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THE INFLUENCE OF MILITARY ACTIONS ON ATMOSPHERIC AIR QUALITY IN UKRAINE

During the research of the assessment of the consequences of military actions on atmospheric air quality, general scientific research methods were used: methods of analysis and synthesis, which involve the collection, analysis and generalization of information. Information on the assessment of the consequences of military actions on atmospheric air quality in Ukraine and the world was collected, analyzed, structured and summarized. The main sources of emissions of pollutants during military operations were analyzed and identified. It was established that they can be divided into three groups: 1) emissions of pollutants as a result of explosions and shelling of industrial facilities; 2) emissions of pollutants due to fires in ecosystems; 3) emissions due to the burning of fuel by military transport. A number of pollutants entering the atmospheric air from the specified sources have been identified. All pollutants are divided into three groups. The first group is the main pollutants ($PM_{2.5}$, PM_{10} , O_3 , SO_2 , CO , NO_x , heavy metals, etc.). The second group is specific pollutants (a huge variety of them is introduced). The third group is greenhouse gases (CO_2 , CH_4 , N_2O). It has been determined that pollutant emissions based on the required input information on fuel mass or burning area can be estimated using emission factors used in EPA, EMEP, etc. reports. In the absence of emission factors, pollutant emissions can be specified taking into account the technical requirements of atmospheric transfer models. As a result of constant bombings, artillery fire, fires and accidents that occur, the movement of heavy military transport, there is a significant emission of pollutants into the atmosphere. It has a very negative effect on its quality. Knowing the causes and sources of pollution, as well as pollutants entering the air as a result of military actions, is extremely important and relevant. After all, this will directly help to assess the consequences of such an impact on the life and health of the population and can become indisputable evidence for the state when deciding the issue of reparations.

Keywords: air pollution, emission factors, military actions, explosions, fires, fuel burning.

Introduction. Scientists have estimated that over the past 5500 years, the world's population has survived 14 550 thousands small and large wars, in which 3640.5 million people died. The wars of the 20th century fundamentally differed from the previous ones in the scale, maneuverability and duration of military actions, exceptional cruelty and severe consequences for the warring states. 38 countries were involved in the First World War of 1914–1918. Military actions were conducted on the territory of 4.1 million km². About 100,000 tons of toxic substances were produced by the industry of the warring states. The total number of people affected by toxic substances was 1.3 million. The Second World War was the most destructive war in human history. 61 states, more than 1.7 billion people participated in it. Military actions were conducted on the territory of 40 states with a total area of 22.6 million km² (Dovhusha, Kudryn, Tykhonov, 1995).

The aggression of the Russian Federation against Ukraine, which began in 2014 with the occupation and annexation of Crimea and heavy hostilities in the east of Ukraine, turned into a full-scale invasion of the Russian Federation troops on the territory of our state on February 24, 2022. Heavy and prolonged hostilities cause very significant environmental damage. The consequences of such damage are negative not only for the territories where active hostilities are taking place, but also for the rest of the territory of Ukraine and neighboring countries. In the course of hostilities, there is significant pollution of the environment with chemical toxic pollutants, highly active poisonous pollutants, metal fragments and heavy metals. Atmospheric air is one of the main components of the natural environment. It is an integral part of human life and other living organisms. As a result of constant bombings, artillery fire, fires and accidents that occur, the movement of heavy military transport, there is a significant emission of pollutants into the atmosphere. It has a very negative effect on its quality. Therefore, the issue of atmospheric air pollution caused by explosions, fires at oil depots, chemical plants, ecosystems, and the movement of heavy military transport is extremely relevant today. Knowing the causes and sources of pollution, as well as pollutants entering the air as

a result of military actions, is extremely important. After all, this will directly help to assess the consequences of such an impact on the life and health of the population and can become indisputable evidence for the state when deciding the issue of reparations.

