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THE ROLE OF MODERN REMOTE SENSING TECHNOLOGIES IN ATMOSPHERIC AIR MONITORING UNDER MARTIAL LAW IN UKRAINE

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Approaches to environmental monitoring during martial law in Ukraine are analyzed. A comprehensive approach to improving the effectiveness of monitoring during the armed aggression against Ukraine and its post-war recovery is proposed. The contribution of modern remote sensing technologies to the system of atmospheric air monitoring under martial law is investigated. The article describes remote sensing methods and analyses their effectiveness for collecting environmental data, assessing the extent of chemical and radiation pollution, and predicting changes in air quality. The limitations of using remote sensing technologies under martial law in Ukraine are considered. The importance of introducing innovative technologies to ensure environmental safety and timely response to threats caused by the consequences of the war in Ukraine is emphasized.

In accordance with the Draft Recovery Plan of Ukraine of 9 August 2022 [1], in order to further implement the objectives of the resolutions 'Implementation of the Unified Environmental Platform EcoSystem of the National Environmental Automated Information and Analytical System for Providing Access to Environmental Information and its Network'[2] and 'Reducing Environmental Risks Caused by Industrial Pollution and Critical State of Chemical, Nuclear and Radiation Safety', in order to achieve the goal of «clean and safe environment», it is necessary to implement national programmes to achieve the goals and results and implement reforms to develop and subsequently adopt the necessary legal framework in the field of environmental protection, nuclear and chemical safety, climate and sustainable use of natural resources in accordance with the requirements of EU legislation and to develop an environmental monitoring system.

At the same time, in order to achieve the strategic goal of post-war recovery, which includes minimising risks to ensure environmental safety (chemical and radiation safety) and achieving European standards of public administration in the field of environmental protection, it is important to focus on improving and implementing a comprehensive approach to organising and conducting air monitoring to quickly respond to threats and challenges or prevent the impact of potential sources of air pollution at the state level.

In Ukraine, in the context of martial law and post-war recovery, it is advisable to monitor the atmospheric air using remote sensing technologies. This will make it possible to predict changes and trends in the distribution of concentrations of pollutants in the air and their impact on climate change within the framework of the Recovery Plan of Ukraine [1], especially in areas that are inaccessible or dangerous for sampling atmospheric air by mobile monitoring stations.

EXISTING AIR MONITORING SYSTEMS IN UKRAINE AND INTERNATIONAL REQUIREMENTS FOR ENVIRONMENTAL MONITORING

In order to harmonise and implement European legislation in the field of environmental protection, rational use of natural resources and environmental safety, and in accordance with the requirements of international documents, Ukraine, according to the Law on Access to Public Information [3], should have open access to environmental information, inform the public about the state of the environment in real time and conduct long-term systematic monitoring of the state of the environment with open access to environmental information for international organisations.

Atmospheric air monitoring is a subsystem of state environmental monitoring [4, 5] and is carried out in accordance with the norms of the current national legislation of Ukraine. The main regulatory documents governing the procedure for organising and conducting atmospheric air monitoring are the Law of Ukraine 'On Atmospheric Air Protection' [6], the Law of Ukraine 'On Environmental Protection' [7], which provides for the creation of a system for monitoring and observing the state of the environment and the level of its pollution, and the Resolution of the Cabinet of Ministers of Ukraine of 14.08.2019 No. 827 'Some Issues of State Monitoring in the Field of Atmospheric Air Protection' in amended on 7 May 2024, No. 513 [8]. This resolution prescribes obtaining information on the concentration of LIST A pollutants in the air, such as SO_2, NO_2, benzene, CO, As, PM10, PM2.5, Cd, Hg, Ni, suspended particulate matter of undifferentiated composition (TSP), benzo(a)pyrene, O_3 and pollutants from LIST B, as well as indicators and components of the atmosphere, including NH_3, H_2S, soot, volatile organic hydrocarbons and others, and determination of meteorological

parameters – wind speed, wind direction, temperature, relative humidity and atmospheric pressure.

The official website of the Ministry of Environmental Protection and Natural Resources of Ukraine has created a functional module of the Ecosystem Unified Environmental Platform [2], which organisationally and functionally consists of the website and the Ecozagroza mobile application [9]. The Ecozagroza application is designed to automatically collect and record information about environmental threats in real time and with geographic reference. The Ecozagroza application provides a detailed map of air monitoring stations with the designation of stations in each region. For the radiation component assessment, it is necessary to use the map of radiation pollution and monitoring and the relevant applications for real-time threats.

