UDC 504.06:614.8:355.01(477)
DOI https://doi.org/10.32782/2521-6643-2026-2-72.34

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ECOLOGICAL STANDARDIZATION AND CIVIL PROTECTION MANAGEMENT UNDER MARTIAL LAW AT CRITICAL INFRASTRUCTURE FACILITIES

Relevance. Under the conditions of full-scale armed aggression against Ukraine, the anthropogenic load on the natural environment has undergone fundamental and catastrophic changes. The traditional planned technogenic impact has transformed into chaotic, massive, and highly toxic pollution of a multimedia nature. In such conditions, the existing static system of ecological standardization, based on sanitary and hygienic maximum permissible concentrations (MPC) and maximum permissible emissions (MPE), has proven methodologically incapable of effectively responding to unpredictable challenges. This creates a critical gap in the national life safety system and limits the ability of civil protection (CP) units to implement scientifically sound operational management of ecological and technogenic risks during the mitigation of attacks on critical infrastructure facilities.

Goal. To develop and scientifically substantiate innovative methodological approaches for adapting the anthropogenic load standardization system, as well as to create a conceptual model for its integration with civil protection management mechanisms under martial law and post-conflict recovery (using the example of the oil and gas industry).

Methodology. The study utilizes a comprehensive approach combining systemic and risk analysis methods, the theory of territorial ecological capacity, the concept of socio-ecosystem resilience, and principles of mathematical modeling of pollutant dispersion in the atmosphere.

Results. The fundamental necessity of implementing flexible, multi-level standardization tools has been proven. The implementation of a mechanism for temporary emergency standards (MPC-EMERGENCY), adapted similarly to international AEGL and ERPG standards, is proposed for use directly in active combat zones and areas of critical infrastructure damage. A concept of a unified digital management contour has been developed, in which real-time local environmental monitoring data, processed using geographic information systems (GIS) and artificial intelligence (AI) algorithms, serve as automatic triggers for activating specific CP protocols (evacuation, sheltering, zone isolation). Additionally, the concept of transitional standardization (MPC-TRANSITION) for the safe management of destruction waste and land reclamation is substantiated.

Conclusions. It is proven that adaptive ecological standardization must evolve from a passive tool for recording environmental damage into a proactive, preventative management mechanism within the civil protection system. Integrating

ecological criteria into safety protocols will minimize sanitary and hygienic losses among the population and rescuers, and ensure the sustainable post-conflict recovery of territories in accordance with European "Build Back Better" principles.

Key words: *anthropogenic load, ecological standardization, maximum permissible concentrations, civil protection, critical infrastructure, ecological capacity, oil and gas industry, ecological risk.*

Перкун І. В., Погребняк В. Г., Цимбал Б. М., Погребняк А. В. Екологічне нормування та управління цивільним захистом в умовах воєнного стану на об'єктах критичної інфраструктури

В умовах повномасштабної збройної агресії проти України антропогенне навантаження на навколишнє природне середовище зазнало докорінних, катастрофічних змін. Традиційний плановий техногенний вплив трансформувався у хаотичне, залпове та високотоксичне забруднення мультимедійного характеру. У таких умовах існуюча статична система екологічного нормування, що базується на санітарно-гігієнічних гранично допустимих концентраціях (ГДК) та гранично допустимих викидах (ГДВ), виявилася методологічно нездатною ефективно реагувати на непередбачувані виклики. Це створює критичну прогалину в національній системі безпеки життєдіяльності та обмежує можливості підрозділів цивільного захисту (ЦЗ) щодо науково обґрунтованого оперативного управління еколого-техногенними ризиками під час ліквідації наслідків ударів по об'єктах критичної інфраструктури.

Мета – Розробка та наукове обґрунтування інноваційних методологічних підходів до адаптації системи екологічного нормування антропогенного навантаження, а також створення концептуальної моделі її інтеграції з механізмами управління цивільним захистом в умовах воєнного стану та постконфліктного відновлення (на прикладі об'єктів нафтогазової галузі).

У дослідженні використано комплексний підхід, що поєднує методи системного та ризик-аналізу, теорію екологічної ємності територій, концепцію стійкості соціоекосистем, а також принципи математичного моделювання дисперсії забруднюючих речовин в атмосферному повітрі.