Analysis of recent studies and publications. Despite numerous wars in certain regions of the world, the global experience of assessing the consequences for atmospheric air quality as a result of military actions is insignificant. The most detailed information is available for the Persian Gulf War of 1990–1991. For this war, pollutant emissions were estimated. It was established that during the war, the atmospheric air received: carbon dioxide (CO_2) – 71 million tons, solid dust particles – 6959 tons (of which elemental carbon (C) – 4911 tons), carbon monoxide (CO) – 42160 tons, nitrogen oxides (NO_x) – 107086 tons, sulfur oxides (SO_x) – 270 tons. Emissions of other pollutants were much smaller (Sadiq, McCain, 1993).

It was established that a significant part of the emissions came from the operation of machinery on diesel fuel. Industrial objects containing dangerous and toxic pollutants suffered a lot of destruction. However, the lack of information about the fact of the presence of these pollutants in the damaged objects and their quantity led to the lack of assessments regarding the consequences of such emissions. A number of highly dangerous chemicals were released during shell explosions. However, no estimates have been made due to military secrecy regarding the statistics of such explosions (Sadiq, McCain, 1993). It was found that a significant part of the emissions of particulate matter during the Persian Gulf War came from the movement of military machines, dust raising, soil erosion, etc. (Sadiq, McCain, 1993). Total emissions from the use of military machines were also assessed during the Persian Gulf War. In particular, fighters, helicopters, airplanes, tanks, military vehicles and armored vehicles were taken into account. Calculations are based on the average number of military movements and the amount of fuel used (Sadiq, McCain, 1993). During the Persian Gulf War, it was determined that one of the largest sources of emissions was the burning of oil and damage to oil wells. During this, measurements of Na, Al, S, Cl, SO_4 , SO_2 ,

VOC, C, PHCs, PM₁₀, benzo(a)pyrene were carried out, including with the involvement of a German mobile laboratory (Austin, Bruch, 2000).

Estimates of the distribution of emissions from oil burning sites were actively carried out with the involvement of modeling using the HYSPLIT and CALPUFF models. In particular, the modeling was carried out by Saudi Arabia, Iran and Kuwait. Iran used satellite sensing to confirm modeling pollutant transport events (Payne, Sand, 2011). Considerable attention was also paid to the issue of assessing economic losses and paying reparations. After the Persian Gulf War, Saudi Arabia demanded reparations for crop losses due to air pollution from oil burning (Payne, Sand, 2011). Considerable attention was paid to the assessment of population health consequences. Saudi Arabia investigated the issue of the increase in mortality among the population, which was caused by an increase in the number of chronic diseases resulting from long-term exposure of the human body to atmospheric air pollutants. Iran has also investigated the issue of population health damage due to emissions from oil burning. Both countries included medical expenses in the calculation of losses due to the increase in morbidity after oil burning. Impacts were determined using atmospheric transport modeling, the results of which were supported by satellite sounding data on the spread of emissions. The increase in cases was compared with previous years. The increase in morbidity was recorded in a 200-kilometer zone from the territory of Kuwait. In total, Iran accounted for an additional 3263 cases of disease due to oil burning pollution (Payne, Sand, 2011). Kuwait and Saudi Arabia assessed mortality from PM₁₀ air pollution. Since it is impossible to identify the number of deaths, they used special mathematical models that combine information about exposure and the expected increase in mortality due to said exposure. Kuwait assessed pollution not only from burning oil, but also from rising dust in the deserts and from the burning of diesel fuel by heavy military machines. Kuwait estimates were made using CALPUFF and HYSPLIT models (Payne, Sand, 2011).

