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CRISIS ENVIRONMENTAL MANAGEMENT IN THE EDUCATION SYSTEM OF FUTURE PROFESSIONALS: RELEVANCE IN WARTIME AND POST-WARTIME PERIODS

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INTRODUCTION

Since the start of the full-scale war, all existing environmental problems not only in Ukraine but also, at least, in neighboring countries have significantly worsened, and new issues have emerged. Daily news about destroyed oil depots, burned equipment, and ruined irrigation systems only highlights the scale of the environmental catastrophe, which is growing every day. As a result of Russian attacks on important infrastructure and industrial sites such as nuclear power plants (NPPs), hydropower plants (HPPs), and large chemical factories, serious environmental risks have arisen, not only on a regional scale but also at a planetary level. Examples of this include the impact on nuclear facilities[1], such as the occupation of the Chornobyl and Zaporizhzhia NPPs, the damage to the Khmelnytskyi NPP, as well as the situation with the "Klevazh" facility[2]. According to the IAEA reports, Russia violates all seven principles of nuclear safety[3,4]. Time has become one of the critical resources, as environmental damage is growing much faster than we can find solutions to the problem, let alone implement them.

[1] Hamilton R. Coal mines, land mines and nuclear bombs: The environmental cost of the war in Eastern Ukraine. FPRI: Foreign Policy Research Institute. 2019. URL: https://policycommons.net/artifacts/1341707/coal-mines-land-mines-and-nuclear-bombs/1953827/ (дата звернення 15.10.2024)

[2] Anisimova H., Haltsova V., Donets O., Samoshchenko I., & Shynkarov O. An environmental and legal component of criminal offenses in conditions of the Russian-Ukrainian international military conflict. European Energy and Environmental Law Review. 2023. Т. 32, № 1. С. 47–65. URL: https://kluwerlawonline.com/journalarticle/European+Energy+and+Environmental+Law+Review/32.1/EELR2023004 (дата звернення 11.10.2024)

[3] Nuclear Safety, Security and Safeguards in Ukraine: 2nd Summary Report by the Director General, 28 April – 5 September 2022. IAEA, Vienna, 2022. URL: https://www.iaea.org/sites/default/files/22/09/ukraine-2ndsummaryreport_sept2022.pdf

[4] Nuclear Safety, Security and Safeguards in Ukraine: Summary Report by the Director General, 24 February – 28 April 2022. IAEA, Vienna, 2022. URL: https://www.iaea.org/sites/default/files/22/04/ukraine-report.pdf

1. Environmental consequences of the Russo-Ukrainian war

According to the Ministry of Environmental Protection and Natural Resources of Ukraine[5,6], the environmental damage caused by Russian aggression exceeds 51.3 billion euros. For comparison, during Green Week 2023, it was stated that this amount is 8 times higher than the figures for Green Week 2022. More than 1800 criminal proceedings related to environmental crimes have been recorded. Since February 24, 2022, the State Environmental Inspectorate of Ukraine has documented over 2500 such crimes. For instance, during the period from 2014 to 2019, Eurojust registered only 57 environmental crimes, while Ukraine recorded several violations in one year which is 30 times higher than the combined figures from 16 national offices in Europe during the five-year peaceful period.

Ukraine is currently the most mine-contaminated country in the world, with mined areas reaching approximately 174,000 km², equivalent to Iceland's territory. Carbon emissions caused by combat activities exceed 120 million tons, significantly moving the world further away from achieving the goals of the Paris Agreement. If these emissions were converted into a financial equivalent based on current market prices in the European Union Emissions Trading System, the amount would reach 10.2 billion euros. This sum accounts for half of the necessary investments for the capital reconstruction of Ukraine's water resource management and distribution system for the next decade.