Доведено фундаментальну необхідність впровадження гнучких, багаторівневих інструментів нормування. Запропоновано імплементацію механізму тимчасових аварійних нормативів (ГДК-АВАРІЯ), адаптованих за аналогією до міжнародних стандартів AEGL та ERPG, для використання безпосередньо в зонах активних бойових дій та ураження об'єктів критичної інфраструктури. Розроблено концепцію єдиного цифрового контуру управління, в якому дані локального екологічного моніторингу в режимі реального часу, оброблені за допомогою геоінформаційних систем (ГІС) та алгоритмів штучного інтелекту (ШІ), слугують автоматичними тригерами для активації конкретних протоколів ЦЗ (евакуація, укриття, ізоляція зони). Додатково обґрунтовано концепцію перехідного нормування (ГДК-ПЕРЕХІД) для безпечного управління відходами руйнування та рекультивації земель.

Доведено, що адаптивне екологічне нормування має еволюціонувати від пасивного інструменту фіксації екологічних збитків до проактивного, превентивного механізму управління в системі цивільного захисту. Інтеграція екологічних критеріїв у протоколи безпеки дозволить мінімізувати санітарно-гігієнічні втрати серед населення та рятувальників, а також забезпечить стійке постконфліктне відновлення територій відповідно до європейських принципів «Build Back Better».

Ключові слова: *антропогенне навантаження, екологічне нормування, гранично допустимі концентрації, цивільний захист, критична інфраструктура, екологічна ємність, нафтогазова галузь, екологічний ризик.*

Problem statement. The fundamental basis of sustainable development, national security, and life safety is maintaining a strict balance between the economic activity of society and the ecological capacity of territories. In peacetime, effective management of anthropogenic load on the natural environment is carried out through a comprehensive system of ecological standardization. The main instruments of this regulation are the establishment of maximum permissible emissions (MPE) for atmospheric air, maximum permissible discharges (MPD) for water bodies, and waste disposal limits. This system is based on a scrupulous calculation of the assimilative potential of local ecosystems – that is, their ability to neutralize, process, and self-purify from pollutants without the risk of irreversible functional degradation.

However, the full-scale armed aggression against Ukraine has completely and irreversibly destroyed this static ecological paradigm. Systematic missile and drone strikes on critical infrastructure facilities, primarily oil and gas complexes, chemical industries, and thermal and hydroelectric power plants, generate extreme, absolutely uncontrolled anthropogenic loads. Under such conditions, traditional ecological standardization, which was calculated for stable operating conditions of enterprises, completely loses its primary regulatory function. Today, ecological standards (in particular, MPC) have turned exclusively into a tool for post-factum recording of damage and calculating ecological harm for future reparations.

At the same time, units of the State Emergency Service of Ukraine (SES) and the Civil Protection (CP) system are forced to mitigate the consequences of disasters amid an acute shortage of operational ecological and toxicological data. A paradoxical and dangerous situation arises: ecological services and CP services operate in parallel, weakly connected coordinates. This causes an acute, vital need for a scientifically substantiated transformation of anthropogenic load standards and their deep integration into the operational management mechanisms of the civil protection system.

Analysis of recent research. The issue of managing ecological and technogenic risks in emergency situations and military conflicts is currently an object of close attention of both the domestic and global scientific communities.

The general theoretical foundations of ecological security and risk management are thoroughly considered in the works [1–4], etc. The international experience of post-conflict recovery of socio-ecosystems is reflected in UNEP protocols, NATO directives on environmental protection in military operations, and World Bank methodologies (the Build Back Better concept).

The transformation of occupational safety and civil protection systems under the influence of military risks is also addressed in previous works of the authors of this article. In particular, studies [5–8] detail strategies for integrating civil protection into corporate management systems at high-risk facilities, especially in the oil and gas industry, where occupational and military risks are modeled. Special attention is paid to emergency management technologies and increasing the efficiency of fire extinguishing systems [9].

However, a deep analysis of the scientific literature and existing regulatory legal acts shows that most modern regulations (both ecological and CP regulations) consider the ecological factor in isolation from the overall dynamic picture of anthropogenic pressure on the territory during hostilities [10–12].

Despite the significant interest of the scientific community in the ecological consequences of the war, the issue of directly adapting the methodology of standardizing anthropogenic load to the specific needs of operational, proactive management by CP units remains conceptually unresolved. There are no scientifically substantiated, mathematically supported algorithms for using ecological pollution indicators as instant triggers to activate evacuation, sheltering, and population protection protocols in real time. The existing regulatory framework of Ukraine does not contain mechanisms for temporary or emergency ecological standardization, which creates a legal and managerial vacuum during the mitigation of massive technogenic disasters caused by the war [13, 14].

The main goal of the article is to develop comprehensive theoretical and methodological foundations for adapting the system of standardizing anthropogenic load on the environment to the conditions of martial law, as well as to scientifically substantiate innovative mechanisms for its digital and algorithmic integration into the civil protection management system at critical infrastructure facilities (with a focus on the oil and gas sector).