The issue of the consequences of military actions on atmospheric air quality was not actively considered in Ukraine. Some scientists studied the consequences of military actions for the East of Ukraine. For example, the work (Lisova, 2017) highlights the ecological danger of military actions in Ukraine. The results of research by the International Charity Organization "Ecology – Law – Man" and the Eastern Ukrainian Ecological Institute were analyzed. The impact of military actions on all spheres of the geographical envelope is characterized. Attention is focused on the flooding of mines and the exit of mine waters to the surface, the destruction of treatment facilities, chemical and radiation pollution of water resources, pollution of atmospheric air and soils, the destruction of landscapes, vegetation, and large areas of forests. The work (Kravchenko, Vasyliuk, Voitsikhovska, Norenko, 2015) analyzed the main factors of environmental pollution and destruction as a result of military actions in Eastern Ukraine. Areas destroyed by fire were calculated, the dynamics of fires in the East of Ukraine were analyzed, and compared to previous years, the soils of the Krasnolymansky District and the water of the Siverskyi Donets river were analyzed.

The purpose of the study. To analyze the main sources of atmospheric air pollution as a result of military actions on the territory of Ukraine. To establish pollutants entering the atmosphere as a result of bombings, artillery shelling, fires and accidents, movement of heavy military machines. To

analyze methods of assessment of emissions of pollutants and their consequences.

Methodology and methods. During the study of the assessment of the consequences of military actions for atmospheric air quality, general scientific research methods were used. Namely, the methods of analysis and synthesis, which involve the collection, analysis and generalization of information. Information on the assessment of the consequences of military actions for atmospheric air quality in Ukraine and the world was collected, analyzed, structured and summarized. In addition, descriptive and comparative geographical research methods were applied.

Results. Main sources of emissions. Military actions lead to emissions of pollutants into the atmosphere through various processes, including: explosions and destruction of industrial facilities; damage to oil and gas pipelines; shell explosions; fuel burning by heavy military, sea and air machines; fires in ecosystems, residential and non-residential premises, oil depots, etc. Among the available sources of emissions, the most powerful and dangerous are explosions at industrial facilities and numerous unorganized emissions. A significant number of pollutants enter as a result of fires in ecosystems caused by military actions and fuel burning by military machines. Unorganized emissions, including explosions at oil depots and damage to oil pipelines, lead to the release of such pollutants into the atmosphere as nitrogen compounds (NO_x), carbon monoxide (CO), sulfur dioxide (SO₂), non-methane volatile organic compounds (NMVOCs), heavy metals, benzo(a)pyrene (C₂₀H₁₅), greenhouse gases, soot (black carbon) and solid dust particles (PM₁₀ and PM_{2.5}) (Venting and flaring, 2019). During the Persian Gulf war, oil wells were actively burning, and the spread of plumes of polluted air was observed. The composition of these plumes was studied. During this study, the following chemical components of atmospheric air were detected: sodium (Na), aluminum (Al), sulfur (S), chlorine (Cl), sulfur oxides (SO_x), volatile organic compounds (VOC), polyhalogen compounds (PHCs), PM₁₀, benzo(a)pyrene (C₂₀H₁₅) (Development of emissions inventory methods for Wildland Fire. EPA Final Report, 2002).

Ecosystem fires lead to rapid burning of biomass. They can be fixed both by satellite data and by the data of the State Emergency Service of Ukraine. These fires contribute to emissions of pollutants, including nitrogen compounds (NO_x), carbon monoxide (CO), sulfur dioxide (SO₂), non-methane volatile organic compounds (NMVOCs), ammonia (NH₃); greenhouse gases, soot (black carbon), solid dust particles (PM₁₀ and PM_{2.5}) (Austin, Bruch, 2000, Field burning of agricultural residues, 2019; Forest fires, 2019). The burning of fuel by military machines leads to the release of the following pollutants into the atmosphere: nitrogen compounds (NO_x), carbon monoxide (CO), sulfur dioxide (SO₂), non-methane volatile organic compounds (NMVOCs), heavy metals, benzo(a)pyrene (C₂₀H₁₅), ammonia (NH₃), greenhouse gases, solid dust particles (PM₁₀ and PM_{2.5}), etc. (Road transport, 2019; Aviation, 2019; Navigation (shipping) 2019). Statistical data on the use of shells, missiles, bombs, the number of launches and explosions can be complicated by military secrecy and insufficient information on the pollutants used in a particular type of projectile (Sadiq, McCain, 1993). Typical substances used to initiate the explosion reaction are: lead azide (Pb(N₃)₂), lead styphnate (C₆H₃N₃O₈Pb), lead mononitroresorcinat (C₁₂H₈N₂O₈Pb), potassium dinitrobenzofuroxan, barium styphnate (C₆H₃BN₃O₈), zirconium – potassium perchlorate, and others (Sadiq, McCain, 1993). Such

