D, Levy BS, Prodanchuk M, Kravchuk O, Bubalo N, Hryhorczuk A, Erickson	Review article	Divisions of Environmental and Occupational Health Sciences and	2022-2023	User conducted an integrative review of academic, institutional, and media information	In Kyiv, the concentration of fine particulate matter on March 19, 2022 – less than 1 month after the start of Russia's invasion –	There has been widespread chemical contamination	Empirical judgments out of the indirect health effects of	Generalizing the available information did not show that an unequivocal answer was received regarding

	TB. The environmental health impacts of Russia's war on Ukraine. J Occup Med Toxicol. 2024 Jan 5;19(1):1. doi: 10.1186/s12995-023-00398-y (36)		Epidemiology, University of Illinois School of Public Health, Chicago, USA L.I.Medved's Research Center of Preventive Toxicology, Food and Chemical Safety, Ministry of Health, Kyiv, Ukraine		resources on the environmental health impacts of Russia's war in Ukraine in English and Ukrainian.	was 27.8 times the World Health Organization recommended guideline. During the first 2 weeks of the war, satellite images demonstrated reductions in atmospheric concentrations of nitrogen dioxide, fine particulate matter, and carbon monoxide.	of air, water, and soil, and 30% of Ukraine has been contaminated with landmines and unexploded ordnance.	the layer have likely accounted for an even greater amount of civilian morbidity and mortality.	atmospheric air pollution during the war.
14	Review of the state of environmental pollution in Ukraine for the first half of 2023. The state emergency service of Ukraine: Boris Sresnevsky Central Geophysical Observatory; 2023. 19 p. (In Ukrainian) (181)	Research project report	Boris Sresnevsky Central Geophysical Observatory; The State Emergency Service of Ukraine, Ukraine	The first half of 2023	Analysis of data from the network of observations of the National Hydrometeorological Service of Ukraine	Average concentrations of harmful substances exceeded the daily maximum permissible concentrations (MPCs) for formaldehyde by 2.0 times and for nitrogen dioxide by 1.4 times. Exceedances of the MPCs were recorded for nitrogen dioxide in 20 cities, formaldehyde in 16 cities, suspended particles in 9 cities, phenol in 5 cities, carbon monoxide, soot, hydrogen fluoride in 2 cities, sulphur dioxide, nitrogen oxide, ammonia in one city. The comprehensive air pollution index (CAPI) in Ukrainian cities in the first half of 2023 was 6.0, slightly lower than the same period last year (which was 6.3). In 10 cities, there was a decrease in CAPI, while in 8 cities, it increased, with the highest increase observed in Vinnytsia and Zaporizhzhia.	No generalization was made since the report only covers the first half of 2023.	It was not held	The analysis was conducted by comparing the level of air pollutants with the maximum permissible concentrations (MPCs) and by analyzing the Comprehensive Air Pollution Index (CAPI). The analysis was conducted over a relatively short period, no other types of analysis were performed, no conclusions were drawn, and the digital analysis appears convincing.

Table 4.15 Analysis of selected literary sources regarding the impact of war on air pollution in Ukraine and its health consequences

One of the studies assessing the impact of military actions on public health through air pollution is the work by Turos O.I., et al. (2023). In this study, an increased risk of mortality was identified due to the influence of elevated levels of PM_{10} and $PM_{2.5}$, which escalated during bombings. The researchers relied on gas analyzers for particulate matter as their source of information, enabling them to identify high daily average levels of PM_{10} and $PM_{2.5}$ air pollution during bombardments (174).

Half of the studies included in the analysis did not assess the impact of polluted air during wartime on public health, and one report did not consider the environmental consequences.

International experts note that as of February 2022, the three main environmental problems in Ukraine were water pollution and scarcity, management of industrial and household waste, and poor air quality. These issues worsened after the full-scale invasion (30,53).

Military actions in Ukraine had a significant negative impact on the environmental situation, including air pollution, as emphasized by many researchers worldwide (9,178,182–189) and in Ukraine (36,46,190,191).

According to Ecodozor (35) from February 2022 to January 2024, various sources reported 2599 threats and environmental incidents at 1384 facilities all over Ukraine, including 68 incidents at 58 sites only in January 2024. The majority of incidents occurred in heavy industry (23.8%), followed by the food industry and agriculture (20.5%), and transportation (18.5%) (Table 4.4).

The ratio of facilities to incidents overall is 1:1.9, with the highest intensity of incidents recorded in the energy sector at 1:7.3, predominantly in nuclear energy at 1:20.3. The highest number of reports of destruction or damage during the specified period came from Donetsk Oblast.

There is a geographical unevenness in the distribution of pollution risks, including risks of air pollution, which are mainly localized near areas of active combat or shelling (Figure 4.6).

Sector	Number of facilities		Number of incidents	
	n	%	n	%
Heavy industry	329	23.8	920	35.4
Power generation	49	3.5	360	13.9
Food and Agriculture	283	20.5	326	12.5
Resource supply	217	15.7	251	9.7
Transport	256	18.5	477	18.4
Other	250	18.1	265	10.2
Total	1384	100	2599	100

Table 4.16 Incidents of disruptions or accidents at industrial and critical infrastructure facilities From February 2022 to January 2024 in Ukraine (7)

Short-term exposure to polluted air is associated with an increased risk of hospitalization and death. Studies conducted in Poland have demonstrated statistically significant relative risks of hospitalization due to cardiovascular and respiratory diseases with increasing levels of $PM_{2.5}$ and PM_{10} by 10 $\mu g/m^3$ (192).

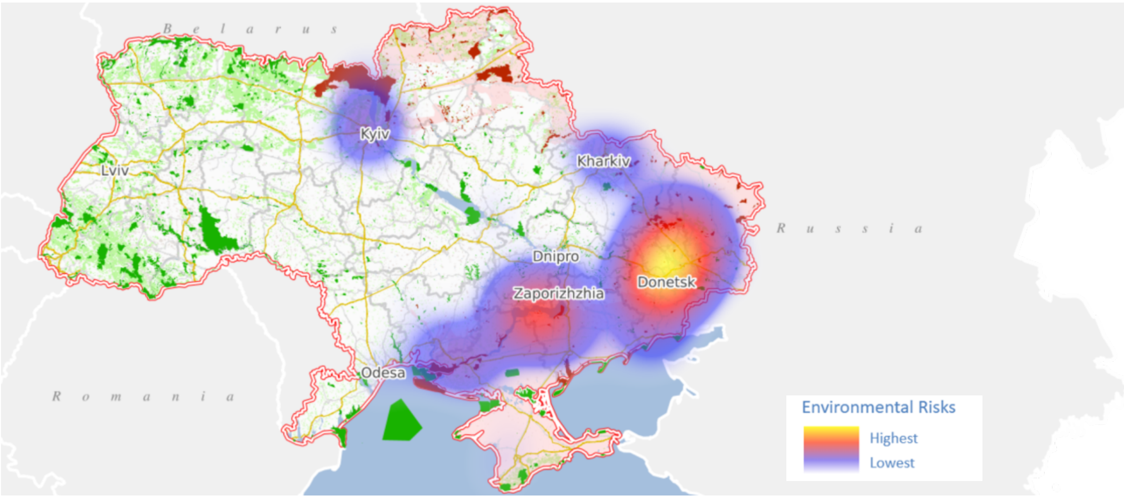


Figure 4.46 Environmental air risks of the fighting in Ukraine (35)

Taking into account environmental damage, organizations of medical care, in particular cancer treatment, allocate different zones. For example: 1) zone active hostilities (humanitarian disaster); 2) zone probability of missile/bomb damage (humanitarian problems); 3) zone average probability of missile/bomb damage (humanitarian alertness); 4) zone low probability of missile/bomb damage (humanitarian stability) (193).

The estimated environmental damages caused by the full-scale war, as of November 2023, amount to $59.7 billion. Among them, the largest share, 46.4%, is attributed to air pollution, totaling $27.7 billion (194). The destruction of Russian military equipment has led to the release of 72.7 thousand tons of harmful substances into the atmosphere (194).

Air emissions due to the full-scale war, as of November 2023: 5.9 mln tons total air emissions; 721.8 thou. tons the amount of oil, oil products, and gas burned; 66.9 thou. ha, the area of burned forests and other forest plantations (194).

Ukrainian government institutions, civil society organizations, and international partners have gathered an unprecedented amount of data on the impact of the war on the environment (36). Reports on the environmental situation and air pollution from civil initiatives, supported by foreign donors, typically do not include information on the impact of pollution on public health. They generally only mention potential negative consequences for health (190,191). The analyzed chemical composition and characteristics of certain types of munitions (190) have shown that they can be a source of environmental pollution through emissions of CO, HCN, NO, NO_2, and other complex chemical compounds.

In Estill J.'s study for UNDP (2022), which focused on analyzing the pre-war period, it was shown that air pollution is just one of numerous factors in the network of determinants associated with various diseases and disorders. Furthermore, promoting resource conservation and environmental preservation measures, while simultaneously investing in new pollution-reducing technologies, could effectively improve the health and quality of life of the Ukrainian population (180).

The initial studies on the consequences of the 2014 anti-terrorist operation showed the potential for increased levels of SO_2, NO_2, and CO in the air after bombings (175).

Ukrainian researchers investigated changes in $PM_{2.5}$ in the air after the onset of active military operations; however, conclusive evidence regarding negative trends was not obtained (177).

Researchers from SaveDnipro identified a significant decrease in emissions in the South and East of Ukraine during the war, which they attribute to reduced industrial activity. They point out the localized nature of pollution after explosions when a lot of fine particulate matter and other pollutants are released, followed by their gradual decrease over the next 48 hours (46).

The study by Meng X., et al. (176), which appears quite convincing and comprehensive, relied on data from the Global Air Quality Index project (195), it covered the period from 2016 to 2022 and analyzed cities within a radius of less than 1000 km from the center of Ukraine, including cities in the aggressor country. However, it did not include an examination of the situation within Ukraine itself due to the lack of official information from the country's environmental protection agency. It should be noted that Ukrainian cities are represented in the World Air Quality Index project, with data available from 551 stations (196), including information from organizations like SaveDnipro, which is involved in national air monitoring, and the organizer of the largest environmental chatbot in Ukraine, SaveEcoBot (197). Additionally, data is provided by the Ukrainian real-time air quality monitoring system "LUN City AIR," which has over 100 air quality stations in major cities of Ukraine, including Kyiv (40).

The authors point out (176), that a simple comparison of air pollutant levels before and after the onset of war is a crude and inaccurate indicator in any attempt to quantitatively assess the impact of war on changes in air quality. However, based on their own developed models, they concluded the positive impact of the COVID-19 quarantine on air quality in Europe. They also highlight the negative impact of war on air quality in cities located near battlefields, including Moscow, Krakow (one explanation being the influence of wind), and others, which, in our view, do not seem very appropriate.

While this study emphasizes the urgent need to cease fire from an environmental standpoint, it, in our view, aims to downplay the consequences of losses in European countries due to COVID-19 and does not take into account the real situation in Ukraine, which was not included in the model calculations. As for the positive aspects of this study, they lie in the fact that the results obtained suggest that air pollution during wartime affects not only the countries under attack but also the aggressors.

Paying attention to the environmental problems of the aggressor country and defining them in the border regions and not defining them in Ukraine can be traced in the article by other Chinese scientists Zhang C. et al. (178), which is devoted to atmospheric nitrogen dioxide (NO_2). The results obtained using high-resolution satellite spectroscopy showed that significant decreases in NO_2 concentrations occurred in most Ukrainian cities at the beginning of the war, in contrast to dramatic increases in NO_2 concentrations in Russian cities outside the northern border.

The multidisciplinary team study by Zalakeviciute R, et al. (98), based on satellite imagery of NO_2, CO, O_3, SO_2, and $PM_{2,5}$ over the territory of Ukraine, along with ground monitoring data of $PM_{2.5}$ for Kyiv, showed that NO_2 and $PM_{2.5}$ correlated most strongly with military actions. Levels of CO and O_3 increased, while the concentration of SO_2 and $PM_{2.5}$ decreased (by 38.3% across Ukraine), which the authors attribute to reduced anthropogenic activities during the war.

Malarvizhi AS, et al. (171) employed a complex research design utilizing various datasets, satellite imagery, results from aerospace laboratories, mathematical models, dynamic series, and others. They concluded that the quarantine measures during the COVID-19 pandemic led to a decrease in NO_2 and SO_2 concentrations in the troposphere of Ukraine. Noticeable reductions in air pollutant emissions were observed in cities such as Kyiv, Donetsk, and Dnipro. During the Russian invasion, there was a significant decrease in NO_2 concentration in most eastern regions due to reduced anthropogenic activities, while NO_2 levels increased in the areas around Kharkiv, which were heavily affected by the war. During the war, SO_2 exhibited fluctuations with a tendency to decrease across Ukraine, except in Kyiv and some central regions.

Satellite imagery analysis regarding NO_2 levels compared to the pre-war period showed a general decrease in pollution levels in the eastern part of Ukraine. The most significant reduction (over 30%) was observed in large cities such as Kyiv, Kryvyi Rih, and Zaporizhzhia, but to a lesser extent in smaller towns, including those in Donetsk Oblast. The authors attribute this phenomenon to the decrease in economic activity due to the war and the reduction in population density as a result of the wartime conditions. Additionally, no association was found between explosions and NO_2 concentration in the air, which, according to the authors, indicates that this pollutant is not among the most significant pollutants released during explosions (191).

The research utilizing satellite imagery was conducted by Ukrainian scientists from the Ukrainian Hydrometeorological Institute (24). Savenets M, et al., assessed the impact of the war on cities based on their distance from the front line, the presence of critical infrastructure, and the status of "occupied - not occupied". The results obtained by them show that the most crucial changes were observed during the first months of the war, indicating a decrease in NO_2 levels in major cities, an increase in NO_2 close to the borders, including eastern and northeastern Ukraine, and elevated CO content over wildfires near the front line. Short-term dangerous pollution cases are well detected for industrial damages and wildfires near the front line (24).

The authors note that with the onset of the war, the role of remote sensing has increased, allowing scientists and decision-makers to track environmental changes in Ukraine. The Tropospheric Monitoring Instrument (TROPOMI) onboard the Sentinel-5 Precursor (Sentinel-5P) can be among the best solutions for analysis due to its spatial resolution (24).

Comparison of TROPOMI data with other data sources in Ukraine has shown mostly good correlation; however, remote sensing is limited in heavily polluted areas. There are discrepancies between remotely sensed data and conventional methods for various pollutants, with results strongly influenced by seasonality, weather conditions, and cloud cover (198).

Researchers emphasize that at the current stage of scientific development, the use of remote sensing data is an effective tool for monitoring the impact of military conflicts on the environment (24,199).

A comprehensive review of the available literature conducted by American and Ukrainian scientists revealed that the impacts of the war on air quality in Ukraine have been complex and dynamic. These impacts have included both increases and decreases in air pollution levels. The emissions of several priority pollutants, such as nitrogen dioxide and sulphur dioxide, have decreased due to the negative impacts of the war on Ukraine’s economy. This reduction is a result of closed factories and construction sites, as well as decreased civilian use of vehicles (36).

According to the Ukraine Ministry of Environmental Protection and Natural Resources given in the report «Ukraine war: environmental impact» (2023), causes of improving air quality due to the war: closure of industrial enterprises, reducing emissions from cars due to population migration, closure of construction sites, decrease in electricity consumption, reduced energy capacity as a result of massive shelling of energy facilities. Due to Russia's armed aggression, emissions have decreased, as missile strikes have often targeted energy infrastructure – 50% of generation capacities were destroyed, Emissions from thermal power plants and large boiler houses decreased by 40.4% (194).

The reduction in the first weeks of the war can be attributed to diminished anthropogenic activity, as many parts of Ukraine received a huge quantity of Russian airstrikes or shelling, forcing people to emigrate or hide in underground shelters (98).

The assessment of air pollution in Ukrainian cities during the first half of 2023, based on observations in 33 cities at 113 stationary posts of hydrometeorological monitoring organizations, revealed that when comparing the data with the average daily maximum permissible concentrations (MPCs), exceedances of MPCs of pollutants, including heavy metals, were observed in most monitored cities. However, there was a slight decrease in the level of air pollution (181).

In the latest World Air Quality Report (2023) Ukraine ranked 107th out of 134 countries in terms of population-weighted, 2023 average $PM_{2.5}$ concentration (µg/m³), among 43 European countries, Ukraine ranked 31st. (Figure 4.7), Kyiv ranked 93rd out of 114 cities (200).

The authors of the report emphasized that despite the ongoing war, the number of air quality monitoring stations increased from 22 in 2022 to 28. $PM_{2.5}$ levels continued to decline in most parts of the country (by 11% over the year) due to deindustrialisation resulting from the war (200).

In the spring of 2024, the ranking of the most polluted areas in Ukraine (196) still includes cities in the Kyiv region. Therefore, we do not observe a change in locations regarding the most polluted areas in Ukraine due to the impact of the war.

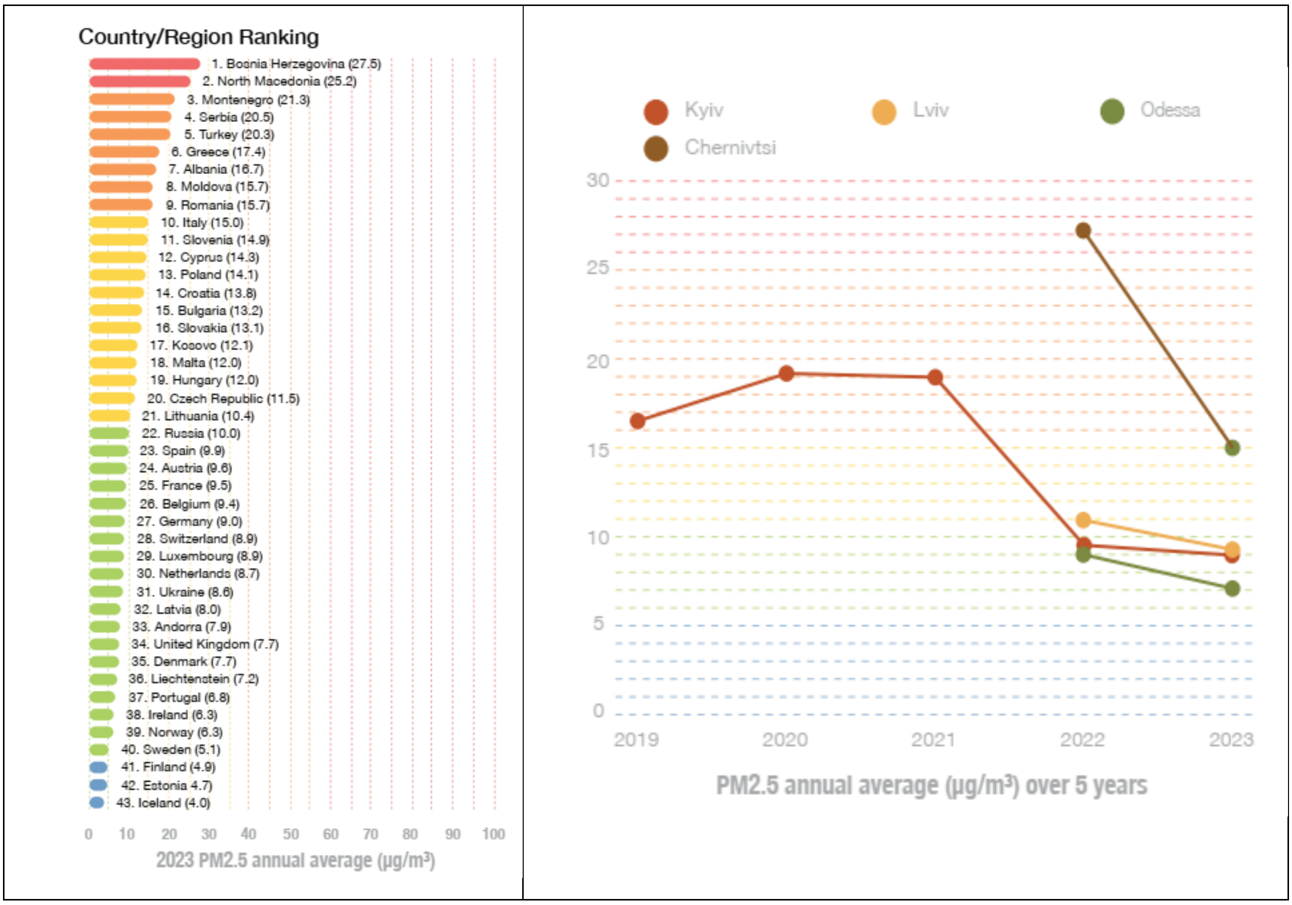


Figure 4.47 Population weighted, 2023 average $PM_{2.5}$ concentration (µg/m³) for European countries and dynamics in individual cities of Ukraine (200)

During the wartime period, the air quality improved on the scale of large cities and the country as a whole due to reduced economic activity of enterprises. However, wartime actions led to local events characterized by heavy air pollution and negative impacts on public health. These events included bombings, emissions into the air from chemical facilities, and dust from weapon debris; fires caused by combat actions; explosions and destruction of buildings; accidents at industrial and infrastructure facilities across various industries; consequences of attacks on fuel depots, storage sites for fuel, raw materials, ammunition, or industrial waste; forest fires; digging of tunnels and trenches; intensive movement of military equipment, and so on (9,30,35).

The use of weapons, bombings, and other consequences of military actions result in high levels of air pollutants in the form of particulate matter, toxic gases, and heavy metals, collectively harming public health (9,177).

The increase in $PM_{2.5}$ levels was observed during the winter season of 2022-2023 due to attacks and damage to Ukraine's energy infrastructure, which required the use of solid fuel sources for heating buildings (201). The monthly levels of $PM_{2.5}$ peaked in January 2023, increasing by an average of 65% compared to 2022 in the cities of the Kyiv region (200).

According to the data from the civic organization "LUN City AIR" (40) during the year of full-scale war, over 90% of the time the air in Kyiv was clean. A very high air quality index was recorded for 194 hours (2.2% of total observation time), which was associated with fires caused by active combat actions around Kyiv (60% of the time when the air quality index was high or very high). Among other reasons were transboundary dust storms and meteorological conditions (202).

Ecological factors for the development of diseases during the war include polluted water or its lack due to shelling, polluted air due to fires, shelling of oil depots, and other industrial facilities, soil contaminated as a result of hostilities, unburied bodies that decompose and pollute the soil and groundwater. Other factors: stress, anxiety, mental exhaustion, unsanitary conditions, lack of food, lack of medicine and medical personnel, damaged and destroyed medical infrastructure, and low level of population vaccination. The main diseases caused by war: are infectious (hepatitis A, diphtheria, measles, poliomyelitis, cholera), non-infectious diseases (diabetes, arthritis, cardiovascular and respiratory diseases), oncology, weakening of the immune system, alcohol and drug addiction, injuries, amputations, contusions, mental, post-traumatic and stress disorders, behavioral disorders (194).

During the Russian-Ukrainian war, there has been increased pressure on the healthcare sector due to a rise in medical problems among the population, this includes issues related to mental health (203–207), substance abuse (208–212), COVID-19 (213), HIV/AIDS (214), oncological diseases (193,215–218), cessation of patients' participation in clinical trials (219–222), and other (223), and direct attacks on healthcare facilities (224–227).

The World Health Organization notes that despite the challenges facing healthcare facilities due to the war, including damage, security issues, lack of utilities (water, electricity, heating), internet connectivity, and staffing shortages, the availability of medical services for the population remains wide but with reduced functional and financial accessibility, especially in frontline regions (228).

A survey conducted by Gradus Research in 2023 showed that overall, 40% of the population of Ukraine (with a sample size of 1091 individuals) are dissatisfied with the current state of the healthcare system, while 55% are dissatisfied with the environmental situation (229).

The war significantly impacts the process of medical care, leading to increased risks and delays in diagnosis and treatment. Experts predict that even a slight delay in treating five common types of cancer for 4 months could result in over 3,600 deaths from cancer in the coming years (215).

According to a survey conducted in April 2024 among 289 Ukrainian cancer patients, it was determined that the quality of oncological medical care has not undergone significant changes. The problem lies in the timeliness of its provision – the waiting time for treatment has increased the most in the eastern and southern regions of Ukraine, leading to 21% of respondents leaving their region precisely because of this issue. There is also a decrease in the accessibility of oncological services – 79% of respondents indicated that they fully pay for treatment out of their own pockets (230).

The impact of the war on the ability to treat cancer patients in Ukraine has also been felt by European countries. Ukrainian patients and doctors have sought assistance from countries such as Romania, Poland, the Czech Republic, Slovakia, Hungary, Finland, Sweden, and others in Europe (231,232).

However, some countries are experiencing significant pressure on their healthcare systems due to the large number of refugees with chronic non-communicable diseases, including cancer. Moldova (233); has reported such challenges. Additionally, there has been a decrease in the quality of life, particularly in the psychological sphere, for populations living close to the border with Ukraine. Romania (234) is one of the countries that has reported this issue. The largest number of reports on healthcare issues related to providing medical assistance to refugees in general (235) and cancer patients specifically (236–240) has been observed in Poland. It's reported that there's a difference between countries regarding a preventive approach, where early diagnosis and timely initiation of appropriate therapy for neoplasms play a key role in treatment outcomes.

The influence of other risk factors on cancer incidence during the war (research data and expert assessment)

Before the full-scale invasion in 2019, according to the results of the STEPS survey, a stepwise approach by the World Health Organization (STEPwise approach to noncommunicable disease risk factor surveillance) in the population aged 18-69 in Ukraine, there were widely prevalent behavioral and biological risk factors (241,242): one-third (33.9%) were active smokers; half (55.6%) consumed alcohol in the last 30 days; two-thirds (66.4%) of the population did not consume enough fruits and vegetables (five servings daily); almost half of the population (44.9%) always or often added salt or salty sauce to their food; almost three-fifths (59.1%) were overweight (BMI ≥ 25 kg/m2), including a quarter of the population (24.8%) suffering from obesity (BMI ≥ 30 kg/m2); one-third of the population (34.8%) had elevated blood pressure or hypertension (SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg or they were taking antihypertensive medications at the time); 40.7% of the population had a total cholesterol level of ≥5.0 mmol/L; and 7.1% had elevated fasting plasma glucose (≥7.0 mmol/L).

The level of physical activity in Ukraine was high and ranked among the highest in the WHO European Region. Only 10% of the population did not meet the WHO recommendation for at least 150 minutes of moderate-intensity physical activity per week, or equivalent. Regarding mental health, every eighth adult (12.4%) in Ukraine reported symptoms corresponding to a clinical diagnosis of depression.

More than half of all women (53.1%) underwent cervical cancer screening at least once in their lifetime. Among women who received abnormal/positive results, suspicion of cancer, or an undetermined result, a significant proportion (91.4%) received treatment for cervical cancer (241,242).

The World Health Organization's study on alcohol consumption in Ukraine, conducted in December 2023, showed that after the start of the full-scale invasion, the proportion of those who reduced alcohol consumption significantly exceeded the proportion of those who increased it since the beginning of the full-scale war: 21.5% of those who had ever consumed alcohol reported a decrease in alcohol consumption, with 6.8% completely abstaining; 5.5% started drinking more, and 2.9% resumed alcohol consumption after a period of abstention (243).

These data correspond to the results of a survey conducted among residents of the Dnipropetrovsk, Lviv, Poltava, and Rivne regions (975 individuals aged 18 and older) regarding awareness, attitudes, and behavior regarding noncommunicable diseases in 2022, as part of the Ukraine-Switzerland project "Acting for Health". The data obtained show a multifaceted impact of the war on the behavioral risk factors of the population: the percentage of respondents who reported consuming alcohol in the last 30 days decreased from 37% to 32% over the year; the percentage of regular cigarette smokers remained unchanged at 21%. However, among them, 45% reported smoking more after the start of the war, compared to 12% who reported smoking less; 30% of respondents stated that they started walking more due to the war, while 28% reported sitting or lying down more; consumption of processed meat products decreased by 40%, and consumption of high-sugar products decreased by 32%, at the same time, consumption of fruits and vegetables decreased by 22% (244).

According to a study conducted by the Ukrainian Institute of the Future in May 2023 with a sample of 1205 respondents: the proportion of individuals consuming alcoholic beverages overall is 82%; 18% of respondents consume alcohol regularly or quite often; 28% of those surveyed reported an increase in alcohol consumption since the start of the full-scale war; for 16% of respondents, alcohol consumption is an important way to relax and unwind (245).

According to a study conducted by the Kyiv International Institute of Sociology (KIIS) with the support of the WHO and the Ministry of Health of Ukraine among 2020 adult residents of Ukraine aged 18 and older in April 2023, it was determined that the prevalence of smoking and the use of new tobacco products among the adult population has not undergone significant changes during the war. Approximately 27.4% of respondents indicated that they use any tobacco and nicotine products, with 23.0% using them daily. 42.3% of respondents indicated that the full-scale war did not affect the intensity of their tobacco or nicotine consumption; 40.2% mentioned that they started using a little more or significantly more tobacco or nicotine; 12.6% reported that they started consuming less or significantly less (246).

According to the special project titled "Experience of war: Food and culinary practices in Ukraine", there has been a certain shift in Ukrainians' eating habits towards the poorer frequency of meals and their nutritional composition during the war period (247).

The results of the third wave of research conducted by the sociological company Gradus Research within the All-Ukrainian Mental Health Program showed an increase in the proportion of respondents who perceive their mental health as unsatisfactory (from 9% in 2022 to 13% in 2024) (248).

Against the backdrop of negative emotions, chronic illnesses have worsened, as evidenced by an increased demand for tranquilizers, antihypertensive, and antidiabetic medications (249).

We conducted our research aimed at studying changes in the prioritization of factors influencing chronic NCDs, including oncological diseases, during wartime (250).

As of 2019, the top ten risk factors contributing to the loss of years of life due to chronic NCDs were as follows: high systolic blood pressure, unhealthy diet, smoking, high levels of low-density lipoprotein (LDL) cholesterol, high body mass index (BMI), alcohol abuse, high fasting plasma glucose levels, air pollution, kidney dysfunction, and suboptimal temperature (11).

The priority of individual risk factors was measured based on expert assessment using a 10-point scale. The panel of experts consisted of 17 individuals, of whom 11 (64.7%) were clinicians (general practice, family medicine, therapy, epidemiology, etc.) with experience in healthcare management; 13 (76.5%) held advanced medical qualifications, and 6 (35.3%) held academic degrees. The number of experts was deemed sufficient, and their competency coefficients were high (above 0.85). The level of agreement among the experts on the researched question, assessed by Kendall's coefficient of concordance, was sufficiently high, measuring 0.69 ($p<0.001$).

During the war, the priorities of influencing factors changed (Table 4.5). According to experts, the factor contributing to the greatest loss of life years due to chronic non-communicable diseases in 2019 was high systolic blood pressure. However, irrational diet dropped to the third position, while smoking rose by two places. Alcohol consumption moved up to the second position, while high levels of LDL cholesterol dropped by two positions. It's worth noting that the priority, as in previous years, predominantly belongs to behavioral risk factors, while environmental factors occupy the last position. Moreover, the impact rank of air pollution decreased according to the opinions of surveyed experts, yielding to metabolic risk factors.

This hierarchy reflects problematic aspects with behavioural risk factors, which were primarily affected by wartime conditions.

Risk	2019 rank (11)	Rank according to experts	Change of rank
High blood pressure*	1	1	–
Dietary risks	2	3	↓1
Tobacco	3	2	↑1
High LDL*	4	6	↓2
High body-mass index*	5	5	–
Alcohol use	6	4	↑2
High fasting plasma glucose*	7	7	–
Air pollution**	8	9	↓1
Kidney dysfunction*	9	8	↑1
Non-optimal temperature**	10	10	–

Table 4.17 Ranking of risk factors that lead to the greatest loss of life years due to chronic non-communicable diseases, including cancer

Notes: No mark – behavioural risks; * – metabolic risks; ** – environmental/occupational risks

According to experts, high systolic blood pressure has the greatest impact on the development of cardiovascular diseases during wartime, with an intensity of 76.5% (95% CI 63.8 - 89.2), and it also affects the development of oncological diseases by 31.8% (95% CI 15.2 - 38.8). Air pollution is considered to have the greatest impact on the development of oncological diseases during wartime by 68.2% (95% CI 43.1 - 75.0), followed by dietary risks at 63.5% (95% CI 36.8 - 68.5), smoking at 51.2% (95% CI 30.9 - 60.3), and alcohol consumption at 37.1% (95% CI 30.9 - 46.7) (Table 4.6).

In addition to the mentioned influencing factors, 14 out of 17 experts (82.4%) noted a significant increase in the impact of psycho-emotional stress on health during wartime.

Full-scale war remains the biggest source of stress - 77% of Ukrainians surveyed by Gradus Research recently experienced stress or high nervousness. This figure has remained unchanged since the fall of 2023 (248). Psychological exhaustion, emotional anxiety, and sleep disturbances are observed in 15-17% of the population (245).

Risk	Cardiovascular diseases	Oncological diseases
	M (95% CI), %	
High blood pressure*	76.5 (63.8 – 89.2)	31.8 (15.2 – 38.8)
Dietary risks	44.7 (33.5 – 60.6)	63.5 (36.8 – 68.5)
Tobacco	57.1 (50.2 – 79.3)	51.2 (30.9 – 60.3)
High LDL*	62.9 (51.6 – 75.4)	24.7 (18.1 – 53.1)
High body-mass index*	59.4 (48.1 – 69.6)	30.6 (26.5 – 38.3)
Alcohol use	41.2 (38.5 - 62.7)	37.1 (30.9 – 46.7)
High fasting plasma glucose*	50.6 (46.8 – 68.5)	29.4 (36.8 – 58.5)
Air pollution**	31.8 (21.8 - 50)	68.2 (43.1 – 75.0)
Kidney dysfunction*	48.2 (41.3 – 67)	15.9 (10.4 – 38.4)
Non-optimal temperature**	14.7 (11.5 – 33.2)	19.4 (9.9 – 28.9)

Table 4.18 The frequency of the intensity of exposure during hostilities to risk factors for the development of cardiovascular and oncological diseases

Notes: No mark – behavioural risks; * – metabolic risks; ** – environmental/occupational risks

According to Ukrainian researchers, the ranking of stressors among Ukrainians during a full-scale invasion is as follows (from most severe to least severe): traumatic experiences such as heavy memories, stressors related to social interactions (conflicts, lack of support, discrimination), deterioration of living conditions, health problems, and the threat to life as a possibility due to the war (251).

Legislative regulation of the fight against oncological diseases during the war in Ukraine

The Ukrainian government acknowledges the issue of increased oncological diseases following the full-scale invasion and has taken corresponding legislative initiatives, including the Decision of the National Security and Defense Council of Ukraine "On Prevention, Early Diagnosis, and Treatment of Malignant Neoplasms," which was put into effect by the Decree of the President of Ukraine dated December 22, 2023, No. 842/2023. The document includes the implementation of a multi-level system of measures for the prevention of malignant neoplasms, taking into account available and updated information on the distribution and intensity of factors influencing their occurrence, including behavioral risk factors

(252).

The National Strategy for Cancer Control for the period up to 2030 and the Action Plan for the Implementation of the National Strategy for Cancer Control have been developed and published for public discussion. These documents aim to prioritize and ensure the implementation of state policies on cancer control to gradually reduce the incidence and mortality caused by cancer, improve the quality of life of patients, ensure the creation of a system for providing accessible high-quality medical services in Ukraine, and address systemic issues in the field (253).

Additionally, a draft resolution of the Cabinet of Ministers of Ukraine "On Approval of the Strategy for the Development of the Healthcare System until 2030 and Approval of the Operational Plan for its Implementation in 2024-2026" has been developed and published for public discussion. It aims to reduce premature mortality from prevalent conditions and diseases, namely cardiovascular diseases, neoplasms, diabetes mellitus, chronic obstructive pulmonary diseases, as well and road traffic injuries by one-third (254).

This suggests that the system of prevention and control of oncological diseases will continue to be actively addressed during wartime and will further develop in post-war times.

Summarizing the conducted literature review, the following can be noted

At present, based on the analysis of the literature, it is not possible to make definitive conclusions regarding the nature of air pollution resulting from war and its impact on public health, including oncological diseases. Most researchers agree on the deterioration of the ecological situation due to wartime activities, although there is currently no compelling evidence regarding atmospheric air pollution.

The different data obtained regarding air pollution are due to various observation periods, the use of diverse information from different sensors, stations, and organizations, different meteorological conditions, and the analysis of its impact.

Research studies are primarily focused on the ecological consequences of military actions, with some addressing the impact of war on health, albeit more often addressing the urgent tasks of organizing medical assistance. There is mention of the potential negative impact of environmental issues in general and air pollution in particular on the population's health, but investigating this chain of causality at the current time is often not feasible.

For a more accurate assessment of overall risk, it is necessary to consider all sources of air pollution and all associated diseases. There is a complex negative impact on the environment, as air pollutants from smoke and chemical trails settle on vegetation, soil, and water (30). It is also necessary to consider psychosocial modifiers of stress response. People suffering from post-traumatic stress disorder experience chronic systemic inflammation and respond poorly to environmental disasters, such as the impact of air pollutants (9).

The level of pollutants in the environment can also vary depending on weather conditions, even if the emissions of pollutants into the air remain constant. Meteorological factors account for approximately 31.21% of fluctuations in air pollutant levels (176).

The connection between air pollution levels and wartime factors can be relatively weak in areas located far from the battlefields (176).

In addition to changes in emissions, another possible explanation for the pollution of large areas of Europe is related to its flat terrain, which provides favorable conditions for the spread of these pollution emissions through the wind (176).

Recommendations for ensuring air quality from the Conflict and Environment Observatory (CEOBS) include optimizing research efforts, which involve detailed analysis of currently available air quality data, including satellite and ground-based data, studying relevant hospitalization records, restoring and expanding air quality monitoring with measurements of a wider range of pollutants and with greater temporal and spatial coverage (30).

Increased monitoring of pollution and a focus on sustainable practices in industrial and energy production should play an important role in the post-war reconstruction period (200).

Our findings justify the need for more rigorous longitudinal cohort studies of the Ukrainian population during and immediately after the conflict, aligning with the views of other researchers (145).

The impact of air pollution as an environmental risk factor intensified by war cannot be viewed in isolation from the influence of other behavioural and socio-economic determinants. It requires consideration of the influence of stress as a triggering mechanism for health-preserving behaviours among the population and as an independent determinant that significantly affects the population's health status.

Assessment of the current levels of pollution and prognosis on the long-term based on air monitoring and other pollution sensors in place in Ukraine (epidemiological ecological study)

Data and Methods

Regions

The data about cancer epidemiology and air pollution was presented for Ukraine and Dnipropetrovsk oblast. When possible, the data about air pollution and cancer epidemiology were stratified by the area of data collection. The information about the military actions intensity and consequences of missile attacks was collected from publicly available sources of information (Institute for the study of War, social media, websites with the statistics of missile attacks, etc.), similarly as in the study by Malarvizhi et al. (171). Further, according to the information about the intensity of military actions, several locations for in-depth analysis were selected and ranked according to the damage caused by the war. The locations are depicted on the Figure 4.8 and were the following:

1. Dnipropetrovsk oblast - in order to assess the overall trends in pollution levels in the region.
2. Nikopol and Marhanets (severely damaged, rank 1) - two towns, near which there are several industrial objects that may significantly influence the level of pollution, from the first weeks of the Zaporizhzhia region occupation remain a target for a regular artillery fire from the opposite bank of the river Dnipro.
3. Kryvyi Rih (significantly damaged, rank 2) - the second after Dnipro city in the region by the number of population. It is an area of concentrated powerful industrial objects that may influence significantly the level of pollution, it has a large number of sensors of air quality, it has been attacked multiple times from air (especially in the first half of 2022, while Kherson region was occupied by russian troops), it is being regularly attacked from air by the Russian troops.
4. Dnipro city (moderately damaged, rank 3) - the main administrative centre of the region, which has the largest number of population, has powerful industrial objects that may significantly influence the level of pollution and a large number of sensors of air quality, it is being regularly attacked from air by the Russian troops.

5. Other – towns and villages in Dnipro (excluding Dnipro city), Kamianske, and Novomoskovsk raions (moderately damaged, rank 4) – areas with relatively few reports of missile/artillery strikes, were included for the comparison with the more damaged areas.

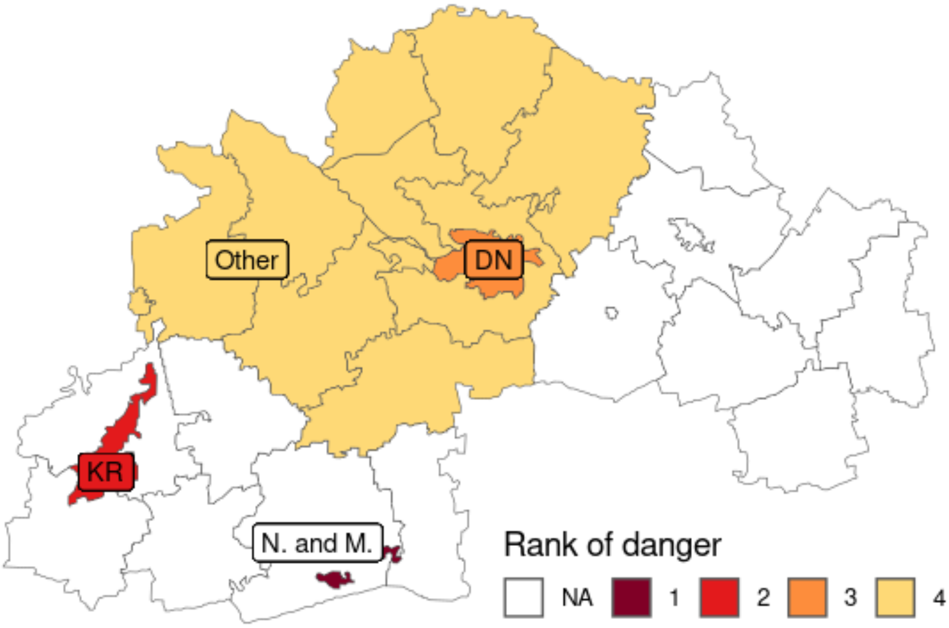


Figure 4.48 Dnipropetrovsk oblast map with rank of danger of the areas in the analysis.

Notes: DN – Dnipro (city), KR – Kryvyi Rih, N. & M. – Nikopol and Marhanets.

Air pollution data

The analysis of the pollution data was designed to describe, first of all, standard pollutants (particulate matter (PM_{10}); fine particulate matter ($PM_{2.5}$); ozone (O_3); nitrogen dioxide (NO_2); sulphur dioxide (SO_2)) (255). However, due to the limited availability of the data some of the pollutants were not described. Whenever possible, information about additional available pollutants was provided.

Pollutants in the study:

- Dust – one of the most important and omnipresent pollutants in the atmospheric air, is included in the calculation of European Air Quality Index (255). According to Global Burden of Diseases Study 2019, particulate air pollution is one of the most influential risk factors of premature death and morbidity worldwide (256). Fine particles ($PM_{2.5}$) and particulate matter (PM_{10}) are monitored according to the EU and Ukrainian standards (257,258). Mostly, dust comes from regular human activities, i.e. power plants, industries and automobiles (259). However, in conditions of war an increase in ambient air dust concentration may be expected. Together with warfare emissions and fuel burning, other sources of dust may contribute significantly: bomb explosions, destruction of buildings, forest fires, etc (176). The upper recommended limits for undifferentiated dust were 0.15 mg/m^3 [260], for $PM_{2.5}$ (annual and 24-hour) – 5 $\mu g/m^3$ and 15 $\mu g/m^3$, for PM_{10} (annual and 24-hour) – 15 $\mu g/m^3$ and 45 $\mu g/m^3$ [261].

- Sulphur dioxide (SO_2) – is a product of fossil fuels burning. In high concentrations may cause environmental and health problems (mostly for respiratory system) (262). The upper recommended daily average limits were set as 0.05 mg/m^3 (181).
- Hydrogen sulphide (H_2S) – possible sources are petroleum, natural gas, soil, sewer gas. Exposure to H_2S might cause cardiovascular, pulmonary and ocular symptoms (263).
- Soot – is a product of incomplete combustion of hydrocarbons (264). Is a group 1 cancerogenic substance according to International Agency for Research on Cancer (265). The upper recommended daily average limits were set as 0.05 mg/m^3 (260).
- Hydrogen fluoride (HF) – is used in various industries, mostly for refrigerants manufacturing. Contact with HF in high concentrations may lead to body surface irritation or damage (266). The upper recommended daily average limits were set as 0.005 mg/m^3 (260).
- Hydrogen chloride (HCl) - is used in various industries, and may be present in domestic cleaning products. Contact with HCl in high concentrations may lead to body surface irritation or damage (267). The upper recommended daily average limits were set as 0.2 mg/m^3 (260).
- Nitrogen dioxide (NO_2) - is used as an indicator of other nitrogen oxides in the atmosphere and is included in the calculation of the European Air Quality Index (255,268). High concentrations of NO_2 can irritate the human respiratory system and lead to deterioration of respiratory diseases (268). NO_2 is not currently recognised as cancerogenic substance (269). Nevertheless, it may be considered as a proxy for traffic-related air pollution (270). Several recent studies found an association between NO_2

pollution and both respiratory and non-respiratory cancers (4,270,271). Fuel consumption by military equipment and massive destruction of fuel reservoirs are likely to contribute to the war-related NO_2 pollution in Ukraine (176). The upper recommended daily average limits were set as 0.04 mg/m^3 (260).

- Carbon monoxide (CO) - is among the most common air pollutants found worldwide, it is a product of burning, its main sources are devices that require fossil fuel for their functioning, is not recognised as a cancerogen (272). High levels of CO may lead to poisoning, but it is unlikely for ambient air (272). Increase of CO atmospheric pollution may be expected during a war time due to engagement of military vehicles and explosives that may cause CO emission (176,272). The upper recommended limits were set as 3 mg/m^3 (260).
- Formaldehyde - it is recognised as a human cancerogen (273,274). Group 2A cancerogenic substance according to International Agency for Research on Cancer (265). It is a common substance that is widely used in industry and is present in various objects that are needed in daily life (275). Due to its widespread formaldehyde is considered as the most abundant carbonyl compound released from anthropogenic activities (275). One of the sources of formaldehyde is traffic emissions (274). Although it is not directly related to the military actions, its level may depend on the industrial activity and density of population in the areas of interest. The upper recommended limits were set as 0.003 mg/m^3 (260).
- Ammonia (NH_3) - is a very important industrial chemical, as a crucial alkaline compound in the troposphere, can deteriorate air quality by favouring secondary aerosol formation (276,277). It is normally present in air, water and soil. Typical exposure doesn't lead to health effects, high levels of NH_3 may lead to body surface irritation or damage (278,279). It is not recognised as a cancerogen (279) and is not a part of military equipment. However, during military actions intended or not-intended damage to ammonia reservoirs is possible, which happened several times during Russian full-scale military invasion to Ukraine in Donetsk and Luhansk oblasts (1). The upper recommended limits were set as 0.04 mg/m^3 (260).