2. The impact of military actions on protected areas and soils

The Lower Dnipro National Park, spanning over 80,000 hectares – an area comparable to the size of Berlin – has come under threat. Nearly half of Ukraine's protected areas, approximately 500,000 hectares, are either occupied or located in active combat zones, where they have been transformed into military bases and training grounds. A similar area of forests has been affected by military activities, and currently, about

[5] Стрілець Р. Виступ Міністра Руслана Стрільця на полях Конференції ОБСЄ з питань зміни клімату у Відні // Міністерство захисту довкілля та природних ресурсів України. 2024. URL: https://mepr.gov.ua/mediatsentr/teksty-vystupiv/vystup-ministra-ruslana-striltsya-na-polyah-konferentsiyi-obsye-z-pytan-zminy-klimatu-u-vidni/ (дата звернення 15.10.2024)

[6] Стрілець Р. Виступ Міністра Руслана Стрільця у рамках панельної дискусії «Наслідки війни: шкода, завдана довкіллю в Україні, пріоритетні виклики та плани відновлення» на EU Green Week у Брюсселі // Міністерство захисту довкілля та природних ресурсів України. 2023. URL: https://mepr.gov.ua/mediatsentr/teksty-vystupiv/vystup-ministra-ruslana-striltsya-u-ramkah-panelnoyi-dyskusiyi-naslidky-vijny-shkoda-zavdana-dovkillyu-v-ukrayini-priorytetni-vyklyky-ta-plany-vidnovlennya-na-eu-green-week-u-bryusseli/ (дата звернення 15.10.2024)

2.4 million hectares of de-occupied forests require urgent restoration. For comparison, this area exceeds the size of many European countries, underscoring the scale of destruction caused by Russian forces.

The Holy Mountains National Nature Park in eastern Ukraine has suffered significant losses due to active combat since 2014. To date, approximately 80% of the park's conservation potential has been lost, an area comparable to half of Saxon Switzerland National Park – one of Europe's largest national parks.

Additionally, Europe's largest uninhabited island, Dzharylhach, has suffered extensive damage. Russian occupiers have allowed illegal hunting on the island and buried the crossing to it under sand, turning it into a peninsula and establishing a military training ground there. The Askaniya-Nova Biosphere Reserve and the Black Sea Biosphere Reserve, both UNESCO-listed sites, have also been occupied. Their restoration will take decades and require millions of euros[7,8].

Soils are a particular concern in the field of agroecology due to their significant vulnerability to military activities. The historical example of the Battle of Verdun during World War I, where large-scale soil disruption occurred, remains relevant even today and serves as a stark illustration of the severe environmental consequences of warfare for land resources. Even decades after the Battle of Verdun, much of the area remains unsuitable for human activity, highlighting the long-term effects of environmental contamination. A similar situation is observed in modern-day Bakhmut[9,10],

[7] Стрілець Р. Виступ Міністра Руслана Стрільця на полях Конференції ОБСЄ з питань зміни клімату у Відні // Міністерство захисту довкілля та природних ресурсів України. 2024. URL: https://mepr.gov.ua/mediatsentr/teksty-vystupiv/vystup-ministra-ruslana-striltsya-na-polyah-konferentsiyi-obsye-z-pytan-zminy-klimatu-u-vidni/ (дата звернення 15.10.2024)

[8] Стрілець Р. Виступ Міністра Руслана Стрільця у рамках панельної дискусії «Наслідки війни: шкода, завдана довкіллю в Україні, пріоритетні виклики та плани відновлення» на EU Green Week у Брюсселі // Міністерство захисту довкілля та природних ресурсів України. 2023. URL: https://mepr.gov.ua/mediatsentr/teksty-vystupiv/vystup-ministra-ruslana-striltsya-u-ramkah-panelnoyi-dyskusiyi-naslidky-vijny-shkoda-zavdana-dovkillyu-v-ukrayini-priorytetni-vyklyky-ta-plany-vidnovlennya-na-eu-green-week-u-bryusseli/ (дата звернення 15.10.2024)

[9] Дудар В., Гандзюра В., Романюк В., Берегуля Р. Пропозиції щодо управління землями, які забруднені вибуховими речовинами від вибухонебезпечних пережитків війни. Grail of Science. 2024. № 37. С. 195–210. DOI: https://doi.org/10.36074/grail-of-science.15.03.2024.029

[10] Gomza I. Roger That: Russia's Coup-Proofed Army and Its Combat Effectiveness, 2022–2023. The Journal of Slavic Military Studies. 2023. Т. 36, № 4. С. 435–473. DOI: https://doi.org/10.1080/13518046.2023.2293371

where soil contamination with flammable substances is so severe that the soils themselves pose a fire hazard.