processes as mechanical destruction and dismantling of rubble are a source of emissions of solid dust particles into the atmosphere (Construction and demolition, 2019).

List and classification of pollutants. To create a list and further classification of pollutants that can be taken into account as a result of military actions on the territory of Ukraine, international recommendations and national methods, which are in a certain way oriented to the internal characteristics of atmospheric air pollution and emission sources, are taken into account. According to the reports of the World Health Organization (WHO), the main scientifically proven air pollutants that affect public health include dust particles suspended in the air (PM₁₀ та PM_{2.5}) and gaseous pollutants, including: ozone (O₃), sulfur dioxide (SO₂), carbon monoxide (CO), nitrogen compounds (NO_x) and heavy metals (in particular, cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), chromium VI (Cr (VI)), nickel (Ni)) (*Ambient (outdoor) air pollution, 2021; Review of evidence on health aspects of air pollution – REVIHAAP: technical report. Copenhagen: WHO Regional Office for Europe, 2013; State of Global Air, 2018; Health Risks of Air Pollution in Europe – HRAPIE: Technical Report. Copenhagen: WHO Regional Office for Europe, 2014; 1998 Protocol on Heavy Metals, 2012*). In the European Directives, atmospheric air pollutants are considered to be: PM₁₀ і PM_{2.5}, O₃, SO₂, NO_x, CO, Pb, Cd, As, Ni, benzene (C₆H₆), and benzo(a)pyrene (C₂₀H₁₅) (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; Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air).

In Ukraine, the approved methods of the Ministry of Emergency Situations (now the State Service of Ukraine for Emergency Situations) are used to assess the consequences of accidents with emissions of highly toxic pollutants into the air (*Metodyka prohnozuvannya naslidkiv vylyvu (vykydu) nebezpechnykh khimichnykh rehovyn pry avariakh na promyslovykh ob'ektakh i transporti, 2001*), as well as methods (*Methodology for identifying and*

assessing the chemical situation during the destruction (accident) of objects containing highly toxic substances, 1989; *Methodology for predicting the scale of contamination with highly active toxic substances in case of accidents (destructions) at chemically hazardous facilities and transport, 1991*).

The methodology of the Ministry of Emergency Situations allows calculations for 28 chemically hazardous substances. Among them, 8 are the main ones: chlorine (Cl₂), ammonia (NH₃), sulfur dioxide (SO₂), hydrogen sulfide (H₂S), carbon disulfide (CS₂), hydrochloric acid (HCl), chloropicrin (CCl₂NO₂), formaldehyde (CH₂O); and 20 additional ones: aniline (C₆H₇N), vinyl chloride (C₂H₃Cl), hydrogen fluoride (HF), hydrogen cyanide (HCN), divinyl or butadiene (C₄H₆), dimethylamine (C₂H₇N), ethylene (C₂H₄), chloride (R-COCl), ethyl mercaptan (C₂H₆S), ethyl chloride (C₄H₄Cl₂O₃), methylamine (CH₃NH₂), methyl chloride (CH₃Cl), acrylic acid nitrile (C₃H₃N), nitrobenzene (C₆H₅NO₂), ethylene oxide (C₂H₄O), nitrogen oxides (N_xO_y), oleum or sulfur acid (H₂SO₄), styrene (C₈H₈), tetraethyl lead (C₈H₂₀Pb), furfural (C₅H₄O₂). *Methodology (Methodology for identifying and assessing the chemical situation during the destruction (accident) of objects containing highly toxic substances, 1989)* is used to perform calculations for 18 hazardous chemical substances: Cl₂, dioxin (C₄H₄O₂), amyl (N₂O₄), nitric acid (HNO₃), heptyl (C₂H₈N₂), hydrazine (N₂H₄), ammonia NH₃, dichloroethane (C₂H₄Cl₂), carbon monoxide (CO), acrylonitrile (C₃H₃N), sulfur dioxide (SO₂), carbon disulfide (CS₂), C₈H₂₀Pb, phosgene (COCl₂), hydrogen fluoride (HF), CCl₂NO₂, HCN. Greenhouse gases can be considered separately, in particular, carbon dioxide (CO₂), methane (CH₄) and nitrogen oxide (N₂O) (Greenhouse gases. World Meteorological Organization, Overview of Greenhouse Gases) that can be emitted in significant quantities in atmosphere as a result of military actions.