- Phenol - is highly irritative to human body surfaces, phenol poisoning can occur in humans after skin absorption, inhalation of vapours or ingestion. It is not recognised as a cancerogen (280). Phenol exhibits the properties of a protoplasmic poison and is dangerous for any tissues in the body. It is being used in polymers production and can be found in several medical products. The upper recommended limits were set as 0.003 mg/m^3 (260).
- Heavy metals - are naturally occurring chemical elements in the environment with an atomic mass greater than 63.5 and a specific gravity greater than 5.0 g/cm^3, usually composed of metals and metalloids, which are generally required for the better functioning of biological cells in low concentrations (trace elements) or are potentially toxic elements, especially in high concentrations (281). Heavy metals do not undergo decomposition processes, but can only be redistributed between natural environments. They are a serious environmental problem worldwide due to their toxicity, stability in environmental objects, wide distribution and higher potential toxicity and bioaccumulation in living organisms, causing various pathological processes (282–285). Military activities (burning of rocket fuel, gunshot discharge, etc.) may result in heavy metal environmental pollution (1,286).

Data about ambient air pollution were taken from:

1. Ministry of Environmental Protection and Natural Resources of Ukraine (MEPNRU) (22) and Central Geophysical Observatory (CGO) named after Borys Sreznevsky (181) – public reports about the condition of the environment in Ukraine in 2017-2023.
2. State Statistics Service of Ukraine (Ukrstat) – data about overall and pollutant-wise (PM, NO_2, SO_2, CO) atmospheric emissions by different types of sources in 2008-2021 for Ukraine in general and region-wise (287).
3. Dnipro Regional Centre of Hydrometeorology (RCGM) - monthly average values and number of single measurements above MPCs.m. of undifferentiated dust, NO_2, CO, phenol and formaldehyde. Used for the analysis of air pollution in Dnipro and Kryvyi Rih for the period 2009-2022. In total, data about 64,466 measurements were enrolled into analysis.
4. State institution "Dnipropetrovsk Regional Center for Disease Control and Prevention of the Ministry of Health of Ukraine" - data about excess

concentration of salts of heavy metals (manganese, mercury, lead, chromium) above MPC in the air, 36,483 measurements.

5. Ukrainian citizen air quality monitoring network EcoCity - average values of pollutants for 20-minutes intervals in different locations of Dnipropetrovsk oblast from February 2019 till September 2023 (288). Daily and monthly average levels were analysed. The amount of data enrolled into analysis for each pollutant was the following: $PM_{2.5}$ - 74,243,321 measurements, February 2019-December 2023; PM_{10} - 73,755,321 measurements, February 2019-December 2023; NO_2 - 17,229,516 measurements, February 2020-December 2023; CO - 16,053,565 measurements, February 2020-December 2023; NH_3 - 32,986,706 measurements, September 2019-December 2023; formaldehyde - 7,558,301 measurements, October 2019-December 2023.
6. Public organisation SaveDnipro - hourly average values of NowCast $PM_{2.5}$ Air Quality (289) index from February 2019 till September 2023 in different locations of Dnipropetrovsk oblast (290). Data about 511,784 hourly measurements was enrolled into analysis.

In order to ensure the reliability of the data received, before enrolling to the analysis raw data from citizen air monitoring networks were cleaned. Unrealistically low values and values above three-fold maximum permissible concentration limits according to Ukrainian legislation (260) were considered as outliers (or values caused by extreme meteorological conditions) and were omitted. Although this approach could introduce a bias to the results of observations, the bias was systematic and should have equally influenced the whole data massive. Since the goal of the presented study was to detect changes related to the beginning of the full-scale military invasion, the measurements with a systematic bias still should make possible detection of a rapid change in the pollution level in a given time point. Moreover, the values after the cleaning were close to the values obtained from governmental services dealing with air quality monitoring during the corresponding time intervals. Therefore, they were considered to be reliable and applicable for the analysis.

To assess the quality of atmospheric air, such indicators as average daily, average monthly and average annual concentrations of pollutants were assessed. Air pollution measurements were compared with thresholds for daily average maximum permissible concentrations (MPCd.a.) and single measurement maximum permissible concentrations (MPCs.m.) from national guidelines (260). The thresholds for of PM2.5 and PM10 in atmospheric air are regulated by Resolution of the Cabinet of Ministers of Ukraine dated August 14, 2019 No. 827 in accordance with Directive 2008/50/EC (291). However, in 2021 WHO updated air quality guidelines for several pollutants, including $PM_{2.5}$ and PM_{10}, which were used for the air pollution assessment (261).

The data that were available in particles per million or per billion (ppm or ppb) were converted to mg/m^3 in order to assess them according to national guidelines (260). Conversion to mg/m^3 was performed using average seasonal values of temperature and atmospheric pressure . For the conversion the following equations were used (292):

$$Concentration(mg/m^3) = \frac{pressure(mmHg)xmolecularweightxconcentration(ppm)}{62.4x(273.2 + T°C)}$$

$$Concentration(mg/m^3) = \frac{pressure(mmHg)xmolecularweightxconcentration(ppb)}{62.4x(273.2 + T°C)x1000}$$

To assess the influence of war on the air pollution levels the following approaches were applied:

1. Evaluation of association between annual levels of air pollution from 2009 till 2022 with Russian military offensives in 2014 and 2022 and air pollution. This part of the analysis was limited to Dnipro (city) and Kryvyi Rih, due to the data availability only for these locations.
2. Evaluation of association between daily, monthly and annual average levels of air pollution during February 2019-December 2023, with the Russian military offensive in 2022. In this part of the analysis data were analysed for the whole Dnipropetrovsk oblast, Dnipro (city), Kryvyi Rih, Nikopol and Marhanets and Other locations.
3. Daily average levels of air pollutants in Dnipro and Kryvyi Rih were assessed in timepoints of missile attacks during the beginning of the invasion (February-May 2022) and during autumn-winter 2022/2023 when multiple massive missile attacks took place (293–327). These locations were selected because of a high number of sensors and frequent missile attacks. For the study were selected either attacks that were described as massive in media or that resulted in significant destruction, even despite a small

number of missiles involved (severe damage/destruction of industrial objects, oil reservoirs or multi storey living buildings). Change in air pollution levels in Dnipro and Kryvyi Rih was analysed separately with the account for the location of the missile attack. If the daily average level of a pollutant increased within 48 hours from the attack, this elevation was considered as related to the attack.

4. Additionally, average values of 20-minutes intervals for two time intervals were investigated. These were the 22-26 February 2022 (for Dnipro and Kryvyi Rih) as the beginning of the full-scale Russian military invasion; and 28 March - 08 April 2022, (for Dnipro only) as during this time three missile attacks with oil reservoirs/fuel storage destruction and one massive missile attack took place (297,299–301).

Additionally, air pollution related cancer risk and non-cancerogenic risk for population was assessed, as well as their change after the beginning of the full-scale Russian military invasion.

Cancer risks for populations exposed to cancerogenic substances (formaldehyde, soot) was calculated according to the National recommendations on cancerogenic and non-carcinogenic risk for the population health, provided by the Ministry of Health of Ukraine (265).

$$Cancerrisk = \frac{CxCRxEFxED}{BWxATx365}xSF,$$

where C is an average concentration of a cancerogen, CR – speed of air income to a body (was set as 20 m^3/day), EF – frequency of exposure, per year (was set as 365 days), ED – duration of exposure (was set as 70 years), BW – body weight (was set as 70 kg), AT – duration of exposure averaging (was set as 70 years), SF – cancerogen potential of the substance.

Thresholds for the cancer risk interpretation: $<10^{-6}$ – minimal (optimal), 10^{-4} – 10^{-6} – low (acceptable), 10^{-3} – 10^{-4} – average (acceptable for industries, but unacceptable for population; requires additional control). $>10^{-3}$ – high (unacceptable neither for industries, nor for population, measures for the pollution reduction are needed) (265).

Hazard quotient (HQ) for population exposed to non-cancerogenic substances was calculated as following (265):

$$HQ = \frac{Concentration of a substance}{Reference concentration}$$

HQs for different pollutants were summarised to get the value of hazard index (HI), in order to assess the overall influence of air pollutants on the population health.

$$HI = \Sigma HQ_i$$

Thresholds for the hazard index interpretation:

Hazard quotient	Hazard index	Risk level
>3	>6	high
1.1-3.0	3.1-6.0	alarming
0.11-1.0	1.1-3.0	acceptable
≤0.1	≤1.0	minimal (optimal)

Table 4.19 Thresholds for the hazard index interpretation.

Cancer epidemiology data

Data about cancer epidemiology was taken from the reports of the National Cancer Registry of Ukraine (NCRU) (158), the statistical reports of the Ministry of Health of Ukraine (MoHU) (328) and Dnipro Cancer Registry (DCR).

The following information was analysed:

1. Total and respiratory (C32-C34) cancer incidence and mortality;
2. Oncologists' services utilisation was calculated as (number of visits to oncologists / population of a given area) * 100,000 (for Dnipropetrovsk oblast only);
3. Percent of deaths within one year after the disease onset was calculated as (number of deaths that occurred within 1 year from the diagnosis onset in a given year / total number registered patients in a given year) * 100% (for Dnipropetrovsk oblast only);
4. Survival analysis of patients with cancer depending on the area of residence and depending on the time of cancer diagnosis (for Dnipropetrovsk oblast only).

Additionally, the data about incidence and mortality from the following types of cancers was analysed in correlation analysis with air pollutants emissions: C00-C96 - Malignant neoplasms of all localisations; C16 - Malignant neoplasm of stomach; C32 - Malignant neoplasm of larynx; C33-C34 - Malignant neoplasm of trachea, bronchus and lung; C50 - Malignant neoplasm of breast; C53 - Malignant neoplasm of cervix uteri. The information was collected by the country region, from publicly available NCRU reports.

Information about new cancer cases, deaths from cancer for Ukraine and Dnipropetrovsk oblast in 2009-2021 were extracted from the reports by the Ministry of Health of Ukraine. The data about population of Ukraine and Dnipropetrovsk oblast was taken from State Statistics Service of Ukraine (287). For the calculation of the epidemiological indicators for Ukraine in 2014-2022, the population of Donetsk, Luhansk oblasts and Crimea was not accounted, using the same approach as in the NCRU (158).

Periodisation

Where it was possible data were compared in the following time intervals: 2009-2013 (time before Russian invasion in 2014), 2014-2019 (time after Russian invasion and before COVID-19 pandemic), 2020-2023 (time of COVID-19 pandemic and full-scale Russian invasion in 2022, for in-depth analysis of influence of the war on the air pollution).

Statistical analysis

Data processing and statistical analysis were conducted using LibreOffice, Google Docs, Jupyter Notebook (329) and R (version 4.3.1) (330) environments. Standard methods of descriptive and analytical statistics were employed for data analysis. 95% confidence intervals (95% CI) were computed for both summary averages and relative indicators. The analysis of dynamic series, with calculation of visibility index, annual average growth rate using the method of least squares, and linear regression models were used for the assessment of trends in air pollution and cancer epidemiology over the time of observation. Prognosis of air pollution level was made based on linear regression models, as in the study by Ferlay et al. (331). Prognosis of air pollution in Ukraine was made for 2024-2025 time interval. Prognosis of air pollution in Dnipropetrovsk oblast was made for 2023-2025 time interval when using the RCGM data (14 years of observation), and for 2024 when using the EcoCity data (5 years of observation).

The direction of linear trends (increase/decrease) was assessed using the method used by Qin et al. (332). An estimated annual percentage changes (EAPCs) and limits of 95% CI of a regression coefficient were calculated. The EAPCs were estimated using a linear regression model: $y = \alpha + \beta x + \varepsilon$, where y is an outcome variable, x is the calendar year, and ε is the error term. The EAPCs were calculated as $100 \times (\exp(\beta) - 1)$. If the EAPC and the lower limit of the 95% CI were both >0, the trend was considered to be increasing. If the EAPC and the upper limit of the 95% CI were both <0, the trend was considered to be decreasing.

Assessment of correlations between air pollutant emissions and cancer epidemiology. Region-wise crude and age-standardized (for the world and Ukraine) incidence and mortality rates in 2014-2019 years were collected from the publicly available NCRU reports. Observations for 2020 and 2021 were severely affected by the COVID-19 pandemic and demonstrated a steep fall in incidence and tremendous distortions in mortality rates that did not fit the previous years, and therefore were excluded from the analysis. Per square kilometre (km^2) air pollutants emission rates were enrolled to the analysis. It was apriori assumed that pollutant levels per km^2 could be a proxy for the concentration of air pollutants. This assumption was proved empirically since after performing all the correlations, emissions per km^2 levels had on average stronger correlations than crude values. Therefore they were selected for the reporting. Calculation of air pollutant emissions per km^2 was performed using the information about the total square of each region of Ukraine (Ukrstat data). The analysis was based on the assumption that levels of air pollutants affect incidence/mortality rates with some delay (lag). Thus, Y_t may correlate with X_{t-n}, where Y_t is an incidence/mortality rates at some point in time "t", and X_{t-n} is an air pollutant levels "n" years before the time "t". The actual lag "n" could be different for different X's and Y's so all possible X and Y combinations and numerous lags (from 1 to 6) were tested to get the full picture. Spearman's rank correlation coefficient was calculated for association between air pollutants emissions and cancer incidence/mortality. The values of air pollutants emissions and cancer incidence/mortality were ranked separately within each region before enrolling into the analysis.

The impact of missile attacks on air quality was calculated with the help of mathematical predictive modelling. The AutoRegressive Integrated Moving Average eXtended (ARIMAX) model is a time series analysis technique used to forecast future values based on past observations (333). It extends the traditional

ARIMA model by incorporating exogenous variables. It allows for more accurate predictions by considering additional factors (e.g., a fact of a missile attack during the day or weather conditions) that may influence the analysed time series (e.g., pollutant levels). Obtained coefficients of ARIMAX models for exogenous variables show the absolute increase (if positive) or decrease (if negative) of the studied parameter (pollutant levels) given the presence of external factors (missile attack) during the day. Two types of models were used. The first one used only preceding levels of pollutants and information about missile attacks for prediction. In the second one additional parameters such as temperature, atmospheric pressure on the sea level, humidity, wind speed and cloudiness were also incorporated into the model to account for the possible impact of weather conditions.

Survival analysis was conducted for patients in Dnipropetrovsk oblast using building Kaplan-Meier curves and calculation of Cox proportional hazards regression models. Stratification by the area of residence and time of cancer diagnosis was applied in order to assess the influence of war intensity and time of cancer diagnosis on the survival of the patients. The starting time point was the date of cancer diagnosis. The end time point was the date of last observation. Difference between survival curves was assessed using log-rank test. Median survival and hazard risk (HR) with 95% CI were calculated. Critical value of p for evaluation of statistical hypotheses was set as <0.05.

Impact of war on air pollution

Ukraine

Total amount of atmospheric emissions from stationary sources in Ukraine had an overall decreasing non-linear trend (Figure 4.9). It was stable in 2008-2013. In 2014, with the beginning of Russian-Ukrainian war and occupation of territories of Donetsk and Luhansk oblasts the amount of emissions abruptly decreased. In 2017 the trend of atmospheric emissions stabilised and remained above 2000 thousands of tons per year till 2021, with a gradual decrease. The presented data do not account for the emissions coming from occupied territories after 2014 (334), which means that the actual degree of air pollution might be higher.

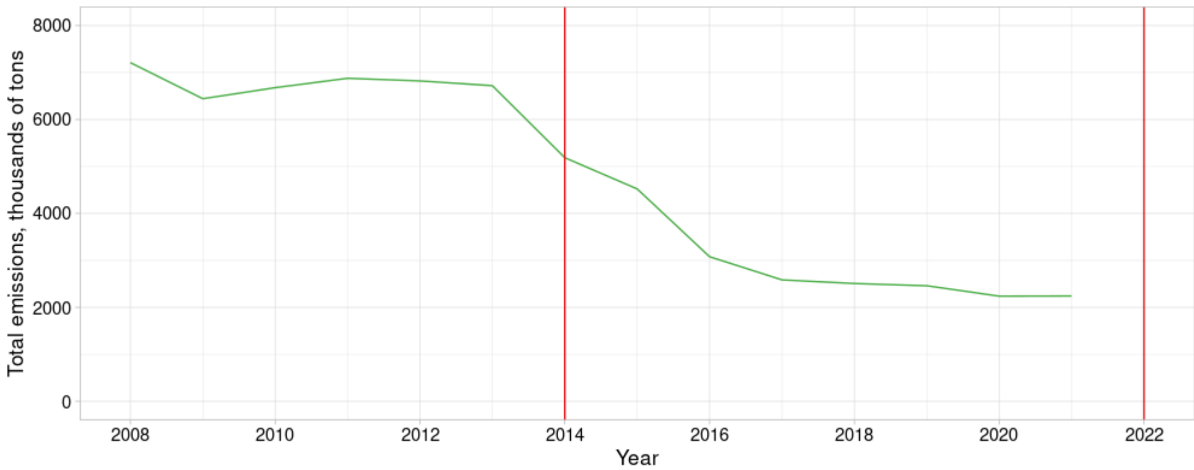


Figure 4.49 Total amount of atmospheric emissions from stationary sources in Ukraine in 2008-2021. Ukrstat data.

The air pollution index in Ukraine fluctuated between 6.0 and 8.2 (Table 4.8), and was mostly characterised as high (22). Air pollution in Ukraine before the full-scale Russian military invasion of Ukraine in 2022 was characterised as high, according to the air pollution level. The highest levels of air pollution were registered mostly in the Eastern regions of Ukraine, where is the highest concentration of industries that produce emissions. The average values of air pollutants in Ukraine are in the table below. Despite the gradual decrease of atmospheric emissions amount from stationary sources (which are considered to be the most significant contributor to air pollution) in 2017-2021, the air pollution index had not decreased and remained above 7.0. The main contributors to the air pollution were formaldehyde, phenol, HF, NH_3, NO_2, dust, CO (22).

Substance	Year, mg/m^3						
	2017	2018	2019	2020	2021	2022	2023 (1st half)
Undifferentiated dust	0.14	0.13	0.13	0.13	0.12	0.11	0.12
SO_2	0.016	0.015	0.018	0.019	0.017	0.018	0.019
CO	1.8	1.7	1.6	1.4	1.4	1.3	1.2
NO_2	0.06	0.06	0.06	0.06	0.06	0.06	0.06
NO	0.03	0.03	0.03	0.03	0.03	0.03	0.03
H_2S	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Soot	–	–	–	0.03	0.03	0.03	0.02
Phenol	0.003	0.004	0.004	0.003	0.003	0.003	0.003
HF	0.004	0.004	0.004	0.003	0.004	0.003	0.003
HCl	0.06	0.05	0.04	0.05	0.05	0.04	0.05
NH_3	0.02	0.02	0.02	0.02	0.02	0.02	0.01
Formaldehyde	0.007	0.007	0.008	0.007	0.007	0.007	0.006
Air pollution index	7.2	7.6	8.2	7.0	7.1	6.5	6.0

Table 4.20 Annual average levels of pollutants in Ukraine in 2017-2023. CGO and MEPNRU data.

Linear trend equations: undifferentiated dust: $y = 8.06 - 0.0039x$ ($p=0.01$); SO_2: $y = -0.99 + 0.0005x$ ($p=0.07$); CO: $y = 203.48 - 0.1000x$ ($p<0.01$); NO_2: NA; NO: NA; H_2S: NA; soot: $y = 6.09 - 0.0030x$ ($p=0.22$); phenol: $y = 0.22 - 0.0001x$ ($p=0.28$); HF: $y = - 0.36 -0.0002x$ ($p=0.07$); HCl: $y = 2.93 - 0.0014x$ ($p=0.31$); NH_3: $y = 2.18 - 0.0011x$ ($p=0.14$); formaldehyde: $y = 0.29 - 0.0001x$ ($p=0.21$); air pollution index: $y = 504.87 - 0.2464x$ ($p=0.05$). CGO and MEPNRU data.

In 2022-2023 the air pollution index has declined to 6.3 (5.8-6.7), as compared to 7.1 (6.0-7.2) in 2020-2021 (Table 4.9). The 2022-2023 average levels of undifferentiated dust, CO, soot, HF, HCl, NH_3, and formaldehyde were lower than in 2020-2021, but this difference was not statistically significant. The average level of one pollutant – sulphur dioxide – increased in 2022-2023 (ns).

Substance (mg/m^3)	Average level (95% CI)			p value (2020-2021 vs 2022-2023)
	2017-2019	2020-2021	2022-2023	
Undifferentiated dust	0.133 (0.126-0.14)	0.125 (0.115-0.135)	0.115 (0.105-0.125)	0.29
SO_2	0.016 (0.014-0.018)	0.018 (0.016-0.020)	0.018 (0.017-0.019)	0.71
CO	1.700 (1.587-1.813)	1.400 (1.400-1.400)	1.250 (1.152-1.348)	0.20
NO_2	0.060 (0.060-0.060)	0.060 (0.060-0.060)	0.060 (0.060-0.060)	1.00
NO	0.030 (0.030-0.030)	0.030 (0.030-0.030)	0.030 (0.030-0.030)	1.00
H_2S	0.002 (0.002-0.002)	0.002 (0.002-0.002)	0.002 (0.002-0.002)	1.00
Soot	NA	0.030 (0.030-0.030)	0.025 (0.015-0.035)	0.50
Phenol	0.0037 (0.0030-0.0044)	0.0030 (0.0030-0.0030)	0.0030 (0.0030-0.0030)	1.00
HF	0.0040 (0.0040-0.0040)	0.0035 (0.0025-0.0045)	0.0030 (0.0030-0.0030)	0.50
HCl	0.050 (0.039-0.061)	0.050 (0.050-0.050)	0.045 (0.035-0.055)	0.50

NH_3	0.020 (0.020-0.020)	0.020 (0.020-0.020)	0.015 (0.005-0.025)	0.50
Formaldehyde	0.0073 (0.0066-0.0080)	0.0070 (0.0070-0.0070)	0.0065 (0.0055-0.0075)	0.50
Air pollution index	7.7 (7.1-8.2)	7.1 (6.0-7.2)	6.3 (5.8-6.7)	0.18

Table 4.21 Comparison of 2017-2021 and 2022-2023 annual average levels of pollutants in Ukraine. CGO and MEPNRU data.

There was an increase of the maximum single measurement levels of air pollutant concentrations in 2022-2023, when compared to the pre-invasion years, especially 2020-2021 (Table 4.10). Maximum single measurement concentrations increased for sulphur dioxide (0.437 mg/m^3 in 2023), CO (30.4 mg/m^3 in 2022), NO_2 (2.33 mg/m^3 in 2022), soot (0.25 mg/m^3 in 2022), HF (0.066 mg/m^3 in 2022), NH_3 (0.33 mg/m^3 in 2022). At the same time, maximum single measurement levels of phenol and formaldehyde were decreasing in 2022-2023.

Substance	Year, mg/m^3						
	2017	2018	2019	2020	2021	2022	2023 (1st half)
Undifferentiated dust	2.2	2.0	2.4	2.1	2.1	2.1	2.1
SO_2	0.271	0.236	0.573	0.409	0.289	0.0285	0.437
CO	21.0	44.0	31.8	22.0	26.3	30.4	10.0
NO_2	1.14	0.066	0.81	0.9	0.8	2.33	0.5
NO	0.23	0.61	1.01	0.45	0.44	0.026	0.16
H_2S	0.025	0.039	0.039	0.037	0.039	0.039	0.069
Soot	–	–	–	0.26	0.22	0.25	0.20
Phenol	0.043	0.041	0.003	0.041	0.037	0.029	0.024
HF	0.055	0.0048	0.005	0.051	0.055	0.066	0.029
HCl	0.63	0.54	0.20	0.98	0.80	0.60	0.60
NH_3	0.57	0.43	0.04	0.56	0.23	0.33	0.20
Formaldehyde	0.134	0.17	0.003	0.107	0.18	0.077	0.063

Table 4.22 Maximum single measurement levels of pollutants in Ukraine in 2017-2023. CGO and MEPNRU data.

In 2022-2023 the percentage of locations with the average levels of undifferentiated dust, phenol, and hydrogen fluoride above MPCd.a. was higher than in 2020-2021 (Table 4.11). In 2022 there was the highest percentage of locations with the average level of CO, soot, phenol and formaldehyde above MPCd.a., when compared to the neighbouring years.

Substance	Year , %						
	2017	2018	2019	2020	2021	2022	2023 (1st half)
Undifferentiated dust	23	28	28	18	18	20	28
SO_2	0	0	3	3	0	3	3
CO	11	8	8	5	2	5	0
NO_2	54	56	67	64	67	61	3
NO	4	9	9	9	9	9	5
H_2S	–	–	–	–	–	–	–
Soot	–	–	–	0	0	17	0
Phenol	47	41	53	35	35	41	38
HF	18	18	27	0	18	9	22
HCl	0	0	0	0	0	0	0
NH_3	6	6	13	13	6	6	8
Formaldehyde	80	83	83	77	80	83	73

Table 4.23 Percentage of cities with annual average air pollution levels above MPCd.a. in Ukraine in 2021-2023. CGO and MEPNRU data.

In 2022-2023 the percentage of locations with maximum levels of pollutants above MPCs.m. was generally lower than in 2017-2021 (Table 4.12). However, in 2022 the percentage of locations with soot and NH_3 above MPCs.m. was the highest, when compared to the neighbouring years.

Substance	Year , %						
	2017	2018	2019	2020	2021	2022	2023 (1st half)
Undifferentiated dust	44	49	41	51	43	38	28
SO_2	0	0	3	0	0	0	0
CO	54	51	49	53	47	34	19
NO_2	51	51	59	49	51	44	34
NO	0	4	4	4	4	0	0
H_2S	36	36	55	36	45	36	30
Soot	–	–	–	33	33	50	17
Phenol	100	82	82	94	88	88	69
HF	55	55	45	45	45	45	22
HCl	40	30	30	30	20	30	29
NH_3	6	6	13	13	6	12	0
Formaldehyde	43	53	53	53	53	43	36

Table 4.24 Percentage of cities with maximum single measurement air pollution levels above MPCs.m. in Ukraine in 2021-2023. CGO and MEPNRU data.

The air pollution in Ukraine in 2017-2023 was characterised by mostly high level. After the full-scale Russian military invasion of Ukraine in 2022 the air pollution index, as well as the average levels of several pollutants, in Ukraine has decreased, when compared to 2020-2021. However, this decrease was not statistically significant. The average level of SO_2 has increased in 2022-2023, when compared to previous years, but this increase was statistically non-significant. In all probability, the overall decrease of air pollution in Ukraine in 2022-2023 was related to the rapid decline in industrial activity and emigration from the country. Also, the energy sector in Ukraine is the most significant contributor to the atmospheric emissions (22). Russian attacks led to the destruction of around 50% of Ukrainian energy infrastructure (194), which, in all probability, substantially contributed to the decrease in air pollution.

Despite that, there was an increase in maximum single measurement concentrations of sulphur dioxide, CO, NO_2, soot, hydrogen fluoride, and NH_3 in 2022-2023, which were higher than in the pre-invasion years. In 2022 there was the highest, when compared to the neighbouring years, percentage of locations with the elevated average levels of CO, soot, phenol, and elevated maximum levels of soot and NH_3.

Also, in 2022-2023 for several air pollutants there was an increase in percentage of locations with the average level of pollutants above MPCd.a. and MPCs.m. The pollutants involved were products of burning (CO, NO_2, soot), short-term increase in concentration of which is expectable during air strikes, fuel burning (including damage of fuel reservoirs), forest fires etc. But there was also an increase of sulphur dioxide, hydrogen fluoride, phenol, NH_3, and formaldehyde, which are not directly related to the military equipment, but which may release due to the damage of industrial objects.

Dnipropetrovsk oblast

Undifferentiated dust

In Dnipro, over the period 2009-2022 the annual average levels of undifferentiated dust remained relatively stable with a fluctuation between 225.0 μg/m^3 in 2021 and 366.7 μg/m^3 in 2013 (Figure 4.10). The annual average dust levels were 1.6-2.5 times above the $MPC_{d.a.}$ throughout the period of observation. There was a slight decline in the annual average dust levels in 2018-2021. With the beginning of the full-scale Russian military invasion in 2022 there was a 9% increase in the annual average dust level, as compared to the previous year (from 225 (199.4-250.6) μg/m^3 to 241.7 (212.6-270.8) μg/m^3, $p<0.05$). In Kryvyi Rih the annual average levels of undifferentiated dust fluctuated between 308.3 μg/m^3 in 2009 (2.1 times above

MPC$_{d.a.}$) and 791.7 µg/m^3 in 2015 (5.3 times above MPC$_{d.a.}$). In contrast with Dnipro, in 2022 it was lower than in 2021.

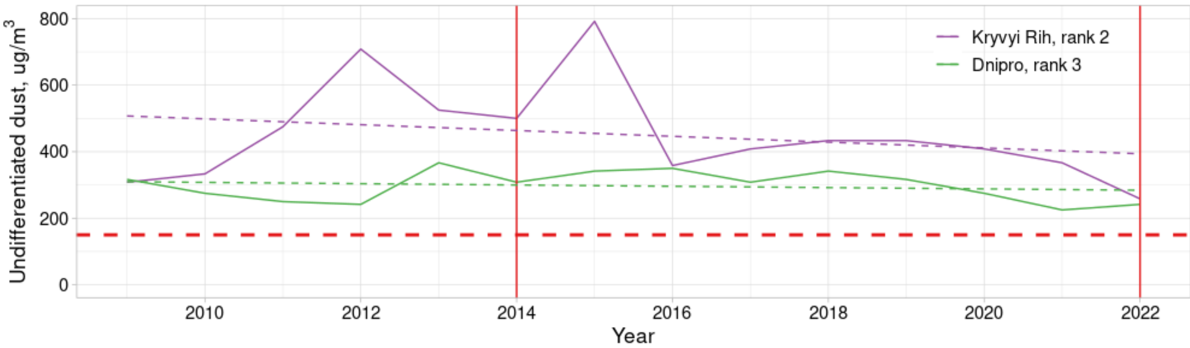


Figure 4.50 Dynamics of average levels of undifferentiated dust in Dnipro and Kryvyi Rih from 2009 till 2022. RCGM data.

Notes: red dashed line - MPCd.a.; dashed lines of corresponding colours - linear trend lines; vertical red solid lines - beginnings of military offensives (2014, 2022). Linear trend equations (per year): Dnipro: y = 4246.81 – 1.9597x (p=0.54); Kryvyi Rih: y = 18058.53 -8.7363x (p=0.39). RCGM data.

The frequency of undifferentiated dust values above MPCs.m. in Dnipro in 2022 was 12 times higher than in 2021 – 24 vs 2 (Table 4.13). The highest frequencies were observed in February-April, July-September and November-December, which coincides with the time periods of active missile attacks. The same analysis in Kryvyi Rih did not reveal similar findings. However, the frequency of values above MPCs.m. in February, 2022, was 4.5 times higher than in February, 2021 (Chi-square test p-value <0.01).

City	Year	Number of measurements above MPCs.m., n (%)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dnipro	2021	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.6)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.5)	0 (0)	0 (0)
	2022	0 (0)	2 (1)	5 (2.5)	2 (1)	0 (0)	0 (0)	2 (1)	4 (1.9)	2 (1)	0 (0)	4 (2.2)	3 (1.7)
Kryvyi Rih	2021	8 (3.4)	8 (3.3)	28 (11.2)	44 (17.6)	63 (28)	44 (19.1)	131 (50.4)	27 (11.3)	37 (15.3)	55 (23.4)	21 (8.4)	13 (5.6)
	2022	10 (4.2)	37 (15.8)	19 (12)	42 (16.8)	6 (2.4)	61 (23.5)	48 (18.5)	10 (4.1)	4 (1.7)	0 (0)	0 (0)	0 (0)

Table 4.25 Number of undifferentiated dust levels above MPCs.m. in Dnipro and Kryvyi Rih in 2021-2022. RCGM data.

PM$_{2.5}$, PM$_{10}$ and NowCast AQI

There was a clear seasonal fluctuation (increase during cold months and decrease during warm months) of $PM_{2.5}$ and PM_{10} ambient air levels in all observed locations (Figures 4.11, 4.12). In general, the EcoCity data correspond to 2019-2022 RCGM data. There was a general downward trend of $PM_{2.5}$ levels in all studied locations in 2019-2023 ($p<0.01$). There was a small elevation of $PM_{2.5}$ in all studied areas in February 2022, which could be attributed to the massive rocket attack on 24 February 2022.

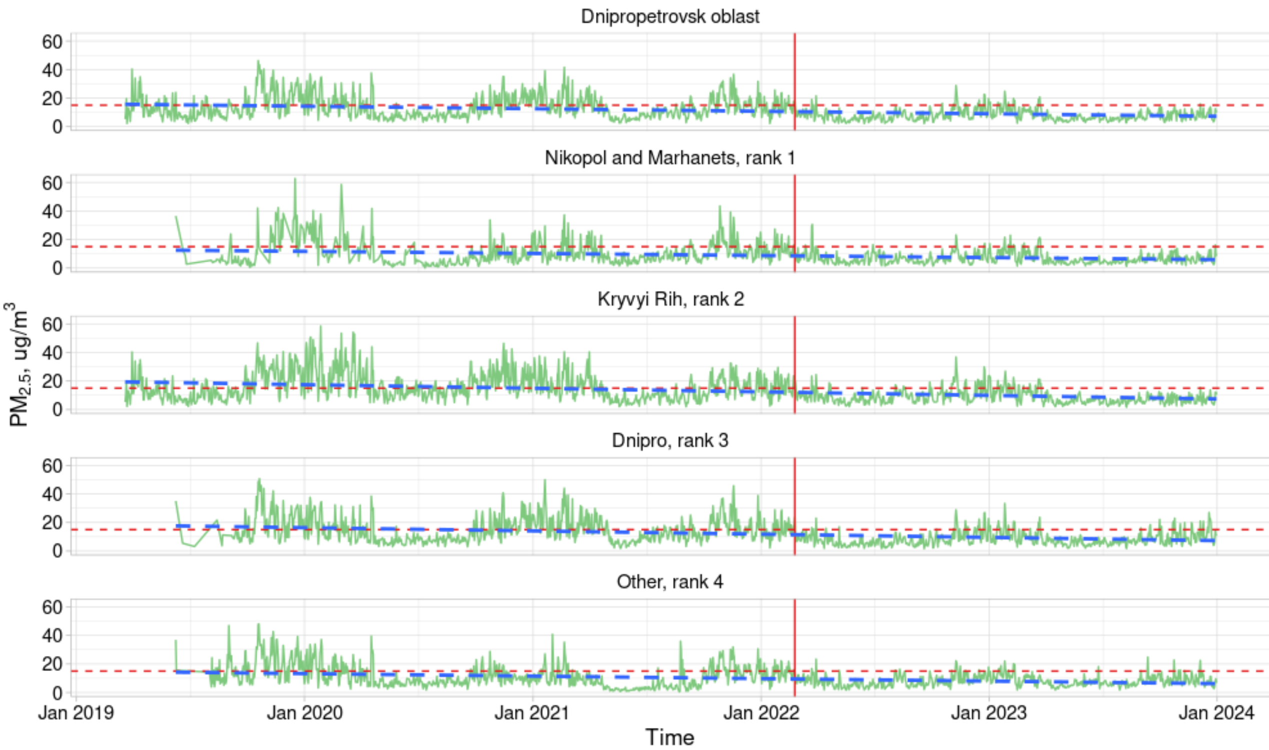


Figure 4.51 Dynamics of daily average levels of $PM_{2.5}$ in Dnipropetrovsk oblast in March 2019 - December 2023. EcoCity data.

Notes: red dashed line - threshold for poor air quality (WHO); blue dashed lines - linear trends; vertical red solid line - time of active military offensive (February, 2022). EcoCity data.

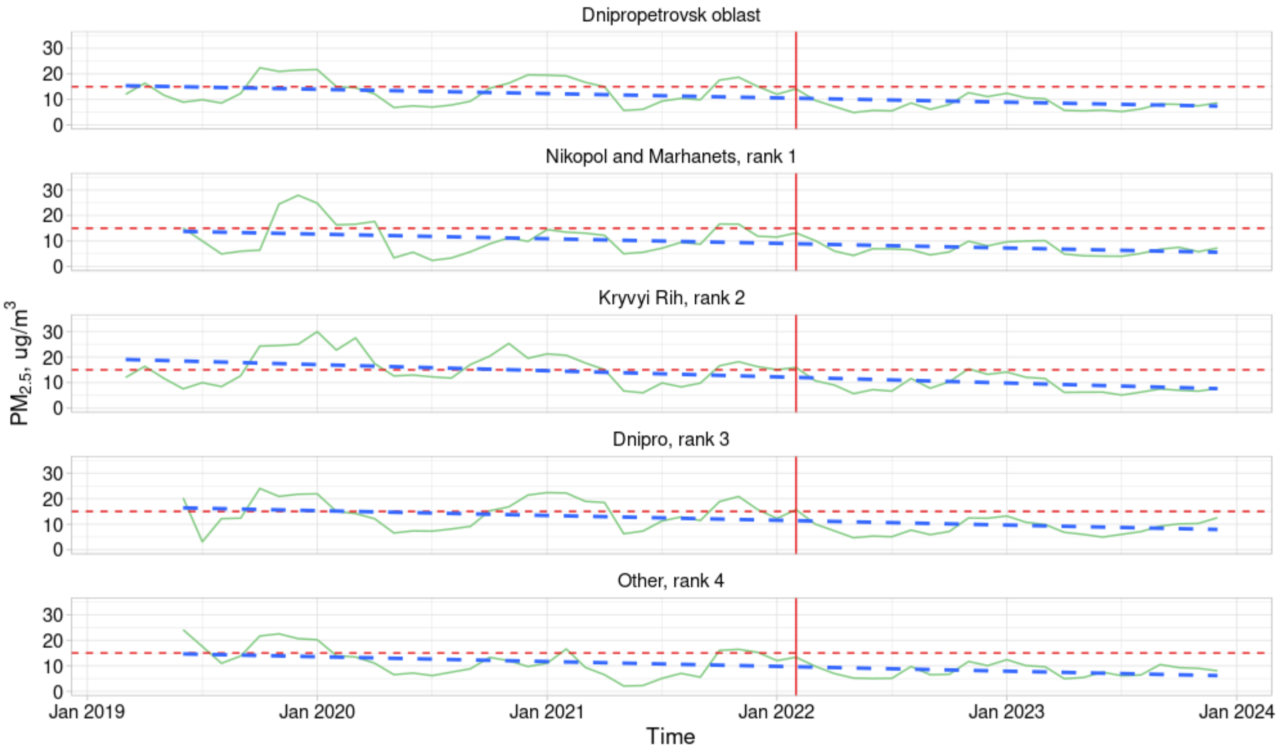


Figure 4.52 Dynamics of monthly average levels of $PM_{2.5}$ in Dnipropetrovsk oblast in March 2019 - December 2023. EcoCity data.

Notes: red dashed line - threshold for poor air quality (WHO); green dashed lines - linear trends; vertical red solid line - time of active military offencive (February, 2022). Linear trend equations (per year): Dnipropetrovsk oblast: y = 3407.46 - 1.6799x ($p<0.01$, decreasing), Dnipro: y = 3806.56 - 1.8768x ($p<0.01$, decreasing), Kryvyi Rih: y = 4857.29 - 2.3962x ($p<0.01$, decreasing), Nikopol and Marhanets: y = 3666.78 - 1.8089x ($p<0.01$, decreasing), Other: 3820.57 - 1.8846x ($p<0.01$, decreasing). EcoCity data.

The number of days with daily average $PM_{2.5}$ level above 15 µg/m³ in Dnipropetrovsk oblast was 107-126 per year in 2019-2021, and 19-34 per year in 2022-2023 (Table 4.14).The number of days with daily average $PM_{2.5}$ level above 15 µg/m³ was the lowest in 2023 in all locations, being the lowest in the Nikopol and Marhanets area. The minimum daily average $PM_{2.5}$ value was 0.06 µg/m3 in the Nikopol and Marhanets area in 2020, the maximum daily average $PM_{2.5}$ value was 62.8 µg/m³ in the Nikopol and Marhanets area in 2019.

Location	Year, n (%)					Chi-square p-value
	2019	2020	2021	2022	2023	
Dnipropetrovsk oblast	107/287 (37.28%)	116/366 (31.69%)	126/365 (34.52%)	34/362 (9.39%)	19/365 (5.21%)	<0.001
Nikopol and Marhanets, rank 1	36/109 (33.03%)	46/261 (17.62%)	78/365 (21.37%)	26/362 (7.18%)	16/365 (4.38%)	<0.001
Kryvyi Rih, rank 2	116/287 (40.42%)	211/366 (57.65%)	130/365 (35.62%)	67/361 (18.56%)	32/365 (8.77%)	<0.001

Dnipro, rank 3	72/122 (59.02%)	115/366 (31.42%)	159/365 (43.56%)	45/362 (12.43%)	40/365 (10.96%)	<0.001
Other, rank 4	91/152 (59.87%)	70/366 (19.13%)	71/364 (19.51%)	32/362 (8.84%)	19/363 (5.23%)	<0.001

Table 4.26 Number of days with $PM_{2.5}$ levels above 15 µg/m³ in Dnipropetrovsk oblast in 2019-2023. EcoCity data.

The dynamics of annual average $PM_{2.5}$ in Dnipropetrovsk oblast was decreasing (Table 4.15), but exceeded the annual threshold for poor air quality (WHO) of 5 µg/m³ throughout the period of observation. The difference between the values of 2021 and 2022 in all areas was statistically significant ($p<0.05$). The difference between the values of 2022 and 2023 was non-significant for Dnipro and Other areas. The relative decrease in annual average level of $PM_{2.5}$ was the lowest in more damaged by the war areas.

Location	Year, average (95%CI)					Annual average growth rate
	2019	2020	2021	2022	2023	
Dnipropetrovsk oblast, µg/m³	19.1 (18.9-19.4)	12.1 (12.0-12.2)	13.7 (13.5-14.0)	9.1 (9.0-9.3)	7.8 (7.7-7.9)	-41.2%
Nikopol and Marhanets, µg/m³	11.8 (9.7-14)	8.6 (7.8-9.3)	11.4 (10.9-11.8)	8.0 (7.6-8.3)	6.5 (6.3-6.7)	-24.1%
Kryvyi Rih, µg/m³	17.0 (16.1-17.9)	19.3 (18.7-20.0)	13.9 (13.4-14.4)	11.2 (10.7-11.6)	7.7 (7.5-7.9)	-38.7%
Dnipro, µg/m³	20.2 (19.8-20.6)	12.1 (12.0-12.3)	15.5 (15.1-15.8)	9.0 (8.8-9.2)	8.8 (8.5-9.1)	-39.5%
Other, µg/m³	19.8 (19.2-20.3)	11 (10.7-11.2)	11.1 (10.4-11.9)	9.0 (8.7-9.3)	8.3 (8-8.7)	-41.2%

Table 4.27 Dynamics of annual average levels of $PM_{2.5}$ in Dnipropetrovsk oblast in 2019-2023. EcoCity data.

There was a general downward trend of PM_{10} levels in all studied locations in 2019-2023 (Figures 4.13, 4.14). There was a small elevation of PM_{10} level in all studied areas in February 2022, which could be attributed to the massive rocket attack on 24 February 2022.

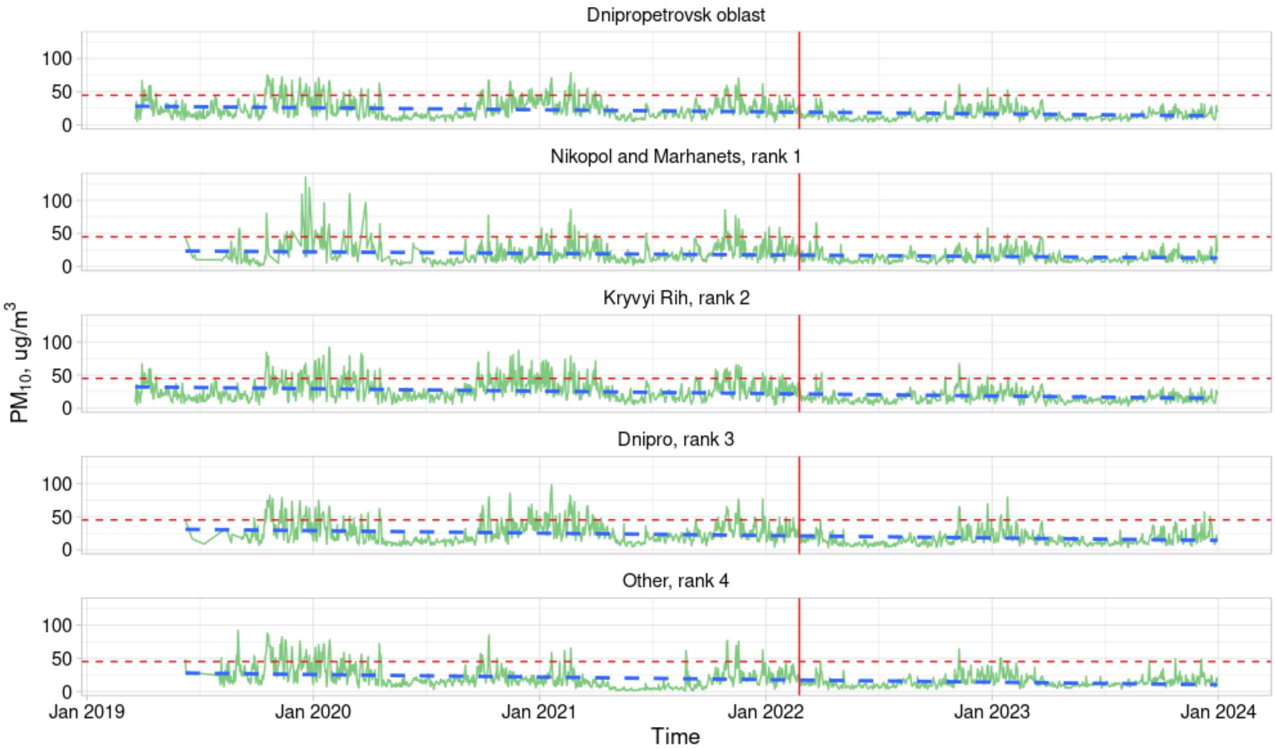


Figure 4.53 Dynamics of daily average levels of PM_{10} in Dnipropetrovsk oblast in March 2019 -December 2023. EcoCity data.