Presentation of the main research material.

Transformation of the types and physicochemical nature of anthropogenic load under conditions of armed conflict. The methodology of classical ecological standardization, formed over decades in Ukraine and worldwide, operates with categories of planned, chronic (continuous) anthropogenic load on the environment. In peacetime, the ecological capacity of territories is calculated based on daily average and maximum single sanitary-hygienic concentrations. It is assumed that the emission source is known, its intensity is controlled by treatment facilities, and the dispersion of pollutants obeys standard Gaussian distribution laws.

Full-scale hostilities fundamentally change both the physicochemical and spatiotemporal nature of anthropogenic pressure. There is a sudden transition from a predicted chronic impact to an acute, emergency, and extreme load [2]. The destruction of critical infrastructure facilities (oil refineries, fuel and lubricant storages, ammonia pipelines) generates a unique synergy of military-technogenic threats. Instead of standardized emissions from smokestacks, uncontrolled ground-level sources of massive emissions are formed.

A characteristic feature of military pollution is the emergence of a *multimedia effect*. Pollutants do not localize and dissipate in a single natural environment. For example, as a result of a missile strike on an oil depot, there is a simultaneous and massive impact on the atmospheric air (due to colossal emissions of combustion products: carbon oxides, nitrogen, dioxins, polycyclic aromatic hydrocarbons, and highly dispersed soot), the hydrosphere, and the pedosphere. Pollution of soils and groundwater occurs not only as a result of oil product spills but also through the intensive infiltration of toxic residues of extinguishing agents (in particular, fluorine-containing film-forming foams – PFAS, which belong to the category of "forever chemicals" and practically do not decompose in nature).

In such a situation, the assimilative capacity of the natural environment does not just decrease – it is instantly and completely exhausted. The ecosystem loses its ability to perform buffer functions, which transfers the problem from the plane of long-term ecological monitoring directly to the sphere of critical competence of Civil Protection, as a direct, urgent threat to the life and health of large masses of the population arises.

The MPC-EMERGENCY mechanism as a decision-making tool in the CP system: adaptation of international experience. As noted above, basic sanitary-hygienic MPCs are designed to prevent minimal pathological changes or even reflex reactions in the human body under daily exposure throughout life. Therefore, the exceedances of traditional MPCs by thousands of times recorded during the extinguishing of fires at industrial facilities only state the fact of an ecological disaster. They do not provide any specific algorithm of actions for rescuers and local self-government bodies [3]. To be guided by peacetime MPCs during a war means paralyzing the decision-making system, as the territory of an entire region could formally be considered uninhabitable.

To eliminate this conceptual and legal gap, it is necessary to substantiate the critical need to introduce a new category into the regulatory legal field of Ukraine – *temporary emergency standards (MPC-EMERGENCY)*. The methodological basis for developing national MPC-EMERGENCY should be the adaptation of advanced international experience, in particular the American AEGL (Acute Exposure Guideline Levels) system and the European ERPG (Emergency Response Planning Guidelines) guidelines, developed for the US Environmental Protection Agency (EPA) and the chemical industry.

The proposed architecture of MPC-EMERGENCY standards should be graded depending on a strictly limited exposure time (e.g., 10 minutes, 30 minutes, 1 hour, 4 hours, 8 hours). In the CP system, these numerical indicators should serve not as statistical material, but as *automatic command triggers* for the immediate activation of safety protocols. A three-level activation scale is proposed:

Level 1 (Warning / Discomfort). Achieving a concentration above which the population may experience irritation of the mucous membranes, non-lethal but noticeable effects. CP Protocol: activation of the warning system, mandatory sealing of premises ("Shelter in place" mode), shutdown of ventilation systems, prohibition of staying outdoors.

Level 2 (Danger / Irreversible consequences). A concentration above which there is a risk of irreversible or serious long-term health consequences that impede independent evacuation. CP Protocol: mandatory use of respiratory personal protective equipment (PPE) for the entire population, strict limitation of the working time of rescue teams in the zone.

Level 3 (Critical risk / Threat to life). A concentration above which the impact of pollutants is life-threatening or lethal even with short-term exposure. CP Protocol: immediate, forced evacuation of the population from the affected area; the territory legally receives the status of "Critical Pollution Zone (Zone I)" with a complete ban on access without highest-class isolating protective equipment.

Management of ecological and technogenic risks at critical infrastructure facilities through the prism of digitalization. The specific nature of emergency anthropogenic load is clearly visible on the example of oil and gas industry facilities and trunk pipelines. Effective management of CP units at such facilities is impossible with the use of manual data collection or laboratory analyses that require hours for processing.