After analyzing the information on possible sources of emissions, the above-mentioned methods and standards, as well as the peculiarities of assessing the consequences of exposure to individual pollutants, all chemical components can be divided into three groups: basic, specific, and greenhouse gases (Table 1).

Table 1. Classification of pollutants, taking into account the sources of emissions, regulatory documents and the possibility of impact assessment

Basic	Specific	Greenhouse gases
PM _{2.5} , PM ₁₀ , O ₃ , SO ₂ , CO, NO _x , heavy metals (Cd, Pb, Hg, As, Cr (VI), Ni, Se, Zn), (Cl ₂ , NH ₃ , CS ₂ , H ₂ S, HCl, CCl ₃ NO ₂ , CH ₂ O, C ₆ H ₆ , C ₂₀ H ₁₅)*	C ₆ H ₇ N, C ₂ H ₃ Cl, HF, HCN, C ₄ H ₆ , C ₂ H ₇ N, C ₂ H ₄ , R-COCl, C ₂ H ₆ S, C ₄ H ₄ Cl ₂ O ₃ , CH ₃ NH ₂ , CH ₃ Cl, C ₃ H ₃ N, C ₆ H ₅ NO ₂ , C ₂ H ₄ O, H ₂ SO ₄ , C ₈ H ₈ , C ₈ H ₂₀ Pb, C ₅ H ₄ O ₂ , C ₄ H ₄ O ₂ , N ₂ O ₄ , HNO ₃ , C ₂ H ₈ N ₂ , N ₂ H ₄ , C ₂ H ₄ Cl ₂ , C ₃ H ₃ N, COCl ₂ , CCl ₂ NO ₂ , NMVOCs, POPs, BC, OC	CO ₂ , CH ₄ , N ₂ O

*are considered specific in some methods.

Methods of estimating emissions and their consequences. There are known methods for estimating emissions and their consequences (*Metodyka prohnozuvannya naslidkiv vylyvu (vykydu) nebezpechnykh khimichnykh rehovyn pry avariakh na promyslovykh ob'ektakh i transporti, 2001; Methodology for identifying and assessing the chemical situation during the destruction (accident) of objects containing highly toxic substances, 1989; Methodology for predicting the scale of contamination with highly active toxic substances in case of accidents (destructions) at chemically hazardous facilities and transport 1991*), to date in Ukraine. The main quantities used in these methods are the mass of the primary cloud m_0 and the evaporation time of the secondary cloud τ , which can be used to model the further distribution of pollutants in the

atmosphere. If the total mass of the substance m , which was in the damaged container or was formed during a spill, is known, then in the presence of the parameters m_0 and τ , the further spread can be modeling by atmospheric transfer models, specifying two sources: instantaneous, with a mass of m_0 and long-term, with an intensity of $Q = (m - m_0)/\tau$. In some cases, the time-dependent evaporation intensity Q_e and the spill radius r may also be of interest for modeling.