Notes: red dashed line - threshold for poor air quality (WHO); blue dashed lines - linear trends; vertical red solid line - time of the full-scale military invasion (February, 2022).

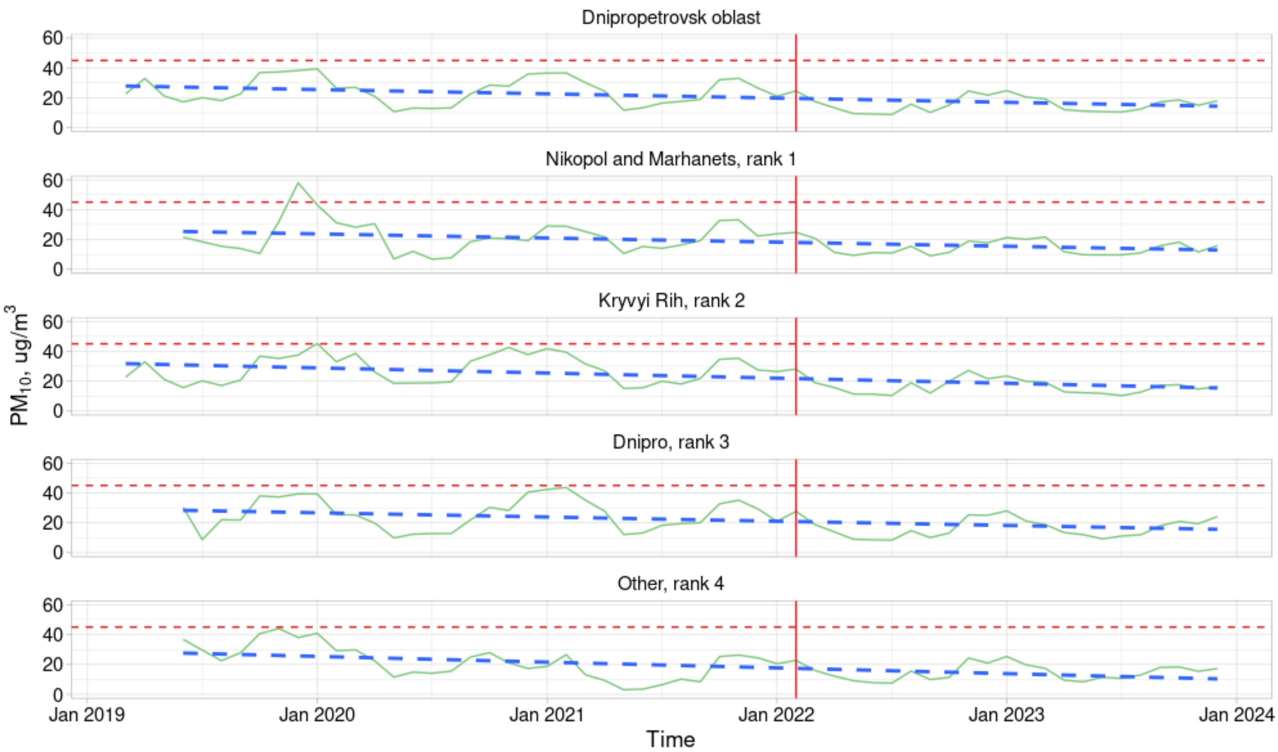


Figure 4.54 Dynamics of monthly average levels of PM_{10} in Dnipropetrovsk oblast in March 2019 - December 2023. EcoCity data.

Notes: red dashed line - threshold for moderate air quality (5); green dashed lines - linear trends; vertical red solid line - time of active military offencive (February, 2022). EcoCity data. Linear trend equations (per year): Dnipropetrovsk oblast: y = 5765.66 - 2.8416x ($p<0.01$, decreasing), Nikopol and Marhanets: y = 5599.34 - 2.7602x ($p<0.01$, decreasing), Kryvyi Rih: y = 6961.06 - 3.4317x ($p<0.01$, decreasing), Dnipro: y = 5738.28 - 2.8275x ($p<0.01$, decreasing), Other: 7795.80 - 3.8467x ($p<0.01$, decreasing).

The number of days per year with daily average PM_{10} level above 45 μg/m^3 in Dnipropetrovsk oblast was 33-39 per year in 2019-2021, and 1-3 per year in 2022-2023 (Table 4.16).The number of days per year with daily average PM_{10} level above 45 μg/m^3 was the lowest in 2023 in all locations, except the Other area. The minimum daily average PM_{10} value was 0.16 μg/m3 in the Nikopol and Marhanets area in 2020, the maximum daily average PM_{10} value was 135.0 μg/m^3 in the Nikopol and Marhanets area in 2019.

Location	Year					Chi-square p-value
	2019	2020	2021	2022	2023	
Dnipropetrovsk oblast	39/287 (13.59%)	38/366 (10.38%)	33/365 (9.04%)	3/362 (0.83%)	1/365 (0.27%)	<0.001
Nikopol and Marhanets, rank 1	15/107 (14.02%)	18/261 (6.9%)	26/365 (7.12%)	7/362 (1.93%)	3/365 (0.82%)	<0.001
Kryvyi Rih, rank 2	33/287 (11.5%)	70/366 (19.13%)	51/365 (13.97%)	12/361 (3.32%)	1/365 (0.27%)	<0.001
Dnipro, rank 3	36/122 (29.51%)	46/366 (12.57%)	49/365 (13.42%)	10/362 (2.76%)	8/365 (2.19%)	<0.001
Other, rank 4	44/152 (28.95%)	34/366 (9.29%)	13/364 (3.57%)	2/362 (0.55%)	6/363 (1.65%)	<0.001

Table 4.28 Number of days with PM_{10} levels above 45 μg/m^3 in Dnipropetrovsk oblast in 2019-2023. EcoCity data.

The dynamics of annual average PM_{10} in Dnipropetrovsk oblast was mostly decreasing (Table 4.17), but exceeded the annua threshold for poor air quality (WHO) of 15 μg/m^3 throughout the period of observation, except Nikopol and Marhanets in 2023. The difference between the values of 2021 and 2022 in all areas was statistically significant ($p<0.05$). The difference between the values of 2022 and 2023 was non-significant for Dnipro, Nikopol and Marhanets, and Other areas. In Dnipro 2023 values were higher than in 2022 (ns). The relative decrease in annual average level of PM_{10} was lower in more damaged by the war areas.

Location	Year, average (95%CI)					Annual average growth rate
	2019	2020	2021	2022	2023	

Dnipropetrovsk oblast, μg/m^3	33.7 (33.1-34.2)	22.1 (21.9-22.4)	24.8 (24.4-25.3)	16.3 (16.0-16.6)	15.6 (15.4-15.9)	-37.3%
Nikopol and Marhanets, μg/m^3	21.2 (17.2-25.2)	18.0 (16.6-19.5)	22.6 (21.7-23.5)	15.6 (14.9-16.3)	14.4 (13.8-15.0)	-17.4%
Kryvyi Rih, μg/m^3	27.9 (26.4-29.3)	31.5 (30.4-32.5)	27.0 (26.2-27.9)	19.4 (18.8-20.1)	15.1 (14.8-15.5)	-31.2%
Dnipro, μg/m^3	35.0 (34.3-35.8)	21.6 (21.3-21.9)	27.0 (26.4-27.7)	16.3 (15.9-16.7)	17.2 (16.6-17.9)	-34.9%
Other, μg/m^3	37.9 (36.8-39)	23.1 (22.6-23.7)	17.5 (16.3-18.7)	15.5 (14.8-16.1)	15.4 (14.6-16.1)	-48.1%

Table 4.29 Dynamics of annual average levels of PM_{10} in Dnipropetrovsk oblast in 2019-2023. EcoCity data.

The NowCast AQI trend (Figure 4.15) was similar to those for $PM_{2.5}$ and PM_{10}, except in Kryvyi Rih, where a very modest and non-significant decline over time was observed, and Nikopol and Marhanets, where NowCast increased over time of observation. There was a small elevation of NowCast AQI in all studied areas in February 2022, which could be attributed to the massive rocket attack on 24 February 2022.

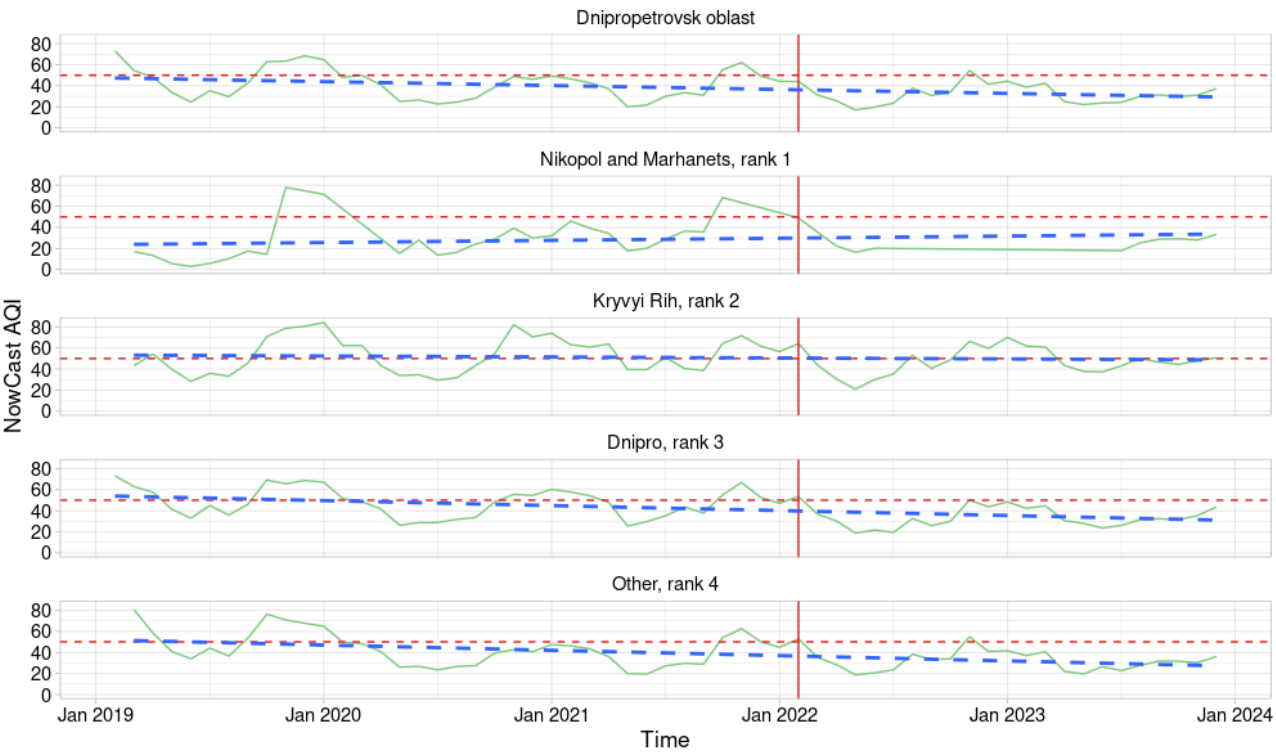


Figure 4.55 Dynamics of monthly average levels of NowCast AQI in Dnipropetrovsk oblast in February 2019 – December 2023. EcoCity data.

Notes: red dashed line – threshold between 'good' and 'moderate' air quality categories; green dashed lines – linear trends; vertical red solid line – time of active military offencive (February, 2022). SaveEcoBot data. Linear trend equations (per year): Dnipropetrovsk oblast: y = 7567.80 – 3.72x ($p<0.01$, decreasing), Nikopol and

Marhanets: y = -4123.74 + 2.05x (p=0.30), Kryvyi Rih: y = 1938.64 - 0.93x (p=0.64), Dnipro: y = 9580.15 - 4.71x ($p<0.01$, decreasing), Other: y = 10205.53 - 5.03x ($p<0.01$, decreasing). *data from July 2022 till June 2023 in Nikopol and Marhanets were missing.

During the missile attacks in February-May 2022 the daily average level of PM increased in 7 of 10 cases in Dnipro, and in 3 of 5 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.16). However, there were increases of PM levels in both locations that were of the same or larger magnitude that could be related to other factors.

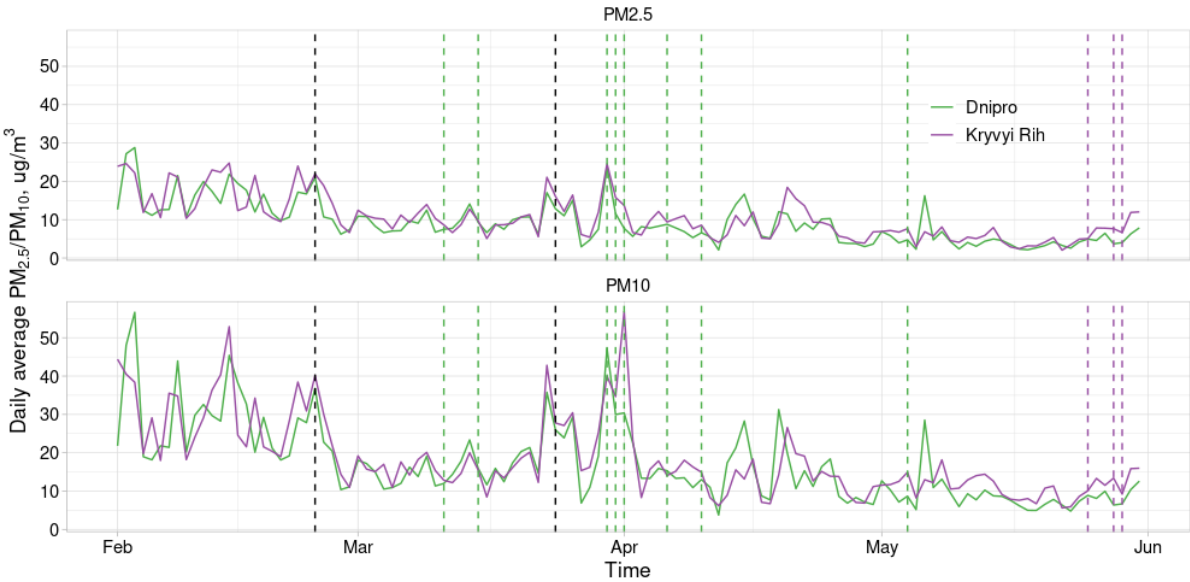


Figure 4.56 Dynamics of daily average levels of $PM_{2.5}$ and PM_{10} in Dnipro and Kryvyi Rih in February-May 2022. EcoCity data

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks of both locations.

During September 2022-January 2023, the average levels of PM increased in 7 of 12 cases in Dnipro, and in 13 of 14 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.17). As in for the previous period, there were increases of PM levels in both locations that were of the same or larger magnitude that could be related to other factors.

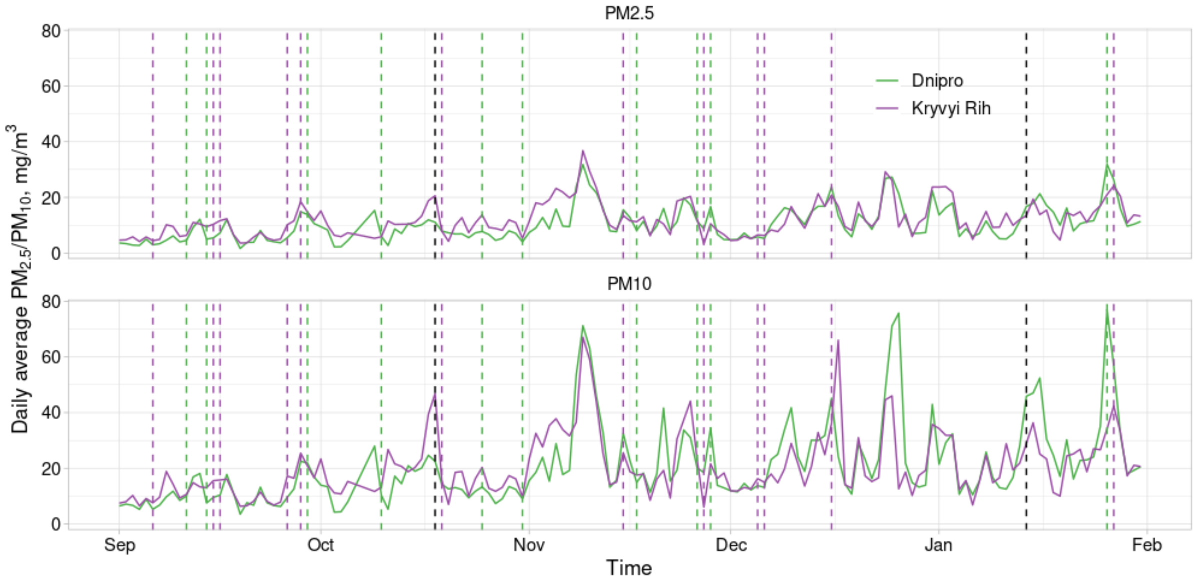


Figure 4.57 Dynamics of daily average levels of $PM_{2.5}$ and PM_{10} in Dnipro and Kryvyi Rih in September 2022 - January 2023. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks on both locations.

Shortly after the beginning of the full-scale military invasion at 05.00 on 24 February 2022, there were increases in PM levels in Dnipro and Kryvyi Rih, followed by the decline of dust levels till the evening of the same day (Figure 4.18). Despite the Russian military invasion began in the morning of the 24th February, the rise of dust levels was observed from the second half of the 23rd February.

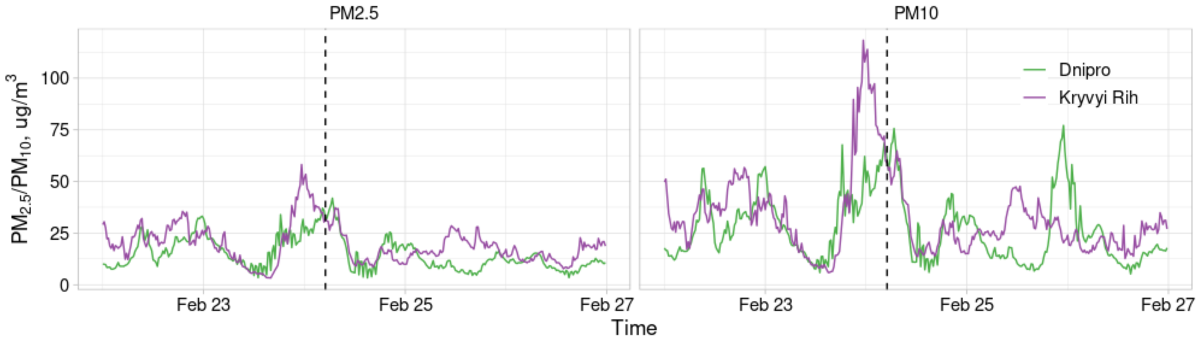


Figure 4.58 Dynamics of average levels of 20-minutes intervals of $PM_{2.5}$ and PM_{10} in Dnipro and Kryvyi Rih on 24 February 2022. EcoCity data.

Notes: sertical dashed black line - time of rocket strikes (24 February, 2022, ~05h 00m).

Missile attacks that led to the destruction of oil reservoirs in Dnipro on 30 March 2022, and 06 April 2022, were coincided with the increase in $PM_{2.5}$ and PM_{10} levels (Figure 4.19). The attack on 31 March 2022 and the massive missile attack on Dnipro on 01 April 2022, with around 10 explosions heard in the city (299,300), did not coincide with a notable increase in PM levels. Also, the attack on 31 March, during which a fuel storage was damaged (299), was preceded by an increase in PM pollution. Since the exact information about the timing of the attack is not available, this increase could be potentially related to the attack.

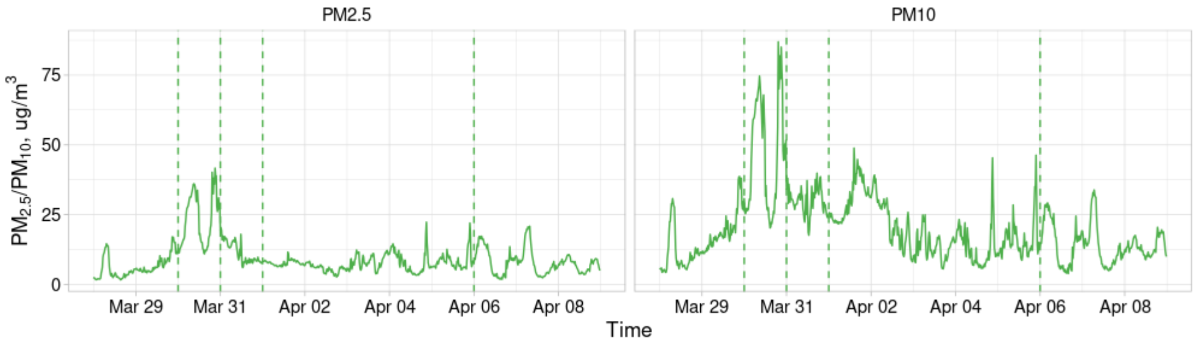


Figure 4.59 Dynamics of average levels of 20-minutes intervals of $PM_{2.5}$ and PM_{10} in Dnipro in 28 March - 08 April 2022.

Notes: vertical dashed lines - times of missile attacks.

According to the conducted ARIMAX modelling, the daily average level of $PM_{2.5}$ in the days of missile attacks was 1.67-1.89 μg/m^3 higher than predicted values (Table 4.18). The relative increase of $PM_{2.5}$ in the days of attacks was 7.12%-15.20%, depending on the model. The daily average level of PM_{10} in the days of missile attacks was 4.79-4.85 μg/m^3 higher than predicted values. The relative increase of PM_{10} in the days of attacks was 14.77%-21.05%, depending on the model.

Although the impact of missile attacks on daily average levels of some air pollutants was statistically significant, it is worth mentioning that the actual local impact is supposedly higher than it was calculated. The analysis was carried out using both daily and geographical average levels of pollutants for particular location. It was not possible to accurately determine exact time or place of missile attack and its destructive impact due to confidential nature of such information during the wartime. The absence of statistically significant association between the missile attacks and daily average PM levels could be additionally explained by its geographical configuration. The large length of Kryvyi Rih might create additional obstacles to registration of explosion-related shifts, due to increased distance between sensors in different city areas.

Pollutant	Model	Coefficient (95% CI)	p value	Relative change
$PM_{2.5}$	Attacks	1.89 (0.133-3.639)	0.035	7.12% (-7.92%; 31.38%)
	Attacks + weather	1.67 (-0.081-3.412)	0.062	15.20% (2.54%; 31.78%)

PM_{10}	Attacks	4.79 (1.948-7.637)	0.001	14.77% (-1.60%; 37.72%)
	Attacks + weather	4.85 (2.226-7.468)	<0.001	21.05% (6.44%; 39.10%)

Table 4.30 The impact of missiles attacks on daily average $PM_{2.5}$ and PM_{10} levels in Dnipro. EcoCity data.

In 2009-2022 years in Dnipro and Kryvyi Rih were characterised by a stable or slowly decreasing levels of undifferentiated dust, which remained above recommended thresholds throughout the period of observation. The levels of undifferentiated dust decreased in both locations in 2019-2022, which could be related to the decrease in the amount of industrial emissions (335). In Dnipro annual average 2022 level of undifferentiated dust was higher than in 2021, which could be attributed to the beginning of the full-scale Russian military invasion of Ukraine.

Trends in daily average and annual average levels of $PM_{2.5}$ and PM_{10} in 2019-2023 were decreasing in all studied locations. The number of days with $PM_{2.5}$ and PM_{10} during the invasion (2022-2023) was lower, than in the pre-invasion years (2019-2021). However, the more damaged by the war the area was, the lower relative decrease in $PM_{2.5}$ and PM_{10} was observed. Annual average levels of $PM_{2.5}$ and PM_{10} in 2019-2023 exceeded the threshold for poor air quality (WHO) throughout the period of observation. Interestingly that the rise of $PM_{2.5}$ and PM_{10} levels was observed from the second half of 23 February. It is confirmed by the study by Zalakeviciute et al., according to which the days before the invasion cannot be considered as "normal" conditions, but more likely the early days of war (98). Also, the obtained results correspond to the study by SaveDnipro, where the increase in PM within 48 hours after missile attacks was demonstrated (46).

Massive missile attacks or the attacks that resulted in damaging civil/industrial infrastructure in Dnipro and Kryvyi Rih, frequently coincided with the increase of daily average $PM_{2.5}$ and PM_{10} levels. The data from Dnipro has shown that 7.12%-15.20% increase in $PM_{2.5}$ level and 14.77%-21.05% increase in PM_{10} levels may be expected in the days of missile attacks.

It is important to highlight the fact that chemical composition of dust that comes from explosion of missiles and from fires in industrial objects might be difficult to assess. The same could be applied to the implications for health after the contact of such products of burning, even if it was a short-term exposure. The modern warfare (drones, missile electronics, etc) contains numerous substances, except gunpowder or rocket fuel, products of burning of which may have an unpredictable effect on health (1).

Nitrogen dioxide (NO_2)

Dnipro over the period 2009-2022 was characterised by significant NO_2 pollution (Figure 4.20), 2-3 times above MPCd.a. from the national standards and is largely above WHO annual AQG levels. In Dnipro annual average NO_2 levels fluctuated between 66.7 μg/m³ in 2009 (1.5 times above MPCd.a.) and 125.8 μg/m³ in 2017-2018 (3 times above MPCd.a.). There was a slight decline in annual average NO_2 levels in 2018-2021 despite a general increasing trend (ns). In Kryvyi Rih annual average NO_2 levels were slightly above MPCd.a. from the national standards, and unlike Dnipro there was a general decreasing trend (p=0.03). In Kryvyi Rih annual average NO_2 fluctuated between 35 μg/m³ in 2022 and 60 μg/m³ in 2013 (1.5 times above $MPC_{d.a.}$). It should be noted that annual average levels of NO_2 in 2020-2022 were notably lower than during the preceding time intervals. In both locations 2022 annual levels were lower than in 2021.

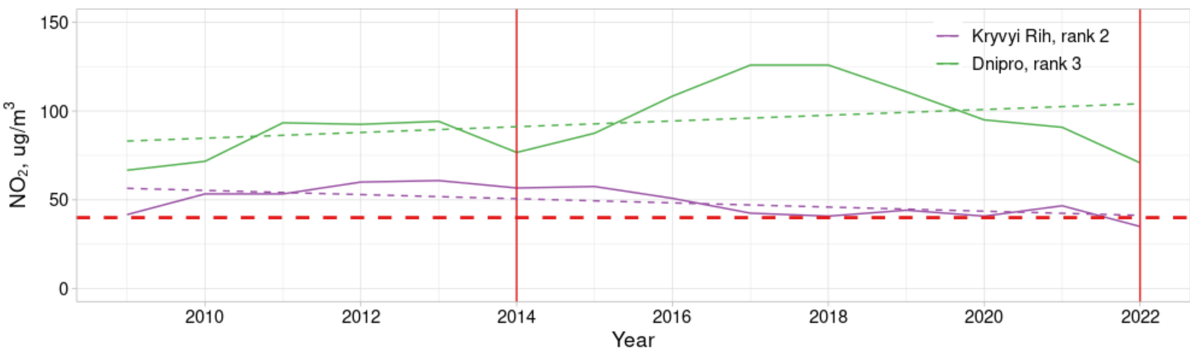


Figure 4.60 Dynamics of average levels of NO_2 in Dnipro and Kryvyi Rih in 2009-2022. RCGM data.

Notes: red dashed line - $MPC_{d.a.}$; dashed lines of corresponding colours - linear trends; vertical red solid lines - beginnings of military offensives (2014, 2022). Linear trend equations (per year): Dnipro: y = -3162.24 + 1.6154x (p=0.21); Kryvyi Rih: y = 2407.67 -1.1703x (p=0.03, decreasing).

In 2019-2023 there was a seasonal fluctuation of NO_2 levels: increase during colder months and decrease during warm months, which was also observed in other studies (336) (Figures 4.21, 4.22). The EcoCity and 2019-2022 RCGM data for Kryvyi Rih correspond well. In Dnipro, despite both the EcoCity and 2019-2022 RCGM data showing a declining trend, the values from 2019-2022 RCGM data were approximately twice as high as the EcoCity values. Notably, in March 2022 there was an increase of NO_2 pollution in all studied locations, being the highest in Kryvyi Rih and Nikopol and Marhanets areas.

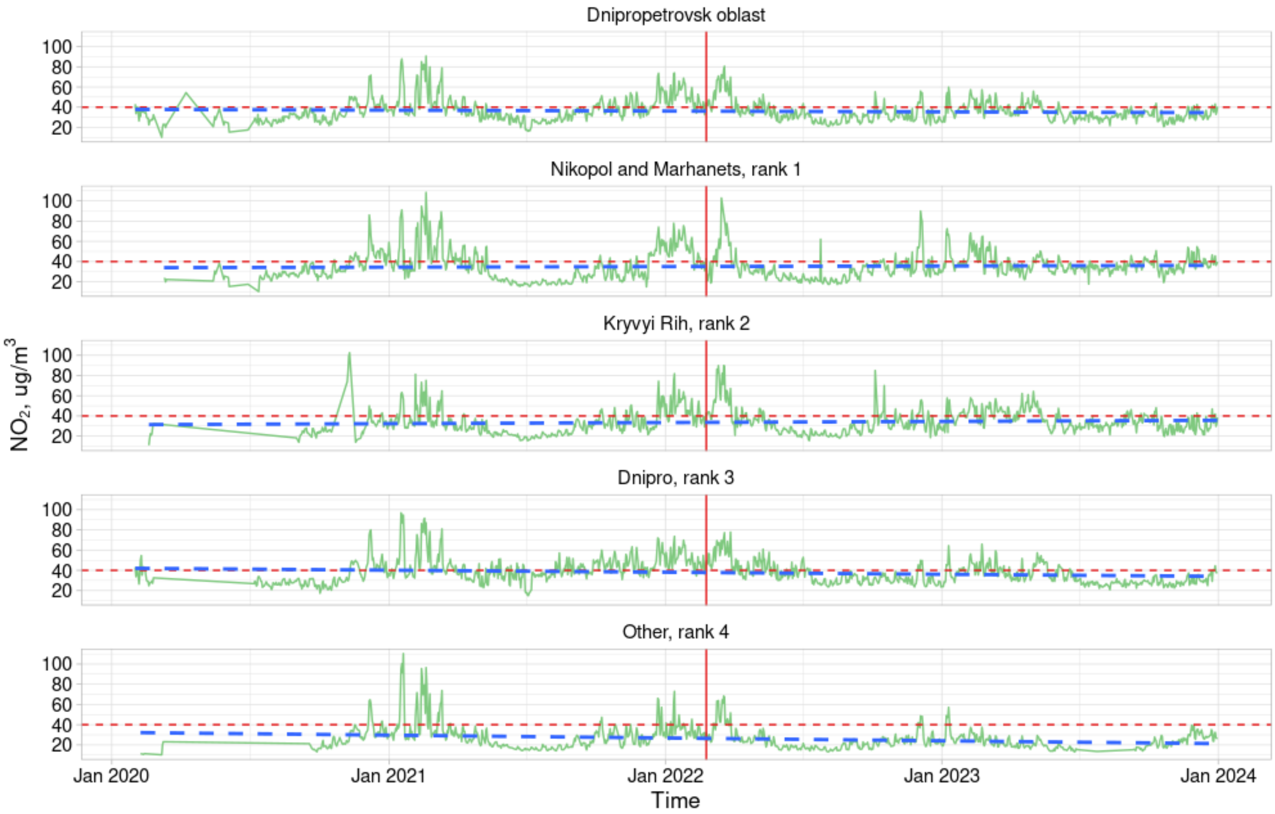


Figure 4.61 Dynamics of average levels of NO_2 in Dnipropetrovsk oblast in February 2020 - August 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; dashed lines of corresponding colours - linear trends; vertical red solid line - time of active military offencive (February 2022).

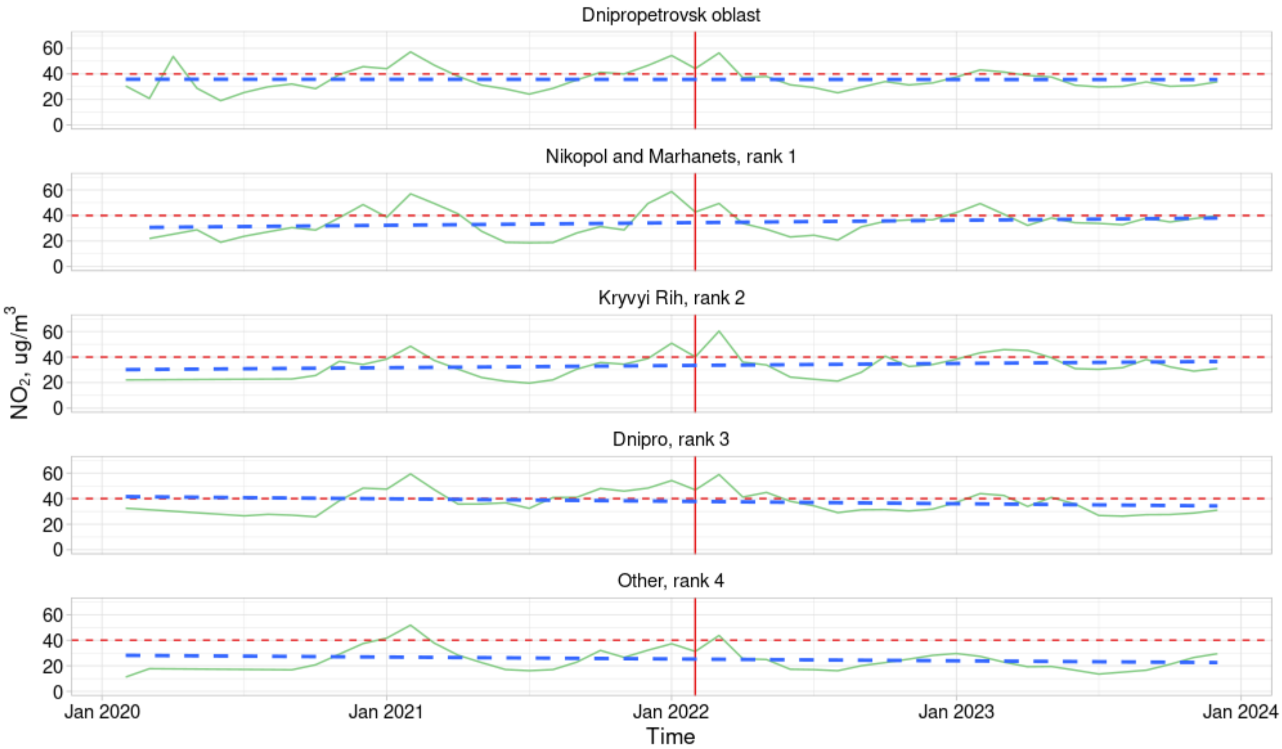


Figure 4.62 Dynamics of monthly average levels of NO_2 in Dnipropetrovsk oblast in February, 2020-August, 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; dashed lines of corresponding colours - linear trends; vertical red solid line - time of active military offencive (February, 2022). Linear trend equations (per year): Dnipropetrovsk oblast: y = 163.99 - 0.0634x (p=0.96), Nikopol and Marhanets: y = -3886.85 + 1.9392x (p=0.17), Kryvyi Rih: y = -3329.31 + 1.6630x (p=0.24), Dnipro: y = 3888.48 – 1.9043x (p=0.15), Other: 2995.98 – 1.4689x (p=0.28).

The number of days per year with daily average NO_2 level above 40 µg/m^3 in Dnipropetrovsk oblast was 43-120 in 2019-2021, and 80-107 in 2022-2023 (Table 4.19). There was no marked difference in the number of days with daily average NO_2 between years in all locations except for Kryvyi Rih, where with each next year the number of days with daily average NO_2 level above 40 µg/m^3 increased. The minimum daily average NO_2 level was 10.2 µg/m^3 in the Other area in 2020, the maximum daily average NO_2 level was 110 µg/m^3 in the Other area in 2021.

Location	Year, n (%)				Chi-square p-value
	2020	2021	2022	2023	
Dnipropetrovsk oblast	43/224 (19.2%)	120/365 (32.88%)	107/362 (29.56%)	80/365 (21.92%)	<0.001
Nikopol and Marhanets, rank 1	42/189 (22.22%)	105/364 (28.85%)	86/358 (24.02%)	95/365 (26.03%)	0.30
Kryvyi Rih, rank 2	9/89 (10.11%)	54/365 (14.79%)	103/361 (28.53%)	117/365 (32.05%)	<0.001

Dnipro, rank 3	45/202 (22.28%)	184/365 (50.41%)	141/362 (38.95%)	80/365 (21.92%)	<0.001
Other, rank 4	9/109 (8.26%)	43/353 (12.18%)	30/362 (8.29%)	5/289 (1.73%)	<0.001

Table 4.31 Number of days with NO_2 levels above 40 µg/m³ in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

The annual average NO_2 level in Dnipropetrovsk oblast was stable with statistically non-significant 2.8% reduction from 2020 to 2023 (Table 4.20). When compared to 2021, in 2022 NO_2 level decreased in Dnipro and Other areas, but increased in Kryvyi Rih, and Nikopol and Marhanets ($p<0.05$). In 2023 NO_2 level decreased in Dnipropetrovsk oblast, Dnipro, and Other areas, when compared to 2022 ($p<0.05$). Also, in the areas with a higher rank of war-related damage there was an increase of annual average NO_2 level in 2020-2023, while in less damaged areas annual average NO_2 level in 2020-2023 decreased.

Location	Year, average (95%CI)				Annual average growth rate
	2020	2021	2022	2023	
Dnipropetrovsk oblast, µg/m³	35.4 (34.6-36.2)	38.0 (37.4-38.6)	37.9 (37.3-38.5)	34.4 (34.0-34.9)	-0.9%
Nikopol and Marhanets, µg/m³	32.6 (31.5-33.8)	32.6 (31.5-33.7)	39.4 (37.8-41)	37.8 (36.8-38.7)	+6.3%
Kryvyi Rih, µg/m³	30.2 (27.5-32.9)	31.0 (30.0-31.9)	35.8 (34.7-36.8)	35.8 (35.2-36.5)	+6.5%
Dnipro, µg/m³	35.1 (34.1-36.2)	43.2 (42.2-44.2)	39.9 (39.0-40.7)	32.4 (31.6-33.1)	-3.0%
Other, µg/m³	26.9 (24.9-28.9)	28.7 (27.1-30.3)	25.8 (24.7-26.8)	23.1 (22.3-23.9)	-5.5%

Table 4.32 Dynamics of annual average levels of NO_2 in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

During February-May, 2022, the daily average NO_2 levels increased in 10 of 10 cases in Dnipro, and in 4 of 5 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.23). As in the case with $PM_{2.5}$ and PM_{10}, there were increases of NO_2 levels in both locations that were of the same or larger magnitude that could be related to other factors.

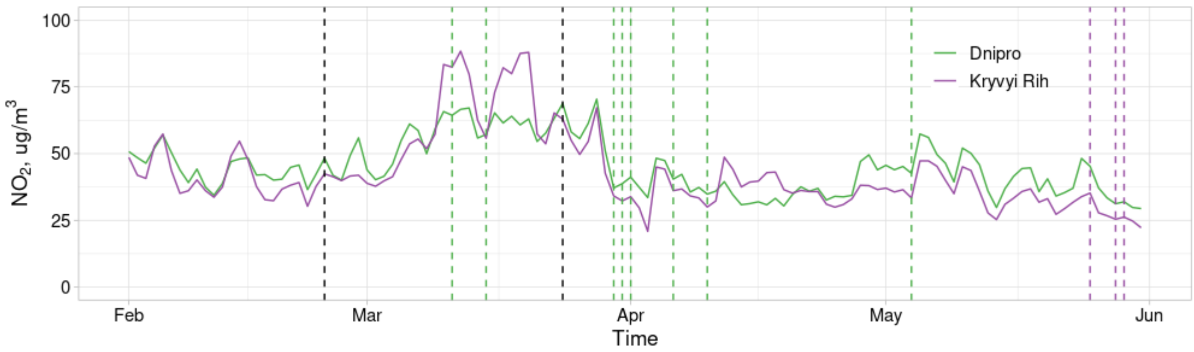


Figure 4.63 Dynamics of average daily levels of NO_2 in Dnipro and Kryvyi Rih in February-May, 2022. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks of both locations.

During September, 2022–January, 2023, the daily average levels of NO_2 increased in 10 of 12 cases in Dnipro, and in 8 of 14 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.24). As for the previous period, there were increases of NO_2 levels in both locations that were of the same or larger magnitude that could be related to other factors.

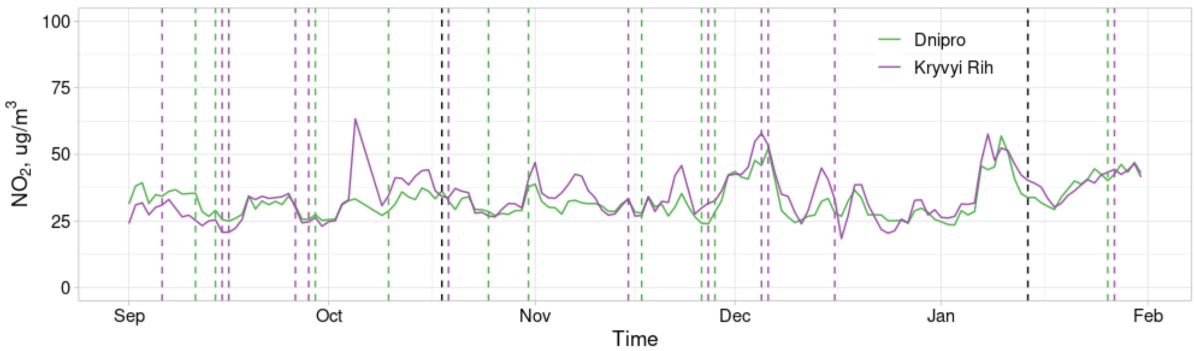


Figure 4.64 Dynamics of average daily levels of NO_2 in Dnipro and Kryvyi Rih in September 2022 - January 2023. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks on both locations.

Shortly after the beginning of the full-scale military invasion at 05.00 on 24th February, 2022, there was an increase of NO_2 level in Dnipro, but not in Kryvyi Rih, followed by the decline of NO_2 levels till the evening of the same day (Figure 4.25). Similar pattern of NO_2 dynamics was observed the day before, on 23, February, but not during the consequent days. In the days of all four attacks between 30 March and 06 April there was an increase of NO_2 level in the end of the day. Possibly, that could be related to the missile attacks, but the information about the exact timing of the attacks is not available.

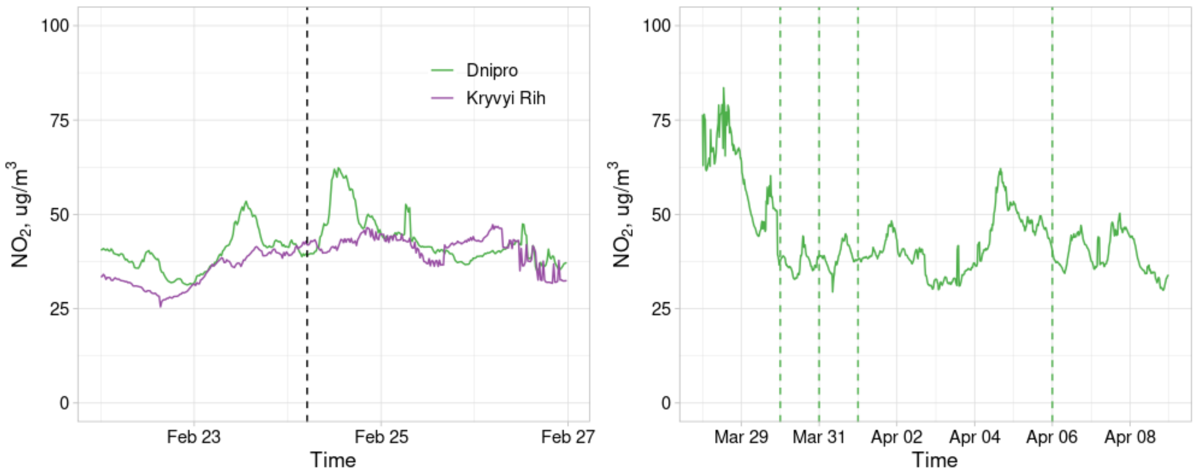


Figure 4.65 Dynamics of average levels of 20-minutes intervals of NO_2 in Dnipro and Kryvyi Rih on 24 February 2022, and in 28 March - 08 April 2022. EcoCity data.

Notes: vertical dashed lines - times of missile attacks.

Dnipro over the period 2009-2022 was characterised by significant NO_2 pollution, 2-3 times above MPCd.a. from the national standards and is largely above WHO annual AQG levels. In Kryvyi Rih annual average NO_2 levels were slightly above MPCd.a. from the national standards. Analysis of NO_2 dynamics fits well with the earlier reports by other researchers, indicating the general reduction of NO_2 pollution in Ukraine after the beginning of the full-scale Russian military invasion (98,179). At the same time, the presented study shows that NO_2 level increased in the areas that were more damaged by the war. This finding correspond to the data from Central Geophysical Observatory, where the increase in maximum NO_2 concentrations in 2022 was observed (181). Also, missile attacks frequently coincided with increases in NO_2 air pollution, which could be an additional argument of the negative short-term effect of missile attacks on air pollution.

Carbon monoxide (CO)

Dnipro over the period 2009-2022 was characterised by a weak, but non-significant increasing trend of annual average CO levels, which remained within recommended ranges (Figure 4.26). As in case with undifferentiated dust and NO_2, there was a slight decline in annual average CO level in 2019-2022. In Dnipro annual average CO levels fluctuated between 2.0 mg/m^3 in 2014 and 2022, and 2.75 mg/m^3 in 2012. In Kryvyi Rih annual average CO levels were slightly above MPCd.a. in 2010-2011, and unlike Dnipro there was a decreasing trend ($p<0.01$). In Kryvyi Rih annual average CO levels fluctuated between 1.17 mg/m^3 in 2022 and 3.33 mg/m^3 in 2011. In both locations 2022 annual average levels were lower than in 2021.