The modern CP architecture must be based on the principle of *end-to-end integrated monitoring*. The concept assumes that data from a network of local automated ecological control posts (IoT sensors of gas analyzers installed directly on industrial sites and along the perimeter of the sanitary protection zone) should be transmitted in real time, bypassing bureaucratic chains, to the secure cloud information systems of the State Emergency Service (SES).

The risk management algorithm in such a system looks like this: a sensor records an emission (e.g., sulfur dioxide or carbon monoxide from a fire in a reservoir) → data arrives at the server → Artificial Intelligence (AI) algorithms continuously compare the actual concentrations with the matrix of MPC-EMERGENCY standards → the system integrates these data with current and predicted meteorological parameters (wind speed and direction at different altitudes, the presence of temperature inversion that "presses" smoke to the ground), using geographic information systems (GIS), a highly accurate predicted 3D model of the toxic cloud spread is instantly generated [15].

This dynamic map is superimposed on cadastral and demographic plans of territories. As a result, the fire extinguishing manager or CP headquarters receives not just dry concentration figures, but a specific forecast: in 14 minutes, a cloud with a "Level 2" concentration will cover residential area "A", which requires the immediate redirection of evacuation buses there and sending SMS alerts. Such an approach provides a quantum leap from mitigating consequences "blindly" to scientifically sound, risk-oriented management.

Restorative standardization: management of destruction waste and the principle of transitional standards (MPC-TRANSITION). Another extremely important aspect is the period that begins after the acute phase of the emergency is eliminated. The problem of managing residual anthropogenic load moves to the plane of post-conflict recovery and reclamation. Territories around destroyed energy and industrial facilities turn into zones of ecological disaster. A separate colossal problem is millions of tons of destruction waste (DW) – debris of buildings, concrete, metal structures contaminated with heavy metals, explosive residues, asbestos, and oil products.

Applying standard peacetime ecological standards to such territories and waste will lead to a legal collapse: any economic activity to clear debris or process DW will formally be considered a violation of environmental legislation. Accordingly, investors and contractors will not be able to legally start rebuilding.

To overcome this collision, it is necessary to implement the concept of *adaptive transitional standardization (MPC-TRANSITION)*. The essence of the concept lies in legalizing temporary, technically and economically achievable standards for residual contamination of soils and building materials. MPC-TRANSITION is a compromise marker: these indicators are higher than ideal background values, but they are proven to be safe for conducting specialized engineering and restoration works (provided that builders use PPE and adhere to enhanced occupational safety requirements).

Granting the territory the status of an MPC-TRANSITION zone allows starting demilitarization works, sorting DW for further use of inert fractions (for example, cleaned crushed concrete for road bedding), and launching soil bioremediation processes [2]. However, the law must strictly define: territories with the MPC-TRANSITION status are categorically forbidden to be used for agriculture, growing food products, or residential development. Return to full civil use is permitted only after the complete completion of reclamation and laboratory confirmation of achieving the indicators of basic (permanent) ecological standards of Ukraine and the EU (EU Acquis) [16].

Conclusions

1. Under martial law and the continuous impact of kinetic weapons on industrial facilities, the standardization of anthropogenic load on the environment goes far beyond purely ecological audit or control. It becomes an integral, fundamental basic component of managing the civil protection system and the national security architecture as a whole.

2. The catastrophic synergy of military and technogenic threats at critical infrastructure facilities (especially in the oil and gas industry) inevitably requires a transition from static indicators of ecological capacity to the concept of dynamic risk management. Classical methods of calculating MPC and MPE must be supplemented by algorithms for assessing the multimedia effects of pollution.

3. The implementation of innovative legal and engineering mechanisms of emergency (MPC-EMERGENCY) and transitional (MPC-TRANSITION) standardization is a critical requirement of the time. These standards, combined in a single digital contour with local monitoring systems, GIS technologies, AI, and SES warning systems, will ensure a transition from a reactive to a proactive management model. This will save the lives and health of the population during attacks, reduce risks for rescuers, and guarantee a scientifically sound approach to the post-conflict recovery of socio-ecosystems in accordance with the "Build Back Better" strategy.

Prospects for further research consist in developing specific mathematical and toxicological models for calculating precise numerical values of MPC-EMERGENCY standards for specific multicomponent toxicants of the oil and gas complex (in particular, products of incomplete combustion of fuel mixtures and fluorine-containing foams) with the aim of their further legislative approval by the Ministry of Environmental Protection and Natural Resources of Ukraine together with the Ministry of Health and the SES.

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Дата першого надходження статті до видання: 20.03.2026
Дата прийняття статті до друку після рецензування: 17.03.2026
Дата публікації (оприлюднення) статті: 30.05.2026