Use of emission factors. Today, one of the most popular methods for determining emissions of pollutants in the world is the use of emission factors. The use of emission factors is usually the basis of reporting by many international organizations regarding the entry of pollutants into the atmosphere. A fundamental work based on the use of

emission factors recognized in use by various international organizations is the work (Lemieux, Lutes, Santoianni, 2004). This work is devoted to the analysis of combustion processes in the open air. European Monitoring and Evaluation Program (EMEP) approaches can be used to estimate pollutant emissions (EMEP Program Page). Also the methods of the US Environmental Protection Agency (US EPA) (EPA GHG Emission Factors Hub). EMEP contains a database of emission factors (EMEP: emission factors database), using which emissions can be estimated according to the general formula:

$$\text{Emission} = \text{source activity} * \text{emission factor} \quad (1)$$

The EMEP provides reference information for calculating emissions by sector whose emission factors can be represented as emission factors for calculating the effects of military action. These are the following sectors: fuel burning during industrial processes in the energy sector; the aviation sector, in particular emissions from military aviation; burning of various types of fuel by vehicles; emissions of the chemical industry; industrial production of mineral raw materials; emissions during the destruction or clearing of the territory from debris; fires in agricultural fields; emissions from sea transport, including warships; unorganized emissions, including emissions on gas pipelines. A separate user guide has been created for all sectors, which contains emission factors for pollutions entering the atmosphere as a result of the activities of each sector.

Fires in ecosystems make a significant contribution to the increase in emissions of pollutants during military actions. To estimate emissions during fires in ecosystems, it is important to know: 1) the burned area and the type of vegetation; 2) the volume of the burned substance and its characteristics; 3) fuel consumption; 4) emissions of pollutions entering the air as a result of combustion. There is a set of formulas for calculating each component. Emissions will be calculated according to the following formula:

$$E = S \cdot EF \quad (2)$$

where E – substance emission [kg]; S – area of the fire (area of the burned territory) [ha]; EF – emission factor of the substance [kg/ha].

Fires at oil depots, oil and gas pipelines and accidents accompanied by the burning of oil products are powerful sources of emissions of pollutants. Their emissions can be calculated using the EMEP method, with a general emission calculation formula using source activity and an emission factor. In the case of explosions at oil depots or other similar cases, the activity of the source will be considered the amount of substance (eg oil products) burned. Emission factors can be used by linking either to the amount of substance or to energy in gigajoules, which may also depend on the amount of substance (EMEP Guidebook. Energy. Fugitives, 2019). To estimate emissions from the movement of heavy ground military machines, you can use the estimates that have been made for diesel-powered trucks. For the activity of the source, in this case, the amount of burned fuel is taken (EMEP Guidebook. Combustion, 2019). The US Environmental Protection Agency (EPA) performed an assessment of emission factors for greenhouse gases. Emissions of greenhouse gases during fires, accidents, fuel burning should also be taken into account as consequences of military actions. Typically, emission factors are defined for CO₂, CH₄ and N₂O (EPA.

GHG Emission Factors Hub). There are also EPA emission factors for rockets, projectiles, and detonation. Emission factors for determining pollutant emissions from ordnance detonation are in EPA reports (AP 42, Fifth Edition, Volume I Chapter 15: Ordnance Detonation). In particular, there are emission factors for a number of basic and toxic substances for different types of ammunition. Among them are: ammunition with a caliber of less than 30 mm; ammunition with a caliber of 30 – 75 mm; ammunition with a caliber greater than 75 mm; grenades; anti-tank missiles; etc.