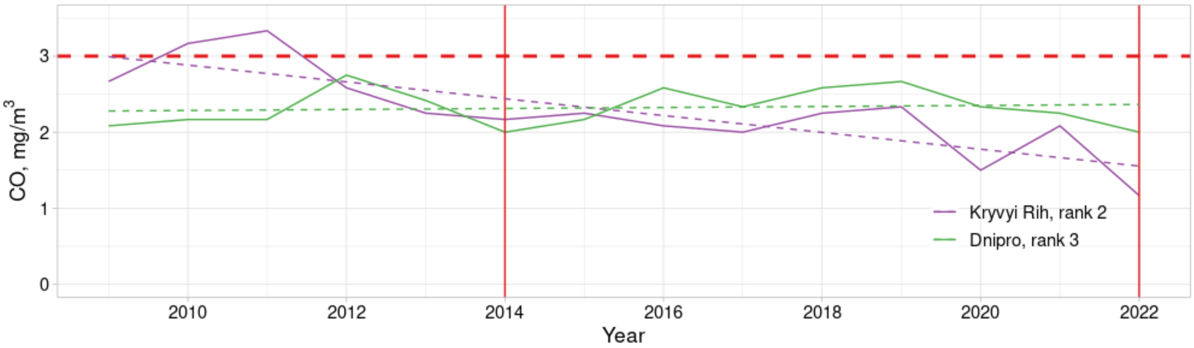


Figure 4.66 Dynamics of average annual levels of CO in Dnipro and Kryvyi Rih in 2009-2022. RCGM data.

Notes: red dashed line - $MPC_{d.a.}$; dashed lines of corresponding colours – linear trends; vertical red solid lines – beginnings of military offensives (2014, 2022). Linear trend equations (per year): Dnipro: y = -10.97 + 0.00659x (p=0.46); Kryvyi Rih: y = 225.22 - 0.11062x (p<0.01, decreasing).

In contrast to the dust and NO_2, there was no seasonal fluctuation of CO levels in 2020-2023 (Figures 4.27, 4.28). The EcoCity data showed a gradual and statistically significant increase of CO level in almost all locations, unlike 2020-2022 RCGM data. The steepest increase of CO levels were observed in the Nikopol and Marhanets area. Also, the RCGM data from Dnipro were approximately twice as high as the EcoCity values. Unlike dust and NO_2, there was no increase of CO levels shortly after the beginning of full-scale Russian military invasion.

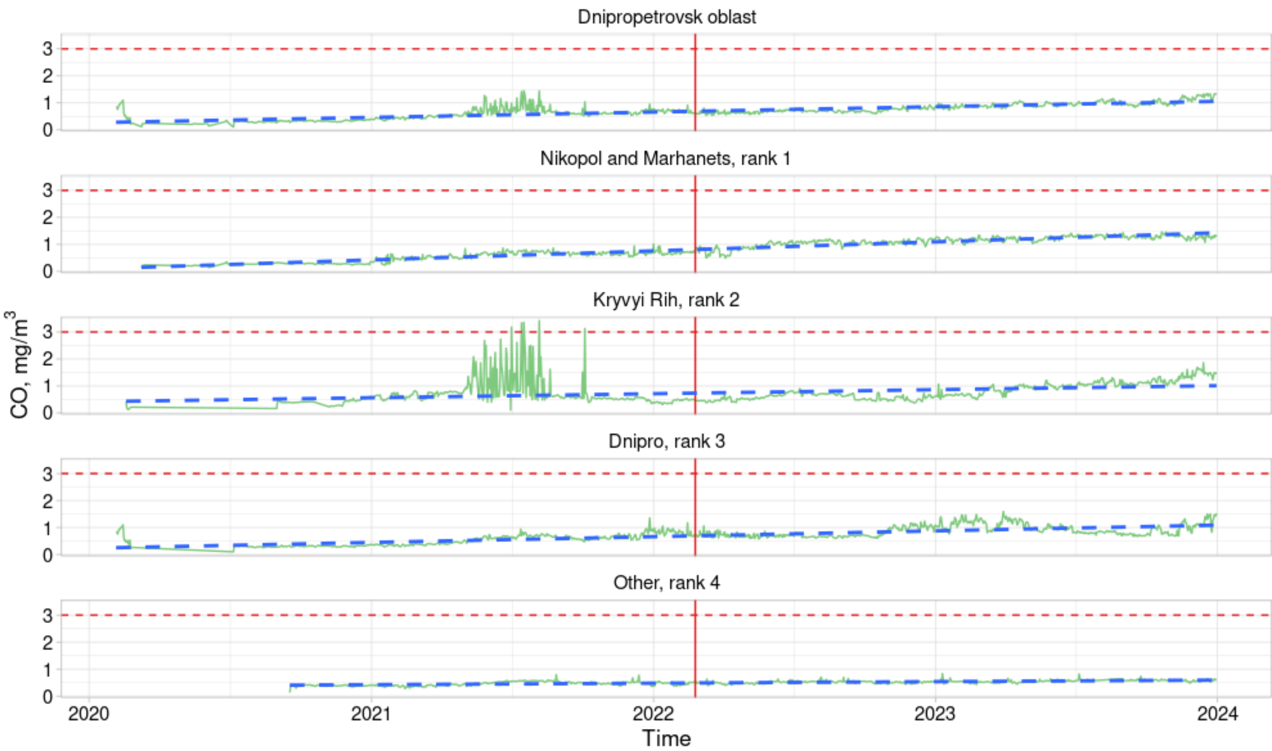


Figure 4.67 Dynamics of daily average levels of CO in Dnipropetrovsk oblast in February 2020 - December 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; blue dashed lines – linear trends; vertical red solid line – time of active military offensive (February, 2022).

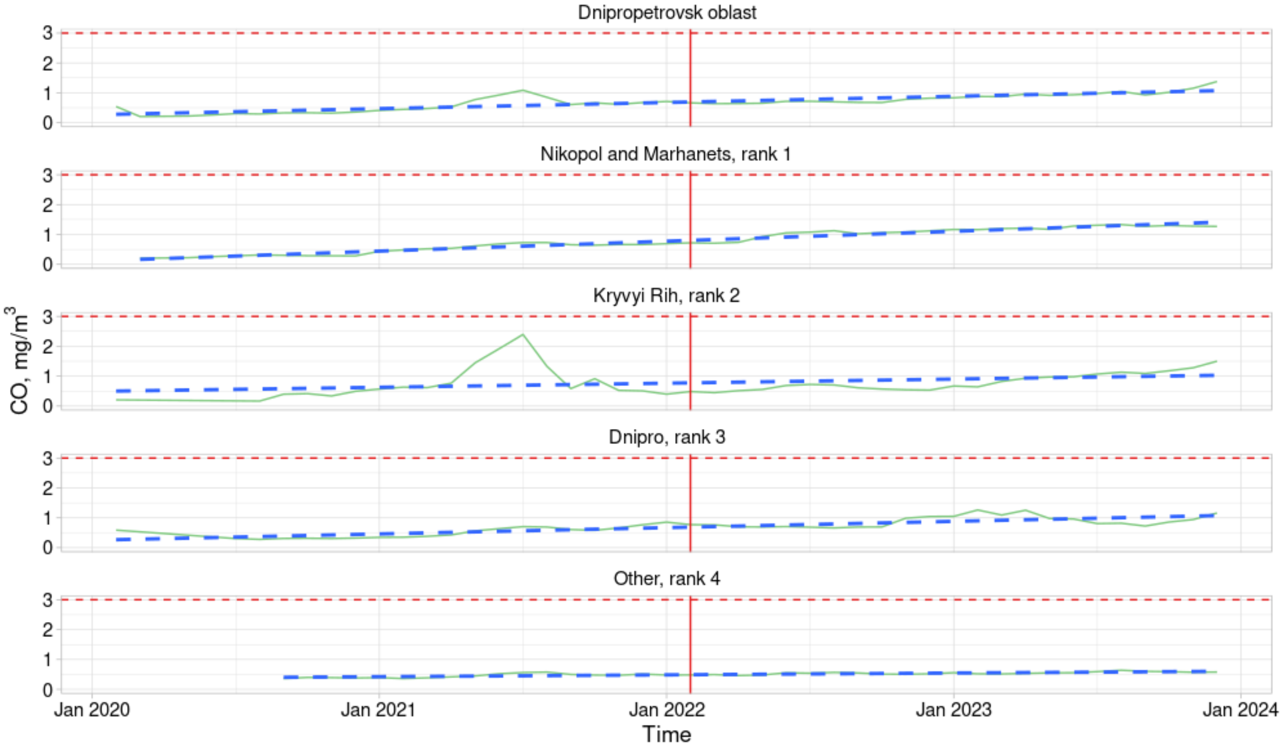


Figure 4.68 Dynamics of monthly average levels of CO in Dnipropetrovsk oblast in February 2020 - December 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; green dashed lines - linear trends; vertical red solid line - time of active military offencive (February, 2022). Linear trend equations (per year): Dnipropetrovsk oblast: $y = -416.52 + 0.206x$ ($p<0.01$, increasing), Nikopol and Marhanets: $y = -669.78 + 0.332x$ ($p<0.01$, increasing), Kryvyi Rih: $y = -277.52 + 0.138x$ ($p=0.04$, increasing), Dnipro: $y = -425.20 + 0.211x$ ($p<0.01$, increasing), Other: $y = -123.92 + 0.0615x$ ($p<0.01$, increasing).

The daily average CO level in Dnipropetrovsk oblast in 2019-2023 was mostly below 3 mg/m^3, except Kryvyi Rih in 2021 for 5 days (Table 4.21). The minimum daily average CO level was 0.10 mg/m^3 in Dnipro in 2020, the maximum daily average CO level was 3.42 mg/m^3 in Kryvyi Rih in 2021.

Location	Year, n (%)				Chi-square p-value
	2020	2021	2022	2023	
Dnipropetrovsk oblast	0/220 (0%)	0/365 (0%)	0/362 (0%)	0/365 (0%)	NA
Nikopol and Marhanets, rank 1	0/165 (0%)	0/365 (0%)	0/362 (0%)	0/365 (0%)	NA
Kryvyi Rih, rank 2	0/94 (0%)	5/364 (1.37%)	0/361 (0%)	0/365 (0%)	0.01

Dnipro, rank 3	0/200 (0%)	0/365 (0%)	0/362 (0%)	0/365 (0%)	NA
Other, rank 4	0/103 (0%)	0/353 (0%)	0/362 (0%)	0/331 (0%)	NA

Table 4.33 Number of days with NO_2 levels above 40 μg/m^3 in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

The dynamics of annual average CO in Dnipropetrovsk oblast was increasing (Table 4.22). The maximum annual average CO levels in were observed in 2023 in all locations. In the most damaged by the war area (Nikopol and Marhanets) there was the largest increase in annual average CO level (+191.2%) in 2020-2023, in the least damaged (Other) it was the lowest (+43.6%). Important caveat here is that the EcoCity data showed 2-3 times lower CO levels, than RCGM data, and the opposite direction of CO dynamics in 2020-2023 (Figure 4.26). Therefore it should be interpreted with caution.

Location	Year, average (95%CI)				Annual average growth rate
	2020	2021	2022	2023	
Dnipropetrovsk oblast, mg/m^3	0.34 (0.34-0.35)	0.63 (0.62-0.65)	0.69 (0.68-0.71)	0.99 (0.97-1.00)	+30.3%
Nikopol and Marhanets, mg/m^3	0.29 (0.28-0.29)	0.62 (0.60-0.64)	0.87 (0.85-0.90)	1.25 (1.24-1.26)	+41.3%
Kryvyi Rih, mg/m^3	0.41 (0.39-0.43)	0.84 (0.77-0.91)	0.56 (0.55-0.57)	1.03 (1.01-1.05)	+22.3%
Dnipro, mg/m^3	0.34 (0.33-0.35)	0.58 (0.57-0.60)	0.76 (0.74-0.77)	0.97 (0.94-0.99)	+31.2%
Other, mg/m^3	0.39 (0.38-0.39)	0.47 (0.46-0.48)	0.51 (0.51-0.52)	0.56 (0.55-0.56)	+11.4%

Table 4.34 Dynamics of annual average levels (95% CI) of CO in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

During February-May 2022, the average daily levels of CO increased in 6 of 10 cases in Dnipro, and in 3 of 5 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.29). As in the case with previously analysed pollutants, there were increases of CO levels in both locations that were of the same or larger magnitude that could be related to other factors.

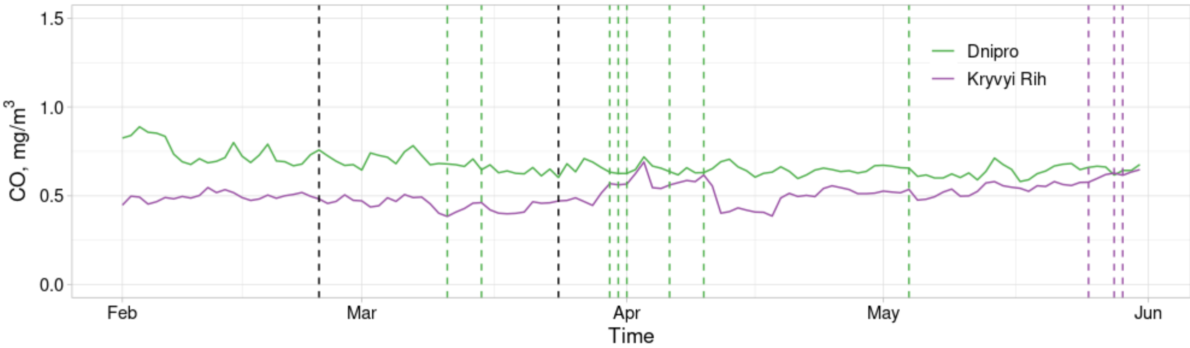


Figure 4.69 Dynamics of daily average levels of CO in Dnipro and Kryvyi Rih in February-May 2022. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks of both locations.

During September 2022-January 2023, the daily average levels of CO increased in 8 of 12 cases in Dnipro, and in 10 of 14 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.30). As for the previous pollutants, there were increases of CO levels in both locations that were of the same or larger magnitude that could be related to other factors.

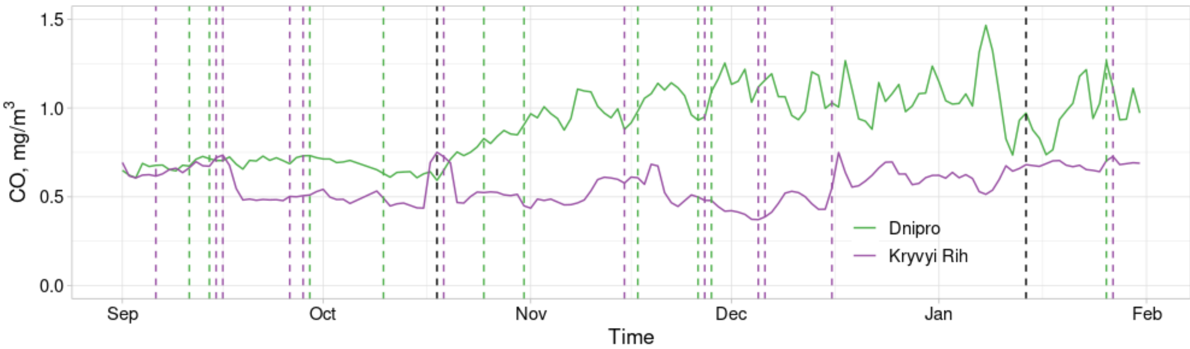


Figure 4.70 Dynamics of daily average levels of CO in Dnipro and Kryvyi Rih in September 2022 - January 2023. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks on both locations.

Shortly after the beginning of the full-scale military invasion at 05.00 on 24th February, 2022, there was an increase of CO level in Dnipro, but not in Kryvyi Rih. Similar pattern of CO dynamics was observed on 22-23 February, but not during the consequent days (Figure 4.31). The attacks on 30 March, 31 March, and 06 April coincided with spikes of CO level that could be attributed to the oil reservoir damage. The massive missile attack on Dnipro on 01 April was not associated with an increase in CO levels.

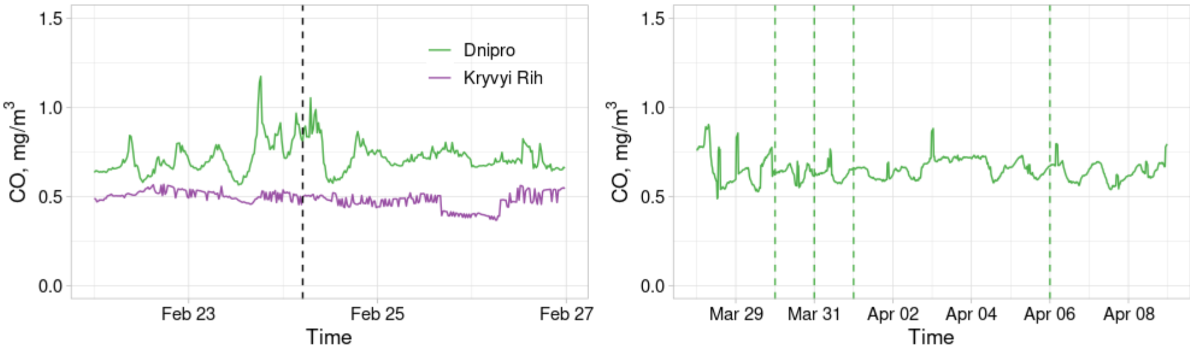


Figure 4.71 Dynamics of average levels of 20-minutes intervals of CO in Dnipro and Kryvyi Rih on 24 February 2022 and in 28 March - 08 April 2022. EcoCity data.

Notes: vertical dashed lines - times of missile attacks.

Average daily and annual CO levels in the Dnipropetrovsk region were within the recommended ranges. On one hand, the data from RCGM and EcoCity show different levels of CO pollution, which demands caution during making conclusions. On the other hand, the increase in CO air pollution in 2022, as was shown by the EcoCity data, corresponds with the CGO data (181) (increase of maximum concentrations in 2022) and with the study by the study by Zalakeviciute et al. (98), where CO level was attributed to the war intensity. In the presented study missile attacks coincided with increases in CO levels. Important finding of the presented study is larger increase in CO concentrations in the areas that more damaged by the war.

Formaldehyde

Dnipro and Kryvyi Rih in 2009-2022 exhibited similar and substantial (3-4 times above the threshold from national standard) formaldehyde air pollution (Figure 4.32). In both locations there was a statistically significant increasing overall trend with a decline in 2019-2022. In Dnipro formaldehyde level fluctuated between 6.9 μg/m^3 in 2009 to 18.1 μg/m^3 in 2019. In Kryvyi Rih it fluctuated between 6.5 μg/m^3 in 2009 to 16.1 μg/m^3 in 2020. In both locations 2022 annual levels were lower than in 2021.

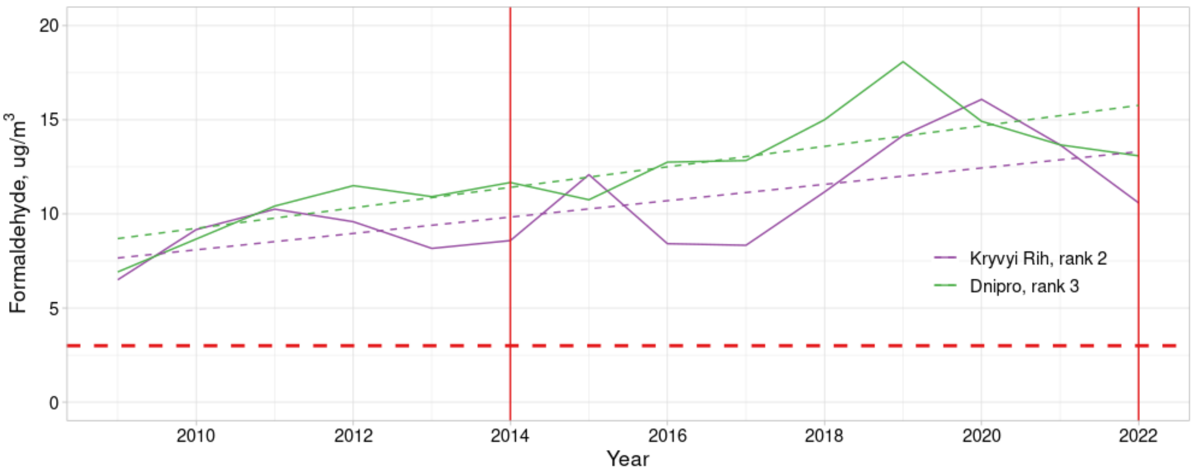


Figure 4.72 Dynamics of annual average levels. of formaldehyde in Dnipro and Kryvyi Rih in 2009-2022. RCGM data.

Notes: red dashed line - $MPC_{d.a.}$; dashed lines of corresponding colours - linear trends; vertical red solid lines - beginnings of military offensives (2014, 2022). Linear trend equations (per year): Dnipro: $y = -1084.86 + 0.5443x$ ($p<0.01$, increasing); Kryvyi Rih: $y = -865.49 + 0.4346x$ ($p<0.01$, increasing).

There were no seasonal fluctuations of formaldehyde levels in 2019-2023 (Figures 4.33, 4.34). There was a statistically significant decrease of formaldehyde levels in Dnipropetrovsk oblast, Dnipro and Nikopol and Marhanets ($p<0.05$), and non-significant increase in Kryvyi Rih. It is worth mentioning that spikes of formaldehyde level in different locations of the oblast before the full-scale invasion were almost absent after February, 2022.

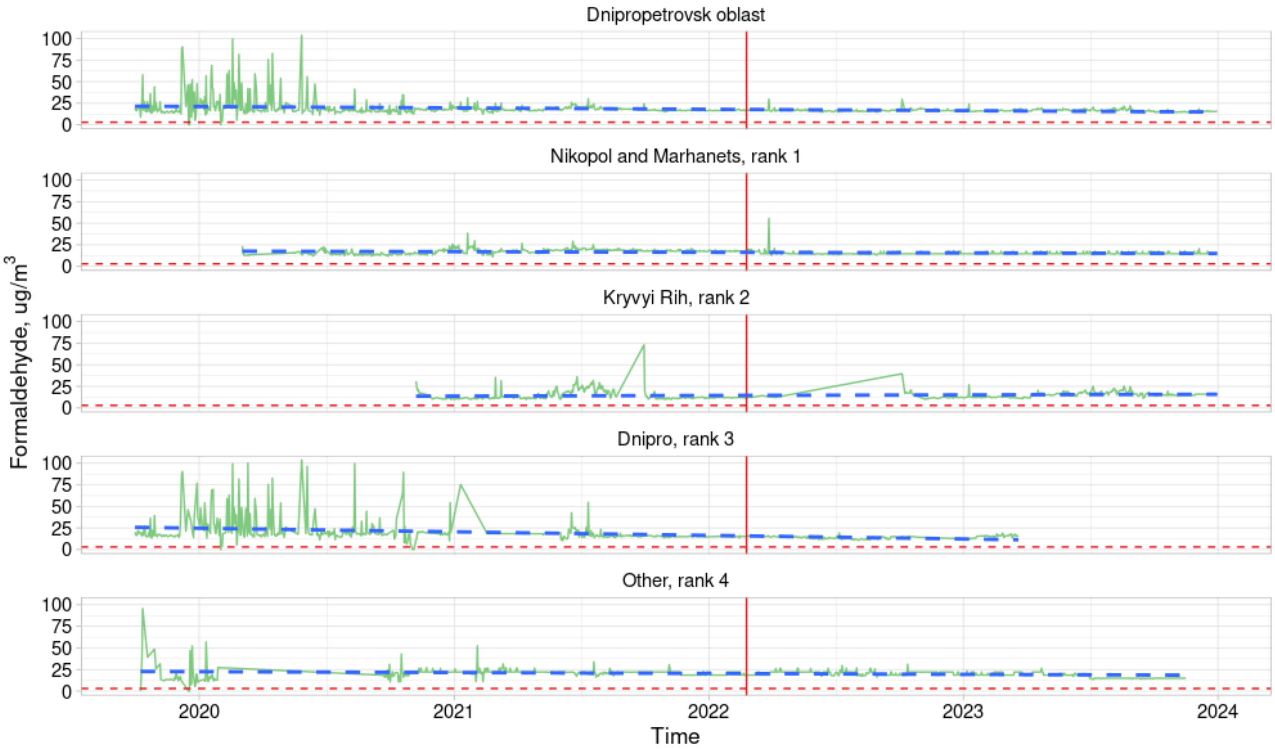


Figure 4.73 Dynamics of daily average levels of formaldehyde in Dnipropetrovsk oblast in October 2019 – December 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; blue dashed lines - linear trends; vertical red solid line - time of active military offencive (February, 2022). *data from Kryvyi Rih during May-September, 2022, were missing.

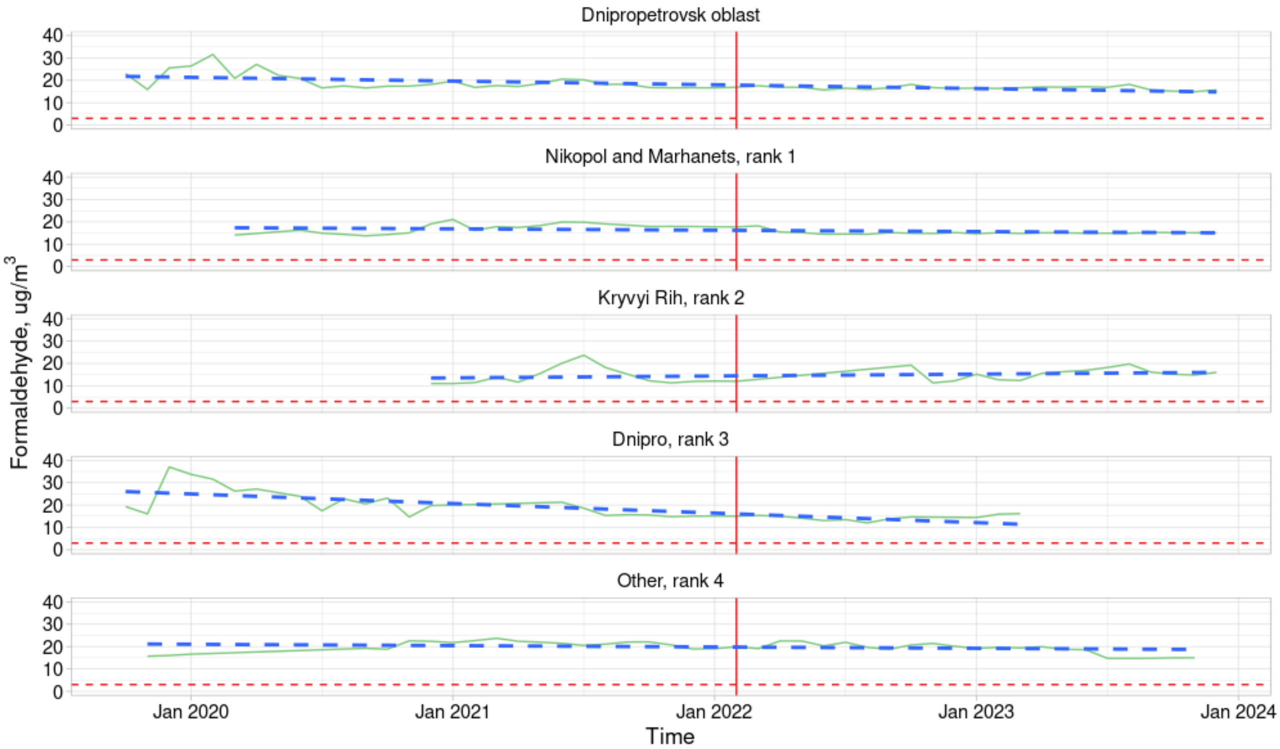


Figure 4.74 Dynamics of monthly average levels of formaldehyde in Dnipropetrovsk oblast and cities/towns from October 2019 till December 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; blue dashed lines - linear trends; vertical red solid line - time of active military offencive (February, 2022). *data from Kryvyi Rih during May-September, 2022, were missing. EcoCity data. Linear trend equation (per year): Dnipropetrovsk oblast: y = 3386.48 – 1.6659x (p<0.01, decreasing), Dnipro: y = 8653.63 – 4.2716x (p<0.01, decreasing), Kryvyi Rih: y = -1677.17 + 0.8366x (p=0.18), Nikopol and Marhanets: y = 1234.74 – 0.6026x (p=0.02, decreasing), Other: 1240.02 – 0.6034x (p=0.09).

Daily average formaldehyde level in Dnipropetrovsk oblast remained above 3 µg/m³ almost every day in 2020-2023 (Table 4.23). The minimum daily average formaldehyde level was 0.2 µg/m³ in Dnipro in 2020, the maximum daily average formaldehyde level was 104.0 µg/m³ in Dnipro in 2020.

Location	Year, n (%)				Chi-square p-value
	2020	2021	2022	2023	
Dnipropetrovsk oblast	334/335 (99.7%)	365/365 (100%)	362/362 (100%)	365/365 (100%)	0.35
Nikopol and Marhanets, rank 1	216/216 (100%)	365/365 (100%)	362/362 (100%)	365/365 (100%)	NA
Kryvyi Rih, rank 2	41/41 (100%)	322/322 (100%)	121/121 (100%)	350/350 (100%)	NA
Dnipro, rank 3	271/275 (98.55%)	222/222 (100%)	296/296 (100%)	71/71 (100%)	0.04

Other, rank 4	118/118 (100%)	353/353 (100%)	362/362 (100%)	286/286 (100%)	NA

Table 4.35 Number of days with formaldehyde levels above 3 μg/m³ in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

The overall decreasing dynamics of annual average formaldehyde level in Dnipropetrovsk oblast, it was not the same in different areas (Table 4.24). In 2022 it decreased in Dnipropetrovsk oblast, the Nikopol and Marhanets area, Kryvyi Rih, and the Other areas ($p<0.05$), when compared to 2021. In 2023 it decreased in Kryvyi Rih and Other areas, but increased in the Nikopol and Marhanets, and Dnipro areas ($p<0.05$). The EcoCity data from Dnipro and Kryvyi Rih corresponded well to 2019-2022 RCGM data.

Location	Year, average (95%CI)				Annual average growth rate
	2020	2021	2022	2023	
Dnipropetrovsk oblast, μg/m³	19.0 (18.2-19.8)	18.1 (17.8-18.3)	16.8 (16.6-17)	16.4 (16.3-16.6)	-5.2%
Nikopol and Marhanets, μg/m³	23.7 (21.8-25.5)	16.6 (16.0-17.1)	14.2 (14.1-14.4)	15.5 (15.2-15.8)	-15.4%
Kryvyi Rih, μg/m³	20.1 (19-21.3)	21.4 (21.0-21.8)	20.2 (19.9-20.5)	18.1 (17.8-18.5)	-3.6%
Dnipro, μg/m³	12.9 (11.5-14.3)	14.7 (14.0-15.4)	15.0 (14.2-15.7)	16.2 (16.0-16.5)	+6.9%
Other, μg/m³	15.4 (15.1-15.8)	18.5 (18.2-18.9)	16.2 (15.9-16.6)	15.0 (14.9-15.1)	-2.2%

Table 4.36 Dynamics of annual average levels of formaldehyde in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

During February-May, 2022, the average daily levels of formaldehyde increased in 9 of 10 cases in Dnipro, and in 1 of 1 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.35). As in the case with previously analysed pollutants, there were increases in formaldehyde levels in both locations that were of the same or larger magnitude that could be related to other factors.

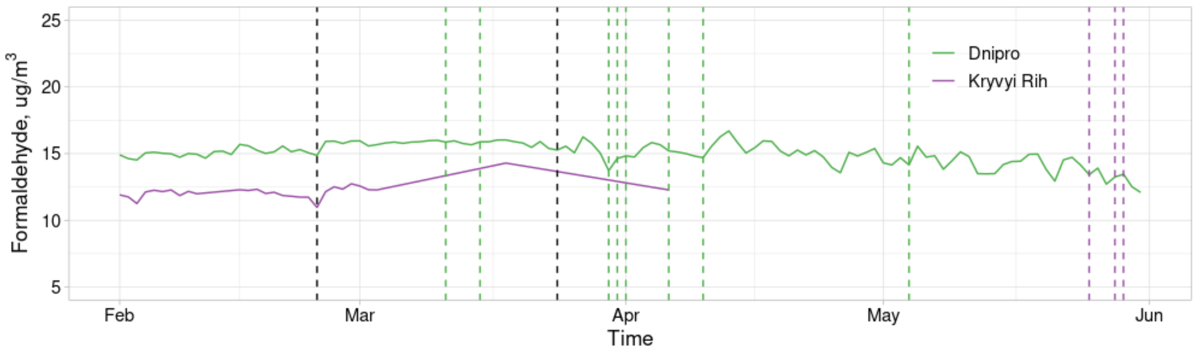


Figure 4.75 Dynamics of daily average levels of formaldehyde in Dnipro and Kryvyi Rih in February-May 2022. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks of both locations.

During September 2022-January 2023 the daily average levels of formaldehyde increased in 5 of 6 cases in Dnipro, and in 6 of 9 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.36). As for the previous analysis, there were increases of formaldehyde levels in both locations that were of the same or larger magnitude that could be related to other factors.

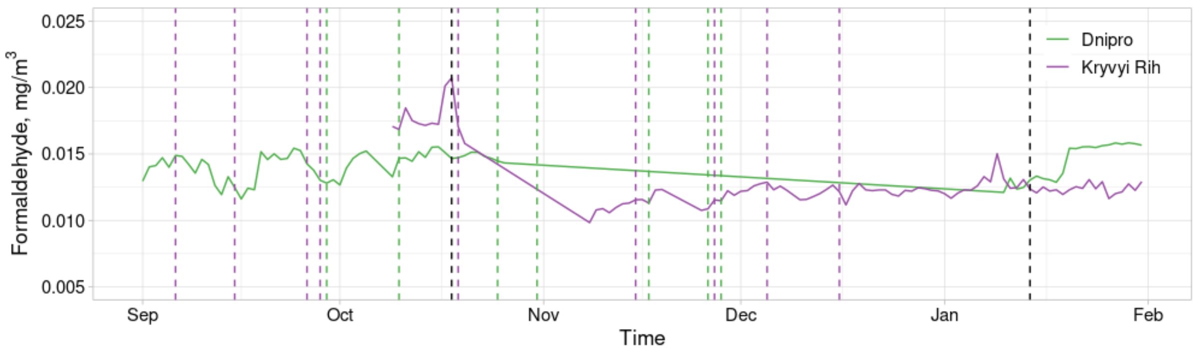


Figure 4.76 Dynamics of daily average levels of formaldehyde in Dnipro and Kryvyi Rih in September 2022-January 2023. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks on both locations.

Shortly after the beginning of the full-scale military invasion at 05.00 on 24 February 2022 there was an increase of formaldehyde level in Dnipro, in Kryvyi Rih it increased after a ~6 hour delay (Figure 4.37). The missile attacks on 30 March, 31 March, 01 April, and 06 April did not coincide with increases of formaldehyde level.

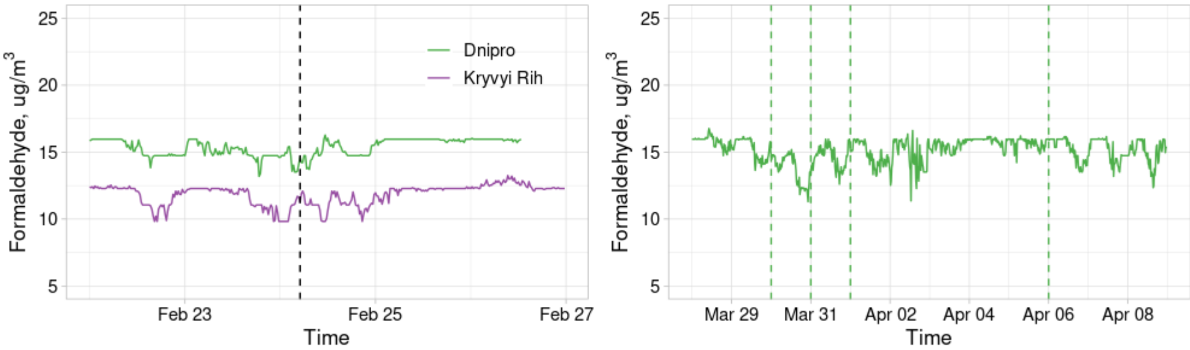


Figure 4.77 Dynamics of average levels of 20-minutes intervals of formaldehyde in Dnipro and Kryvyi Rih on 24 February, 2022 and in 28 March - 08 April 2022. EcoCity data.

Notes: vertical dashed lines - times of missile attacks.

Daily average formaldehyde level in Dnipropetrovsk oblast remained above 3 µg/m³ almost every day in 2020-2023. The overall formaldehyde air pollution in Dnipropetrovsk oblast in 2020-2023 has reduced, which corresponds to the CGO data. Since formaldehyde is a substance which is released by industries, it is an expected change in conditions of industrial shut-down. In the presented study, more damaged areas of Dnipropetrovsk oblast demonstrated larger decrease in formaldehyde air pollution. However, in the presented study the dynamics of formaldehyde air pollution was not linear and deserves several comments.

The annual average formaldehyde level in Dnipro has increased in 2020-2023, despite a visible decrease of formaldehyde levels early 2022. It might be related to the war-related damage of industrial objects, with a subsequent leak of formaldehyde. The former is additionally confirmed by the report by SaveDnipro, where in big cities that underwent severe bombing (Mykolaiv, Odesa) there was an increase of formaldehyde levels (46).

Also, despite the decrease of annual average formaldehyde levels in Ukraine, there was an increase in maximum concentrations of formaldehyde, and in number of locations with daily average formaldehyde levels above recommended (181). In the presented study the missile attacks frequently coincided with the increases in formaldehyde level. Altogether, it warrants the need of further investigation of impact of the war on formaldehyde air pollution.

Ammonia (NH_3)

In 2020-2023 there was a seasonal fluctuation of NH_3 levels: increase during warm months and decrease during cold months (Figures 4.38, 4.39). All studied locations were characterised by low NH_3 air pollution that remained within recommended ranges, but with sporadic spikes. While in the Nikopol and Marhanets and the Other areas NH_3 level was increasing ($p<0.01$), in Dnipropetrovsk oblast and Dnipro it was decreasing ($p<0.01$).

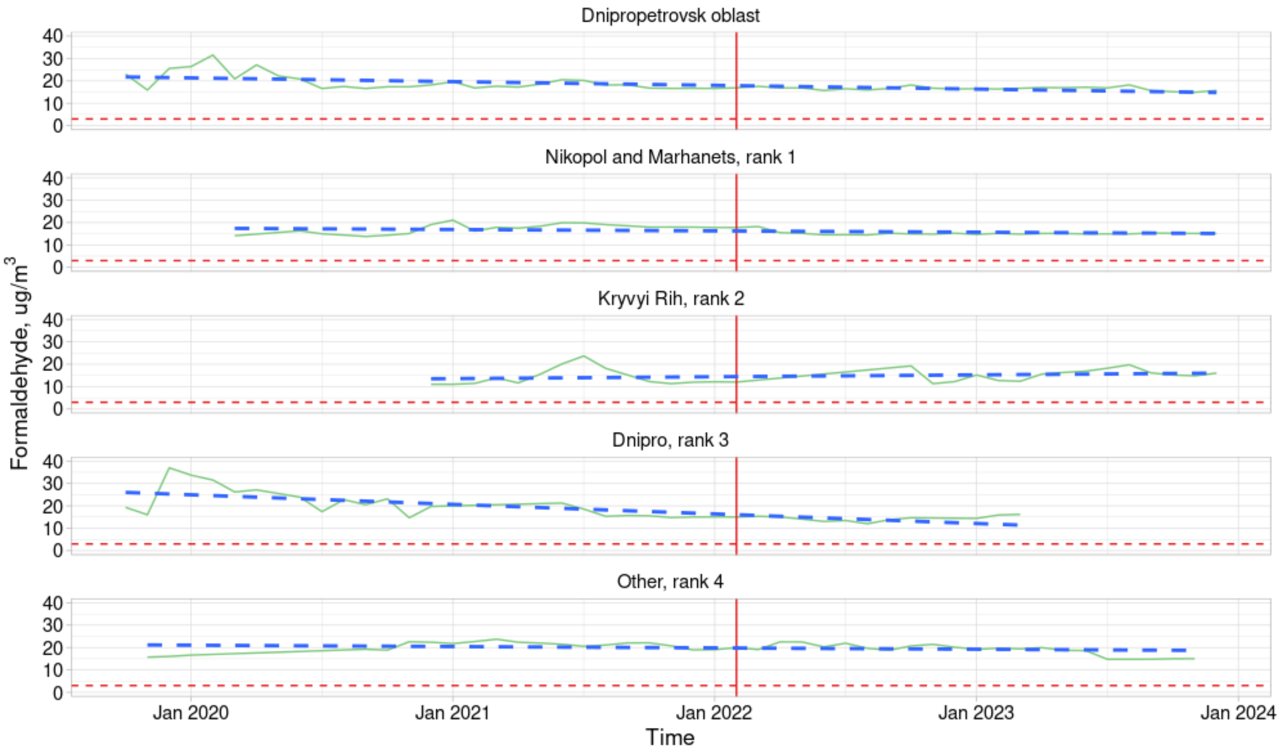


Figure 4.78 Dynamics of daily average levels of NH_3 in Dnipropetrovsk oblast in September 2019 - December 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; blue dashed lines - linear trends; vertical red solid line - time of active military offencive (February, 2022).

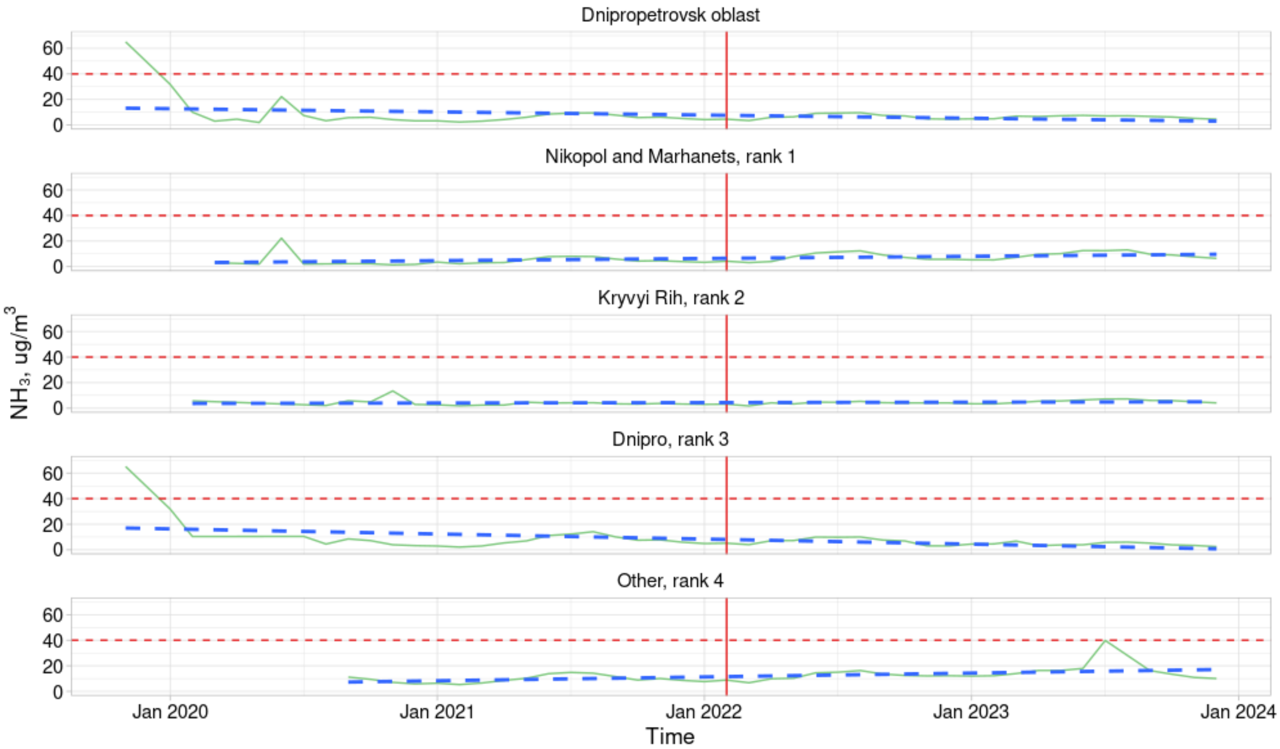


Figure 4.79 Dynamics of monthly average levels of NH_3 in Dnipropetrovsk oblast in September 2019 – December 2023. EcoCity data.

Notes: red dashed line - $MPC_{d.a.}$; blue dashed lines - linear trends; vertical red solid line - time of active military offensive (February, 2022). Linear trend equation (per year): Dnipropetrovsk oblast: $y = 5021.76 - 2.480x$ ($p=0.03$, decreasing), Nikopol and Marhanets: $y = -3452.02 + 1.7104x$ ($p<0.01$, increasing), Kryvyi Rih: $y = -664.31 + 0.3307x$ ($p=0.27$), Dnipro: $y = 8048.12 - 3.9761x$ ($p<0.01$, decreasing), Other: $y = -6060.67 + 3.0029x$ ($p<0.01$, increasing).

The daily average NH_3 level in Dnipropetrovsk oblast remained mostly below 40 μg/m³ 2020-2023 (Table 4.25). The minimum daily average NH_3 level was 2.8 μg/m³ in Kryvyi Rih in 2020, the maximum daily average NH_3 level was 105 μg/m³ in Dnipro in 2020.

Location	Year, n (%)				Chi-square p-value
	2020	2021	2022	2023	
Dnipropetrovsk oblast	2 / 236 (0.85%)	0 / 365 (0%)	0 / 362 (0%)	0 / 365 (0%)	0.03
Nikopol and Marhanets, rank 1	1 / 191 (0.52%)	0 / 365 (0%)	0 / 362 (0%)	0 / 365 (0%)	0.13
Kryvyi Rih, rank 2	1 / 94 (1.06%)	0 / 365 (0%)	0 / 361 (0%)	0 / 364 (0%)	0.01
Dnipro, rank 3	1 / 214 (0.47%)	0 / 365 (0%)	0 / 362 (0%)	0 / 365 (0%)	0.16
Other, rank 4	0 / 102 (0%)	0 / 353 (0%)	0 / 362 (0%)	0 / 289 (0%)	NA

Table 4.37 Number of days with NH_3 levels above 40 μg/m³in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

The annual average NH_3 level in Dnipropetrovsk oblast relatively stable, but in different areas dynamics of annual average NH_3 level was different (Table 4.26). There was a marked increase in annual average NH_3 level in the Nikopol and Marhanets (+295.7%) and the Other (+78.2%) areas in 2023 when compared to 2020. In 2022 and 2023 it has been increasing, as compared to preceding years, in all areas, except Dnipro ($p<0.05$).