In this context, the research conducted by scientists from the National Scientific Center «O.N. Sokolovsky Institute of Soil Science and Agrochemistry»[11,12,13,14,15,16] is particularly noteworthy. They have studied the impact of various military equipment and its debris on soils, analyzing aspects such as soil compaction, increased erosion, and biological and chemical contamination. Areas where military equipment was burned proved especially hazardous, as significant amounts of fuel, lubricants, and explosive substances entered the environment, creating unpredictable ecological consequences. The findings on the accumulation of heavy metals in soils, which is a critical factor in assessing long-term environmental risks are of particular interest.

3. Crisis environmental management as a tool for mitigating consequences

In Ukraine, several groups and initiatives are actively documenting environmental crimes resulting from military actions. One such initiative is the Ecodozor platform[17], established with the support of the OSCE, which

[11] Nuclear Safety, Security and Safeguards in Ukraine: 2nd Summary Report by the Director General, 28 April – 5 September 2022. IAEA, Vienna, 2022. URL: https://www.iaea.org/sites/default/files/22/09/ukraine-2ndsummaryreport_sept2022.pdf

[12] Балюк С. А., Кучер А. В., Солоха М. О., Соловей В. Б., Смірнова К. Б., Момот Г. Ф., Левін А. Я. Вплив збройної агресії та воєнних дій на сучасний стан ґрунтового покриву, оцінка шкоди та збитків, заходи з відновлення: наук. доп. Харків: ФОП Бровін О. В., 2022. 102 с. DOI: https://doi.org/10.13140/RG.2.2.15740.41608

[13] Балюк С., Кучер А., Солоха М., Соловей В. Оцінювання впливу збройної агресії рф на ґрунтовий покрив України. Український географічний журнал. 2024. № 1. С. 7–18. DOI: https://doi.org/1.15407/ugz2024.01.007

[14] Концептуальні підходи до відновлення ґрунтів, що постраждали від збройної агресії: монографія / за ред. С.А. Балюка, А.В. Кучера, І.В. Пліско. Київ: Аграрна наука, 2024. 216 с. DOI: https://doi.org/10.31073/978-966-540-604-4

[15] Солоха М.О., Смірнова К.Б., Винокурова Н.В., Семенцова К.О. Варіабельність геохімічного та гранулометричного складу ґрунтів Лісостепу України під впливом бойових дій. *Аграрні інновації.* 2022. № 14. С. 109–116. DOI: https://doi.org/10.32848/agrar.innov.2022.14.16

[16] Solokha M., Pereira P., Symochko L., Vynokurova N., Demyanyuk O., Sementsova K., Inacio M., Barcelo D. Russian-Ukrainian war impacts on the environment. Evidence from the field on soil properties and remote sensing. Science of the Total Environment. 2023. T. 902. P. 166122. DOI: https://doi.org/10.1016/j.scitotenv.2023.166122

[17] Ecodozor. Екологічні наслідки та ризики бойових дій в Україні. 2024. URL: https://ecodozor.org/ (дата звернення 15.09.2024)

highlights the environmental risks associated with the war in Ukraine and monitors the military's impact on the environment. This website allows users to interact with various map layers, providing information on the current environmental situation in combat zones. According to the platform, from February 2022 to the end of August 2024, among the critical infrastructure facilities damaged by hostilities, the following are particularly hazardous from an environmental standpoint: the "Crimean Titan" plant, the Kakhovka and Kyiv Hydroelectric Power Stations, as well as the Chornobyl and Zaporizhzhia Nuclear Power Plants. In August, additional damage occurred to the Zaporizhzhia Nuclear Power Plant, Hydroelectric Power Stations, Rivne Nuclear Power Plant, South Ukraine Nuclear Power Plant, and the O.O. Skochynsky Mine. These facilities pose a significant threat to the environment due to the high risk of radiation or chemical contamination.

