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STATE AND PROSPECTS OF USING REMOTE AIR MONITORING METHODS IN UKRAINE

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One of the strategic directions of the state environmental policy to achieve the goals of sustainable development of Ukraine on the way to approximation of national legislation to EU legislation on preventive measures to preserve air quality and inform the population about possible risks to their health is to monitor the air during martial law and post-war reconstruction of Ukraine. The article defines the requirements of international legal acts and national legislation to the existing system of organising and conducting atmospheric air monitoring, including remote sensing methods. The article analyses the use of remote sensing methods and tools as effective tools for monitoring atmospheric air under martial law in Ukraine. Modern methods of collecting and processing data obtained from international platforms by means of remote sensing and satellite images are considered. The possibilities of their application in Ukraine for the purpose of identifying sources of pollution, assessing the quality of atmospheric air for further forecasting their changes are determined. An overview of modern remote sensing tools for early warning of environmental threats, forecasting changes in the state of atmospheric air in order to optimise measures to respond to the consequences of military impact and post-war recovery in Ukraine is presented. The importance of integrating innovative methods when implementing them in the State monitoring system to ensure operational control of atmospheric air is substantiated. It is proposed to use an integrated approach, the essence of which will include the selection of environmental information with the adaptation of appropriate models for the territory and conditions of Ukraine from existing international remote monitoring bases, its verification with ground stations for the effectiveness of environmental assessment and forecasting of the state of atmospheric air. *Key words:* state environmental policy, national legislation, remote sensing, international platforms, monitoring, forecasting, atmospheric air, environmental threats, consequences of military impact.

Стан та перспективи використання в Україні методів дистанційного моніторингу атмосферного повітря. Хабарова Г.В., Коваленко Г.Д., Барбашев С.В.

Одним із стратегічних напрямків державної екологічної політики для досягнення цілей сталого розвитку України на шляху наближення національного законодавства до законодавства ЄС щодо здійснення превентивних заходів збереження якості атмосферного повітря та інформування населення про можливі ризики для його здоров'я є ведення моніторингу атмосферного повітря в умовах воєнного стану та післявоєнного відновлення України. У статті визначені вимоги міжнародних нормативно-правових актів та національного законодавства до існуючої системи організації та проведення моніторингу атмосферного повітря, у тому числі дистанційними методами спостереження. Проаналізовано застосування методів та засобів дистанційного зондування як ефективних інструментів для моніторингу атмосферного повітря в умовах воєнного стану в Україні. Розглянуто сучасні методи збору та обробки даних, отриманих із міжнародних платформ засобами дистанційного зондування та за допомогою космічних знімків. Визначено можливості їх застосування в Україні з метою виявлення джерел забруднення, оцінювання якості атмосферного повітря для подальшого прогнозування їх змін. Представлено огляд сучасних засобів дистанційного спостереження для раннього попередження екологічних загроз, прогнозування змін стану атмосферного повітря з метою оптимізації заходів для реагування на наслідки впливу воєнного характеру та післявоєнного відновлення в Україні. Обґрунтовано значимість інтеграції інноваційних методів при їх впровадженні у державну систему моніторингу з метою забезпечення оперативного контролю атмосферного повітря. Запропоновано використання комплексного підходу, сутність якого включатиме вибірку екологічної інформації із адаптацією відповідних моделей для території та умов України з існуючих міжнародних баз дистанційного моніторингу, її верифікацію із наземними станціями для ефективності екологічного оцінювання та прогнозування стану атмосферного повітря. *Ключові слова:* державна екологічна політика, національне законодавство, дистанційне зондування, міжнародні платформи, моніторинг, прогнозування, атмосферне повітря, екологічні загрози.

General statement of the problem. The existing gaps in the field of state monitoring are associated with damage to surveillance systems during military operations, the use of outdated equipment and imperfect systems for filling environmental data bases that require technical and technological re-equipment in accordance with the current requirements of international law and data protection from cyberattacks.