Location	Year, average (95%CI)				Annual average growth rate
	2020	2021	2022	2023	
Dnipropetrovsk oblast, µg/m³	5.3 (5.0-5.6)	6.0 (5.9-6.2)	6.4 (6.3-6.6)	6.3 (6.2-6.4)	+5.6%
Nikopol and Marhanets, µg/m³	2.3 (1.9-2.7)	5.2 (5.1-5.4)	6.0 (5.8-6.2)	9.1 (8.9-9.3)	+37.5
Kryvyi Rih, µg/m³	5.8 (4.6-7.0)	3.5 (3.3-3.6)	3.9 (3.7-4.1)	5.3 (5.3-5.4)	-2.4%
Dnipro, µg/m³	6.3 (5.8-6.7)	7.3 (7.0-7.5)	6.9 (6.7-7.0)	4.6 (4.4-4.7)	-8.8%
Other, µg/m³	7.8 (7.5-8.2)	9.9 (9.7-10.2)	11.6 (11.4-11.9)	13.9 (13.6-14.2)	+18.5%

Table 4.38 Dynamics of annual average levels of NH_3 in Dnipropetrovsk oblast in 2020-2023. EcoCity data.

During February-May 2022, the average daily levels of NH_3 increased in 9 of 10 cases in Dnipro, and in 5 of 5 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.40). As in the case with previously analysed pollutants, there were increases in NH_3 levels in both locations that were of the same or larger magnitude that could be related to other factors.

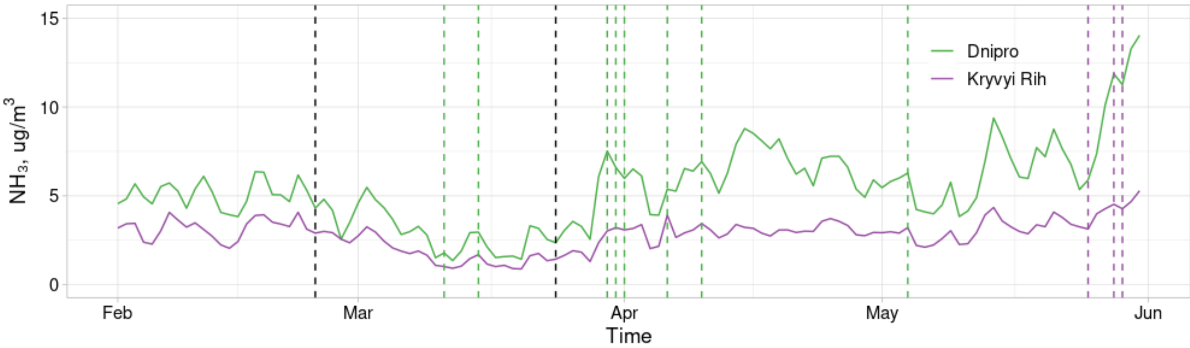


Figure 4.80 Dynamics of daily average levels of NH_3 in Dnipro and Kryvyi Rih in February-May 2022. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks of both locations.

During September 2022-January 2023, the daily average levels of NH_3 increased in 7 of 12 cases in Dnipro, and in 12 of 14 cases in Kryvyi Rih, when compared to the days preceding the attacks (Figure 4.41). As for the previous analysis, there were increases of NH_3 levels in both locations that were of the same or larger magnitude that could be related to other factors.

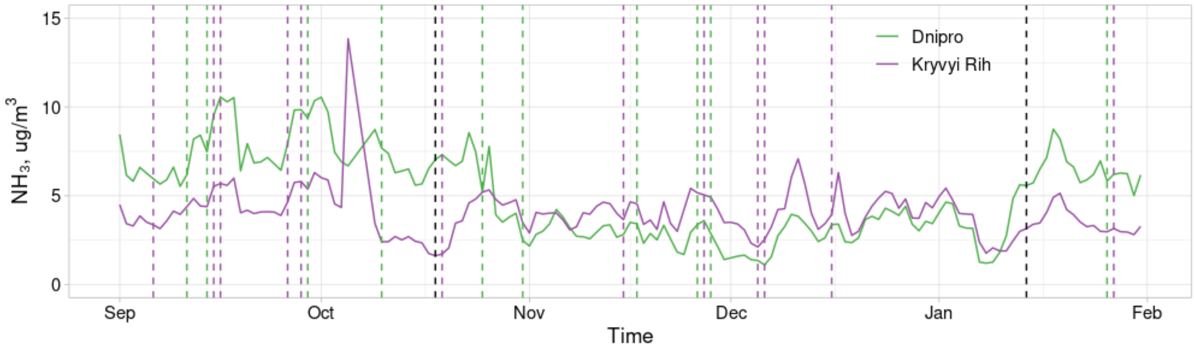


Figure 4.81 Dynamics of daily average levels of NH_3 in Dnipro and Kryvyi Rih in September 2022 - January 2023. EcoCity data.

Notes: vertical dashed lines represent missile attacks. Colours correspond to the location of the attack, black colour marks simultaneous attacks on both locations.

Shortly after the beginning of the full-scale military invasion at 05.00 on 24 February 2022, there was no increase of NH_3 level neither in Dnipro, nor in Kryvyi Rih (Figure 4.42). There were increases in NH_3 levels on 30 March, 31 March, 01 April, and 06 April, that could be related to the missile attacks those days.

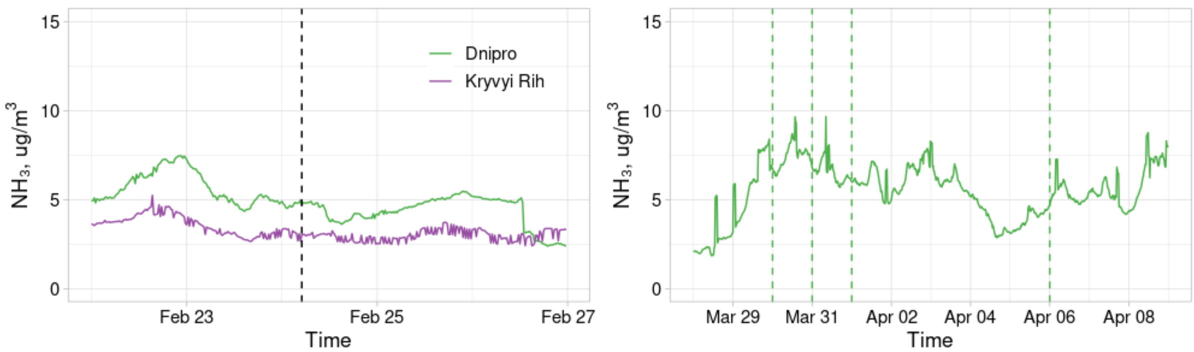


Figure 4.82 Dynamics of average levels of 20-minutes intervals of NH_3 in Dnipro and Kryvyi Rih on 24 February, 2022 and in 28 March - 08 April 2022. EcoCity data.

Notes: vertical dashed lines - times of missile attacks.

Dynamics of NH_3 levels in Dnipropetrovsk oblast was similar to the trend in Ukraine (181). Local trends within the oblast, like 3-fold increase in the Nikopol and Marhanets area in 2023 when compared to 2020, is challenging to explain. In Dnipropetrovsk oblast missile attacks frequently coincided with increases in NH_3 levels. It may be speculated that leak of NH_3 due to explosions took place. Importantly, that in all locations, except Dnipro, annual average NH_3 level increased in 2022-2023. In Ukraine there was an increase in maximum NH_3 levels in 2022, as well as the percentage of locations with average and maximum NH_3 levels above recommended in 2022-2023. Altogether, it may be a sign of the negative short-term impact of missile attacks on NH_3 air pollution.

Phenol

In Dnipro, over the period 2009-2022 the annual levels of phenol were characterised by a statistically significant downward trend ($p<0.01$) (Figure 4.43). It was slightly above the threshold from national standard in 2010-2014, and fluctuated between 2.2 µg/m³ in 2022 and 4.0 µg/m³ in 2011. In Kryvyi Rih over the same period phenol level was statistically non-significantly increasing and within recommended ranges. It fluctuated between 1.0 µg/m³ in 2009 to 2.3 µg/m³ in 2021. In both locations 2022 annual levels were lower than in 2021.

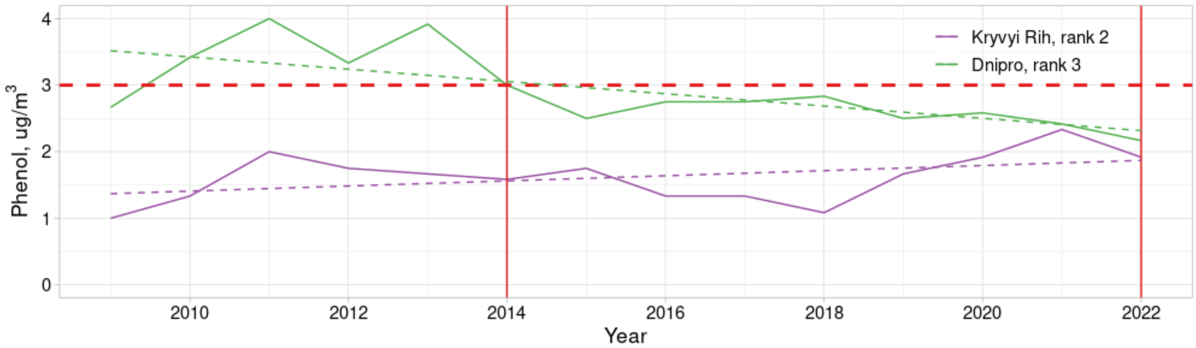


Figure 4.83 Dynamics of annual average levels of phenol in Dnipro and Kryvyi Rih in 2009-2022. RCGM data.

Notes: red dashed line - $MPC_{d.a.}$; dashed lines of corresponding colours - linear trends; vertical red solid lines - beginnings of military offensives (2014, 2022). Linear trend equations (per year): Dnipro: $y = 188.96 - 0.0923x$ ($p<0.01$, decreasing), Kryvyi Rih: $y = -75.90 + 0.0385$ ($p=0.12$).

Salts of heavy metals (manganese, mercury, lead, chromium)

In recent years, environmental and global public health concerns related to environmental pollution with heavy metals have been growing (282–284). Considering the limitations of monitoring data on the level of heavy metals in atmospheric air, it was concluded only that the percentage of air pollution above MPC with heavy metals in 2016-2022 in Dnipro oblast was low and did not exceed 4% in any given year (Figure 4.44). The percentage of values above MPC in later years was mostly lower than in earlier years. No values above MPC were registered in 2022.

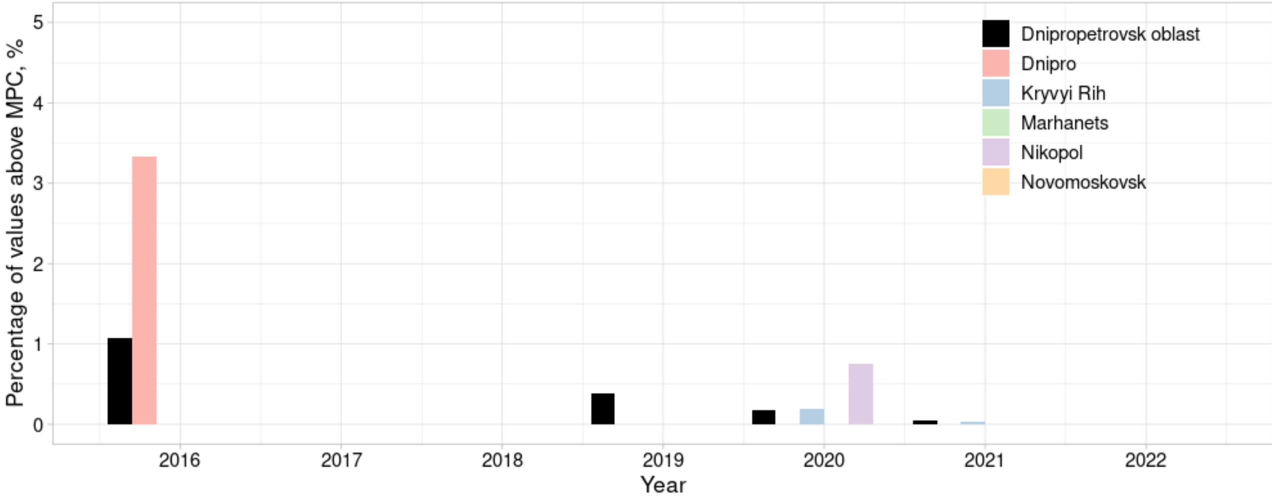


Figure 4.84 Dynamics of percentage of values above MPC for air pollution with salts of heavy metals in Dnipropetrovsk oblast in 2016-2022. State institution "Dnipropetrovsk Regional Center for Disease Control and Prevention of the Ministry of Health of Ukraine" data.

Notes: for Dnipropetrovsk oblast in 2017-2018 data were not available

Heavy metals pose a serious environmental problem worldwide due to their toxicity, stability in environmental objects, wide distribution and higher potential toxicity and bioaccumulation in living organisms, causing various pathological processes (282–284).

Prognosis of air pollution

Ukraine

According to linear models statistically significant decrease in average levels of undifferentiated dust, CO and air pollution index in the whole country may be expected (Table 4.27). Among all air pollutants, only SO2 had an increasing, but statistically non-significant trend. Current and predicted values of NO_2 and formaldehyde are above recommended values.

Substance	Year, mg/m^3	
	2024	2025
Undifferentiated dust	0.110	0.106
SO_2	0.019	0.019
CO	1.085	0.986
NO_2	0.060	0.060
NO	0.030	0.030
H_2S	0.002	0.002
Soot	0.020	0.017

Phenol	0.0029	0.0028
HF	0.0029	0.0027
HCl	0.043	0.041
NH_3	0.014	0.013
Formaldehyde	0.0064	0.0063
Air pollution index	6.1	5.9

Table 4.39 Prognosis of air pollution level in Ukraine.

Dnipropetrovsk oblast

Despite a statistically significant declining trend for undifferentiated dust, $PM_{2.5}$, PM_{10}, their predicted annual concentrations (except PM_{10} in Kryvyi Rih and Dnipro) will remain above MPCd.a. (undifferentiated dust) and annual threshold for poor air quality (WHO) in all studied cities of the Dnipropetrovsk oblast in 2023-2025 (Table 4.28).

Location	Year	
	2024	2025
Undifferentiated dust, µg/m^3		
Kryvyi Rih, rank 2	368.8	360.0
Dnipro, rank 3	279.8	277.8
$PM_{2.5}$/PM_{10}, µg/m^3		
Dnipropetrovsk oblast	7.3/14.3*	NA
Nikopol and Marhanets, rank 1	5.6/12.7*	NA
Kryvyi Rih, rank 2	7.4/15.3*	NA
Dnipro, rank 3	7.9/15.4*	NA
Other, rank 4	6.1/10.1*	NA

Table 4.40 Prognosis of dust pollution level in Dnipropetrovsk oblast.

Notes: *prognosis made using EcoCity data

Prognosis made using the EcoCity data suggests that NO_2 pollution in Dnipropetrovsk oblast in 2024 will be mostly within recommended values (Table 4.29). The prognosis for Dnipro using the RCGM data suggests annual average NO_2 levels 2-3 times above recommended values. It may be a result of mostly increasing 2009-2018 NO_2 levels in the city, which outweighed NO_2 reduction during shorter period of time in 2019-2022.

Location	Year, μg/m^3	
	2024	2025
Dnipropetrovsk oblast, μg/m^3	32.7*	NA
Nikopol and Marhanets, rank 1, μg/m^3	38.1*	NA
Kryvyi Rih, rank 2, μg/m^3	39.6 (36.6*)	38.4
Dnipro, rank 3, μg/m^3	116.6 (34.2*)	118.3
Other, rank 4, μg/m^3	22.9*	NA

Table 4.41 Prognosis of NO_2 pollution level in Dnipropetrovsk oblast.

Notes: *prognosis made using EcoCity data

Prognosis of CO pollution in Dnipro and Kryvyi Rih, made using the RCGM data, suggests the decrease in annual average CO levels in 2023-2025 (Table 4.30). Prediction based on the EcoCity data suggests an increase in annual average CO level in all studied locations. However, it should not exceed the recommended limits.

Location	Year, μg/m^3	
	2024	2025
Dnipropetrovsk oblast, μg/m^3	0.4*	NA
Nikopol and Marhanets, rank 1, μg/m^3	2.2*	NA
Kryvyi Rih, rank 2, μg/m^3	1.4 (1.8*)	1.3
Dnipro, rank 3, μg/m^3	2.4 (1.9*)	2.4
Other, rank 4, μg/m^3	0.6*	NA

Table 4.42 Prognosis of CO pollution level in Dnipropetrovsk oblast.

Notes: *prognosis made using EcoCity data

Formaldehyde pollution in the oblast is predicted to increase in 2023-2025, according to the RCGM data (Table 4.31). The prognosis using the EcoCity data suggests the decrease of formaldehyde levels in 2024. In both cases formaldehyde levels would remain significantly above the recommended limits.

Location	Year, μg/m³	
	2024	2025
Dnipropetrovsk oblast, μg/m³	14.7*	NA
Nikopol and Marhanets, rank 1, μg/m³	15.1*	NA
Kryvyi Rih, rank 2, μg/m³	14.2 (16.1*)	14.6
Dnipro, rank 3, μg/m³	16.8 (7.9*)	17.4
Other, rank 4, μg/m³	18.7*	NA

Table 4.43 Prognosis of formaldehyde pollution level in Dnipropetrovsk oblast.

Notes: *prognosis made using EcoCity data

In Dnipropetrovsk oblast and Dnipro a modest decrease of NH_3 levels is expected (Table 4.32). In Nikopol and Marhanets and Other locations a modest decrease of NH_3 levels is expected. The values of NH_3 in the region are expected to remain within the recommended limits.

Location	Year, μg/m³
	2024
Dnipropetrovsk oblast, μg/m³	2.2*
Nikopol and Marhanets, rank 1, μg/m³	9.8*
Kryvyi Rih, rank 2, μg/m³	5.0*
Dnipro, rank 3, μg/m³	0.5*
Other, rank 4, μg/m³	17.2*

Table 4.44 Prognosis of NH_3 pollution level in Dnipropetrovsk oblast.

Notes: *prognosis made using EcoCity data

Phenol levels are expected to decrease in Dnipro and increase in Kryvyi Rih in 2023-2025 (Table 4.33). In both cases they are expected to remain within recommended limits.

Location	Year, $\mu g/m^3$	
	2024	2025
Kryvyi Rih, rank 2, $\mu g/m^3$	2.0	2.1
Dnipro, rank 3, $\mu g/m^3$	2.2	2.1

Table 4.45 Prognosis of phenol pollution level in Dnipropetrovsk oblast.

According to the linear trends the decrease in dust, CO and air pollution index, no change in NO_2, NO and H2S levels to be expected in Ukraine in 2024-2025. The decrease in dust, no change/slight increase in NO_2, and increase in formaldehyde air pollution to be expected in Dnipropetrovsk oblast in 2024-2025. However, the linear prognosis does not take into account possible variants of the war in Ukraine development.

In Dnipropetrovsk oblast, despite a decreasing trend, the differences in $PM_{2.5}$ and PM_{10} pollution in 2022 and 2023 were minimal, when compared to previous years. It could imply a modest change in dust air pollution in the upcoming years, unless the situation in the region changes dramatically (e.g. intensification of the shelling, approaching of the frontline to the borders of the region/military actions in the region, changes in industrial activity, etc.). It is difficult to draw a solid prognosis of CO levels, since the direction of the predicted change using the RCGM and EcoCity data are discordant. Nevertheless, given the ongoing missile and artillery attacks and recovery of social life in the region, the increase of CO pollution may be expected.

The trends for the formaldehyde air pollution in Dnipropetrovsk oblast based on the RCGM and EcoCity data are also discordant. But there was a notable increase in formaldehyde air pollution starting from the second half of 2022 and in 2023. Trends in air pollution in Kryvyi Rih also may imply the increase in formaldehyde air pollution in the near future. Taking into account the overall increasing trend in 2009-2022, it could be reasonable to assume that air formaldehyde level in the region is going to increase. The opportunity of shelling to impact formaldehyde level requires close investigation, as in several places, that suffered severe bombing its level increased (46).

The linear trends for NH_3 in Dnipropetrovsk oblast, despite being statistically significant, were modest in magnitude. Therefore, significant changes of NH_3 levels in the region in the upcoming years are unlikely. Notably, that the slope of NH_3 increase was the steepest in the Nikopol and Marhanets area and Other area, which will require further investigation. Phenol levels in Dnipro and Kryvyi Rih are expected to become equal, and remain within recommended ranges in the upcoming two years. Given the dynamics of heavy metals air pollution, it is unlikely to expect its increase in the nearest years. However, its increase is possible in case of intensification of the war in the region (e.g. combat over the territories of the oblast) or rise of industrial activity.

In summary, it is likely that air pollution in Ukraine will depend on various factors: war intensity, industrial activity, approaches to emission control in industries, type and scale of damage to industrial objects or chemicals reservoirs, intensity of forest fires, anthropogenic activity and many more. It is already visible, that in the areas that became logistic hubs the air quality has worsen in 2022, when compared to 2021 (Odesa, Izmail) (46,181). Authors' expectations of the change in air pollution during within upcoming years are summarised in the Table 4.34.

Substance	Prognosis
Suspended substances	=/↓*
Sulphur dioxide	↑
Carbon monoxide	=*
Nitrogen dioxide	=*
Nitrogen oxide	↓
Hydrogen sulfide	=/↑
Soot	↓*
Phenol	↓*
Hydrogen fluoride	↓*
Hydrogen chloride	=*
NH_3	↓*
Formaldehyde	↓*
Air pollution index	↓*

Table 4.46 Expectations of the air pollution dynamics in Dnipropetrovsk oblast depending on the progression of the war.

Notes: ↑ - likely to increase, ↓ - likely to decrease, = - no change, * - increase in case of severe damage of area (e.g. bombing) is possible.

Cancer risk and hazard coefficients

Ukraine

For the whole period of observation (2017-2023) formaldehyde-related cancer risk was at acceptable level (9.2×10^{-5}), but it was close to the moderate level threshold (Table 4.35). Soot-related cancer risk was at average level (3.6×10^{-4}), acceptable for industries, but unacceptable for the population, and requiring additional control. Given the impact on the entire population, dynamic control and an in-depth study of the sources and possible consequences of harmful effects are necessary to resolve the issue of risk management measures. Hazard index for all presented pollutants in the table was 6.19, which corresponds to the high level, which indicates a high risk for public health. According to the recommendation of the US EPA (337), such a situation requires urgent health and other measures to reduce it. Both cancer risks and hazard indexes were lower in 2022-2023, when compared to 2017-2021.

Substance	Year, HQ/CR			
	2017-2019	2020-2021	2022-2023	2017-2023
Undifferentiated dust	0.89	0.83	0.77	0.84
SO_2	0.33	0.36	0.37	0.35
CO	0.57	0.47	0.42	0.50
NO_2	1.50	1.50	1.50	1.50
NO	0.50	0.50	0.50	0.50
H_2S	–	–	–	–
Soot	–	**3.9×10^{-4}**	**3.3×10^{-4}**	**3.6×10^{-4}**
Phenol	1.22	1.00	1.00	0.92
HF	0.80	0.70	0.60	0.71
HCl	0.25	0.25	0.23	0.24
NH_3	0.50	0.50	0.38	0.46
Formaldehyde	9.6×10^{-5}	9.2×10^{-5}	8.5×10^{-5}	9.2×10^{-5}
Hazard index	**6.55**	**6.11**	5.75	**6.19**

Table 4.47 Hazard coefficients and cancer risk for the population of Ukraine due to the air pollution.

Notes: HQ – hazard quotient; CR – cancer risk.

Dnipropetrovsk oblast

According to the estimations made using the 2009-2022 RCGM data, the population of Dnipro and Kryvyi Rih are at increased risk of cancer due to the formaldehyde air pollution (Table 4.36). The cancer risk was acceptable for acceptable for industries, but unacceptable for the population. It required additional control and in-depth study of sources of emission and possible consequences of harmful action to resolve the issue of measures to reduce it. The population of Dnipro and Kryvyi Rih is also at the high or alarming risk of non-cancerogenic effects of air pollution, mostly due to the dust and NO_2 air pollution in Dnipro and dust air pollution in Kryvyi Rih.

Location	HQ					Cancer risk
	Undif. dust	NO_2	CO	Phenol	HI	Formaldehyde
Dnipro	3.96	2.34	0.77	0.49	5.22	**$1.6x10^{-4}$**
Kryvyi Rih	6.01	1.22	0.76	0.27	**7.04**	**$1.4x10^{-4}$**

Table 4.48 Hazard coefficients and cancer risk for the population of Dnipro and Kryvyi Rih due to the air pollution. RCGM data

Notes: HQ – hazard quotient; HI – hazard index.

According to the 2019-2023 EcoCity data, cancer risk and non-cancerogenic HI were at acceptable levels (Table 4.37). The possible reason for the difference in risk estimations using the RCGM and EcoCity data is the period of measurement. The EcoCity data included recent years, which were characterised by on average lower levels of air pollution.

Location	HQ						Cancer risk
	$PM_{2.5}$	PM_{10}	NO_2	CO	NH_3	HI	Formaldehyde
Dnipropetrovsk oblast	0.76	0.43	0.90	0.23	0.01	2.33	$2.4x10^{-5}$
Dnipro	0.81	0.25	0.94	0.24	0.01	2.25	$2.5x10^{-5}$
Kryvyi Rih	0.89	0.27	0.85	0.26	0.01	2.28	$1.9x10^{-5}$
Nikopol and Marhanets	0.59	0.18	0.88	0.28	0.01	1.94	$2.1x10^{-5}$
Other	0.67	0.21	0.65	0.17	0.02	1.72	$2.6x10^{-5}$

Table 4.49 Hazard coefficients and cancer risk for the population of Dnipropetrovsk oblast due to the air pollution. EcoCity data

Notes: HQ – hazard quotient; HI – hazard index.

The values of HI for Dnipro was similar to the one for Ukraine and in Kryvyi Rih it was even higher, despite the fact that the calculation was carried out on a smaller number of pollutants. It indicates higher non-cancerogenic risks for the citizens of industrialised areas with significant air pollution and, therefore, such a situation requires urgent health and other measures to reduce it. In contrast to all-Ukrainian data, the risk of cancer caused by formaldehyde in the cities of Dnipro and Kryvyi Rih corresponds to average level (1.6×10^{-4}) - acceptable for industries, but unacceptable for the population, and requiring additional control. Given the impact on the entire population, dynamic control and an in-depth study of the sources and possible consequences of harmful effects are necessary to resolve the issue of risk management measures.

Association between air pollution and cancer epidemiology

After conducting an exploratory data analysis it was clear that the regression or correlation between levels of X and Y for all regions without any adjustment would not be a valid estimate due to a unique situation in every region. An example of association between NO2 emissions per km^2 and malignant neoplasms of all localisations (C00-C96) with 5-year lag is presented on the Figure 4.45.

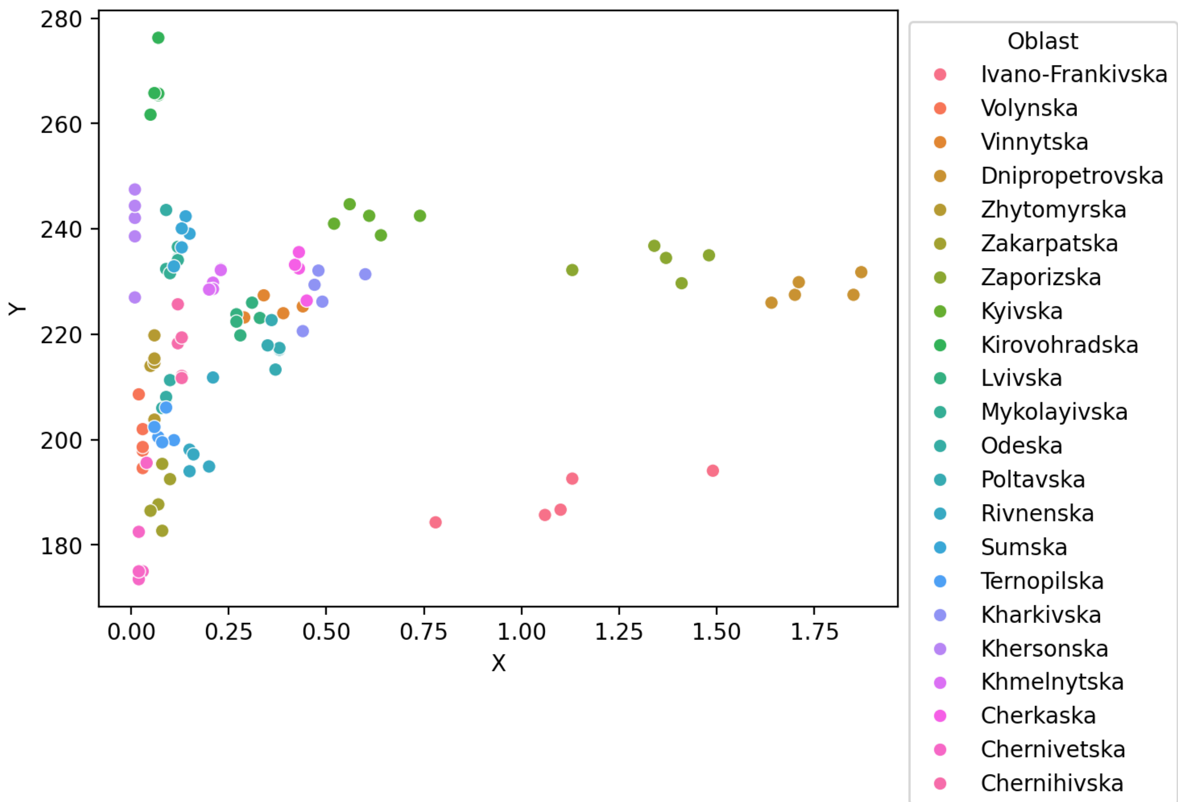


Figure 4.85 Relation between all malignant neoplasms of all localisations (C00-C96) incidence and NO_2 emissions per km^2 with 5-year lag (split by region). Ukrstat and NCRU data.

As can be shown on the scatterplot, multiple years of the same oblast are very close to each other. Such clusterisation of the data could indicate that air pollutant emissions were not the only factor that affected cancer epidemiology. Therefore, the information about the region must be taken into account (Figure 4.46).

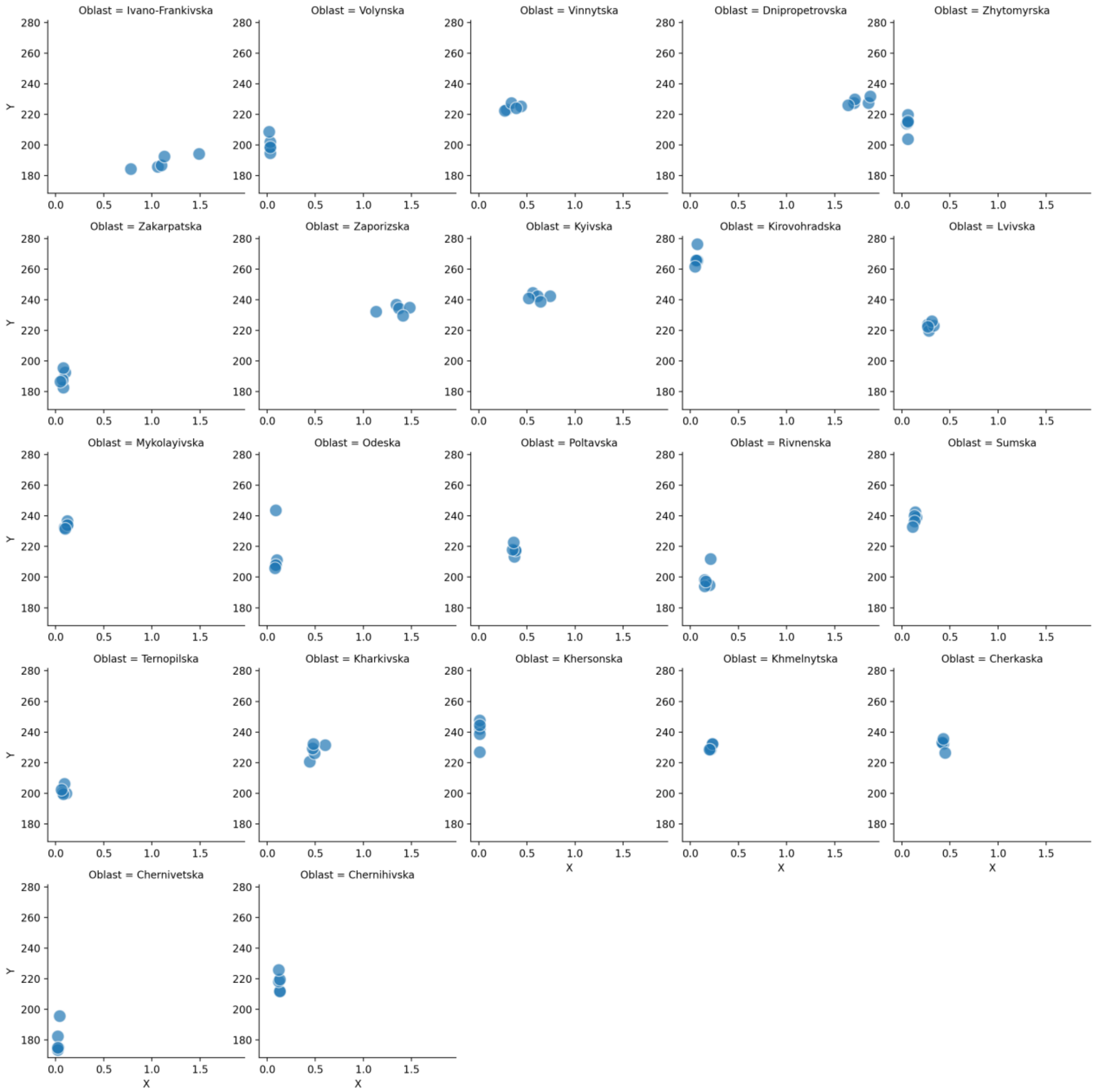


Figure 4.86 Relation between all malignant neoplasms of all localisations (C00-C96) incidence and NO_2 emissions per km^2 with 5-year lag (split by region). X and Y axes are shared between nested plots. Ukrstat and NCRU data.

Sharing X and Y scale (Figure 4.46) makes it difficult to recognise any pattern, but if the same data is plotted in a way when the X and Y scales are not shared and the field of view is magnified to its limit, some patterns can be identified (Figure

4.47).

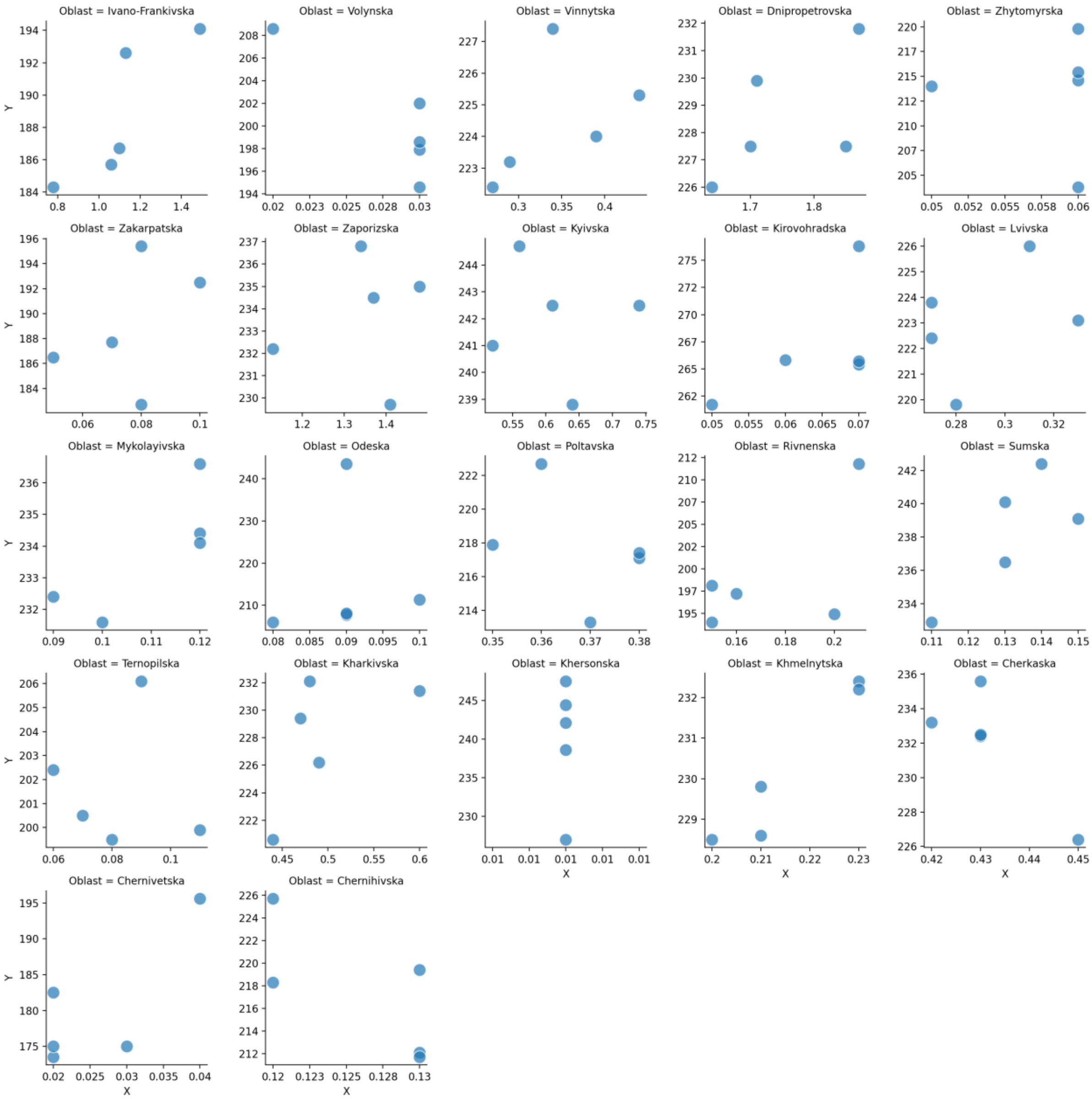


Figure 4.87 Relation between all malignant neoplasms of all localisations (C00-C96) incidence and NO_2 emissions per km^2 with 5-year lag (split by region). X and Y axes are not shared between nested plots. Ukrstat and NCRU data.

The number of data points available for each oblast was not enough to get any statistically significant results using correlation for each region separately, therefore it was decided to rank both X and Y in ascending order and then combine those values in a single dataset (Figure 4.48). Adding this step into the calculation allowed to isolate the impact of the unknown variables for each region and increased the chances of getting statistically significant results. This transformation is somewhat similar to how hierarchical linear models try to adjust for nested data by introducing multilevel intercepts. But since the correlation was applied instead of regression, it was not an option in this case.

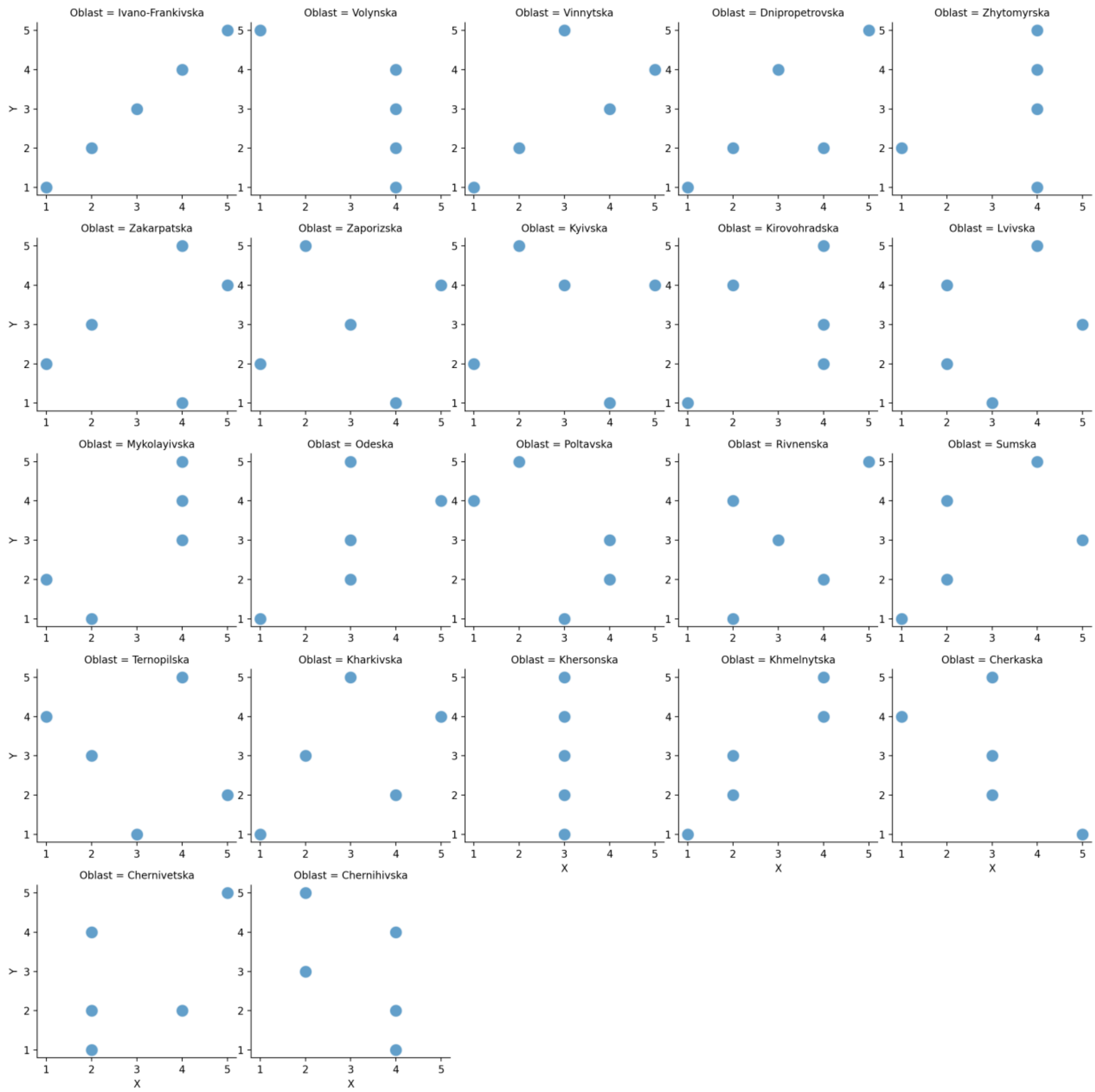


Figure 4.88 Relation between all malignant neoplasms of all localisations (C00-C96) ranked incidence and ranked NO_2 emissions per km^2 with 5-year lag (split by region). Ukrstat and NCRU data.

In cases like on the Figure 4.48, where data points are closely ranked, scatterplots with all observations may become cluttered and difficult to read. Overlapping points in a scatterplot can obscure details and hamper the identification of the data density. Heatmaps handle this more efficiently by providing a clear visual representation where the density of points (or ranking) is indicated by colour, avoiding issues of overlap. Therefore a heatmap chart was chosen to perform a final visualisation step in this process (Figure 4.49).

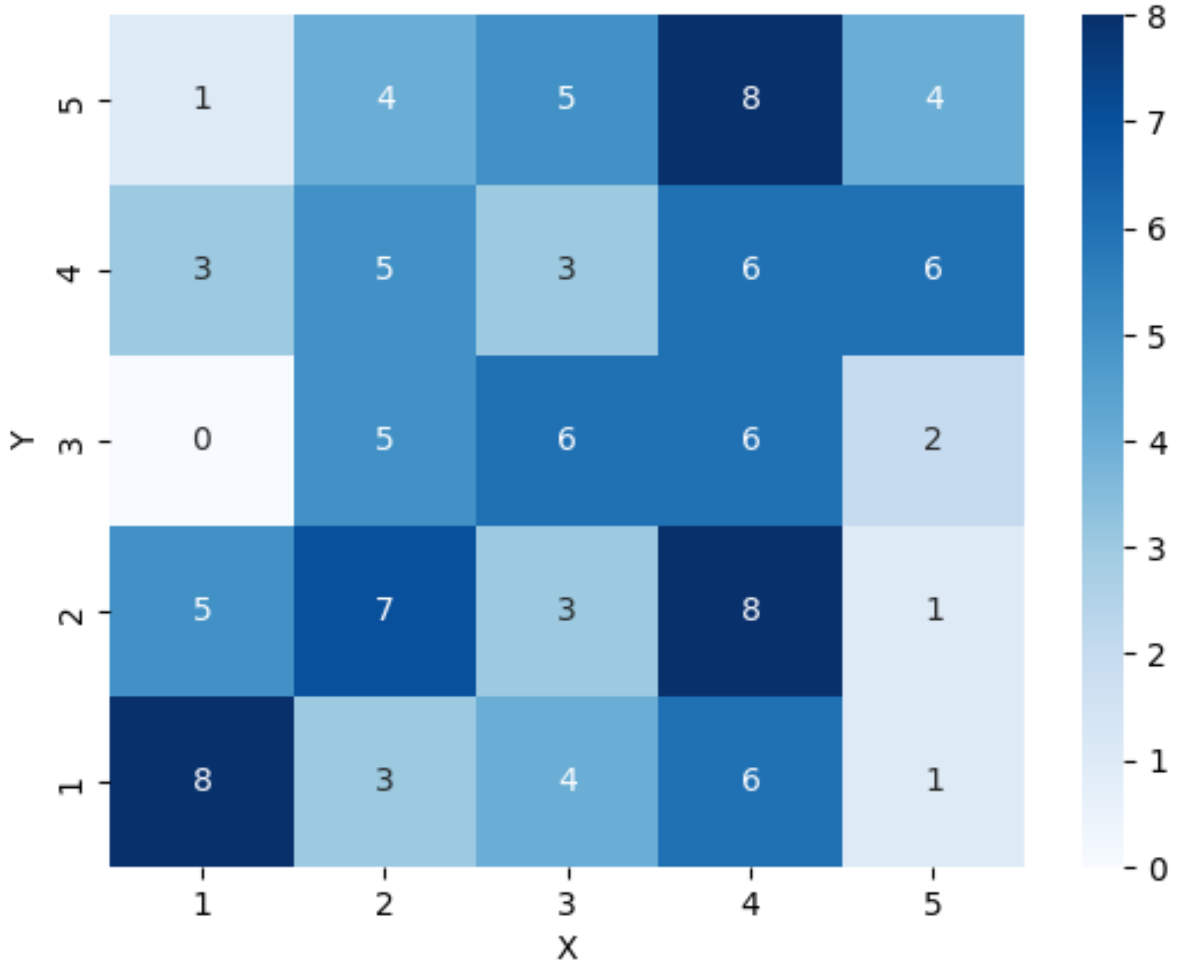


Figure 4.89 Heatmap for relation between all malignant neoplasms of all localisations (C00-C96) ranked incidence and ranked NO_2 emissions per km^2 with 5-year lag (split by region). Ukrstat and NCRU data.