To date, an operational headquarters has been established in Ukraine, on the basis of the State Environmental Inspection of Ukraine, which is a consortium of a large number of scientists and specialists in various fields. This headquarters is engaged in the development of a complex methodology for assessing the damage and consequences of military actions on the territory of Ukraine. Until, in April 2022, a methodology was approved for calculating unorganized emissions of pollutants or a mixture of such substances into atmosphere as a result of emergency situations and/or during martial law and determining the amount of damage caused (*Metodyka rozrakhunku neorhanizovanykh vykydiv zabrudniuchykh rehovyn abo sumishi takykh rehovyn v atmosferne povitria vnaslidok vynyknennia nadzvychainykh situatsii ta/abo pid chas dii voiennoho stanu ta vyznachennia rozmiriv zavadanoi shkody*, 2022). This technique uses an EMEP-like approach to determining pollutant emissions.

Conclusions. The entry of pollutants into the atmosphere as a result of military actions is very diverse. And the list of pollutants is extremely wide. Sources of emissions of pollutants during military actions can be divided into three groups: 1) emissions of pollutants as a result of explosions and shelling of industrial facilities; 2) emissions of pollutants due to fires in ecosystems; 3) emissions due to the burning of fuel by military transport.

All pollutants that can be taken into account during the assessment of the damage caused are better classified into three groups. The first group is the main pollutants (PM_{2.5}, PM₁₀, O₃, SO₂, CO, NO_x, heavy metals, etc.) whose emissions are recommended to be estimated in general over a certain period of time. The second group is specific pollutants that can be modeled for each individual case, have a quick dangerous effect and are used to assess risks to public health. The third group is greenhouse gases, the emissions of which can be estimated in general over a certain period of time.

Pollutant emissions based on required input information on fuel mass or burning area can be estimated using emission factors used in EPA, EMEP, etc. reports. In the absence of emission factors, pollutant emissions can be specified taking into account the technical requirements of atmospheric transfer models.

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ВПЛИВ ВІЙСЬКОВИХ ДІЙ НА ЯКІСТЬ АТМОСФЕРНОГО ПОВІТРЯ В УКРАЇНІ

Під час дослідження питання оцінювання наслідків військових дій для якості атмосферного повітря було використано загальнонаукові методи дослідження: методи аналізу та синтезу, що передбачають збір, аналіз і узагальнення інформації. Було зібрано, проаналізовано, структуровано й узагальнено інформацію про оцінювання наслідків військових дій для якості атмосферного повітря в Україні та світі. Проаналізовано та виділено основні джерела викидів забруднювальних речовин під час військових дій. Установлено, що їх можна поділити на три групи: 1) викиди забруднювальних речовин унаслідок вибухів та обстрілів об'єктів промисловості; 2) викиди забруднювальних речовин унаслідок пожеж у екосистемах; 3) викиди внаслідок спалювання палива військовою технікою. Визначено низку забруднювальних речовин, що потрапляють в атмосферне повітря із зазначених джерел. Усі забруднювальні речовини поділено на три групи. Перша група – основні речовини (PM_{2.5}, PM₁₀, O₃, SO₂, CO, NO_x, важкі метали тощо). Друга група – специфічні забруднювальні речовини (їх унесує величезна різноманітність). Третя група – парникові гази (CO₂, CH₄, N₂O). Визначено, що викиди забруднювальних речовин на основі необхідної вхідної інформації про масу палива чи площу горіння можуть бути оцінені із застосуванням емісійних факторів, що використовуються у звітах EPA, EMEP тощо. У випадку відсутності емісійних факторів, параметри викидів забруднювальних речовин можуть задаватися враховуючи технічні вимоги моделей атмосферного перенесення. Унаслідок постійних бомбардувань, артилерійських обстрілів, пожеж та аварій, що виникають, руху важкої військової техніки, відбувається значна емісія забруднювальних речовин у атмосферне повітря. Це дуже негативно впливає на його якість. Знати причини та джерела забруднення, а також речовини, що надходять у повітря внаслідок військових дій надзвичайно важливо й актуально. Адже це безпосередньо допоможе оцінити наслідки такого впливу на життя і здоров'я населення та може стати беззаперечним доказом для держави під час вирішення питань виплати репарацій.

Ключові слова: забруднення повітря, емісійні фактори, військові дії, вибухи, пожежі, спалювання палива.