It should be noted that Ukraine does not currently have its own remote sensing and satellite observation systems for monitoring the state of the atmospheric air, while the security situation of the consequences of military impact requires continuous environmental information to be obtained at the state level. It should be included in national environmental databases and transferred to international platforms, such as the European

Environmental Agency (EEA) [1]. In Ukraine, there is currently no system for obtaining information in this way. The use of relevant information from international platforms for further analysis, assessment and forecasting of the state of atmospheric air in Ukraine, taking into account environmental data accumulated in international databases, will facilitate the acquisition of environmental data, especially in areas that are difficult to access for air sampling, especially under martial law. This will become an important tool for making management decisions to prevent and minimise threats to the environment and public health.

The relevance of the research. International experience shows that in order to continuously obtain correct (correct, accurate and relevant) environmental data in the organisation and conduct of air monitoring with subsequent rapid response and appropriate decision-making in the event of possible threats to the environment and public health in conditions of man-made load, emergency cases, it is advisable to use remote sensing and satellite technologies. This is also true for Ukraine, if we also take into account the consequences of the war. Environmental data on the state of the atmospheric air obtained by means of remote sensing and satellite technologies reflect data on a large scale – from local areas to entire countries. The availability of these data will allow for timely assessment of air pollution with the presentation and construction of models for forecasting changes in the state of the air, determining the directions of spread of radioactive and chemical substances, and assessing potential risks. The results obtained by means of remote monitoring are appropriate and important for the creation of a national environmental data bank and a significant addition to existing statistics when creating registers of pollutant concentrations obtained by ground-based systems. This will enable prompt measures to be taken to reduce the impact of pollutants and improve air quality both at the national and international levels, taking into account information on transboundary transfers of pollutants.

Relation of the author's work to important scientific and practical tasks. The research is carried out in accordance with the State Programme 2701040 'Scientific and Scientific and Technical Activities in the Field of Environmental Protection and Natural Resources' commissioned by the Ministry of Environmental Protection and Natural Resources of Ukraine, in accordance with the medium-term priority areas of innovation activity at the industry level 'Widespread use of cleaner production technologies and environmental protection', approved by the Resolution of the Cabinet of Ministers of Ukraine No. 787 of 5 July 2024 'Some issues of determining medium-term priority areas of innovation activity'.

Analysis of recent research and publications. Within the framework of the European Union's Copernicus Earth Observation Programme [2], which provides comprehensive information, including forecasts and analyses of the composition of the atmosphere, including the concentration of greenhouse gases, various pollutants and aerosols, the European Space Agency (ESA) [3] provides access to Sentinel satellite data and databases. Some of the EU's Copernicus CAMS satellites are equipped with instruments capable of detecting and measuring radiation contamination. The EU Copernicus Sentinel-5P series satellites are equipped with the TROPOspheric Monitoring Instrument (TROPOMI) [4], which is capable of measuring the concentrations of various gases and aerosols in the atmosphere that affect air quality and climate, and its data are used to assess atmospheric conditions that affect the spread of radioactive substances. The mechanism of radiation background measurement by the EU's Copernicus programme [2] is based on the use of specialised satellite sensors that record gamma radiation. The data undergoes a calibration and correction process, after which it is integrated with information from ground-based systems to create accurate maps of radionuclide contamination distribution. The Moderate Resolution Imaging Spectroradiometer (MODIS) [5] plays an important role in satellite Earth monitoring systems, in particular in the study of the atmosphere, as it is a medium-resolution spectrometer installed on NASA's Terra satellites [6]. The MODIS capabilities allow for the analysis of large areas, at a distance of about 2330 km, which allows for global imagery every 1-2 days. The advantages of using MODIS [5] in satellite air monitoring systems include measuring aerosol optical characteristics, which allows assessing the level of air pollution and the spread of fine particles; detecting pollution clouds, their structure, as well as tracking the concentrations of greenhouse gases and other atmospheric impurities; and global environmental control.

Various available image processing tools and software, including GIS technologies, are used to process remote sensing data.