The same steps were performed for the investigation of association between emissions of all air pollutants in the study per km^2 with incidence and mortality of cancers of all studied localisations with lags from 1 to 6 years. For each association Spearman's rank correlation coefficient was calculated (Table 4.38). Of course, using a regression model would be a better option. However, given the limitations of the data, the authors assumed that the incorporation of regional differences adjustment into rank correlation analysis was a valid approach in this particular case.

The results show that emissions of some pollutants (all registered pollutants, PM and NO_2) correlated most with incidence and/or mortality of cancers of particular localisations (C00-C96, C16, C32, C33-C34, C50) with 3-5 years lag. It means that air-pollution triggered oncological disease and/or disease-related death takes on average 3-5 years to manifest. Emissions of SO_2 and CO didn't show any statistically significant correlation pattern for any year-lag tested. Malignant neoplasm of cervix uteri rates also didn't show any statistically significant correlation pattern across pollutants, just a couple of sporadic values that could happen purely by chance.

Pollutant	ICD-10 code	Indicator	Lag (years)					
			1	2	3	4	5	6
All	C00-C96	Incidence					0.29	
		Mortality		0.26	0.36	0.44	0.42	
	C16	Incidence		0.32	0.35	0.39	0.37	
		Mortality		0.32	0.36	0.35	0.45	
	C32	Incidence			0.25	0.25		
		Mortality			0.3	0.29	0.28	
	C33-C34	Incidence						
		Mortality				0.4	0.37	
	C50	Incidence						
		Mortality			0.31	0.35		
	C53	Incidence						
		Mortality						
PM	C00-C96	Incidence					0.39	
		Mortality				0.49	0.48	
	C16	Incidence				0.36	0.32	
		Mortality				0.4	0.42	0.41
	C32	Incidence						
		Mortality				0.22		
	C33-C34	Incidence						
		Mortality				0.47	0.43	
	C50	Incidence						
		Mortality						
	C53	Incidence					0.34	
		Mortality						
NO_2	C00-C96	Incidence					0.27	
		Mortality		0.31	0.55	0.26		
	C16	Incidence		0.34	0.29	0.25		

		Mortality		0.27	0.39	0.25		
	C32	Incidence			0.29		0.33	
		Mortality			0.32			
	C33–C34	Incidence			0.28			
		Mortality			0.44			
	C50	Incidence						
		Mortality			0.34	0.36		
	C53	Incidence						
		Mortality						
SO_2	C00-C96	Incidence						
		Mortality						
	C16	Incidence						
		Mortality						
	C32	Incidence						
		Mortality						
	C33-C34	Incidence			0.25			
		Mortality						
	C50	Incidence						
		Mortality						
	C53	Incidence						
		Mortality						
CO	C00-C96	Incidence						
		Mortality						
	C16	Incidence						
		Mortality						
	C32	Incidence						
		Mortality						
	C33-C34	Incidence						
		Mortality						
	C50	Incidence						
		Mortality						
	C53	Incidence						0.26
		Mortality						

Table 4.50 Spearman's rank correlation coefficients of different air pollutant emissions per km^2 with incidence and mortality rates of cancer with different localisations (marked by ICD-10 codes) with different lags (in years). Ukrstat and NCRU data.

Notes: Correlation coefficients that are statistically insignificant, negative or less than 0.25 (considered a weak correlation) were filtered out for a more concise visual representation.

In summary, it may be concluded that there is indeed a relation between some air pollutant emission levels per km^2 and incidence and/or mortality rates of some cancers with a 3-5 years lag. Although the data on which the analysis is based is not as precise as desired, it still shows that air pollutants should be considered as an important risk factor for cancerogenesis. Further research in this direction with larger amount of information is required.

Impact of war on cancer epidemiology

Overall trend in cancer incidence was stable in Ukraine and decreasing in Dnipropetrovsk oblast ($p=0.02$), however, the trends were not linear (Figure 4.50). There was a decrease in cancer incidence in 2014 in Dnipropetrovsk oblast; in 2020 and 2022 in both areas. In 2014-2019 total cancer incidence was increasing in both areas.

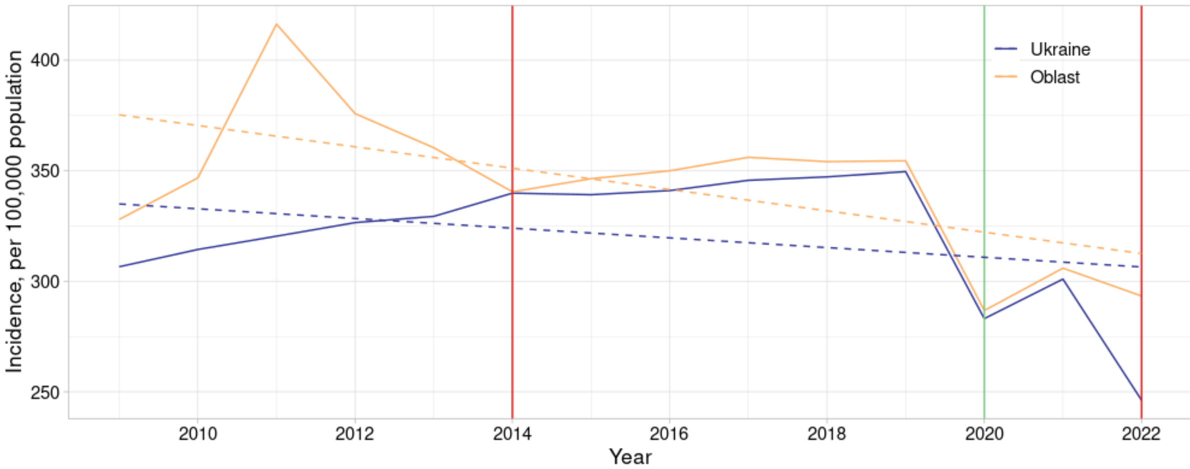


Figure 4.90 Incidence of cancer of all localisations (C00-C97) in Dnipropetrovsk oblast and Ukraine in 2009-2022. MoHU data.

Notes: vertical red solid lines - beginnings of military offensives (2014, 2022); vertical green solid line – beginning of COVID-19 pandemic.

Overall trends in respiratory cancer incidence in Ukraine and Dnipropetrovsk oblast were decreasing ($p<0.01$) (Figure 4.51). There was a decrease in respiratory cancer incidence in 2014 in Dnipropetrovsk oblast; in 2020 and 2022 in both areas. Respiratory cancer incidence in Dnipropetrovsk oblast was higher than in Ukraine. In both areas respiratory cancer incidence remained relatively stable in 2014-2019, with an increase in Dnipropetrovsk oblast.

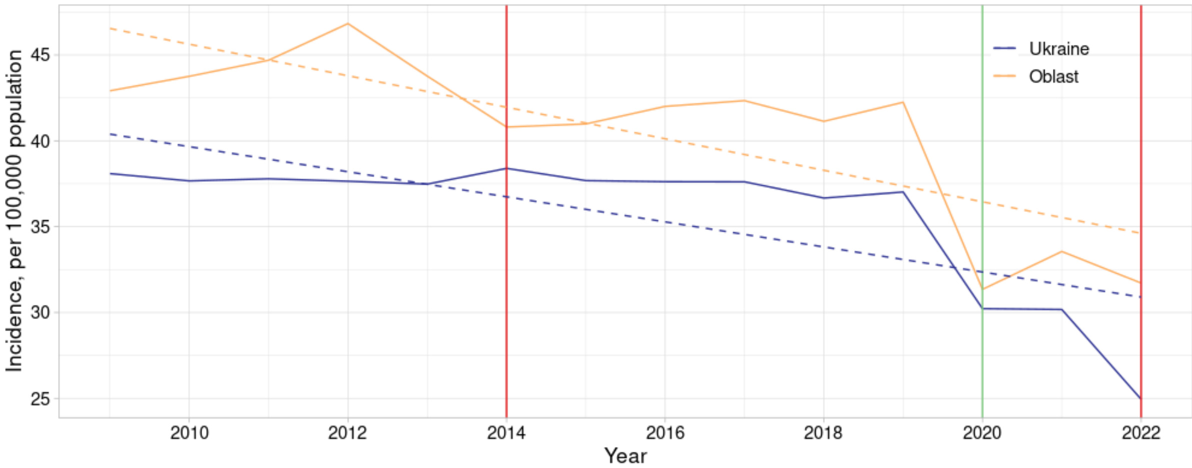


Figure 4.91 Incidence of respiratory (C32-C34) cancer in Dnipropetrovsk oblast and Ukraine in 2009-2022. MoHU data.

Notes: vertical red solid lines - beginnings of military offensives (2014, 2022); vertical green solid line – beginning of COVID-19 pandemic.

Respiratory cancer incidence in Dnipropetrovsk oblast was notably higher, than in Ukraine. Dnipropetrovsk oblast is among the most industrialised regions of Ukraine with one of the highest number of industrial atmospheric emissions (338). Since air pollution is a risk factor of respiratory and non-respiratory cancers (339–341), these findings are not unexpected. Importantly, the amount of atmospheric emissions in Ukraine and Dnipropetrovsk oblast has been decreasing since 2010 (338,342). Nevertheless, total and respiratory cancer incidence in 2014-2019 was stable or even increasing. The rise in cancer incidence could stem from more active detection by oncologists. But, at the same time, it may be an example of cumulative effect of air pollution on cancer incidence, when effects of change in air pollution are not immediately visible. After the Russian occupation of Donetsk and Luhansk regions the emissions from industries on the occupied territories were not included to the Ukrainian statistical reports (334). However, it is probable, that the functioning of those industries was not stopped and they continued to produce atmospheric emissions. At the same time, it may be assumed that the emission control has worsened due to the economical and political isolation of Russian proxy republics created on the occupied territories of Ukraine. Therefore, the rise of respiratory cancer incidence in Dnipropetrovsk oblast may also stem from the air pollution from highly industrialised Ukrainian territories under Russian occupation.

Total cancer incidence increased by 4.2% from 2014 to 2019 in Ukraine, the average one-year increase was 0.8%. One of important drivers of increase in total cancer incidence could be the beginning of the Russian-Ukrainian war, which was localised in the East of Ukraine and Crimea till 2022. The map with the relative increase in total cancer incidence in 2014-2019 is on the Figure 4.52. There is no clear dependency between location of oblasts and relative difference in cancer incidence. However, the only oblasts without increase were in the South or the West of the country.

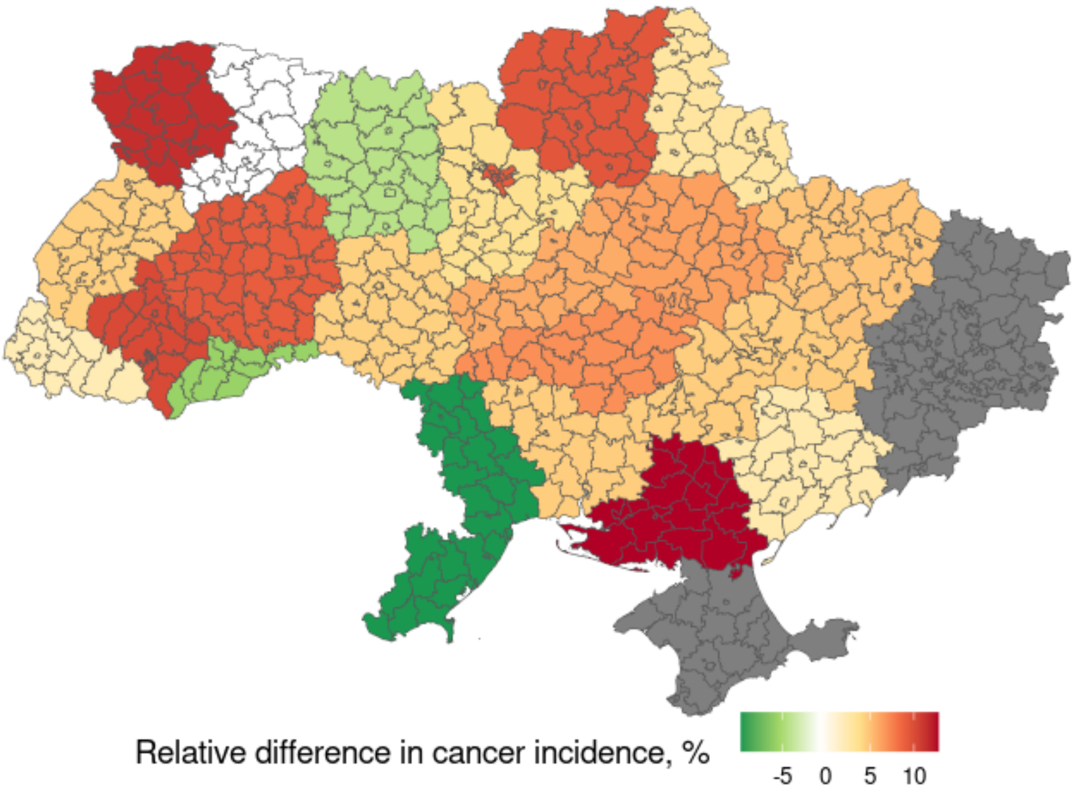


Figure 4.92 Relative increase in total cancer incidence in Ukraine in 2014-2019. NCRU data.

When compared to precise 2021 data, "in Ukraine during 2022 there was 22.3% smaller preliminary number of newly registered diseases (by 26,800 cases), total number of cancer-related deaths was 26.3% smaller (by 13,900 cases). In 2022, due to large-scale military operations on the territory of Ukraine, both the functioning of oncology centers and the receipt of information on cancer patients, both newly discovered and those who were already registered by their divisions (regional cancer registries) were hampered or partially interrupted. The largest difference between 2022 preliminary number and precise 2021 number of new cancer cases was in Zaporizhzhia (-44.5%), Luhansk (-89.0%), Mykolaiv (-55.9%), Kharkiv (-82.1%), Kherson (-54.5%) and Kyiv city (-30.9%) - the regions, where incidence has been among the highest in Ukraine" (158). The map with relative difference between 2021 and 2022 number of total new cancer cases is below

(Figure 4.53). This finding reveals the need of careful interpretation of the latest information on cancer epidemiology, as after the collection of the complete data it might be different.

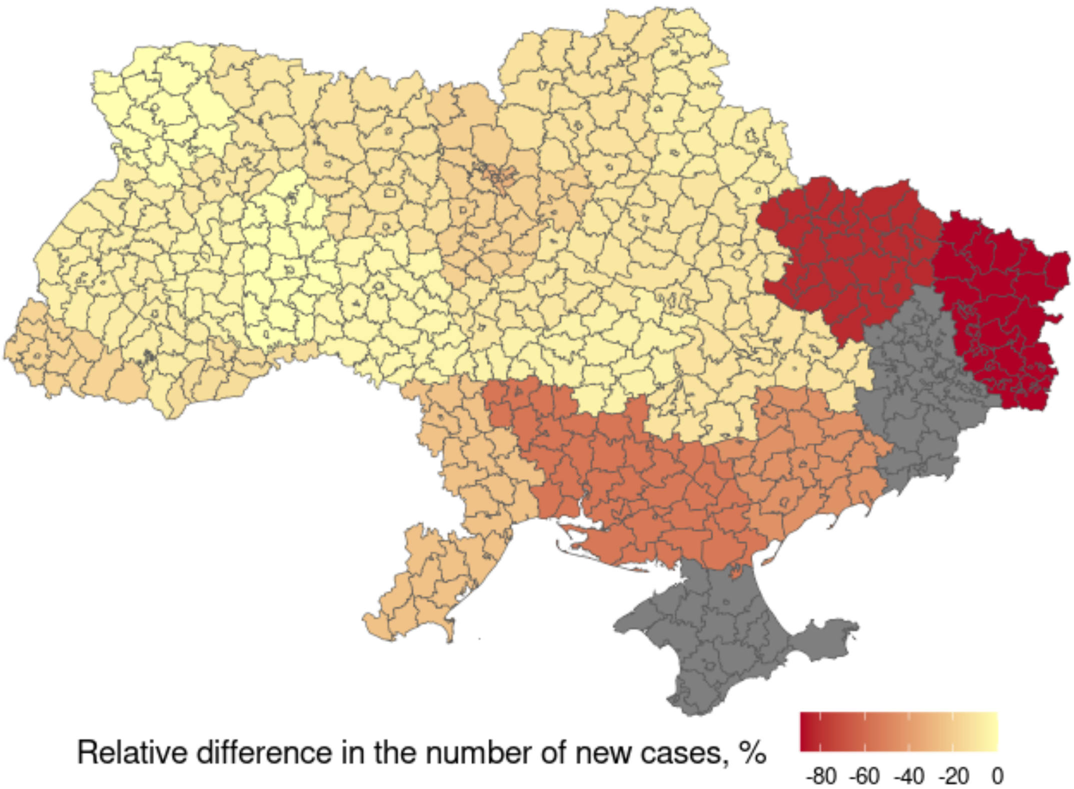


Figure 4.93 Relative difference 2021 and 2022 number of newly registered cancer cases in Ukraine. Adaptation of NCRU data.

Importantly, that the percentage of cancer cases registered in advanced stages in Ukraine in 2022 was 1.4% higher than in 2021. In 2022 the highest percentage of patients with cancer diagnosed in advanced stages was in Kherson and Kharkiv oblasts (32.4%-34.8%) – in the zone of active military actions (158). The higher percentage of cancer cases in advanced stages may reflect the change in priorities for population and decrease in cancer vigilance. As states the 2022 NCRU report, in the frontline-bordering regions patients mostly sought medical care, when symptoms demanded urgent help, i.e. in advanced stages (158). Unfortunately, if the situation does not stabilise in the nearest time, there is a probability that patients, who have asymptomatic and potentially curable forms of cancer today, will seek medical care due to advanced cancer in the future.

The decrease in total cancer incidence in Ukraine in 2024 may stem from the same reasons that in 2014 in Dnipropetrovsk oblast (Figure 4.50), due to the proximity to the battlefield. The abrupt decrease in total incidence in 2020 was related to the lock-down due to COVID-19 pandemic (343). On one hand, the slight gradual increase in cancer incidence in 2014-2019 may be attributed to the improvement of oncological medical services, which will be further confirmed by the increase of oncologists' service utilisation over time. On the other hand, it might be the influence of other factors, like alcohol/smoking, dietary factors, importance of which for the population health was discussed in the literature review. The prevalence of the mentioned risk factors might be in a close relation to the war in the East of Ukraine. Also, according to the Centre of Public Health of Ukraine, there was an increase in prevalence of acute and chronic hepatitis B and C in 2022-2023 (Figure 4.54). Being a risk factor of liver cancer, increase in viral hepatitis incidence is likely to negatively contribute to the total cancer incidence.

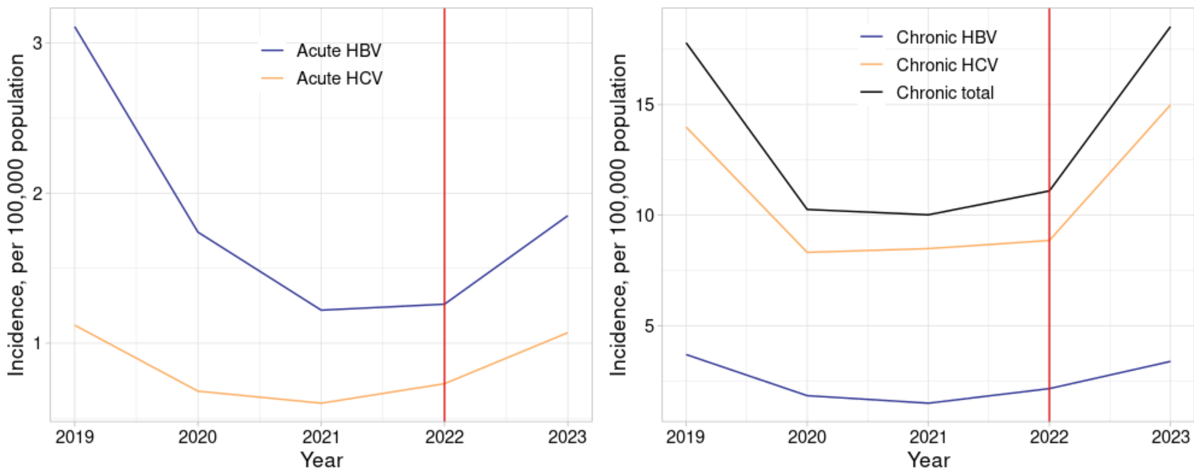


Figure 4.94 Acute and chronic viral viral hepatitis incidence in Ukraine in 2019-2023. Data from the Public Health Centre of Ukraine (344).

Mortality trends from cancer of all localisations in Ukraine and Dnipropetrovsk oblast were decreasing (p=0.01) (Figure 4.55). Annual average decrease in the mortality from 2009 to 2022 was 3.2% in Ukraine and 0.5% in Dnipropetrovsk oblast. In Ukraine mortality trend was relatively stable and decreased in 2021-2022. In Dnipropetrovsk oblast the mortality trend was relatively stable in 2009-2019, with modest increases in 2011-2013 and 2016-2017. In Dnipropetrovsk oblast the mortality was 17.7% higher than in Ukraine (p<0.01), it decreased abruptly by 32.2% in 2020 and rapidly increased by 27.2% in 2021-2022. When analysing the 2021-2022 difference in the number of registered deaths due to cancer, the pattern was the same as for the new cancer cases, but larger in its magnitude (158).

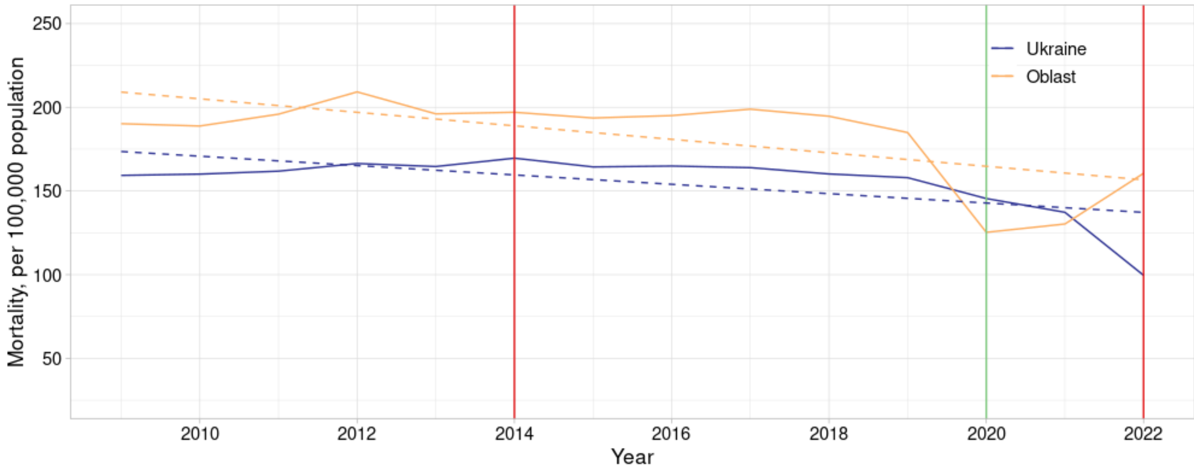


Figure 4.95 Mortality from cancer of all localisations in Dnipropetrovsk oblast and Ukraine in 2009-2022. MoHU data.

Notes: vertical red solid lines - beginnings of military offensives (2014, 2022); vertical green solid line – beginning of COVID-19 pandemic.

Linear trends for mortality from respiratory cancer in Ukraine and Dnipropetrovsk oblast were decreasing ($p<0.01$) (Figure 4.56). In Ukraine mortality from respiratory cancer was stable over time, and decreased in 2020-2022. In Dnipropetrovsk oblast mortality from respiratory cancer was relatively stable in 2009-2019. There was an increase by 3.2% in Dnipropetrovsk oblast in 2017-2019, when compared to 2015-2016, followed by an abrupt decrease in 2020-2021 by 36.8%. The possible reasons for increase in respiratory cancer mortality in 2017-2019 are the same as for the respiratory cancer incidence and were discussed above. Unlike Ukraine, mortality in Dnipropetrovsk oblast increased in 2022. Mortality from respiratory cancer in Dnipropetrovsk oblast was 10.1% higher than in Ukraine, but the difference was statistically non-significant ($p=0.10$).

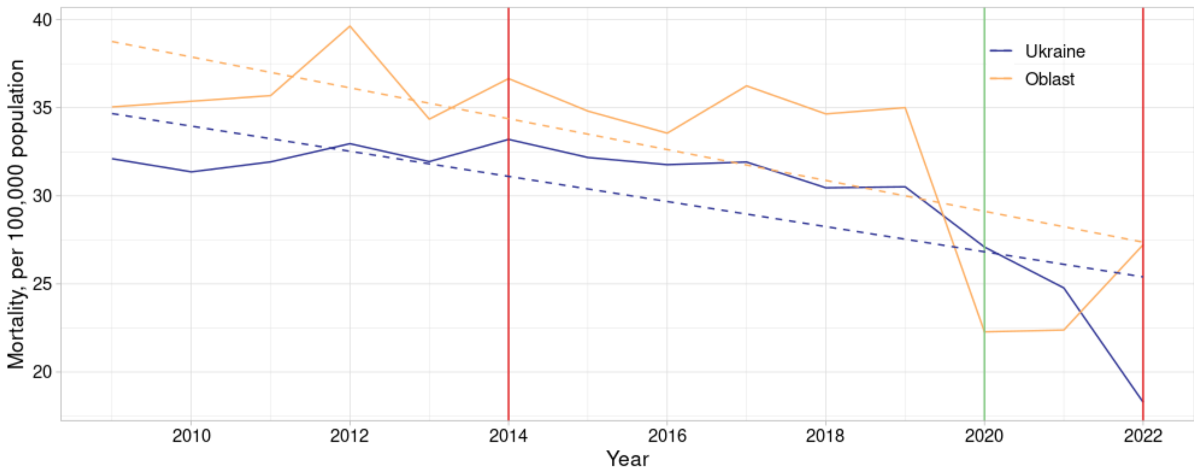


Figure 4.96 Mortality from respiratory (C32-C34) cancer in Dnipropetrovsk oblast and Ukraine in 2009-2022. MoHU data.

Notes: vertical red solid lines - beginnings of military offensives (2014, 2022); vertical green solid line – beginning of COVID-19 pandemic.

Oncologists' service utilisation in Dnipropetrovsk oblast was increasing in 2009-2023 (Figure 4.57). There was a 82.8% increase in the number of visits to oncologists in 2017-2018, when compared to 2016, followed by 13.5% decrease in 2019. Importantly, that the oncologists' service utilisation has not decreased after the beginning of the full-scale Russian miliary invasion in 2022. Given the decrease in the total number of cancer cases in Ukraine and oblast, the increase in the oncologists' service utilisation may be related to the follow-up visits from previously registered patient. The absence of decrease of in the oncologists' service utilisation might be a sign of resilience of Ukrainian medical services that continued their work even in such difficult circumstances.

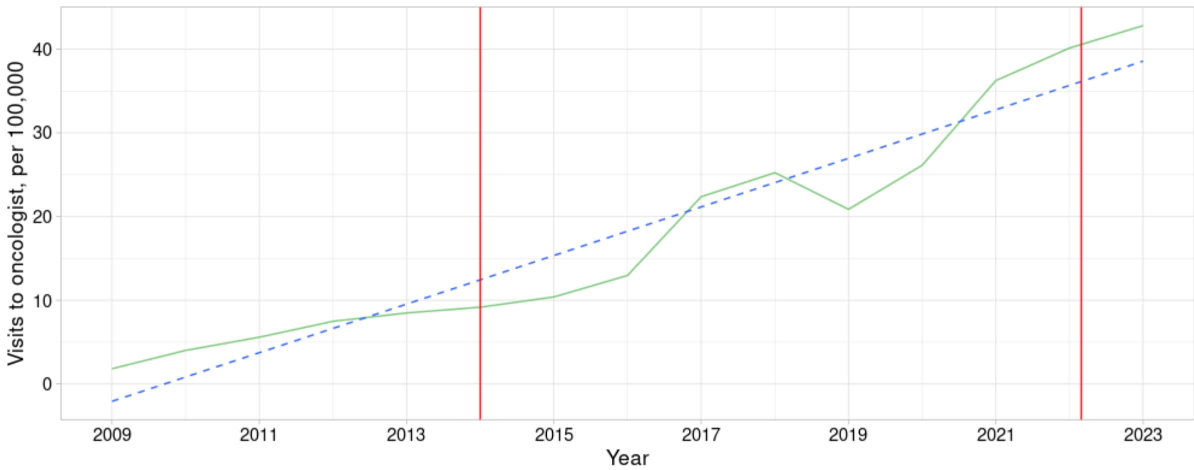


Figure 4.97 Oncologists' services utilisation in Dnipropetrovsk oblast in 2009-2023. Vertical red solid lines - beginnings of military offensives (2014, 2022). DCR data.

In Kryvyi Rih, rank 2, in 2022 cancer incidence was 15.0% than in 2021. Similar situation was in Kryvyi Rih raion (-7.9%) and Kamianske raion (-8.2%, when compared to 2021) (Figure 4.58). In Novomoskovsk raion, rank 4, cancer incidence in 2022 was larger than in 2021 (+27.5%).

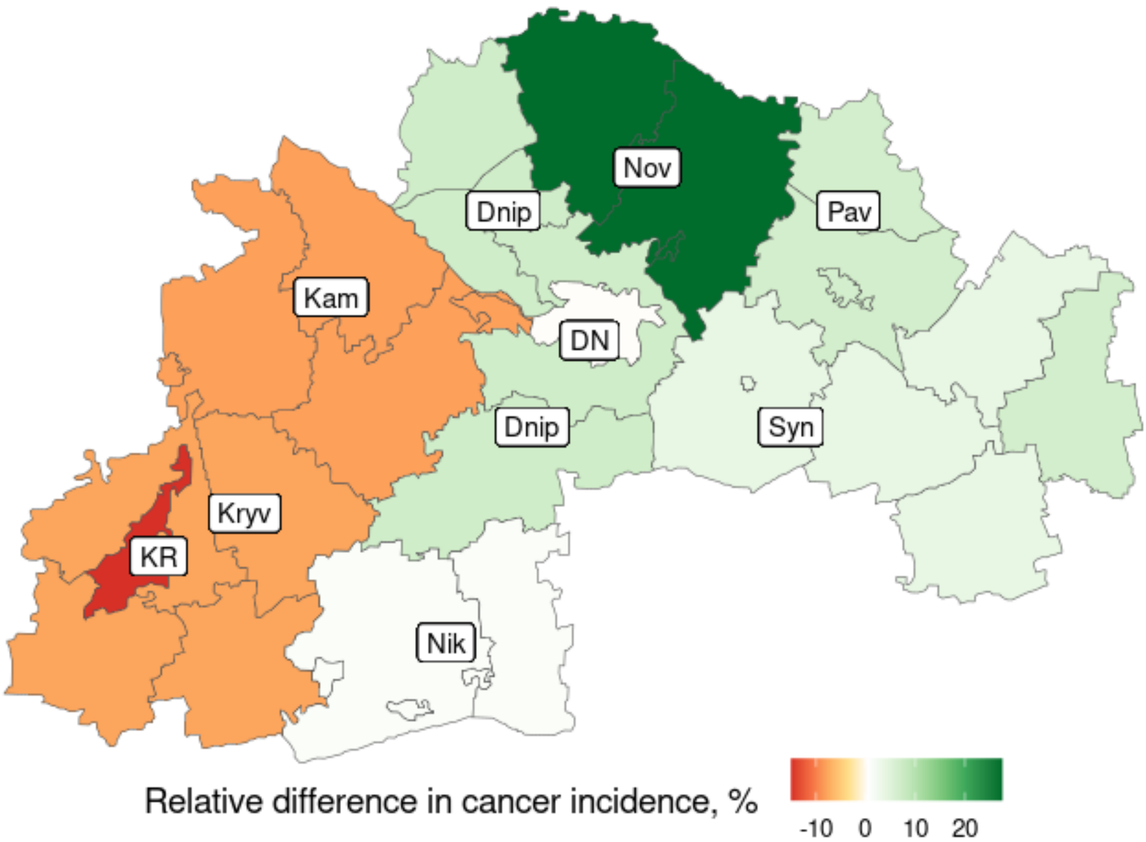


Figure 4.98 Relative difference 2021 and 2022 number of newly registered cancer cases in Dnipropetrovsk oblast. DCR data.

Notes: DN - Dnipro (city), Dnip – Dnipro raion, KR - Kryvyi Rih, Kryv – Kryvyi Rih raion, Nik – Nikopol raion, Nov – Novomoskovsk raion, Pan – Pavlohrad raion, Syn – Synelnykove raion.

The percentage of patients who died within 1 year after the disease onset in 2022 was the largest in the Nikopol and Marhanets area (35.5% (Figure 4.59). At the same time, in 2022 the percentage of patients who died within 1 year after the disease onset was the lowest in Kryvyi Rih (25.9%).

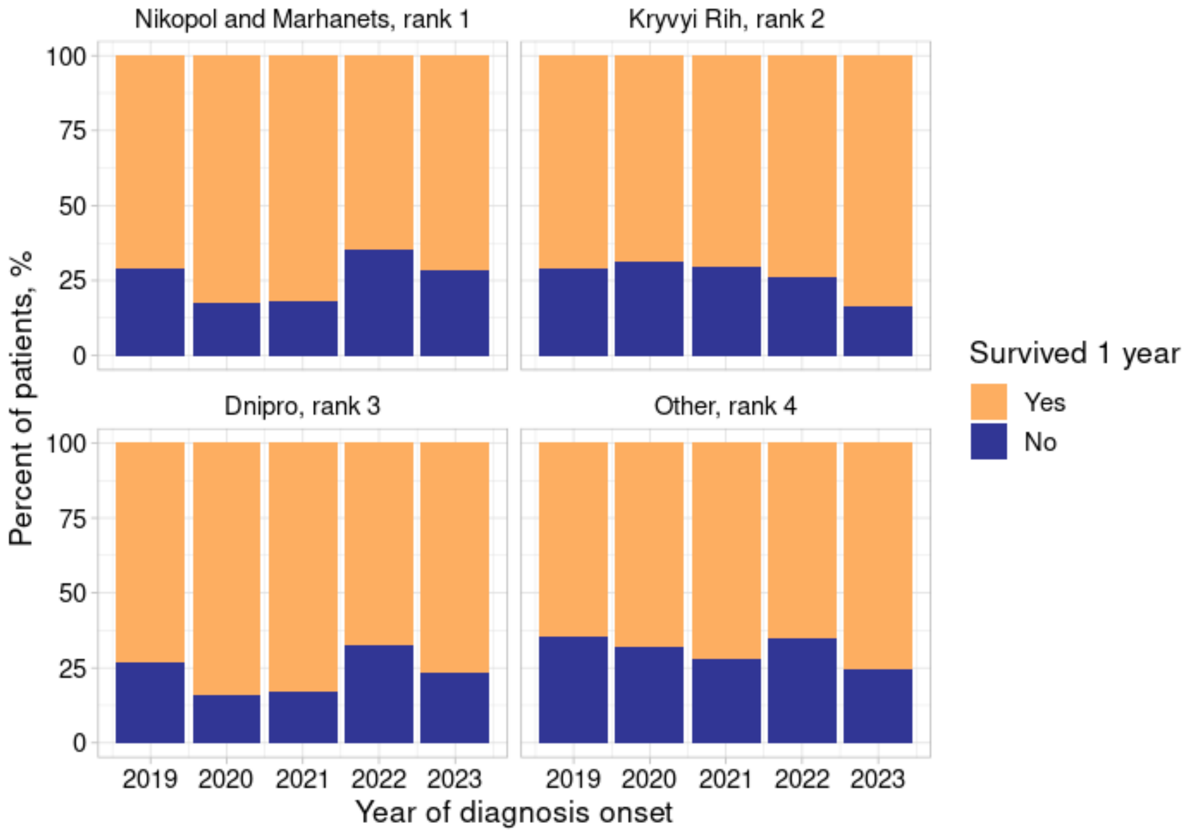


Figure 4.99 The percent of patients who died within 1 year after the disease onset by location in Dnipropetrovsk oblast in 2019-2023 by sex and location. DCR data.

Median survival of patients with cancer in Kryvyi Rih was the highest in the oblast both before and after the full-scale Russian military invasion (Figure 4.60, Table 4.39). Median survival of patients with cancer in Dnipro was the next highest after Kryvyi Rih. In the analysis including the pre-invasion period (2013-2023 and 2019-2023) there was a statistically significant difference in median survival of patients in Dnipro and the rest of locations (Table 4.39). In 2022-2023 the difference in median survival between Dnipro, the Nikopol and Marhanets area and the Other area disappeared. Also, there was a notable decrease in median survival of patients in 2022-2023 in all areas, when compared to other time intervals (Table 4.39). Those changes in patients survival are likely to be related to the negative impact of military actions. HR of death for patients living in more damaged areas was 0.86 (0.83-0.88). However, there was no linear association between degree of area damage and survival in the presented study.

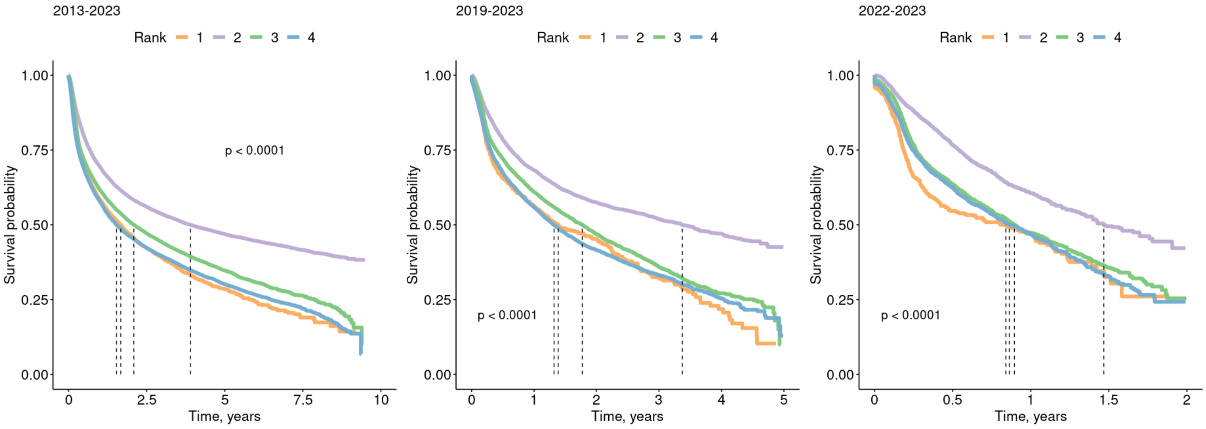


Figure 4.100 Kaplan-Meier curves for survival of the patients with cancer in Dnipropetrovsk oblast in 2013-2023 by rank of war-related damage in 2013-2023, 2019-2023 and 2022-2023 time intervals. DCR data.

Location	2013-2023	2019-2023	2022-2023
Nikopol and Marhanets, rank 1	1.7 (1.5-1.8) yrs	1.4 (1.2-1.8) yrs	0.8 (0.5-1.0) yrs
Kryvyi Rih, rank 2	3.9 (3.7-4.1) yrs	3.4 (3.1-3.6) yrs	1.5 (1.4-1.8) yrs
Dnipro, rank 3	2.1 (2.0-2.2) yrs	1.8 (1.7-1.9) yrs	0.9 (0.8-1.0) yrs
Other, rank 4	1.5 (1.5-1.6) yrs	1.3 (1.2-1.4) yrs	0.9 (0.8-1.0) yrs

Table 4.51 Median survival (95% CI) of the patients with cancer in Dnipropetrovsk oblast in 2013-2023 by rank of war related damage in 2013-2023, 2019-2023 and 2022-2023 time intervals. DCR data.

Patients who were diagnosed with cancer after the beginning of the full-scale Russian military invasion in 2022-2023 had 1.4 years lower median survival (1.0 (1.0-1.1) years), when compared to the patients diagnosed with cancer in 2019-2021 (2.4 (2.3-2.5) years, $p<0.01$) (Figure 4.61). HR of death for the patients diagnosed with cancer in 2022-2023, when compared to the patients diagnosed with cancer in 2019-2021 was 1.54 (1.48-1.60).

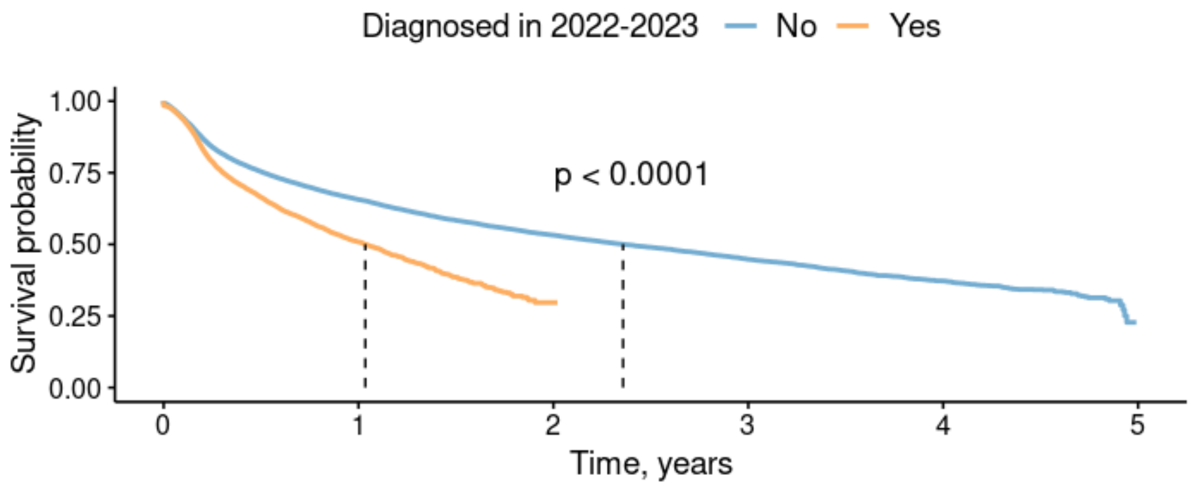


Figure 4.101 Kaplan-Meier curves for survival of the patients with cancer in Dnipropetrovsk oblast in 2019-2023 by the time of cancer diagnosis. DCR data.

Due to the possible bias of the information about the number of population, epidemiological indicators should be interpreted with caution. There were around 7.5 million refugees from Ukraine in Europe in September 2022 (345), part of which were definitely coming from Dnipropetrovsk region. At the same time, Dnipro region has hosted IDPs from neighbouring regions that are now occupied or suffered from the war more heavily. At the moment authors have no access to the information about the number of IDPs and their places of residence, which could shed light on the observed phenomenons.

Limitations

Several limitations should be stated.

1. The full-scale Russian invasion had a serious and devastating impact on multiple spheres of life in Ukraine, including the air monitoring sector. Due to the closure of individual monitoring programs, shortage of personnel (due to migration, mobilisation, occupation, etc), and other reasons, there was a limited availability of data from state air monitoring services. In order to perform the study in the best possible way, the data from citizen air monitoring networks - EcoCity and SaveEcoBot - were used (288,290).
2. Investigation of air pollution in Nikopol and Marhanets after artillery attacks was not performed due to technical complexity of their temporal mapping. They were numerous and their exact timing was impossible to obtain from open sources of information. Moreover, the effect on air pollution of an artillery strike could have been smaller and more difficult to detect than the effect of a missile attack.
3. It is challenging to exclude the effect of random factors (weather conditions, which are accountable for 31.2% of fluctuations in air pollution level (176), direct impact of explosion, etc) on the values coming from citizen air monitoring sensors.
4. The epidemiological indicators which have total number of population should be interpreted with caution due to the limited access to the relevant information about the number of population in Ukraine (287) and Dnipropetrovsk oblast (346) in 2022-2023. Therefore, the data about population of Ukraine and Dnipropetrovsk oblast in 2022-2023 were filled with the 2021 data at end of the year.
5. To analyse the association between air pollution and cancer epidemiology only information about air pollutant emissions by stationary sources was used, because the data on air pollutant emissions by road transport in region-wise representation was available only for a few years. Observations for 2020 and 2021 were severely affected by the COVID-19 pandemic and demonstrated a steep fall in incidence and tremendous distortions in mortality rates that did not fit the previous years, and therefore were excluded from the analysis.

Conclusions:

- At present, based on the analysis of the literature, it is not possible to make definitive conclusions regarding the nature of air pollution resulting from war and its impact on public health, including oncological diseases. Most researchers agree on the deterioration of the ecological situation due to wartime activities, although there is currently no compelling evidence regarding atmospheric air pollution.
- The difference of data regarding air pollution is due to various observation periods, the use of diverse information from different sensors, stations, and organizations, different meteorological conditions, and the analysis of its impact.
- Research studies are primarily focused on the ecological consequences of military actions, with some addressing the impact of war on health, albeit more often addressing the urgent tasks of organizing medical assistance. The potential negative impact of environmental issues in general and air pollution in particular on the population's health is mentioned, but investigating this chain of causality at the current time is often not feasible.
- The impact of air pollution as an environmental risk factor intensified by war cannot be viewed in isolation from the influence of other behavioral and socio-economic determinants. It requires consideration of the influence of stress as a triggering mechanism for health-preserving behaviors among the population and as an independent determinant that significantly affects the population's health status.
- Air pollution in Ukraine before the full-scale Russian military invasion of Ukraine in 2022 was characterised as high, according to the air pollution level. The highest levels of air pollution were registered mostly in the Eastern regions of Ukraine, where is the highest concentration of industries that produce emissions. The main contributors to the air pollution were formaldehyde, phenol, HF, NH_3, NO_2, dust, CO.
- The overall effect of the full-scale Russian military invasion of Ukraine on air pollution is difficult to assess because of different directions of change in levels of different air pollutants. A general not statistically significant downward trend was revealed in the average levels of air pollutants in Ukraine in 2022-2023, which probably was related to the rapid decline in industrial

activity. Russian attacks led to the destruction of around 50% of Ukrainian energy infrastructure and emigration from the country. Despite such tendency to decrease in the average levels of air pollutants in the country, the increase of maximum concentrations of a significant part of pollutants was observed (including cancerogenic substances – soot and formaldehyde) and increase in percentage of locations with the average level of pollutants above MPCd.a. and MPCs.m.