The map of radiation monitoring stations in Ukraine and the results of monitoring in Kharkiv (9 stations) are shown in demonstrative Figure [9].

Map of radiation monitoring stations in Ukraine and monitoring results in Kharkiv

The data from the public monitoring system in Ukraine are displayed in the unified environmental system SaveEcoBot [10], which combines data from various platforms to collect and process information on the current state of the environment, pollution and environmental protection measures. The SaveEcoBot platform displays real-time air quality maps, a map of radiation background and statistics on online monitoring of the radiation situation around Ukrainian nuclear power plants, in Ukrainian cities for a week and their analysis for the last 48 hours, a map of fires and relevant statistics on fires in the regions of Ukraine from 24 h to 3 years, as well as wind direction and speed in Ukraine with details for each region.

In accordance with the UN Framework Convention on Climate Change [11] and the Convention on Long-range Transboundary Air Pollution [12], as well as the current Ukrainian legislation on environmental policy and climate change adaptation, statistical data on greenhouse gas emissions and air pollutants are used to assess air pollution, which are displayed on the unified state open data web portal [13].

The transport of radioactive substances in the air is one of the most important processes in the atmosphere. For its in-depth study, it is necessary to use data obtained by modern computing platforms of the Global Modelling and Assimilation Office, NASA Goddard Space Flight Centre [14].

For the exchange of radiological data at the international level, Ukraine is included in the European Radiological Data Exchange System (EURDEP) [15], which is developed and maintained by the Joint Research Centre of the European Commission. Article 2(b) of the Euratom Treaty establishes uniform safety standards for the protection of the health of workers and the public, and Article 30 of the Euratom Treaty defines 'basic standards' for the protection of the health of workers and the public from threats caused by exposure to ionising radiation [16].

Increasing the efficiency of conducting and organising atmospheric air monitoring in Ukraine for the content of pollutants, especially particulate matter of various diameters containing heavy metals and radioactive elements, taking into account satellite observations, can be achieved by combining satellite data with ground measurements and information obtained through forecasting and the use of atmospheric transport models [17].

During martial law in Ukraine and in the period of post-war recovery, it is important to assess the quality of atmospheric air and its pollution in accordance with a certain list of pollutants in accordance with international standards, taking into account the latest technologies and scientifically sound approaches, which are generally known in the world, which consist in the introduction in Ukraine of remote satellite monitoring using data from the EU Copernicus Atmospheric Monitoring Service (CAMS) [18], which provides continuous data on the composition of the atmosphere, and explores the complex relationship between air quality and climate, showing trends and geographical distribution of pollution.

The use of satellite monitoring is especially important for forecasting changes, determining trends in air quality in areas that are inaccessible or dangerous for sampling atmospheric air by mobile monitoring stations [19].

Currently, in Ukraine, the existing approaches to organising air pollution monitoring are represented by components that include stationary monitoring stations, mobile laboratories, unmanned aerial vehicles (UAVs) and ground-based sensors. The National Academy of Sciences of Ukraine is involved in the process of obtaining environmental data from remote sensing and satellite images.

Let's consider the advantages and disadvantages of such surveillance systems and the organisation of monitoring under martial law in Ukraine.

The advantages of stationary monitoring stations of the state and public systems are continuous data collection at fixed points; high measurement accuracy provided that the equipment is properly maintained; and the possibility of long-term analysis of changes in pollutant concentrations. The main disadvantages of tracking and collecting environmental data from stationary monitoring posts are primarily high installation and maintenance costs; limited geographical coverage; and dependence on power supply and infrastructure, which may be disrupted under martial law.

The use of ground-based sensors for air pollution monitoring has the following advantages: fast and relatively cheap deployment, the ability to create an extensive monitoring network, and automated collection and transmission of environmental data in real time. Among the disadvantages of this system are limited accuracy compared to stationary laboratories, dependence on stable communication and power supply, and vulnerability to technical failures and extreme conditions, including the effects of emergencies and military actions.

The mobile laboratories used by the Ministry of Health of Ukraine have the advantage of being able to quickly move to areas with a high risk of environmental pollution and select locations for air analysis, as well as to respond quickly to emergencies. However, compared to stationary observation posts, there are disadvantages of using mobile laboratories, such as limited operating time due to equipment life, fuel and maintenance costs, and lower accuracy of measurements.