Thus, the acquisition of environmental information by means of remote sensing has been greatly developed in different countries of the world and has expanded the possibilities of environmental monitoring. France has its own research laboratory specialising in the study of physical and chemical processes of the Earth's atmosphere and space observations (LATMOS) [7] and its own CHIMERE platform, which is implemented in the national system for air quality forecasts. In addition to Sentinel satellites, Metop-SG satellites with an innovative optical system with a high spectral resolution for passive infrared remote sensing are actively used throughout France, developed by the European Space Agency (ESA) [3]. Hungary, Spain and Morocco have implemented SAT-CEP-monitor systems [8], which are designed to effectively monitor air quality and integrate satellite data (Sentinel-5P) with local stations and forecasting capabilities in near real time. The world's first geostationary satellite for monitoring atmospheric air quality (GEMS) provides high-precision observations of atmospheric air quality

with wide coverage and hourly frequency for the East Asian region [9].

The scientific and practical experience in Ukraine is represented by the achievements of scientists of the National Academy of Sciences of Ukraine, the Ministry of Education and Science of Ukraine and the National Spacecraft Control and Testing Centre, whose research results are related to remote diagnostics of pre-emergency conditions at nuclear fuel cycle facilities using UAVs, equipped with infrared spectrometers [10], the use of UAVs (octocopters) with a gamma spectrometer to monitor the radiation situation in the areas affected by radiation sources, which allows detecting both point and distributed sources of radioactive contamination in real conditions [11]. The author of [12] proposed a conceptual approach to the development of a network of automated monitoring posts for a single integrated automated environmental radiation monitoring system in Ukraine, which combines existing automated and non-automated air radiation monitoring posts.

With regard to national legislation on atmospheric air monitoring, it should be noted that this issue is regulated by the Laws of Ukraine and regulations, which stipulate that atmospheric air monitoring is carried out, among other things, using innovative remote sensing technologies to obtain environmental data and assess the impact and forecast atmospheric air pollution. The Laws of Ukraine 'On Atmospheric Air Protection' [13] and 'On Environmental Protection' [14] provide the legal framework for monitoring the levels of radiation and chemical pollution in the atmosphere. The Resolution of the Cabinet of Ministers of Ukraine of 13 June 2024 No. 684 'Some Issues of Functioning of the State Environmental Monitoring System and its Subsystems' [15] and the Resolution of the Cabinet of Ministers of Ukraine of 14 August 2019 No. 827 'Procedure for State Monitoring in the Field of Atmospheric Air Protection' [16] provide for the use of modern state-of-the-art methods of monitoring the radiation and chemical state of the atmospheric air, including the use of remote monitoring methods.

The Law of Ukraine 'On Nuclear Energy Use and Radiation Safety' [17] and the Order of the Cabinet of Ministers of Ukraine 'On Approval of the Strategy of the Integrated Radiation Monitoring System for the Period up to 2024' [18] provide for the use of automated monitoring systems when monitoring the radiation situation.

In accordance with the reform of the national environmental policy of Ukraine on the way to EU integration and in accordance with the requirements of the Law of Ukraine 'On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period up to 2030' [19], it is envisaged to improve the radiation and chemical monitoring systems in Ukraine, which requires methodological, technical and legislative changes in accordance with international norms and standards.

In order to harmonise with the goals of the European Green Deal, the EU will significantly tighten standards for concentrations of gaseous substances and fine particles of 2.5 micrometres and less (PM2.5) in the air at the end of 2024 and achieve the set thresholds by 2030. This will be achieved through the use of satellite data, devices that measure the characteristics of objects connected to the Internet, record changes in the environment and convert the data received for further processing and integration in real time. This is done in accordance with the requirements of the new Directive 2024/2881/EU on atmospheric air quality and cleaner air for Europe [20], whose target values are adapted to the World Meteorological Organization (WMO) recommendations for 2024 [21].

Based on the implementation of European developments and their international platforms, taking into account the information received by the Ministry of Environmental Protection and Natural Resources of Ukraine in cooperation with the State Emergency Service of Ukraine on remote fire monitoring in Ukraine, the Ministry has developed its own scientific and practical experience in conducting, improving and developing radiation monitoring systems. It includes proposals of regulatory, methodological, technical nature [22], the concept of an automated system for monitoring the radiation situation in Ukraine and its improvement at NPPs [23].