- Atmospheric air of Dnipropetrovsk oblast was characterized by systematic and constant pollution, especially with undifferentiated dust, NO_2, formaldehyde, $PM_{2.5}$ and PM_{10}. The areas of Dnipropetrovsk oblast that were more damaged by the full-scale Russian military invasion in 2022 experienced the smallest degree of $PM_{2.5}$ and PM_{10} levels reduction, and the highest degree of increase in CO and NO_2 levels in 2022-2023, when compared to the pre-invasion time. The observed findings could be attributed to the consequences of the war.
- The signs of the short-term negative impact of military actions on air pollution in Ukraine were identified. A 20% increase in the daily average PM_{10} level in the day of the missile attack may be expected. Missile attacks may potentially lead to the short-term exposure by cancerogenic substances (soot, formaldehyde) of the population.
- The prognosis of air pollution in Ukraine and Dnipropetrovsk oblast is likely to depend on the war intensity, the type and magnitude of the war-related damage, and industrial activity in Ukraine.
- After the beginning of Russian military invasion of Ukraine in 2014, total cancer incidence in Ukraine had increased by 4.2% from 2014 to 2019.
- In 2022, after the beginning of the full-scale Russian military invasion in 2022, the total number of new cancer cases and cancer related deaths in Ukraine was 22.3% and 26.3% lower than in 2021. The percentage of cancer cases diagnosed in advanced stages in 2022 was 1.4% higher than in 2021. The mentioned phenomenons were the most visible in the severely damaged by the war regions of Ukraine, where patients mostly referred to doctors in cases of emergency.
- Median survival of patients in Dnipropetrovsk oblast who were diagnosed with cancer in 2022-2023 was 1.4 years lower than of those, who were

diagnosed with cancer in 2019-2021. HR of death for the patients diagnosed with cancer in 2022-2023, when compared to the patients diagnosed with cancer in 2019-2021 was 1.54 (1.48-1.60).

- Probably, an increase in cancer incidence and mortality in Ukraine in ~3-5 years perspective can be expected, especially in frontline-bordering regions of Ukraine.
- Our findings justify the need for more rigorous longitudinal cohort studies of the Ukrainian population during and immediately after the conflict, aligning with the views of other researchers.
- Thorough monitoring of pollution and a focus on sustainable practices in industrial and energy production should play an important role in the post-war reconstruction period.

References

1. Angurets O, Khazan P, Kolesnikova K, Kushch M, Černochova M, Havránek M. Environmental consequences of Russian war in Ukraine. 2023. 80 p.
2. World Health Organization. World Health Organization - Regional Office for the Eastern Mediterranean. [cited 2023 Dec 27]. Air pollution. Available from: http://www.emro.who.int/noncommunicable-diseases/publications/air-pollution.html
3. Turner MC, Andersen ZJ, Baccarelli A, Diver WR, Gapstur SM, Pope CA, et al. Outdoor Air Pollution and Cancer: An Overview of the Current Evidence and Public Health Recommendations. CA Cancer J Clin. 2020 Aug 25;10.3322/caac.21632.
4. Wei Y, Danesh Yazdi M, Ma T, Castro E, Liu CS, Qiu X, et al. Additive effects of 10-year exposures to PM2.5 and NO2 and primary cancer incidence in American older adults. Environ Epidemiol. 2023 Aug;7(4):e265.
5. Забруднення повітря [Internet]. 2024 [cited 2024 Mar 7]. Available from: https://www.healthdata.org/research-analysis/health-risks-issues/air-pollution
6. State of Global Air Report 2020 | State of Global Air [Internet]. 2024 [cited 2024 Mar 7]. Available from: https://www.stateofglobalair.org/resources/report/state-global-air-report-2020
7. Institute for Health Metrics and Evaluation [Internet]. 2024 [cited 2024 Mar 6]. GBD Results. Available from: https://vizhub.healthdata.org/gbd-results
8. McDuffie E, Martin R, Yin H, Brauer M. Global Burden of Disease from Major Air Pollution Sources (GBD MAPS): A Global Approach. Res Rep Health Eff Inst. 2021 Dec 1;2021:210.
9. The war in Ukraine is an environmental catastrophe | The Union [Internet]. 2022 [cited 2024 Mar 15]. Available from: https://theunion.org/news/the-war-in-ukraine-is-an-environmental-catastrophe
10. Dong Y, Kang H, Peng R, Song K, Guo Q, Guan H, et al. Global, Regional, and National Burden of Low Bone Mineral Density From 1990 to 2019: Results From the Global Burden of Disease Study 2019. Front Endocrinol. 2022 May 24;13:870905.

11. Ukraine | Institute for Health Metrics and Evaluation [Internet]. 2024 [cited 2024 Mar 14]. Available from: https://www.healthdata.org/research-analysis/health-by-location/profiles/ukraine

12. McDuffie EE, Smith SJ, O'Rourke P, Tibrewal K, Venkataraman C, Marais EA, et al. A global anthropogenic emission inventory of atmospheric pollutants from sector- and fuel-specific sources (1970–2017): an application of the Community Emissions Data System (CEDS). Earth Syst Sci Data. 2020 Dec 15;12(4):3413–42.

13. Air Quality and Health in Serbia | State of Global Air [Internet]. 2024 [cited 2024 Mar 7]. Available from: https://www.stateofglobalair.org/resources/report/air-quality-and-health-serbia

14. Trends in Air Quality and Health in Bulgaria | State of Global Air [Internet]. 2024 [cited 2024 Mar 7]. Available from: https://www.stateofglobalair.org/resources/report/trends-air-quality-and-health-bulgaria

15. Trends in Air Quality and Health in Southeast Europe | State of Global Air [Internet]. 2024 [cited 2024 Mar 7]. Available from: https://www.stateofglobalair.org/resources/report/trends-air-quality-and-health-southeast-europe

16. Ukraine conflict environmental briefing: Fossil fuel infrastructure [Internet]. CEOBS. 2022 [cited 2024 Mar 29]. Available from: https://ceobs.org/ukraine-conflict-environmental-briefing-fossil-fuel-infrastructure/

17. Modelled exposure of PM air pollution exposure [Internet]. 2024 [cited 2024 Apr 4]. Available from: https://www.who.int/data/gho/data/themes/air-pollution/modelled-exposure-of-pm-air-pollution-exposure

18. IQAir | Перший за якістю повітря [Internet]. 2024 [cited 2024 Mar 7]. Available from: https://www.iqair.com/world-air-quality-report

19. World Air Quality Index (AQI) Ranking | IQAir [Internet]. 2024 [cited 2024 Mar 8]. Available from: https://www.iqair.com/world-air-quality-ranking

20. WHO ambient air quality database, 2022 update: status report [Internet]. 2024 [cited 2024 Mar 9]. Available from: https://www.who.int/publications-

detail-redirect/9789240047693

21. Gu Y, Henze DK, Nawaz MO, Cao H, Wagner UJ. Sources of PM2.5-Associated Health Risks in Europe and Corresponding Emission-Induced Changes During 2005–2015. GeoHealth. 2023 Mar 20;7(3):e2022GH000767.

22. Національні доповіді про стан навколишнього природного середовища в Україні – Міністерство захисту довкілля та природних ресурсів України [Internet]. [cited 2024 Mar 24]. Available from: https://mepr.gov.ua/diyalnist/napryamky/ekologichnyj-monitoryng/natsionalni-dopovidi-pro-stan-navkolyshnogo-pryrodnogo-seredovyshha-v-ukrayini/

23. Popov O, Iatsyshyn A, Kovach V, Artemchuk V, Kameneva I, Taraduda D, et al. Risk Assessment for the Population of Kyiv, Ukraine as a Result of Atmospheric Air Pollution. J Health Pollut. 2020 Jan 22;10(25):200303.

24. Savenets M, Osadchyi V, Komisar K, Zhemera N, Oreshchenko A. Remotely visible impacts on air quality after a year-round full-scale Russian invasion of Ukraine. Atmospheric Pollut Res. 2023 Nov 1;14(11):101912.

25. Centre for Research on Energy and Clean Air [Internet]. 2021 [cited 2024 Mar 29]. Health Impacts of Coal Power Plant Emissions in Ukraine. Available from: https://energyandcleanair.org/publication/health-impacts-of-coal-power-plant-emissions-in-ukraine/

26. Екологічний рахунок з охорони атмосферного повітря [Internet]. 2024 [cited 2024 Mar 29]. Available from: https://www.ukrstat.gov.ua/operativ/operativ2020/ns/er_vonps/arh_er_vonps.htm

27. Офіційний вебпортал парламенту України [Internet]. 2024 [cited 2024 Mar 31]. Про охорону атмосферного повітря. Available from: https://zakon.rada.gov.ua/go/2707-12

28. Офіційний вебпортал парламенту України [Internet]. 2024 [cited 2024 Mar 31]. Про охорону навколишнього природного середовища. Available from: https://zakon.rada.gov.ua/go/1264-12

29. Офіційний вебпортал парламенту України [Internet]. 2024 [cited 2024 Mar 31]. Про систему громадського здоров'я. Available from: https://zakon.rada.gov.ua/go/2573-20

30. The environmental consequences of the war against Ukraine: Preliminary 12-month assessment, summary and recommendations [Internet]. CEOBS. 2024 [cited 2024 Mar 12]. Available from: https://ceobs.org/the-environmental-consequences-of-the-war-against-ukraine-preliminary-12-month-assessment-summary-and-recommendations/

31. Міністерство захисту довкілля та природних ресурсів України – офіційний сайт [Internet]. [cited 2023 Dec 27]. Available from: https://mepr.gov.ua/

32. ЕкоСистема - національна онлайн-платформа, яка містить актуальну інформацію про стан довкілля [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://eco.gov.ua

33. е-Повітря [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://eco.gov.ua/categories/e-povitrya

34. ЕкоЗагроза [Internet]. 2024 [cited 2024 Mar 12]. ЕкоЗагроза. Available from: https://ecozagroza.gov.ua/

35. Ecodozor [Internet]. 2024 [cited 2024 Mar 10]. Available from: https://ecodozor.org/index.php?lang=en

36. Hryhorczuk D, Levy BS, Prodanchuk M, Kravchuk O, Bubalo N, Hryhorczuk A, et al. The environmental health impacts of Russia's war on Ukraine. J Occup Med Toxicol. 2024 Jan 5;19(1):1.

37. УкрГМЦ [Internet]. 2024 [cited 2024 Mar 31]. Український гідрометеорологічний центр Державної служби України з надзвичайних ситуацій. Available from: https://www.meteo.gov.ua

38. Набори даних | Державна служба статистики України [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://stat.gov.ua/uk/datasets?f%5B0%5D=ds_topics%3A198

39. Eco-City [Internet]. [cited 2024 Feb 1]. Available from: https://eco-city.org.ua/

40. ЛУН Місто AIR. Про проєкт [Internet]. 2024 [cited 2024 Mar 17]. Available from: https://misto.lun.ua/air-about-for-ua

41. Єдина в України екологічна система - SaveEcoBot [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://www.saveecobot.com

42. Ecoaction [Internet]. 2023 [cited 2024 Mar 31]. Home 2022. Available from:

https://en.ecoaction.org.ua/

43. Environment People Law [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://epl.org.ua/en/

44. Paquets Arpège - Résolution 0,25° - Data Europa EU [Internet]. 2024 [cited 2024 Mar 15]. Available from: https://data.europa.eu/data/datasets/65bd13e557b26b467363b521?locale=en

45. Ukraine Air Quality Index (AQI) and Air Pollution information | IQAir [Internet]. 2024 [cited 2024 Mar 29]. Available from: https://www.iqair.com/ukraine

46. SaveDnipro [Internet]. 2023 [cited 2024 Feb 2]. Звіт про дослідження 'Якість атмосферного повітря в Україні до і під час повномасштабного вторгнення'. Available from: https://www.savednipro.org/research_2023/

47. Air pollution data portal [Internet]. 2024 [cited 2024 Mar 15]. Available from: https://www.who.int/data/gho/data/themes/air-pollution

48. WHO European health information at your fingertips. [Internet]. 2024 [cited 2024 Mar 15]. Available from: https://gateway.euro.who.int/en/datasets/enhis/

49. European Environment Agency. Analysis and data [Internet]. 2024 [cited 2024 Mar 15]. Available from: https://www.eea.europa.eu/en/analysis

50. Брудне небо над головою: Законодавство у сфері охорони атмосферного повітря в Україні та ЄС – Екодія [Internet]. 2020 [cited 2024 Mar 31]. Available from: https://ecoaction.org.ua/brudne-nebo-nad-holovoiu.html

51. Шкідливі викиди в атмосферне повітря . Відповідальність за порушення законодавства у галузі охорони атмосферного повітря — WikiLegalAid [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://wiki.legalaid.gov.ua/index.php/%D0%A8%D0%BA%D1%96%D0%B4%D0%BB%D0%B8%D0%B2%D1%96_%D0%B2%D0%B8%D0%BA%D0%B8%D0%B4%D0%B8_%D0%B2_%D0%B0%D1%82%D0%BC%D0%BE%D1%81%D1%84%D0%B5%D1%80%D0%BD%D0%B5_%D0%BF%D0%BE%D0%B2%D1%96%D1%82%D1%80%D1%8F_._%D0%92%D1%96%D0%B4%D0%BF%D0%BE%D0%B2%D1%96%D0%B4%D0%B0%D0%BB%D1%8C%D0%BD%D1%96%D1%81%D1%82%D1%8C_%D0%B7%D0%B0_%D0%BF%D0%BE%D1%80%D1%83%D1%88%D0%B5%D0%BD%D0%BD%D1%8F_%D0%B7%D0%B0%D0%BA%D0

%BE%D0%BD%D0%BE%D0%B4%D0%B0%D0%B2%D1%81%D1%82%D0%B2%D0%B0_%D1%83_%D0%B3%D0%B0%D0%BB%D1%83%D0%B7%D1%96_%D0%BE%D1%85%D0%BE%D1%80%D0%BE%D0%BD%D0%B8_%D0%B0%D1%82%D0%BC%D0%BE%D1%81%D1%84%D0%B5%D1%80%D0%BD%D0%BE%D0%B3%D0%BE_%D0%BF%D0%BE%D0%B2%D1%96%D1%82%D1%80%D1%8F

52. Державна екологічна інспекція України [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://dei.gov.ua/post/2321

53. Paper: Assessing environmental damage in Ukraine [Internet]. CEOBS. 2024 [cited 2024 Mar 10]. Available from: https://ceobs.org/paper-assessing-environmental-damage-in-ukraine/

54. Environmental Assessment and Recovery Priorities for Eastern Ukraine [Internet]. 2024 [cited 2024 Mar 12]. Available from: https://www.osce.org/project-coordinator-in-ukraine/362566

55. United Nations. Department of Economic and Social Affairs. THE 17 GOALS | Sustainable Development [Internet]. 2024 [cited 2024 Apr 4]. Available from: https://sdgs.un.org/goals

56. UNDP [Internet]. 2024 [cited 2024 Apr 4]. Goal 3: Good health and well-being | Цілі сталого розвитку | United Nations Development Programme. Available from: https://www.undp.org/uk/ukraine/tsili-staloho-rozvytku/good-health

57. Оцінка прогресу досягнення ЦСР в Україні [Internet]. 2024 [cited 2024 Apr 4]. Available from: https://ukrstat.gov.ua/csr_prezent/2.htm

58. Progress Assessment Graphs [Internet]. 2024 [cited 2024 Apr 4]. Available from: https://ukrstat.gov.ua/csr_prezent/2022_new/ukr4_BOM_final/index.html#

59. Sustainable Development Goals Voluntary National Review: Ukraine | United Nations in Ukraine [Internet]. 2024 [cited 2024 Apr 4]. Available from: https://ukraine.un.org/en/151096-sustainable-development-goals-voluntary-national-review-ukraine, https://ukraine.un.org/en/151096-sustainable-development-goals-voluntary-national-review-ukraine

60. Офіційний вебпортал парламенту України [Internet]. 2024 [cited 2024 Mar

31]. Про затвердження Порядку запровадження обов’язкових автоматизованих систем контролю викидів забруднюючих речовин. Available from: https://zakon.rada.gov.ua/go/272-2023-%D0%BF

61. Урядовий портал. Єдиний веб-портал органів виконавчої влади України. Кабінет Міністрів України - В Україні запроваджують моніторинг викидів «на трубі» для промислових підприємств [Internet]. 2024 [cited 2024 Mar 31]. Available from: https://www.kmu.gov.ua/news/v-ukraini-zaprovadzhuiut-monitorynh-vykydiv-na-trubi-dlia-promyslovykh-pidpryiemstv

62. Офіційний вебпортал парламенту України [Internet]. 2024 [cited 2024 Mar 31]. Про внесення змін до деяких законодавчих актів України щодо державної системи моніторингу довкілля, інформації про стан довкілля (екологічної інформації) та інформаційного забезпечення управління у сфері довкілля. Available from: https://zakon.rada.gov.ua/go/2973-20

63. Garry S, Checchi F. Armed conflict and public health: into the 21st century. J Public Health. 2020 Aug 18;42(3):e287–98.

64. OECD [Internet]. 2024 [cited 2024 Apr 1]. Environmental impacts of the war in Ukraine and prospects for a green reconstruction. Available from: https://www.oecd.org/ukraine-hub/policy-responses/environmental-impacts-of-the-war-in-ukraine-and-prospects-for-a-green-reconstruction-9e86d691/#boxsection-d1e252

65. Brake TM, Razum O. Prevention of War: A Scoping Review on Primary Preventive Measures in Public Health. Public Health Rev. 2024 Jan 4;44:1606201.

66. Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and Health Impacts of Air Pollution: A Review. Front Public Health [Internet]. 2020 Feb 20 [cited 2024 Mar 19];8. Available from: https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2020.00014/full

67. Атмосферні канцерогени та рак під час війни в Україні [Internet]. 2024 [cited 2024 Feb 27]. Available from: https://health-ua.com/article/72757-atmosfern-kantcerogeni-tarak-pdchas-vjni-vukran

68. Hopke PK. Contemporary threats and air pollution. Atmos Environ. 2009 Jan

1;43(1):87–93.

69. Rothschild R. Détente from the Air: Monitoring Air Pollution during the Cold War. Technol Cult. 2016;57(4):831–65.

70. Melas D, Zerefos C, Rapsomanikis S, Tsangas N, Alexandropoulou A. The war in Kosovo: Evidence of pollution transport in the Balkans during operation 'Allied Force'. Environ Sci Pollut Res Int. 2000 Feb 1;7:97–104.

71. Vukmirović ZB, Unkašević M, Lazić L, Tošić I. Regional air pollution caused by a simultaneous destruction of major industrial sources in a war zone. The case of April Serbia in 1999. Atmos Environ. 2001 May 1;35(15):2773–82.

72. Rapsomanikis S, Zerefos C, Melas D, Tsangas N. Transport of Toxic Organic Aerosol Pollutants from Yugoslavia to Greece during the Operation "Allied Force". Environ Technol. 2002 Oct 1;23(10):1119–25.

73. Unkasević M, Vukmirović Z, Tosić I, Lazić L. Effects of uncontrolled particulate matter release on precipitation under warfare conditions. Environ Sci Pollut Res Int. 2003;10(2):89–97.

74. Lelieveld J, Beirle S, Hörmann C, Stenchikov G, Wagner T. Abrupt recent trend changes in atmospheric nitrogen dioxide over the Middle East. Sci Adv. 2015 Aug 21;1(7):e1500498.

75. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide [Internet]. 2024 [cited 2024 Mar 15]. Available from: https://www.who.int/publications-detail-redirect/9789240034228

76. Health and Energy Platform of Action report 2020-2022: building connections for better health [Internet]. 2024 [cited 2024 Mar 19]. Available from: https://www.who.int/publications-detail-redirect/9789240071650

77. Compendium of WHO and other UN guidance on health and environment: version with International Classification of Health Intervention (ICHI) codes [Internet]. 2024 [cited 2024 Mar 19]. Available from: https://www.who.int/publications-detail-redirect/9789240088061

78. Ghorani-Azam A, Riahi-Zanjani B, Balali-Mood M. Effects of air pollution on human health and practical measures for prevention in Iran. J Res Med Sci Off J Isfahan Univ Med Sci. 2016 Sep 1;21:65.

79. Brunekreef B, Beelen R, Hoek G, Schouten L, Bausch-Goldbohm S, Fischer P, et al. Effects of long-term exposure to traffic-related air pollution on respiratory and cardiovascular mortality in the Netherlands: the NLCS-AIR study. Res Rep Health Eff Inst. 2009 Mar;(139):5–71; discussion 73-89.

80. Biggeri A, Bellini P, Terracini B, Italian MISA Group. [Meta-analysis of the Italian studies on short-term effects of air pollution]. Epidemiol Prev. 2001;25(2 Suppl):1–71.

81. Short-Term Effects of Atmospheric Pollution on Daily Mortality and Their Modification by Increased Temperatures Associated with a Climatic Change Scenario in Northern Mexico - PMC [Internet]. 2024 [cited 2024 Mar 19]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7763210/

82. Romieu I, Gouveia N, Cifuentes LA, de Leon AP, Junger W, Vera J, et al. Multicity study of air pollution and mortality in Latin America (the ESCALA study). Res Rep Health Eff Inst. 2012 Oct;(171):5–86.

83. Colucci ME, Veronesi L, Roveda AM, Marangio E, Sansebastiano G. [Particulate matter (PM10) air pollution, daily mortality, and hospital admissions: recent findings]. Ig E Sanita Pubblica. 2006;62(3):289–304.

84. Canto MV, Guxens M, García-Altés A, López MJ, Marí-Dell'Olmo M, García-Pérez J, et al. Air Pollution and Birth Outcomes: Health Impact and Economic Value Assessment in Spain. Int J Environ Res Public Health. 2023 Jan 27;20(3):2290.

85. Leirião L, de Oliveira M, Martins T, Miraglia S. A Multi-Pollutant and Meteorological Analysis of Cardiorespiratory Mortality among the Elderly in São Paulo, Brazil—An Artificial Neural Networks Approach. Int J Environ Res Public Health. 2023 Apr 11;20(8):5458.

86. Lipfert FW. Long-term associations of morbidity with air pollution: A catalog and synthesis. J Air Waste Manag Assoc 1995. 2018 Jan;68(1):12–28.

87. Health effects of outdoor air pollution. Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. Am J Respir Crit Care Med. 1996 Jan;153(1):3–50.

88. Schwela D. Air Pollution and Health in Urban Areas [Internet]. 2024 [cited 2024 Mar 19]. Available from:

https://www.degruyter.com/document/doi/10.1515/reveh.2000.15.1-2.13/html

89. Wong CM, Vichit-Vadakan N, Vajanapoom N, Ostro B, Thach TQ, Chau PYK, et al. Part 5. Public health and air pollution in Asia (PAPA): a combined analysis of four studies of air pollution and mortality. Res Rep Health Eff Inst. 2010 Nov;(154):377–418.

90. Orians GH, Pfeiffer EW. Ecological Effects of the War in Vietnam | Science. Science. 1 May;168(3931):554–554.

91. Formoli TA. Impacts of the Afghan–Soviet War on Afghanistan's Environment. Environ Conserv. 1995 Apr;22(1):66–9.

92. Bakrač S, Klem E, Milanović M. Assessment of ecological damage from the NATO bombing of the Republic of Serbia in 1999. Vojno Delo. 2018;70(4):71–81.

93. Hadei M, Shahsavani A, Hopke PK, Naseri S, Yazdanbakhsh A, Sadani M, et al. A systematic review and meta-analysis of human biomonitoring studies on exposure to environmental pollutants in Iran. Ecotoxicol Environ Saf. 2021 Apr 1;212:111986.

94. Sowers J, Weinthal E. Health and Environmental Tolls of Protracted Conflicts in the Middle East and North Africa. Curr Hist. 2021 Dec 1;120(830):339–45.

95. Brimblecombe P. War and Urban-Industrial Air Pollution in the UK and the US. In: Laakkonen S, McNeill JR, Tucker RP, Vuorisalo T, editors. The Resilient City in World War II: Urban Environmental Histories [Internet]. Cham: Springer International Publishing; 2019 [cited 2024 Mar 19]. p. 69–80. Available from: https://doi.org/10.1007/978-3-030-17439-2_4

96. White RH, Stineman CH, Symons JM, Breysse PN, Kim SR, Bell ML, et al. Premature Mortality in the Kingdom of Saudi Arabia Associated with Particulate Matter Air Pollution from the 1991 Gulf War. Hum Ecol Risk Assess Int J. 2008 Jul 29;14(4):645–64.

97. Al-Khalaf B. Pilot study: The onset of asthma among the Kuwaiti population during the burning of oil wells after the Gulf War. Environ Int. 1998 Jan 1;24(1):221–5.

98. Zalakeviciute R, Mejia D, Alvarez H, Bermeo X, Bonilla-Bedoya S, Rybarczyk Y, et al. War Impact on Air Quality in Ukraine. Sustainability. 2022

Jan;14(21):13832.

99. Swiss TPH [Internet]. 2024 [cited 2024 Apr 5]. HealthEffects. Available from: https://www.swisstph.ch/en/projects/ludok/healtheffects

100. Chen J, Hoek G. Long-term exposure to PM and all-cause and cause-specific mortality: A systematic review and meta-analysis. Environ Int. 2020 Oct 1;143:105974.

101. Huangfu P, Atkinson R. Long-term exposure to NO2 and O3 and all-cause and respiratory mortality: A systematic review and meta-analysis. Environ Int. 2020 Nov 1;144:105998.

102. Orellano P, Reynoso J, Quaranta N, Bardach A, Ciapponi A. Short-term exposure to particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), and ozone (O3) and all-cause and cause-specific mortality: Systematic review and *meta*-analysis. Environ Int. 2020 Sep 1;142:105876.

103. Orellano P, Reynoso J, Quaranta N. Short-term exposure to sulphur dioxide (SO2) and all-cause and respiratory mortality: A systematic review and meta-analysis. Environ Int. 2021 May 1;150:106434.

104. Zheng X yan, Orellano P, Lin H liang, Jiang M, Guan W jie. Short-term exposure to ozone, nitrogen dioxide, and sulphur dioxide and emergency department visits and hospital admissions due to asthma: A systematic review and meta-analysis. Environ Int. 2021 May 1;150:106435.

105. Lee KK, Spath N, Miller MR, Mills NL, Shah ASV. Short-term exposure to carbon monoxide and myocardial infarction: *A systematic review and meta-analysis*. Environ Int. 2020 Oct 1;143:105901.

106. Badida P, Krishnamurthy A, Jayaprakash J. Meta analysis of health effects of ambient air pollution exposure in low- and middle-income countries. Environ Res. 2023 Jan 1;216:114604.

107. Liu C, Jia F, Ji M, Qu G, Ye C, Cheng J, et al. The Effect of Short-Term Air Pollutants Exposure on Daily Mortality Among Elderly Individuals in China: A Systematic Review and Meta-Analysis. Water Air Soil Pollut. 2023 Aug 9;234(8):541.

108. Kan H, Chen B, Zhao N, London SJ, Song G, Chen G, et al. Part 1. A time-series study of ambient air pollution and daily mortality in Shanghai, China. Res Rep Health Eff Inst. 2010 Nov;(154):17–78.

109. Cui P, Huang Y, Han J, Song F, Chen K. Ambient particulate matter and lung cancer incidence and mortality: a meta-analysis of prospective studies. Eur J Public Health. 2015 Apr 1;25(2):324–9.

110. Wang W, Meng L, Hu Z, Yuan X, Zeng W, Li K, et al. The association between outdoor air pollution and lung cancer risk in seven eastern metropolises of China: Trends in 2006-2014 and sex differences. Front Oncol. 2022 Sep 29;12:939564.

111. Lipfert FW, Wyzga RE. Longitudinal relationships between lung cancer mortality rates, smoking, and ambient air quality: a comprehensive review and analysis. Crit Rev Toxicol. 2019 Oct 21;49(9):790–818.

112. Fu J, Jiang D, Lin G, Liu K, Wang Q. An ecological analysis of PM2.5 concentrations and lung cancer mortality rates in China. BMJ Open. 2015 Nov 24;5(11):e009452.

113. Andersen ZJ, de Nazelle A, Mendez MA, Garcia-Aymerich J, Hertel O, Tjønneland A, et al. A Study of the Combined Effects of Physical Activity and Air Pollution on Mortality in Elderly Urban Residents: The Danish Diet, Cancer, and Health Cohort. Environ Health Perspect. 2015 Jun;123(6):557–63.

114. Hvidtfeldt UA, Sørensen M, Geels C, Ketzel M, Khan J, Tjønneland A, et al. Long-term residential exposure to PM2.5, PM10, black carbon, NO2, and ozone and mortality in a Danish cohort. Environ Int. 2019 Feb 1;123:265–72.

115. Wang S, Zhang Y, Li X, Zhao J, Zhang N, Guo Y, et al. Effect of short-term exposure to ambient air pollutants on non-accidental mortality in emergency department visits: a time-series study. Front Public Health [Internet]. 2023 Jun 30 [cited 2024 Mar 27];11. Available from: https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2023.1208514/full

116. HEI Collaborative Working Group on Air Pollution, Poverty, and Health in Ho Chi Minh City, Le TG, Ngo L, Mehta S, Do VD, Thach TQ, et al. Effects of short-term exposure to air pollution on hospital admissions of young children for acute lower respiratory infections in Ho Chi Minh City, Vietnam. Res Rep Health Eff Inst. 2012 Jun;(169):5–72; discussion 73-83.

117. Zhang W, Ling J, Zhang R, Dong J, Zhang L, Chen R, et al. Short-term effects

of air pollution on hospitalization for acute lower respiratory infections in children: a time-series analysis study from Lanzhou, China. BMC Public Health. 2023 Aug 25;23(1):1629.

118. Zhang F, Zhang H, Wu C, Zhang M, Feng H, Li D, et al. Acute effects of ambient air pollution on clinic visits of college students for upper respiratory tract infection in Wuhan, China. Environ Sci Pollut Res. 2021 Jun 1;28(23):29820–30.

119. Dong J, You J, Wang J, Bao H. Association between short-term ambient air pollution and outpatient visits for acute exacerbation of chronic obstructive pulmonary disease in Lanzhou, 2013–19. Environ Geochem Health. 2023 May 1;45(5):2495–509.

120. Orellano P, Reynoso J, Quaranta N. Effects of air pollution on restricted activity days: systematic review and meta-analysis. Environ Health. 2023 Mar 30;22(1):31.

121. Canada H. Health Impacts of Air Pollution in Canada 2021 Report [Internet]. 2021 [cited 2024 Mar 21]. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/health-impacts-air-pollution-2021.html

122. Chen X, Zhang L wen, Huang J ju, Song F ju, Zhang L ping, Qian Z min, et al. Long-term exposure to urban air pollution and lung cancer mortality: A 12-year cohort study in Northern China. Sci Total Environ. 2016 Nov 15;571:855–61.

123. Lim EH, Franklin P, Trevenen ML, Nieuwenhuijsen M, Yeap BB, Almeida OP, et al. Exposure to low-level ambient air pollution and the relationship with lung and bladder cancer in older men, in Perth, Western Australia. Br J Cancer. 2023 Oct;129(9):1500–9.

124. Dominski FH, Lorenzetti Branco JH, Buonanno G, Stabile L, Gameiro da Silva M, Andrade A. Effects of air pollution on health: A mapping review of systematic reviews and meta-analyses. Environ Res. 2021 Oct 1;201:111487.

125. Wu K, Ho HC, Su H, Huang C, Zheng H, Zhang W, et al. A systematic review and meta-analysis of intraday effects of ambient air pollution and temperature on cardiorespiratory morbidities: First few hours of exposure matters to life. eBioMedicine. 2022 Oct 30;86:104327.

126. Guo J, Chai G, Song X, Hui X, Li Z, Feng X, et al. Long-term exposure to particulate matter on cardiovascular and respiratory diseases in low- and middle-income countries: A systematic review and meta-analysis. Front Public Health [Internet]. 2023 Mar 28 [cited 2024 Mar 27];11. Available from: https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2023.1134341/full

127. Keinan-Boker L, Vin-Raviv N, Liphshitz I, Linn S, Barchana M. Cancer Incidence in Israeli Jewish Survivors of World War II. JNCI J Natl Cancer Inst. 2009 Nov 4;101(21):1489–500.

128. Hursting SD, Forman MR. Cancer Risk From Extreme Stressors: Lessons From European Jewish Survivors of World War II. JNCI J Natl Cancer Inst. 2009 Nov 4;101(21):1436–7.

129. Koupil I, Plavinskaja S, Parfenova N, Shestov DB, Danziger PD, Vågerö D. Cancer mortality in women and men who survived the siege of Leningrad (1941–1944). Int J Cancer. 2009;124(6):1416–21.

130. Vågerö D, Koupil I, Parfenova N, Sparén P. Long-Term Health Consequences Following the Siege of Leningrad. In Nova Science Publishers, Inc.; 2013 [cited 2024 Mar 21]. p. 207–25. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-88920

131. Huynh MLD, Raab SS, Suba EJ. Association between war and cervical cancer among Vietnamese women. Int J Cancer. 2004 Jul 10;110(5):775–7.

132. Vuong TP. Research on the Relationship between Exposure to Dioxins and Cancer Incidence in Vietnam. Toxics. 2022 Jul;10(7):384.

133. Ariyawardana A, Warnakulasuriya S. Declining oral cancer rates in Sri Lanka: are we winning the war after being at the top of the cancer league table? Oral Dis. 2011 Oct;17(7):636–41.

134. Gulf War and Health: Updated Literature Review of Depleted Uranium | The National Academies Press [Internet]. 2024 [cited 2024 Mar 21]. Available from: https://nap.nationalacademies.org/catalog/12183/gulf-war-and-health-updated-literature-review-of-depleted-uranium

135. Belicza M, Lenicek T, Glasnović M, Elez M, Gladić V, Marton I, et al. [Change in the occurrence of breast cancer in hospital registries (1980-2000)]. Lijec Vjesn. 2002;124(11–12):347–53.

136. Dmitrović B, Kurbel S, D M, Blažičević V, T V. The war and its influence on the malignant tumors' incidence. Med Glas. 2006 Feb 1;3.

137. Fajdic J, Gotovac N, Hrgovic Z, Fassbender WJ. Influence of stress related to war on biological and morphological characteristics of breast cancer in a defined population. Adv Med Sci. 2009;54(2):283–8.

138. Karelović D, Buković D, Strinić T, Ognjenović M, Bojić L, Buković N, et al. Influence of war circumstances on tumor morphological characteristics in patients with breast cancer. Coll Antropol. 2002 Jun;26(1):99–106.

139. Milojković M, Pajtler M, Rubin M. Influence of the war in Croatia on the frequency of gynecological cancer in the University Hospital Osijek in the period from 1985 to 2002. Coll Antropol. 2005 Dec;29(2):573–8.

140. Alajbegović A, Hrnjica M, Dimitrijević J, Zukić T, Bulić G, Ajanović Z, et al. [Central nervous system neoplasms in clinical data from the Neurology Clinic KCU in Sarajevo 1990-1999]. Med Arh. 2002;56(1):15–9.

141. Korda-Vidić V, Vasilj I, Babić D. The stress of war and breast cancer incidence. Psychiatr Danub. 2015 Dec;27 Suppl 2:571–7.

142. Petrović B, Kocić B, Filipović S, Rancić N, Filipović A. Epidemiology of breast cancer in the city of Nis, Serbia. J BUON Off J Balk Union Oncol. 2003;8(2):147–50.

143. Papathanasiou K, Gianoulis C, Tolikas A, Dovas D, Koutsos J, Fragkedakis N, et al. Effect of depleted uranium weapons used in the Balkan war on the incidence of cervical intraepithelial neoplasia (CIN) and invasive cancer of the cervix in Greece. Clin Exp Obstet Gynecol. 2005;32(1):58–60.

144. Vlajinac H, Marinković J, Kocev N, Adanja B, Sipetić S, Pekmezović T, et al. [Trends in mortality in Serbia, excluding the provinces, 1973-1994]. Srp Arh Celok Lek. 2000;128(9–10):309–15.

145. Jawad M, Millett C, Sullivan R, Alturki F, Roberts B, Vamos EP. The impact of armed conflict on cancer among civilian populations in low- and middle-income countries: a systematic review. Ecancermedicalscience. 2020;14:1039.

146. Ryzhov A, Bray F, Ferlay J, Fedorenko Z, Goulak L, Gorokh Y, et al. Recent cancer incidence trends in Ukraine and short-term predictions to 2022. Cancer Epidemiol. 2020 Apr 1;65:101663.

147. Zub V. CANCER EPIDEMIOLOGY IN UKRAINE: ANALYSIS FOR THE PAST DECADE. Acta Medica Leopoliensia. 2021 Dec 23;27(3–4):126–42.

148. Semenov VV, Kriachkova LV, Shestakova N, Khanov V, Donchenko H, Balashova O, et al. Gastric cancer epidemiology from 2009 to 2019 in Dnipro Region, Ukraine. Cancer Epidemiol. 2023 Feb 1;82:102315.

149. Sydorenko OM, Sydorenko MO, Tymoshev MP. Епідеміологія раку щитовидної залози наприкінці XX та на початку XXI століття в Україні та Запорізькій області. Curr Issues Pharm Med Sci Pract [Internet]. 2018 Oct 24 [cited 2024 Mar 24];(3). Available from: http://pharmed.zsmu.edu.ua/article/view/144485

150. Lukach E, Fedorenko Z, Serezhko Y. Some aspects of the population of Ukraine affected by malignant neoplasms of the larynx. Otorhinolaryngology. 2023 Apr 10;6(1–2):10–4.

151. Panfilova HL, Pulnyi YY, Tereshchenko LV, Chernukha VM, Iurchenko GM. Результати групування регіонів України за епідеміологічними показниками раку легенів та бронхів як важлива складова в розробленні раціональних шляхів фінансування фармацевтичної складової державних програм боротьби з онкологічними захворюваннями. Soc Pharm Health Care. 2022 Jul 18;8(1):17–26.

152. Prysyazhniuk AYe, Bazyka DA, Hudzenko NA, Fuzik MM, Trotsiuk NK, Babkina NG, et al. Cancer incidence in the population of Ukraine in remote period after the Chornobyl accident. Environ Health. 2022 Jun;(2 (103)):16–24.

153. Smorodska OM, Moskalenko YV, Vynnychenko OI, Pryvalova AO, Kostiuchenko VV. LUNG CANCER PREVALENCE: FROM LOCAL TO GLOBAL. Art Med. 2021 Jul 3;116–23.

154. Rafalska YD, Kosyachenko KL. Analysis of the morbidity of breast cancer in Ukraine and the city of Kyiv. Farm Zh. 2023 Jun 28;(3):39–47.

155. Leung KM, Shabat G, Lu P, Fields AC, Lukashenko A, Davids JS, et al. Trends in Solid Tumor Incidence in Ukraine 30 Years After Chernobyl. J Glob Oncol. 2019 Dec;(5):1–10.

156. Fedorenko ZP, Kolesnik OO, Gulak LO, Ryzhov AY, Sumkina OV. Колоректальний рак в Україні: епідеміологічні та організаційні аспекти проблеми. Pract Oncol. 2019;2(2):2–9.

157. Kobilnyk Y, Mytsyk Y, Borzhievsky A, Vorobets D, Matskevych V. DYNAMICS OF PROSTATE CANCER RATE AND MORTALITY IN UKRAINE: CURRENT STATE OF AFFAIRS. Proceeding Shevchenko Sci Soc Med Sci [Internet]. 2020 Sep 27 [cited 2024 Mar 24];62(2). Available from: https://mspsss.org.ua/index.php/journal/article/view/319

158. Fedorenko ZP, Zub VO, Gorokh YeL, Goulak LO, Sumkina OV, Ryzhov AYu, et al. Bulletin of the National Cancer Registry of Ukraine [Internet]. Vol. 24. National Cancer Registry of Ukraine; 2023. 148 p. Available from: http://www.ncru.inf.ua/

159. Ryngach N. ДВА РОКИ ПАНДЕМІЇ COVID-19 В УКРАЇНІ: ЗМІНИ СМЕРТНОСТІ ВНАСЛІДОК НОВОУТВОРЕНЬ. Demogr Soc Econ. 2022 Oct 25;49(3):26–45.

160. Michailovich YI, Sumkina OV, Gorokh YL. CANCER INCIDENCE IN UKRAINE: TRENDS IN 2010-2019 AND THE IMPACT OF COVID-19 PANDEMIC. Exp Oncol. 2023;45(4):463–73.

161. Hansen CL, Viboud C, Simonsen L. Disentangling the relationship between cancer mortality and COVID-19. eLife [Internet]. 2024 Feb 28 [cited 2024 Mar 24];13. Available from: https://elifesciences.org/reviewed-preprints/93758

162. Potter AL, Vaddaraju V, Venkateswaran S, Mansur A, Bajaj SS, Kiang MV, et al. Deaths Due to COVID-19 in Patients With Cancer During Different Waves of the Pandemic in the US. JAMA Oncol. 2023 Oct 1;9(10):1417–22.

163. Saini KS, Tagliamento M, Lambertini M, McNally R, Romano M, Leone M, et al. Mortality in patients with cancer and coronavirus disease 2019: A systematic review and pooled analysis of 52 studies. Eur J Cancer. 2020 Nov;139:43–50.

164. Черниченко ІО, Литвиченко ОМ, Цимбалюк СМ, Швагер ОВ, Соверткова ЛС, Баленко НВ. Хімічні канцерогени атмосферного повітря: вплив на захворюваність населення на рак щитоподібної залози. Гігієна Населених Місць. 2015;(66):104–10.

165. Brody M, Caldwell J, Golub A. Developing risk-based priorities for reducing air pollution in urban settings in Ukraine. J Toxicol Environ Health A. 2007 Feb 1;70(3–4):352–8.

166. Kireeva IS, Chernichenko IA, Litvichenko ON. [Hygienic assessment of the

risk of ambient air pollution to human health in the Ukraine's industrial towns]. Gig Sanit. 2007;(1):17–21.

167. Бєлоконь КВ, Матухно ОВ. ОЦІНКА КАНЦЕРОГЕННОГО РИЗИКУ ДЛЯ ЗДОРОВ'Я НАСЕЛЕННЯ ВІД ЗАБРУДНЕННЯ АТМОСФЕРНОГО ПОВІТРЯ М. ЗАПОРІЖЖЯ ФОРМАЛЬДЕГІДОМ. Збірник Наукових Праць Дніпровського Державного Технічного Університету Технічні Науки. 2020;2(37):149–55.

168. Serdiuk AM, Chernychenko IO, Lytvychenko OM, Babii VF, Kondratenko OY, Hlavachek DO. Carcinogenic substances in the atmospheric air of Dnipro city and risk to the population. Medicni Perspekt. 2021 Mar 26;26(1):226–31.

169. State Institution ", O.M. Marzieiev Institute for Public Health of the NAMSU", Chernychenko IO, Balenko NV, State Institution 'O.M. Marzieiev Institute for Public Health of the NAMSU', Lytvychenko OM, et al. Chemical carcinogens in the environment of ukraine: risk to the population, ways of prevention, improvement of hygienic regulation. Environ Health. 2023 Sep;(3 (108)):4–10.

170. Rublevskij V, Rublevskaya N, Zub M, Kurbatova N, Stepanov S, Buryakova L. HYGIENIC ESTIMATION OF THE DYNAMICS OF ATMOSPHERIC AIR POLLUTION BY PHENOL AND FORMALDEHYDE IN INDUSTRIAL CITIES. Mod Eng Innov Technol. 2018;(05–02):46–52.

171. Malarvizhi AS, Liu Q, Trefonides TS, Hasheminassab S, Smith J, Huang T, et al. The spatial dynamics of Ukraine air quality impacted by the war and pandemic. Int J Digit Earth. 2023 Oct 2;16(1):3680–705.

172. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7):e1000097.

173. Sasmoko, Imran M, Khan S, Khan H ur R, Jambari H, Musah MB, et al. War psychology: The global carbon emissions impact of the Ukraine-Russia conflict. Front Environ Sci [Internet]. 2023 Feb 28 [cited 2024 Apr 1];11. Available from: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1065301

174. Turos OI, Petrosian AA, Maremukha TP, Morhulova VV, Brezitska NV, Kobzarenko IV, et al. ASSESSMENT OF AMBIENT AIR POLLUTION BY PARTICULATE MATTER (PM10, PM2.5) AND RISK FOR HUMAN HEALTH

CAUSED BY WAR ACTIONS. Wiadomosci Lek Wars Pol 1960. 2023;76(4):738–44.

175. Лісова НО. ВПЛИВ ВІЙСЬКОВИХ ДІЙ В УКРАЇНІ НА ЕКОЛОГІЧНИЙ СТАН ТЕРИТОРІЇ. Наукові Записки Тернопільського Національного Педагогічного Університету Імені Володимира Гнатюка Серія Географія [Internet]. 2017 [cited 2024 Apr 1];43(2). Available from: http://nzg.tnpu.edu.ua/article/view/157493

176. Meng X, Lu B, Liu C, Zhang Z, Chen J, Herrmann H, et al. Abrupt exacerbation in air quality over Europe after the outbreak of Russia-Ukraine war. Environ Int. 2023 Aug;178:108120.

177. Grynchyshyn NN. ЯКІСТЬ АТМОСФЕРНОГО ПОВІТРЯ ЗА ВМІСТОМ ТВЕРДИХ МІКРОЧАСТИНОК (PM 2,5) У МІСТАХ УКРАЇНИ В УМОВАХ КАРАНТИНУ ТА ВОЄННОГО СТАНУ. Вісник Львівського Державного Університету Безпеки Життєдіяльності. 2023 Jun 22;27:6–15.

178. Zhang C, Hu Q, Su W, Xing C, Liu C. Satellite spectroscopy reveals the atmospheric consequences of the 2022 Russia-Ukraine war. Sci Total Environ. 2023 Apr 15;869:161759.

179. Bohovic R, Hrnčiar M, Muroň M, Chytrý J, Skalský M, Černochová M, et al. Air pollution in Ukraine as seen from space: the effects of the war. Study based on the Copernicus Sentinel 5p satellite imagery. 2023.

180. UNDP [Internet]. 2024 [cited 2024 Apr 4]. Health impacts and social costs associated with air pollution in larger urban areas of Ukraine. Available from: https://www.undp.org/ukraine/publications/health-impacts-and-social-costs-associated-air-pollution-larger-urban-areas-ukraine

181. Центральна геофізична обсерваторія ім. Бориса Срезневського [Internet]. 2023 [cited 2023 Dec 27]. Available from: http://cgo-sreznevskyi.kyiv.ua/uk/

182. Rawtani D, Gupta G, Khatri N, Rao PK, Hussain CM. Environmental damages due to war in Ukraine: A perspective. Sci Total Environ. 2022 Dec 1;850:157932.