During martial law, special attention should be focus on the use of UAVs, which have the advantage of access to hard-to-reach or dangerous areas; real-time data collection; and the ability to equip them with sensors for radiation and chemical analysis, which is relevant in the context of environmental threats caused by air pollution with radiation and chemicals as a result of constant explosions. However, there are disadvantages to using UAVs due to limited flight time and payload capacity, sensitivity to weather conditions, and the risk of losing equipment due to hostilities.

The key advantages of satellite monitoring and remote sensing technologies include wide coverage of the territory, the ability to regularly monitor large areas, which is especially important during martial law and the impossibility of access to the territories where military operations are taking place, and independence from ground infrastructure.

ASPECTS OF THE USE OF REMOTE SENSING TECHNOLOGIES UNDER MARTIAL LAW

In order to further use remote sensing under martial law and improve the efficiency of the existing environmental monitoring system in order to obtain complete environmental data, it is also important to analyse and investigate the problems and limitations during the armed aggression against Ukraine.

The authors propose to focus on the following issues: technical and infrastructural; security; data quality; organisational and legal.

Technical and infrastructural challenges include the following: destruction of ground infrastructure, including damage to data collection stations and equipment; communication obstacles, including disruption of data transmission due to unstable communication networks or jamming of signals; risk of equipment loss, including destruction of satellites, UAVs and other remote sensing equipment due to hostilities related to armed aggression against Ukraine.

In terms of the quality of the environmental data obtained, attention should be focus on data ‘contamination’ caused by difficulties in filtering noise due to smoke from fires and the destruction of industrial facilities or military activity; limited accuracy due to atmospheric conditions (smoke, dust, clouds), which negatively affect the quality of images.

An important organisational problem is access to restricted satellite imagery, commercial or military satellite data.

Among the legal restrictions, attention should be focus on the issue of regulating the use of unmanned systems and satellite monitoring under martial law. It is important to note the coordination between government and civil society in this area, as there are difficulties in establishing operational cooperation between government, military and environmental organisations.

As part of the analysis of these aspects of remote sensing application under martial law, remote sensing technologies will remain one of the key tools for monitoring the state of the atmospheric air and improving environmental safety, especially during military operations in Ukraine and during the period of post-war recovery.

The efficiency of conducting and organising air monitoring can be improved by using a combined monitoring system that will include a remote component to the existing environmental monitoring system, which will allow for a timely response to changes in the state of the air and provide a comprehensive analysis of the situation with subsequent modelling and forecasting of the state of the air under martial law in Ukraine and post-war recovery, as well as reduce environmental and health risks.

RECOMMENDATIONS FOR IMPROVING THE COMPLIANCE OF THE AIR MONITORING SYSTEM IN UKRAINE WITH INTERNATIONAL REQUIREMENTS

Important steps to improve the efficiency of atmospheric air monitoring in Ukraine include the need to modernise the state monitoring system network in line with EU standards, including automated stations and calibrated sensors, and the integration of environmental data obtained from public network systems into the national monitoring system.

CONCLUSIONS

As part of the implementation of the Action Plan for the Post-War Recovery and Development of Ukraine and the key goal of ‘clean and safe environment’, it is necessary to strengthen the environmental component of the effectiveness of the post-war reconstruction process in Ukraine with support from the state, develop the environmental monitoring system with the creation of a state environmental monitoring system in line with European standards and digitalise this area.

The insufficiently effective state of the public administration and environmental monitoring system, especially during the war, which constantly causes negative long-term environmental consequences, requires an immediate response to identify direct and potential threats in order to reduce the risks of identifying and preventing existing threats to nuclear, radiation and chemical safety, improving the

environmental safety of the state and the country's international borders in terms of transboundary transfer of pollutants in the air.

The state monitoring system partially meets international requirements and needs to be modernised. The civic monitoring system ensures speed and transparency, but its accuracy and official status needs to be improved. The best solution is to integrate both systems and bring the regulatory framework in line with EU requirements.

Environmental data obtained by remote sensing tools and technologies, which are a powerful tool in the air monitoring system, are the necessary information base for creating air quality maps of Ukraine's regions. Such data can be used to track changes in the content of pollutants in the air over different periods of time and to provide early warnings to the public about increasing levels of air pollution.

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