It should be noted that the authors of this article have already developed and implemented the first state automated early warning system for radiation accidents: "Gamma-1 and Gamma-2 on the territory of Ukraine [24] and, taking into account the experience gained, modelled and predicted the environmental impact of NPPs and TPPs [25, 26], including in the transboundary context [27, 28].

Already then, the authors of the article proposed approaches to improving the state system of atmospheric air monitoring and developing Ukraine's own remote monitoring system, which includes the use of environmental databases formed in accordance with European standards by incorporating information obtained by remote monitoring in combination with data from stationary observation posts, its integration and verification.

Identification of previously unresolved parts of the general problem to which this article is devoted. Based on the EU's international requirements in the field of air monitoring, the EU initiatives within the framework of the European Zero Pollution Action Plan strategy have been identified [29]. The aim of the strategy is to reduce air pollution and to implement and use an integrated platform for comparing the level of pollution in different EU countries (European Air Quality Index) [30] through the use of the European satellite air monitoring programme – Copernicus Atmosphere Monitoring Service (CAMS) [2] and the transfer of monitoring data with reporting to the European Environment Agency (EEA) [1].

In line with the harmonisation of national legislation with EU requirements, in 2021 Ukraine joined the

European Air Quality Index Initiative [30]. According to this Initiative, environmental monitoring data on the state of air quality should be made available to the EEA platform [1], and radiological data should be made available to the European Radiological Data Exchange System (EURDEP) [31], which is developed and maintained by the European Commission's Joint Research Centre.

Ukraine already has experience in using international satellite technology platforms to obtain environmental monitoring data, including the European CAMS programme [2]. The State Space Agency of Ukraine and the National Space Facilities Management and Testing Centre analyse satellite images to assess changes in the state of the environment, including tracking the radiation background based on the results of atmospheric aerosol analysis using domestic and international remote sensing systems, as well as products and services created on their basis. The Ministry of Environmental Protection and Natural Resources of Ukraine, together with the State Emergency Service of Ukraine and the State Ecological Inspectorate of Ukraine, also use NASA [6] and ESA [3] satellite data to control the radiation situation and monitor forest fires in the Chornobyl zone. The public platform SaveEcoBot [32] uses international platforms of satellite remote sensing systems using NASA Terra satellites to display the results of radiation monitoring and displays the results in real time [6].

Currently, Ukraine does not have its own satellite technologies and platforms that have a database of pollutant concentrations in the air and can be used to assess the environmental status of the entire territory of the country or its individual regions. Ukraine currently has experience in using information obtained by remote sensing from international databases on forest fires [33] and dust storms. Therefore, by integrating this experience with the capabilities of international databases on other important components of atmospheric air monitoring obtained using remote sensing methods, it is possible to increase the effectiveness of the state monitoring system in terms of environmental assessment and modelling in dynamics, interactive mapping and real-time forecasting of the state of atmospheric air [33-35].

Novelty. The authors propose to supplement the existing state environmental monitoring system, which receives information from a network of stationary air monitoring stations in Ukraine [35], with an important component that uses remote monitoring methods, which consist of using modern international platforms, such as Copernicus [2] and NASA [6], to obtain environmental data, using innovative approaches in building models of the distribution of pollutants, taking into account all factors, and adaptation of the information to the territory of Ukraine and integration into its own national databases and platforms for assessing the state of the air.

The authors of this study define the term remote monitoring of the state of atmospheric air as a set of measures that involve contactless acquisition, transmission and processing of information on the state of atmospheric air using automated stations, unmanned aerial vehicles, satellite systems and other technical means without direct operator intervention.

Such an integrated approach will provide an important tool for government agencies, which will increase efficiency in decision-making and help in developing state policy and planning appropriate measures to reduce and prevent air pollution and protect the public.