183. Pereira P, Bašić F, Bogunovic I, Barcelo D. Russian-Ukrainian war impacts the total environment. Sci Total Environ. 2022 Sep 1;837:155865.

184. Bun R, Marland G, Oda T, See L, Puliafito E, Nahorski Z, et al. Tracking

unaccounted greenhouse gas emissions due to the war in Ukraine since 2022. Sci Total Environ. 2024 Mar 1;914:169879.

185. Impacts of the Russia-Ukraine War on Global Food Security: Towards More Sustainable and Resilient Food Systems? - PMC [Internet]. 2024 [cited 2024 Mar 10]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9368568/

186. Chowdhury PR, Medhi H, Bhattacharyya KG, Hussain CM. Severe deterioration in food-energy-ecosystem nexus due to ongoing Russia-Ukraine war: A critical review. Sci Total Environ. 2023 Dec 1;902:166131.

187. War drives forest fire risks and highlights the need for more ecologically-sound forest management in post-war Ukraine - PMC [Internet]. 2024 [cited 2024 Mar 10]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10876951/

188. Koban LA, Pfluger AR. Per- and polyfluoroalkyl substances (PFAS) exposure through munitions in the Russia–Ukraine conflict. Integr Environ Assess Manag. 2023;19(2):376–81.

189. Tollefson J. What the war in Ukraine means for energy, climate and food. Nature. 2022 Apr 5;604(7905):232–3.

190. Все про повітря [Internet]. 2024 [cited 2024 Apr 1]. Environmental consequences of Russian war in Ukraine. Available from: https://cleanair.org.ua/en/publication/environmental-consequences-of-russian-war-in-ukraine/

191. Все про повітря [Internet]. 2024 [cited 2024 Apr 1]. Air Pollution in Ukraine from space in 2022. Available from: https://cleanair.org.ua/publication/air-pollution-in-ukraine-from-space-in-2022/

192. Adamkiewicz Ł, Maciejewska K, Rabczenko D, Drzeniecka-Osiadacz A. Ambient Particulate Air Pollution and Daily Hospital Admissions in 31 Cities in Poland. Atmosphere. 2022 Feb;13(2):345.

193. Gordiichuk P, Kliusov O, Gordiichuk M, Kondratenko A, Ponomarova O, Grushynska T, et al. A view on the problem of providing oncological aid during the war in Ukraine. Contemp Oncol. 2022;26(3):191–5.

194. War in UA Environmental Impact | top lead projects [Internet]. [cited 2024 Mar 27]. Available from: https://www.topleadprojects.com/environmental-

project-main

195. aqicn.org [Internet]. 2024 [cited 2024 Mar 17]. Real-time air pollution index for 100+ countries. Available from: https://aqicn.org/here/

196. aqicn.org [Internet]. 2024 [cited 2024 Mar 17]. Air quality network in Ukraine [Airnet Ukraine]. Available from: https://aqicn.org//station/country/ua/ukraine/

197. Громадська організація 'Збережи Дніпро' [Internet]. 2024 [cited 2024 Mar 17]. Available from: https://www.savednipro.org/en/

198. Savenets M, Dvoretska I, Nadtochii L, Zhemera N. Comparison of TROPOMI NO2, CO, HCHO, and SO2 data against ground-level measurements in close proximity to large anthropogenic emission sources in the example of Ukraine. Meteorol Appl. 2022;29(6):e2108.

199. Serhii AS, Vyshnevskyi VI, Olena PB. The Use of Remote Sensing Data for Investigation of Environmental Consequences of Russia-Ukraine War. J Landsc Ecol. 2022 Dec 1;15(3):36–53.

200. 2023 World Air Quality Report | IQAir [Internet]. 2024 [cited 2024 Mar 21]. Available from: https://www.iqair.com/world-air-quality-report

201. Ukraine: 2023–2024 winter risk assessment, November 2023 [Internet]. 2024 [cited 2024 Mar 21]. Available from: https://www.who.int/andorra/publications/m/item/ukraine-2023-2024-winter-risk-assessment-november-2023

202. Офіційний портал Києва. Офіційний портал КМДА - Головна. 2024 [cited 2024 Mar 17]. Рік повномасштабної війни: понад 90% часу повітря в Києві було чистим, найбільше шкоди завдали пожежі, спричинені бойовими діями довкола столиці (+фото). Available from: https://kyivcity.gov.ua/news/rik_povnomasshtabno_viyni_ponad_90_chasu_povitrya_v_kiyevi_bulo_chistim_naybilshe_shkodi_zavdali_pozhezhi_sprichineni_boyovimi_diyami_dovkola_stolitsi/

203. Goto R, Pinchuk I, Kolodezhny O, Pimenova N, Skokauskas N. Mental health services in Ukraine during the early phases of the 2022 Russian invasion. Br J Psychiatry. 2023 Feb;222(2):82–7.

204. Pinchuk I, Goto R, Kolodezhny O, Pimenova N, Skokauskas N. Dynamics of hospitalizations and staffing of Ukraine's mental health services during the

Russian invasion. Int J Ment Health Syst. 2023 Jun 24;17:20.

205. Lushchak O, Velykodna M, Bolman S, Strilbytska O, Berezovskyi V, Storey KB. Prevalence of stress, anxiety, and symptoms of post-traumatic stress disorder among Ukrainians after the first year of Russian invasion: a nationwide cross-sectional study. Lancet Reg Health - Eur. 2023 Nov 6;36:100773.

206. Seleznova V, Pinchuk I, Feldman I, Virchenko V, Wang B, Skokauskas N. The battle for mental well-being in Ukraine: mental health crisis and economic aspects of mental health services in wartime. Int J Ment Health Syst. 2023 Sep 25;17:28.

207. Mental Health and well-being During the COVID-19 Pandemic and After the Russian Invasion of Ukraine - PMC [Internet]. 2024 [cited 2024 Mar 10]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10881779/

208. Mazhnaya A, Meteliuk A, Pykalo I, Altice FL. Qualitative exploration of the early experiences of opioid use disorder patients from private clinics after Russia's invasion of Ukraine in five major cities in Ukraine. Front Public Health. 2023 Dec 12;11:1238188.

209. Ponticiello M, Azbel L, Tate MM, Bromberg DJ, Pykalo I, Kiriazova T, et al. Introducing methadone maintenance therapy into Ukrainian prisons: a qualitative study of criminal subculture, Russia's full-scale invasion, and contested methadone objects. Front Psychiatry. 2023 Nov 30;14:1227216.

210. Morozova O, Ivanchuk I, Gvozdetska O, Nesterova O, Skala P, Kuzin I, et al. Treatment of opioid use disorder in Ukraine during the first year of the Russia–Ukraine war: Lessons learned from the crisis. Int J Drug Policy. 2023 Jul 1;117:104062.

211. Ivasiy R, Galvez de Leon SJ, Meteliuk A, Fomenko T, Pykalo I, Bromberg DJ, et al. Responding to health policy recommendations on managing opioid use disorder during Russia's invasion of Ukraine: Divergent responses from the frontline to the west. Front Public Health. 2023 Jan 13;10:1044677.

212. Dubov A, Basenko A, Dymaretskyi O, Shoptaw S. Impact of the Russian invasion on opioid agonist therapy programs in Ukraine: A qualitative study. Drug Alcohol Depend. 2024 Feb 1;255:111069.

213. Dhawan M, Choudhary OP, Priyanka, Saied AA. Russo-Ukrainian war amid the

COVID-19 pandemic: Global impact and containment strategy. Int J Surg. 2022 Jun 1;102:106675.

214. Lopatina Y, Żakowicz AM, Shabarova Z, Ford T, Fonseca FF, Odoke W, et al. Safeguarding HIV prevention and care services amidst military conflict: experiences from Ukraine. BMJ Glob Health. 2023 Dec 26;8(12):e014299.

215. Caglevic C, Rolfo C, Gil-Bazo I, Cardona A, Sapunar J, Hirsch FR, et al. The Armed Conflict and the Impact on Patients With Cancer in Ukraine: Urgent Considerations. JCO Glob Oncol [Internet]. 2022 [cited 2024 Mar 11];8. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9470147/

216. Fighting Cancer in Ukraine at Times of War - ScienceDirect [Internet]. 2024 [cited 2024 Mar 11]. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0889858823000898?via%3Dihub

217. Oncology specialists' perspective on caring for patients with cancer during the early days of war in Kyiv, Ukraine - The Lancet Oncology [Internet]. 2024 [cited 2024 Mar 11]. Available from: https://www.thelancet.com/journals/lanonc/article/PIIS1470-2045(22)00204-2/abstract

218. War in Ukraine Disrupts Trials, Cancer Care. Cancer Discov. 2022 May 2;12(5):1178.

219. Talbot A, Connor SG, Austin K, Hannon T, Gabbay E, Clay TD. The impact of the 2022 Ukraine/Russian conflict on cancer clinical trials. J Int Med Res. 2022 Dec 12;50(12):03000605221143284.

220. Bondarenko I, Agarwal A, Hemelrijck MV, Lawler M, Zubaryev M, Sullivan R. Far-reaching impact of the Russian invasion of Ukraine on global cancer research. Eur J Cancer. 2023 Apr 1;183:95–7.

221. Gujinović D, Viđak T, Melnikova M, de Sousa NJF, Marušić A. Changes in Registration Parameters for Ongoing Clinical Trials in Ukraine After 2022 Russian Invasion. JAMA Netw Open. 2023 Jun 26;6(6):e2320202.

222. Enhancing Cancer Care Amid Conflict: A Proposal for Optimizing Oncology Services During Wartime | JCO Global Oncology [Internet]. 2024 [cited 2024 Mar 11]. Available from: https://ascopubs.org/doi/10.1200/GO.23.00304?url_ver=Z39.88-

2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%20pubmed

223. Appraising war's impacts on neurosurgical delivery in Ukraine - Wireko - 2023 - The International Journal of Health Planning and Management - Wiley Online Library [Internet]. 2024 [cited 2024 Mar 10]. Available from: https://onlinelibrary.wiley.com/doi/10.1002/hpm.3633

224. Barten DG, Tin D, Granholm F, Rusnak D, van Osch F, Ciottone G. Attacks on Ukrainian healthcare facilities during the first year of the full-scale Russian invasion of Ukraine. Confl Health. 2023 Dec 8;17:57.

225. Baker MS, Baker J, Burkle FM. Russia's Hybrid Warfare in Ukraine Threatens Both Healthcare & Health Protections Provided by International Law. Ann Glob Health. 2024 Mar 10;89(1):3.

226. Dzhus M, Golovach I. Impact of Ukrainian- Russian War on Health Care and Humanitarian Crisis. Disaster Med Public Health Prep. 2023 Jan;17:e340.

227. Haque U, Naeem A, Wang S, Espinoza J, Holovanova I, Gutor T, et al. The human toll and humanitarian crisis of the Russia-Ukraine war: the first 162 days. BMJ Glob Health. 2022 Sep 23;7(9):e009550.

228. War in Ukraine: situation report from WHO Country Office in Ukraine: issue No. 70, 7 March 2024 [Internet]. 2024 [cited 2024 Mar 26]. Available from: https://www.who.int/europe/publications/i/item/WHOEURO-2024-5319-45083-72985

229. How has the quality of life in Ukraine changed during the war? [Internet]. 2024 [cited 2024 Apr 9]. Available from: https://gradus.app/

230. Досвід лікування онкологічних захворювань до і після початку повномасштабної війни в Україні - Анотація [Internet]. GMKA - Global Medical Knowledge Alliance. 2024 [cited 2024 Apr 5]. Available from: https://gmka.org/uk/news/dosvid-likuvannya-onkologichnih-zahvoryuvan-do-i-pislya-vijni-v-ukrayini-anotatsiya/

231. Kozhukhov S, Dovganych N, Smolanka I, Kryachok I, Kovalyov O. Cancer and War in Ukraine. JACC CardioOncology. 2022 Apr 12;4(2):279–82.

232. Social and Healthcare Impacts of the Russian-Led Hybrid War in Ukraine – A Conflict With Unique Global Consequences | Disaster Medicine and Public Health Preparedness | Cambridge Core [Internet]. 2024 [cited 2024 Mar 11]. Available from: https://www.cambridge.org/core/journals/disaster-

medicine-and-public-health-preparedness/article/social-and-healthcare-impacts-of-the-russianled-hybrid-war-in-ukraine-a-conflict-with-unique-global-consequences/B1FDFC1631CF9739EA57B6BD277FF754

233. Vulpe H, Minzatean A, Magidson S, Tocino I, Mindruta-Stratan R, Lönnback LJ, et al. Cancer in conflict: The impact of the war in Ukraine on Moldova. Eur J Cancer [Internet]. 2023 Aug 1 [cited 2024 Mar 11];189. Available from: https://www.ejcancer.com/article/S0959-8049(23)00241-1/abstract

234. Mărcău FC, Peptan C, Gorun HT, Băleanu VD, Gheorman V. Analysis of the impact of the armed conflict in Ukraine on the population of Romania. Front Public Health. 2022 Jul 29;10:964576.

235. Lewtak K, Kanecki K, Tyszko P, Goryński P, Bogdan M, Nitsch-Osuch A. Ukraine war refugees - threats and new challenges for healthcare in Poland. J Hosp Infect. 2022 Jul;125:37–43.

236. Wareńczak-Florczak Ż, Urbański B. What challenges does the humanitarian crisis and large number of refugees from Ukraine pose for Polish oncology? Rep Pract Oncol Radiother. 2022 Jul 29;27(3):566–70.

237. Thallinger C, Zielinski CC. Ukraine's neighbouring countries accept the burden of cancer care for refugees. Lancet Oncol. 2022 Oct 1;23(10):e440.

238. Didkowska JA, Barańska K, Wojciechowska U, Tyczyński JE. War in Ukraine creates challenges for the cancer care system in Poland. Lancet Oncol. 2022 Oct 1;23(10):1239–40.

239. Püsküllüoğlu M, Grela-Wojewoda A, Szczubiałka G, Zemełka T, Lompart J, Sałek-Zań A, et al. Cancer care for Ukrainian refugees during the first 6 weeks of 2022 Russian invasion – An experience of a cancer reference centre in Poland. Eur J Cancer. 2023 Jan 1;178:234–42.

240. Oncology TL. Conflict in Ukraine and its impact on cancer care. Lancet Oncol. 2022 Apr 1;23(4):439.

241. STEPS prevalence of noncommunicable disease risk factors in Ukraine 2019 [Internet]. 2024 [cited 2024 Apr 8]. Available from: https://www.who.int/europe/publications/i/item/WHO-EURO-2020-1468-41218-56060

242. Національне дослідження STEPS в Україні | Центр громадського здоров'я

[Internet]. 2024 [cited 2024 Apr 8]. Available from: https://phc.org.ua/naukova-diyalnist/doslidzhennya/doslidzhennya-z-neinfekciynikh-zakhvoryuvan/nacionalne-doslidzhennya-steps-v-ukraini

243. Alcohol consumption in Ukraine - behaviour and attitude - December 2023: key findings [Internet]. 2024 [cited 2024 Apr 9]. Available from: https://www.who.int/andorra/publications/m/item/alcohol-consumption-in-ukraine-key-findings

244. Обізнаність, ставлення і поведінка щодо неінфекційних захворювань в Україні у 2022 році [Internet]. 2024 [cited 2024 Apr 9]. Available from: https://www.actforhealth.in.ua/materialy/obiznanist-stavlennya-i-povedunka-shchodo-neinfekciynih-zahvoryuvan-v-ukrayini-u-2022-roci

245. Як змінився психоемоційний стан українців: звіт за результатами онлайн-дослідження [Internet]. UIF. 2023 [cited 2024 Apr 8]. Available from: https://news.uifuture.org/yak-zminivsya-psikhoemociyniy-stan-ukra/

246. Прес-релізи та звіти - Всесвітній день без тютюну 2023: прогрес України та результати опитування [Internet]. [cited 2024 Apr 16]. Available from: https://www.kiis.com.ua/?lang=ukr&cat=reports&id=1240&page=1

247. Petrenko-Lysak A. Izhakultura. 2024 [cited 2024 Apr 8]. On food and culinary practices during war: theoretical study (and) personal experience. Available from: https://eng.yizhakultura.com/material/20221003_1928

248. Gradus Research Company [Internet]. 2024 [cited 2024 Apr 8]. Available from: https://gradus.app/

249. Аптека online [Internet]. 2024 [cited 2024 Apr 8]. Як війна вплинула на здоров'я українців? Available from: https://www.apteka.ua/article/663535

250. Кротова ЛО, Крячкова ЛВ, Кротова ВЮ. ВИЗНАЧЕННЯ ПРІОРИТЕТІВ ЧИННИКІВ ВПЛИВУ НА ХРОНІЧНІ НЕІНФЕКЦІЙНІ ЗАХВОРЮВАННЯ ПІД ЧАС ВІЙНИ. Unpublished. 2024;

251. Стресові стани населення України в контексті війни [Internet]. 2024 [cited 2024 Apr 8]. Available from: http://ratinggroup.ua/research/ukraine/stresovi_stany_naselennya_ukrainy_v_konteksti_viyni.html

252. Офіційний вебпортал парламенту України [Internet]. 2024 [cited 2024 Apr 9]. Щодо профілактики, ранньої діагностики та лікування злоякісних

новоутворень. Available from: https://zakon.rada.gov.ua/go/n0049525-23

253. Устінов ОВ. Клінічна онкологія. 2024 [cited 2024 Apr 9]. Розроблено Національну стратегію контролю злоякісних новоутворень. Available from: https://www.clinicaloncology.com.ua/article/31813/rozrobleno-naczionalnu-strategiyu-kontrolyu-zloyakisnih-novoutvoren

254. Устінов ОВ. Український Медичний Часопис. 2024 [cited 2024 Apr 9]. Розроблено Стратегію розвитку системи охорони здоров'я до 2030 р. | Український Медичний Часопис | Український Медичний Часопис | Український Медичний Часопис. Available from: https://umj.com.ua/uk/novyna-252938-rozrobleno-strategiyu-rozvitku-sistemi-ohoroni-zdorov-ya-do-2030-roku

255. European Air Quality Index [Internet]. [cited 2023 Dec 15]. Available from: https://airindex.eea.europa.eu/Map/AQI/Viewer/#

256. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet Lond Engl. 2020 Oct 17;396(10258):1223–49.

257. EU air quality standards - European Commission [Internet]. [cited 2023 Dec 19]. Available from: https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en

258. Офіційний вебпортал парламенту України [Internet]. [cited 2024 Feb 5]. Постанова Кабінету Міністрів України від 14.08.2019 №827 'Деякі питання здійснення державного моніторингу в галузі охорони атмосферного повітря'. Available from: https://zakon.rada.gov.ua/go/827-2019-%D0%BF

259. US EPA O. Particulate Matter (PM) Basics [Internet]. 2016 [cited 2023 Dec 19]. Available from: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

260. Офіційний вебпортал парламенту України [Internet]. [cited 2023 Oct 24]. Про затвердження гігієнічних регламентів допустимого вмісту хімічних і біологічних речовин в атмосферному повітрі населених місць. Available from: https://zakon.rada.gov.ua/go/z0156-20

261. World Health Organization (WHO) air quality guidelines (AQGs) and estimated reference levels (RLs) — European Environment Agency [Internet]. [cited 2024 Feb 12]. Available from:

https://www.eea.europa.eu/publications/status-of-air-quality-in-Europe-2022/europes-air-quality-status-2022/world-health-organization-who-air

262. US EPA O. Sulfur Dioxide Basics [Internet]. 2016 [cited 2024 Apr 17]. Available from: https://www.epa.gov/so2-pollution/sulfur-dioxide-basics

263. ASSESSMENT UENCFE. IRIS Toxicological Review and Summary Documents for Hydrogen Sulfide (External Review Draft) [Internet]. [cited 2024 Apr 17]. Available from: https://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=29137

264. Omidvarborna H, Kumar A, Kim DS. Recent studies on soot modeling for diesel combustion. Renew Sustain Energy Rev. 2015 Aug 1;48:635–47.

265. Міністерство охорони здоров'я України. Наказ МОЗ України від 18.10.2023 № 1811 "Про затвердження Методичних рекомендацій 'Оцінка канцерогенного та неканцерогенного ризику для здоров'я населення від хімічного забруднення атмосферного повітря' [Internet]. [cited 2024 Mar 15]. Available from: http://moz.gov.ua/article/ministry-mandates/nakaz-moz-ukraini-vid-18102023--1811-pro-zatverdzhennja-metodichnih-rekomendacij-ocinka-kancerogennogo-ta-nekancerogennogo-riziku-dlja-zdorov%E2%80%99ja-naselennja-vid-himichnogo-zabrudnennja-atmosfernogo-povitrja

266. CDC | Facts About Hydrogen Fluoride (Hydrofluoric Acid) [Internet]. 2019 [cited 2024 Apr 17]. Available from: https://emergency.cdc.gov/agent/hydrofluoricacid/basics/facts.asp

267. Public Health England. Hydrogen chloride/ hydrochloric acid. General Information [Internet]. 2016. Available from: https://assets.publishing.service.gov.uk/media/5a82b7f3e5274a2e87dc2a2a/hydrogen_chloride__general_information.pdf

268. US EPA O. Basic Information about NO2 [Internet]. 2016 [cited 2023 Dec 29]. Available from: https://www.epa.gov/no2-pollution/basic-information-about-no2

269. Valavanidis A, Fiotakis K, Vlachogianni T. Airborne particulate matter and human health: toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic

mechanisms. J Environ Sci Health Part C Environ Carcinog Ecotoxicol Rev. 2008;26(4):339–62.

270. Hamra GB, Laden F, Cohen AJ, Raaschou-Nielsen O, Brauer M, Loomis D. Lung Cancer and Exposure to Nitrogen Dioxide and Traffic: A Systematic Review and Meta-Analysis. Environ Health Perspect. 2015 Nov;123(11):1107–12.

271. Amadou A, Praud D, Coudon T, Deygas F, Grassot L, Dubuis M, et al. Long-term exposure to nitrogen dioxide air pollution and breast cancer risk: A nested case-control within the French E3N cohort study. Environ Pollut Barking Essex 1987. 2023 Jan 15;317:120719.

272. US EPA O. Basic Information about Carbon Monoxide (CO) Outdoor Air Pollution [Internet]. 2016 [cited 2024 Jan 2]. Available from: https://www.epa.gov/co-pollution/basic-information-about-carbon-monoxide-co-outdoor-air-pollution

273. IARC. Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol [Internet]. [cited 2023 Oct 23]. Available from: https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Formaldehyde-2-Butoxyethanol-And-1--Em-Tert-Em--Butoxypropan-2-ol-2006

274. Formaldehyde and Cancer Risk - NCI [Internet]. 2011 [cited 2023 Oct 23]. Available from: https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/formaldehyde/formaldehyde-fact-sheet

275. Khoshakhlagh AH, Mohammadzadeh M, Manafi SS, Yousefian F, Gruszecka-Kosowska A. Inhalational exposure to formaldehyde, carcinogenic, and non-carcinogenic risk assessment: A systematic review. Environ Pollut. 2023 Aug 15;331:121854.

276. Wu C, Lv S, Wang F, Liu X, Li J, Liu L, et al. Ammonia in urban atmosphere can be substantially reduced by vehicle emission control: A case study in Shanghai, China. J Environ Sci. 2023 Apr 1;126:754–60.

277. Wu C, Wang G, Li J, Li J, Cao C, Ge S, et al. Non-agricultural sources dominate the atmospheric NH3 in Xi’an, a megacity in the semi-arid region of China. Sci Total Environ. 2020 Jun 20;722:137756.

278. US EPA O. Ammonia [Internet]. 2015 [cited 2024 Jan 2]. Available from: https://www.epa.gov/caddis-vol2/ammonia

279. Ammonia | ToxFAQs™ | ATSDR [Internet]. [cited 2024 Jan 2]. Available from: https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsDetails.aspx?faqid=10&toxid=2

280. Phenol. 108-95-2 [Internet]. Available from: https://www.epa.gov/sites/default/files/2016-09/documents/phenol.pdf

281. Machate DJ. Anthropogenic hyperactivity for natural resources increases heavy metals concentrations in the environment: Toxicity of healthy food and cancer risks estimated. J Trace Elem Miner. 2023 Jun 1;4:100057.

282. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol. 2014 Jun;7(2):60–72.

283. Kumar S, Islam R, Akash PB, Khan MHR, Proshad R, Karmoker J, et al. Lead (Pb) Contamination in Agricultural Products and Human Health Risk Assessment in Bangladesh. Water Air Soil Pollut. 2022 Jun 29;233(7):257.

284. Liu J, Liu YJ, Liu Y, Liu Z, Zhang AN. Quantitative contributions of the major sources of heavy metals in soils to ecosystem and human health risks: A case study of Yulin, China. Ecotoxicol Environ Saf. 2018 Nov 30;164:261–9.

285. Wei J, Cen K. Assessment of human health risk based on characteristics of potential toxic elements (PTEs) contents in foods sold in Beijing, China. Sci Total Environ. 2020 Feb 10;703:134747.

286. Shukla S, Mbingwa G, Khanna S, Dalal J, Sankhyan D, Malik A, et al. Environment and health hazards due to military metal pollution: A review. Environ Nanotechnol Monit Manag. 2023 Dec 1;20:100857.

287. State Statistics Service of Ukraine (Державна служба статистики України) [Internet]. [cited 2023 Jan 5]. Available from: https://www.ukrstat.gov.ua/

288. NGO 'Free Arduino'. Ukrainian citizen air quality monitoring network Eco City. Researcher account of the Ukrainian Air Quality. [Internet]. 2023. Available from: https://archive.eco-city.org.ua

289. Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI) [Internet]. U.S. Environmental Protection Agency;

2018. Available from: https://www.airnow.gov/sites/default/files/2020-05/aqi-technical-assistance-document-sept2018.pdf

290. SaveEcoBot. Щогодинний індекс якості атмосферного повітря для дрібнодисперсного пилу фракції 2.5 мікронів в населених пунктах України [Internet]. 2023. Available from: https://data.gov.ua/organization/savednipro

291. DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe [Internet]. [cited 2024 Feb 12]. Available from: https://eur-lex.europa.eu/eli/dir/2008/50/oj

292. Government of Canada CC for OH and S. CCOHS: Converting Occupational Exposure Limits from mg/m^3 to ppm [Internet]. 2024 [cited 2024 Feb 1]. Available from: https://www.ccohs.ca/oshanswers/chemicals/convert.html

293. Institute for the Study of War. Institute for the Study of War. 2022 [cited 2024 Feb 22]. Ukraine Conflict Update 7. Available from: https://www.understandingwar.org/backgrounder/ukraine-conflict-update-7

294. TCH.ua [Internet]. 2022 [cited 2024 Feb 22]. У Дніпрі показали наслідки російських авіаударів (фото). Available from: https://tsn.ua/ato/u-dnipri-pokazali-naslidki-rosiyskogo-aviaudaru-foto-2005594.html

295. KP.UA [Internet]. [cited 2024 Feb 22]. Ракетна атака та потужні вибухи у Дніпрі: від аеропорту не залишилося живого місця, – Валентин Резніченко. Available from: https://kp.ua/ua/incidents/a647614-znovu-potuzhni-vibukhi-u-dnipri-vid-aeroportu-ne-zalishilosja-zhivoho-mistsj

296. Росія завдала ракетного удару по військовій частині в Дніпропетровській області – портал новин LB.ua [Internet]. [cited 2024 Mar 22]. Available from: https://lb.ua/society/2022/03/31/511740_rosiya_zavdala_raketnogo_udaru.html

297. LB.ua [Internet]. 2022 [cited 2024 Feb 22]. Окупанти завдали ракетного удару по нафтобазі в Дніпрі (оновлено). Available from: https://lb.ua/society/2022/03/30/511676_okupanti_zavdali_raketnogo_udaru.html

298. Ситуація на Дніпропетровщині – по військовій частині завдали ракетного

удару, двоє людей загинуло, п'ять поранених » Слово і Діло [Internet]. [cited 2024 Mar 22]. Available from: https://www.slovoidilo.ua/2022/03/31/novyna/suspilstvo/okupanty-zavdaly-raketnoho-udaru-po-vijskovij-chastyni-dnipropetrovshhyni-ye-zahybli

299. Слово і Діло [Internet]. 2024 [cited 2024 Mar 28]. Окупанти завдали ракетного удару по військовій частині на Дніпропетровщині, є загиблі. Available from: https://www.slovoidilo.ua/2022/03/31/novyna/suspilstvo/okupanty-zavdaly-raketnoho-udaru-po-vijskovij-chastyni-dnipropetrovshhyni-ye-zahybli

300. Українська правда [Internet]. [cited 2024 Feb 22]. Дніпро: масована ракетна атака росіян. Available from: https://www.pravda.com.ua/news/2022/04/2/7336466/

301. На Дніпропетровщині рашисти обстріляли нафтобазу та завод [Internet]. 2022 [cited 2024 Feb 22]. Available from: https://www.ukrinform.ua/rubric-ato/3449807-na-dnipropetrovsini-rasisti-obstrilali-naftobazu-ta-zavod.html

302. Українська правда [Internet]. [cited 2024 Feb 22]. Війна. День 46. ОНЛАЙН. Available from: https://www.pravda.com.ua/articles/2022/04/10/7338515/

303. Ракетні удари по Дніпру: одну ракету збила ППО, друга поцілила у залізничну інфраструктуру [Internet]. [cited 2024 Mar 22]. Available from: https://tsn.ua/ato/raketni-udari-po-dnipru-odnu-raketu-zbila-ppo-druga-pocilila-u-zaliznichnu-infrastrukturu-2053822.html

304. Ворог вранці тричі вдарив ракетами по Кривому Рогу [Internet]. 2022 [cited 2024 Feb 22]. Available from: https://www.ukrinform.ua/rubric-ato/3491564-vorog-vranci-trici-vdariv-raketami-po-krivomu-rogu.html

305. Внаслідок ракетного удару по Кривому Рогу зруйновано підприємство, – голова ОВА | Магнолія-ТВ [Internet]. [cited 2024 Feb 22]. Available from: https://magnolia-tv.com/news/74228-vnaslidok-raketnoho-udaru-po-kryvomu-rohu-zruynovano-pidpryyemstvo-holova-ova

306. Удар по Кривому Рогу: ворожі ракети знову влучили у гідротехнічні споруди [Internet]. [cited 2024 Feb 22]. Available from:

https://www.slovoidilo.ua/2022/09/16/novyna/suspilstvo/udar-po-kryvomu-rohu-vorozhi-rakety-znovu-vluchyly-hidrotexnichni-sporudy

307. Оперативне командування 'Південь'/Operational Command "South". Поточна оперативна обстановка на півдні України: станом на 13.00 06.09.2022 [Internet]. [cited 2024 Feb 22]. Available from: https://www.facebook.com/watch/?v=5764037823629468

308. Українська правда [Internet]. [cited 2024 Mar 22]. РФ випустила ракету по Дніпру, з "Градів" обстріляла Нікополь, є поранені. Available from: https://www.pravda.com.ua/news/2022/09/11/7366967/

309. Ракетний удар по Кривому Розі 14 вересня – ворог хотів створити режим НС » Слово і Діло [Internet]. [cited 2024 Mar 22]. Available from: https://www.slovoidilo.ua/2022/09/14/novyna/suspilstvo/kryvoho-rohu-pryletilo-8-raket-voroh-xotiv-stvoryty-nadzvychajnu-sytuacziyu-op

310. Українська правда [Internet]. [cited 2024 Feb 22]. Росіяни поцілили ракетою Х-59 в аеропорт Кривого Рогу. Available from: https://www.pravda.com.ua/news/2022/09/26/7369189/

311. Українська правда [Internet]. [cited 2024 Feb 22]. Російська ракета влучила у підприємство у Кривому Розі – там значні руйнування. Available from: https://www.pravda.com.ua/news/2022/09/28/7369543/

312. Новий ракетний удар рашистів по Дніпру: знову жертви, згоріло понад сто автобусів в АТП [Internet]. 2022 [cited 2024 Feb 22]. Available from: https://novynarnia.com/2022/09/30/atp-dnipro/

313. Institute for the Study of War. Institute for the Study of War. 2022 [cited 2024 Feb 22]. Russian Offensive Campaign Assessment, October 10. Available from: https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-october-10

314. Дніпро вразили випущені із Волгодонська ракети Х-101 – Вілкул [Internet]. 2022 [cited 2024 Feb 22]. Available from: https://fakty.com.ua/ua/ukraine/20221018-u-nebo-zdijmayetsya-dym-u-kryvomu-rozi-grymlyat-vybuhy/

315. Некрасов А. StopCor. 2022 [cited 2024 Feb 22]. Окупанти обстріляли Кривий Ріг: пошкоджено енергетичну інфраструктуру і житловий будинок. Available from: https://www.stopcor.org/ukr/section-suspilstvo/news-

okupanti-obstrilyali-krivij-rig-poshkodzheno-energetichnu-infrastrukturu-i-zhitlovij-budinok-19-10-2022.html

316. Інформатор Дніпро [Internet]. 2022 [cited 2024 Feb 22]. У Дніпрі ворожа ракета Х-59 влучила у АЗС: подробиці від рятувальників. Available from: https://dp.informator.ua/uk/u-dnipri-vorozha-raketa-h-59-vluchila-u-azs-podrobici-vid-ryatuvalnikiv

317. Institute for the Study of War. Institute for the Study of War. 2022 [cited 2024 Feb 22]. Russian Offensive Campaign Assessment, October 31. Available from: https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-october-31

318. Institute for the Study of War. Institute for the Study of War. 2022 [cited 2024 Feb 22]. Russian Offensive Campaign Assessment, November 15. Available from: https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-november-15

319. Інформатор Дніпро [Internet]. 2022 [cited 2024 Feb 22]. Суботній ракетний удар по Дніпру забрав життя однієї людини. Available from: https://dp.informator.ua/uk/subotniy-raketniy-udar-po-dnipru-zabrav-zhittya-odniyeji-lyudini

320. Постраждали 5 людей: окупанти вдарили ракетами по промисловому підприємству у Дніпрі - Дніпро Vgorode.ua [Internet]. [cited 2024 Feb 22]. Available from: https://dp.vgorode.ua/ukr/news/sobytyia/a1225367-postrazhdali-5-ljudej-okupanti-vdarili-raketami-po-promislovomu-pidprijemstvi-u-dnipri

321. Слово і Діло [Internet]. 2024 [cited 2024 Feb 22]. Удар по Дніпру: по місту було випущено чотири ракети, пожежа на місці прильоту загашена. Available from: https://www.slovoidilo.ua/2022/11/29/novyna/bezpeka/udar-po-dnipru-po-mistu-bulo-vypushheno-chotyry-rakety-pozhezha-misczi-prylotu-zahashena

322. Слово і Діло [Internet]. 2024 [cited 2024 Feb 22]. Рф вночі завдала ракетного удару по Кривому Рогу: загинув працівник підприємства, є поранені. Available from: https://www.slovoidilo.ua/2022/12/05/novyna/suspilstvo/rf-vnochi-zavdala-raketnoho-udaru-po-kryvomu-rohu-zahynuv-praczivnyk-

pidpryyemstva-ye-poraneni

323. Кривий Ріг – раптовий вибух без оголошення тривоги: що відомо – Суспільство – StopCor [Internet]. [cited 2024 Mar 22]. Available from: https://www.stopcor.org/ukr/section-suspilstvo/news-krivij-rig-raptovij-vibuh-bez-ogoloshennya-trivogi-scho-vidomo-06-12-2022.html

324. Institute for the Study of War. Institute for the Study of War. 2022 [cited 2024 Feb 22]. Russian Offensive Campaign Assessment, December 16. Available from: https://understandingwar.org/backgrounder/russian-offensive-campaign-assessment-december-16

325. Що відомо про влучання російської ракети у багатоповерхівку у Дніпрі. BBC News Україна [Internet]. [cited 2024 Feb 22]; Available from: https://www.bbc.com/ukrainian/news-64280832

326. Ракетні удари по Україні — Російські терористи вдарили по Дніпру, Запоріжжю, Харкову та Херсону » Слово і Діло [Internet]. [cited 2024 Mar 22]. Available from: https://www.slovoidilo.ua/2023/01/25/novyna/bezpeka/ataka-rosijskyx-terorystiv-ukrayinu-vybuxy-chuty-zaporizhzhi-xersoni-dnipri-ta-xarkovi

327. У Запоріжжі та Кривому Розі пролунали потужні вибухи » Слово і Діло [Internet]. [cited 2024 Mar 22]. Available from: https://www.slovoidilo.ua/2023/01/27/novyna/suspilstvo/zaporizhzhi-ta-kryvomu-rozi-prolunaly-potuzhni-vybuxy-podrobyczi

328. Центр медстатистики - Статистичні дані системи МОЗ [Internet]. [cited 2024 Mar 13]. Available from: http://medstat.gov.ua/ukr/statdanMMXIX.html

329. Project Jupyter [Internet]. [cited 2024 Apr 19]. Available from: https://jupyter.org

330. R Core Team. R: A language and environment for statistical computing. [Internet]. Vienna, Austria: R Foundation for Statistical Computing, Vienna, Austria.; 2022. Available from: https://www.R-project.org/

331. Ferlay J, Shin HR, Bray F, Forman D, Mathers C, Parkin DM. Estimates of worldwide burden of cancer in 2008: GLOBOCAN 2008. Int J Cancer. 2010;127(12):2893–917.

332. Qin X, Zi H, Zeng X. Changes in the global burden of untreated dental caries from 1990 to 2019: A systematic analysis for the Global Burden of Disease

study. Heliyon. 2022 Sep 21;8(9):e10714.

333. Box GEP, Jenkins GM, Reinsel GC. Time Series Analysis: Forecasting and Control. 3rd Edition. Englewood Cliffs: Prentice-Hall; 1994.

334. Викиди забруднюючих речовин і парникових газів у атмосферне повітря від стаціонарних джерел забруднення [Internet]. [cited 2024 Mar 31]. Available from: https://www.ukrstat.gov.ua/operativ/operativ2018/ns/vzap/arch_vzrap_u.htm

335. Програма державного моніторингу у галузі охорони атмосферного повітря на 2023 – 2027 роки Дніпропетровської зони (State monitoring program in the field of atmospheric air protection for 2023-2027 of the Dnipropetrovsk zone) [Internet]. Dnipro regional council; 2023 [cited 2023 Dec 12]. Available from: https://oblrada.dp.gov.ua/rishennia/%d0%bf%d1%80%d0%be-%d0%bf%d1%80%d0%be%d0%b3%d1%80%d0%b0%d0%bc%d1%83-%d0%b4%d0%b5%d1%80%d0%b6%d0%b0%d0%b2%d0%bd%d0%be%d0%b3%d0%be-%d0%bc%d0%be%d0%bd%d1%96%d1%82%d0%be%d1%80%d0%b8%d0%bd%d0%b3%d1%83-2/

336. Huang Z, Xu X, Ma M, Shen jw. Assessment of NO2 population exposure from 2005 to 2020 in China. Environ Sci Pollut Res. 2022 Jun 17;29:1–15.

337. US EPA. Guidelines for the Health Risk Assessment of Chemical Mixtures [Internet]. 2014 [cited 2024 Apr 22]. Available from: https://www.epa.gov/risk/guidelines-health-risk-assessment-chemical-mixtures

338. Державна служба статистики України. Статистичний щорічник України 2021. Державна служба статистики України; 2022.

339. Turner MC, Krewski D, Diver WR, Pope CA, Burnett RT, Jerrett M, et al. Ambient Air Pollution and Cancer Mortality in the Cancer Prevention Study II. Environ Health Perspect. 2017 Aug 21;125(8):087013.

340. Youogo LMAK, Parent ME, Hystad P, Villeneuve PJ. Ambient air pollution and prostate cancer risk in a population-based Canadian case-control study. Environ Epidemiol Phila Pa. 2022 Aug;6(4):e219.

341. Sun M, Gao M, Luo M, Wang T, Zhong T, Qin J. Association between air

pollution and primary liver cancer in European and east Asian populations: a Mendelian randomization study. Front Public Health. 2023 Jul 27;11:1212301.

342. Державна служба статистики України, Головне управління статистики у Дніпропетровській області. Довкілля Дніпропетровщини. Статистичний збірник. 2020. 2021.

343. Fedorenko ZP, Goulak LO, Gorokh YL, Ryzhov AYu, Soumkina OV, Koutsenko LB. Bulletin of the National Cancer Registry of Ukraine [Internet]. Vol. 23. National Cancer Registry of Ukraine; 2022. 86 p. Available from: http://www.ncru.inf.ua/

344. Інфекційна захворюваність населення України | Центр громадського здоров'я [Internet]. [cited 2024 Mar 31]. Available from: https://phc.org.ua/kontrol-zakhvoryuvan/inshi-infekciyni-zakhvoryuvannya/infekciyna-zakhvoryuvanist-naselennya-ukraini

345. Ukraine Refugee Situation [Internet]. [cited 2022 Sep 29]. Available from: https://data.unhcr.org/en/situations/ukraine

346. ГОЛОВНЕ УПРАВЛІННЯ СТАТИСТИКИ У ДНІПРОПЕТРОВСЬКІЙ ОБЛАСТІ (The Main Statistics Department in Dnipro Region) [Internet]. Available from: http://www.dneprstat.gov.ua/

Appendix

Tables with prediction of air pollutants levels in the days of missile attacks using ARIMAX modelling.

Pollutant	Model	Coefficient (95% CI)	p value	Relative change
$PM_{2.5}$	Attacks	1.89 (0.133–3.639)	0.035	7.12% (–7.92%; 31.38%)
	Attacks + weather	1.67 (–0.081–3.412)	0.062	15.20% (2.54%; 31.78%)
PM_{10}	Attacks	4.79 (1.948–7.637)	0.001	14.77% (–1.60%; 37.72%)
	Attacks + weather	4.85 (2.226–7.468)	<0.001	21.05% (6.44%; 39.10%)
NO_2	Attacks	0 (–0.003–0.001)	0.215	–1.67% (–6.51%; 3.47%)
	Attacks + weather	0 (–0.002–0.001)	0.655	–0.54% (–4.14%; 2.89%)
CO	Attacks	0.01 (–0.012–0.032)	0.366	2.25% (–1.01%; 7.00%)
	Attacks + weather	0.02 (–0.004–0.036)	0.124	3.26% (0.19%; 7.84%)
Formaldehyde	Attacks	0 (–0.066–0.065)	0.994	–1.15% (–2.28%; 0.36%)
	Attacks + weather	0 (–0.019–0.019)	1	1.26% (–2.61%; 8.06%)
NH_3	Attacks	0 (–0.003–0.003)	0.843	8.38% (–2.45%; 29.24%)
	Attacks + weather	0 (–0.004–0.004)	0.907	5.49% (–0.10%; 13.70%)

Table 4.52 The impact of missiles attacks on daily average levels of air pollutants in Dnipro. EcoCity data.

Pollutant	Model	Coefficient (95% CI)	p value	Relative change
$PM_{2.5}$	Attacks	0.74 (–2.319–3.797)	0.636	8.41% (–6.15%; 22.90%)
	Attacks + weather	0.57 (–3.855–4.988)	0.802	11.00% (–6.93%; 39.39%)
PM_{10}	Attacks	2.45 (–2.830–7.724)	0.364	11.14% (–4.87%; 25.91%)
	Attacks + weather	2 (–3.477–7.468)	0.475	10.83% (–4.59%; 28.26%)

NO_2	Attacks	0 (-0.002-0.002)	0.892	-4.02% (-12.66%; 0.26%)
	Attacks + weather	0 (-0.002-0.000)	0.091	0.03% (-7.32%; 5.64%)
CO	Attacks	0.03 (-0.269-0.324)	0.856	5.34% (-0.96%; 14.83%)
	Attacks + weather	0.01 (-0.339-0.368)	0.936	6.16% (1.90%; 16.60%)
Formaldehyde	Attacks	0 (-0.005-0.005)	0.98	-2.21% (-6.39%; 0.56%)
	Attacks + weather	0 (-0.004-0.004)	0.912	-0.80% (-5.15%; 2.82%)
NH_3	Attacks	0 (-0.005-0.004)	0.928	2.20% (-2.23%; 7.37%)
	Attacks + weather	0 (-0.007-0.007)	0.971	-0.93% (-6.73%; 2.11%)

Table 4.53 The impact of missiles attacks on daily average levels of air pollutants in Kryvyi Rih. EcoCity data.

Common conclusions

The presented report summarised current body of evidence of influence of military conflicts on air pollution and cancer epidemiology. The presented study concentrated on findings from Montenegro, North Macedonia and Ukraine where military conflicts took place recently or are ongoing.

Similar consequences of military conflicts were revealed in all three studied countries. In all cases a massive ecological impact was described. Immediate worsening of air quality due to explosions, fires and destruction of civil and industrial infrastructure was found. It is reasonable to suggest that war had contributed significantly to the long-term contamination of water and soil. Lacking of historical data and technical limitations of data collection are among the main obstacles for the conclusive research on the subject.

In each country there were short- and long-term negative consequences in cancer epidemiology due to military actions. A steady increase in cancer epidemiology after 2010 was observed, which could be related to the past or ongoing military conflicts. The increase in cancer incidence and mortality correlated with the deterioration of ecological situation. However, the isolated impact of war on cancer epidemiology requires further clarification, since other influential factors were present: destruction of medical infrastructure, massive displacements, decreased access to healthcare, stress, behavioural factors. Another challenge for drawing solid conclusions about impact of war on cancer epidemiology is lacking of either historical data on cancer incidence and mortality from Montenegro and North Macedonia, or current data from Ukraine.

The results of the conducted study allow to define the following priorities in dealing with the war-related consequences for cancer epidemiology:

- Development of ecological monitoring programs, including air, water and soil condition surveillance. The emphasis should be made on accessibility of ecological monitoring data to ensure the timely analysis and adequate relation depending on the obtained results.
- Conducting more rigorous longitudinal cohort studies of the affected by war population during and immediately after the conflicts is needed. Unique situation in each military conflict requires extensive data for designing proper mitigation strategies.

- Development of policy recommendations at the European level. The aim of such recommendation is to reduce the negative impact of the military conflicts both at national and international levels. Policy recommendations designing is foreseen in the upcoming work packages of the current project.
- Reducing influence of cancer risk factors on the population via intensification of preventive campaigns. Cooperation of healthcare specialists with relevant stakeholders should ensure adequate accessibility of healthcare services along with promotion of healthy behaviours in the populations affected by war.