Methodological or general scientific significance. The use in Ukraine of international platforms for obtaining remote air monitoring data, such as Copernicus [2] and NASA [6], and the latest satellite technologies will expand Ukraine's capabilities in collecting data on the concentration of radioactive substances, harmful chemicals and greenhouse gases in order to assess the state of the atmospheric air, track, model and predict its changes, taking into account the atmospheric processes of pollutant spreading. Combining existing national capabilities with international ones will help to provide early warning of negative processes in the air and monitor compliance with environmental standards, as well as allow for more accurate and more efficient management decisions to prevent harmful effects on the air.

To determine the possibility of implementing the proposed integrated approach in Ukraine, it is important to know the technical characteristics of remote sensing and satellite technologies in terms of obtaining environmental data in chemical and radiation monitoring of atmospheric air, as well as the aspects and advantages of their use [33, 35].

The authors of [34] note that the advantages of using the latest systems containing environmental data obtained by remote sensing are that they allow monitoring the state of atmospheric air in hard-to-reach areas in order to ensure efficiency in the event of emergencies and emergencies, and especially in martial law.

Thus, remote sensing data and satellite technologies for monitoring atmospheric air for radioactive and chemical pollution, together with data from stationary observation posts, are an important tool for timely detection and assessment of threats to improve the effectiveness of state-level warning systems and protect the public [33-35].

Conclusions. Currently, Ukraine does not have its own remote sensing systems and satellite technologies, and environmental monitoring data is provided by European and American platforms. The integration of environmental monitoring data from various sources, using satellite, aircraft, drone and ground-based systems, will provide a complete picture of the distribution of radioactive and chemical substances over a large area. This will allow us to respond to possible threats and air pollution in a timely manner. It is important to implement reforms at the legislative, organisational and methodological levels to improve the existing state environmental monitoring system. In addition, it is important to improve sensor technologies, namely the development

of new types of sensors with increased sensitivity and resolution to improve measurement accuracy through calibration between different platforms, including satellite data.

The use of satellite technologies to monitor atmospheric air for radiation and chemical pollution has a number of advantages that can significantly supplement the state monitoring system with environmental data, which is especially relevant in the context of martial law and post-war recovery in Ukraine. The use of satellite technologies, in particular the CAMS [2] and NASA [6] platforms, will increase the reliability of the results of monitoring the state of atmospheric air under conditions of man-made pollution, including during martial law in Ukraine. In addition, it will increase the efficiency of comparative analysis of air quality in different regions of Ukraine in order to identify high-risk areas, provide daily air forecasts, and monitor the process of global long-distance transport of pollutants in the air. The integration of satellite monitoring data into the state monitoring system will be useful in obtaining data for a comprehensive study of atmospheric air composition and making operational management decisions in Ukraine.

The application of the proposed integrated approach using remote sensing data and satellite technologies at the state level in the development of the state's environmental policy in accordance with the requirements of EU legislation will increase the efficiency of monitoring and obtaining a complete reliable assessment of the state of the atmospheric air with forecasting its changes and preventing possible consequences.

Prospects for using the research results. Further prospects for the development of this study are filling and creating databases for Ukraine through the use of international databases and platforms containing information obtained by remote sensing and satellite technologies, developing algorithms and models for combining this information with further integration and regulation, including with the help of artificial intelligence. The use of remotely sensed information in conjunction with information obtained from ground-based observation systems will make it possible to assess the environmental state of the air, predict its condition and minimise the impact of pollutants on public health. The implementation of the proposed integrated approach will be ensured by the availability of own databases and air monitoring platforms with verified values, which will allow for interactive mapping of the territory of Ukraine according to the list of priority air pollutants.

An important area for the development of satellite technologies in Ukraine is to attract international funds and partners with experience in satellite monitoring, especially at the initial stage of work. The ambitious goals are to create our own platforms and surveillance network that will meet European requirements, using our own satellites with integration into the international satellite surveillance network, based on the best international practices. In addition, it is important to engage international experts to train specialists in working with the latest remote monitoring systems, including processing and analysing data from such systems.

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