Thus, Ukraine is currently experiencing a complex environmental crisis that transcends being a purely national issue and has the potential to evolve into a broader, multilayered crisis in the future (Figure 1). Decision-makers tasked with managing such situations often lack the necessary professional and psychological preparedness, significantly complicating crisis management. The most challenging responsibility falls on high-level specialists who must develop a multi-tiered strategy not only for recovery but also for the modernization of entire industries, regions, and infrastructure amidst a prolonged armed conflict, high uncertainty, limited resources, and tight time constraints. Although many strategies developed are well-conceived, their coordination and practical feasibility often leave much to be desired. Research institutions struggle to respond to new challenges promptly, while the business sector tends to react first. However, the existing disconnect between scientific institutions, businesses, society, and government significantly slows down the process of effective decision-making and its implementation in practice.

One of the urgent tasks remains the establishment of an adequate system for training environmental specialists capable of working under complex and unconventional ecological crises. There is a pressing need to develop an educational course on crisis environmental management aimed at preparing professionals to perform the functions of crisis environmental managers. Such management requires collaboration among scientific institutions, businesses, the public, and authorities, as well as the integration of knowledge from various fields, including ecology, management, communications, sociology, and psychology. Achieving effective results is only possible through close cooperation among institutions working in diverse areas. Unfortunately, this is still a rarity, as most scientific organizations remain isolated and focused on narrow fields of activity, failing to address the realities of the current environmental crisis and societal needs.

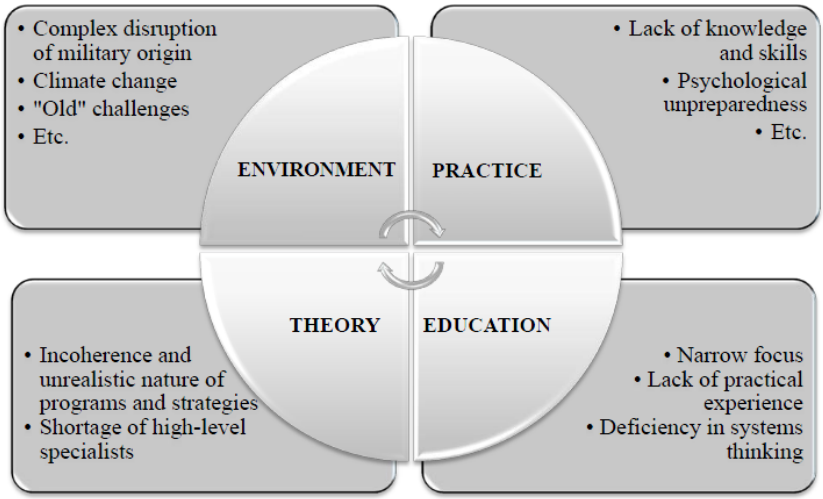

Fig. 1. Key components of Ukraine's comprehensive environmental crisis

The global environmental crisis triggered by armed conflicts has both local and global consequences, exacerbating traditional environmental problems. This is evidenced by examples such as Chornobyl[18], Bakhmut, the Kakhovka Hydroelectric Station[19,20], and numerous studies on climate change. Environmental issues can no longer be addressed in isolation; a comprehensive approach incorporating innovative technologies and forecasting methods is essential.

[18] Chubina T. D., Fedorenko Y. A., Spirkin O. O. Environmental and Socio-Demographic Consequences of the Chornobyl Nuclear Power Plant Accident: A Historical Retrospective after 36 Years. Studia Regionalne i Lokalne. 2023. Special Issue. C. 101–109. DOI: https://doi.org/10.7366/15094995s2307

[19] Tsaryk L., Kuzyk I. Russian-Ukrainian War: Environmental Aspect. Scientific Notes Ternopil National Volodymyr Hnatyuk Pedagogical University. Series «Constructive Geography and Geoecology». 2022. № 53(2). P. 100–106. URL: http://dspace.tnpu.edu.ua/handle/123456789/27214

[20] Tuchkovenko Y. S., Stepanenko S. The impact of destruction of the Kakhovka dam on the environmental status of the Odesa area of the Black Sea. Problems of Water Supply Sewerage and Hydraulic. 2023. № 44. P. 71–80. DOI: https://doi.org/10.32347/2524-0021.2023.44.71-80

A separate challenge lies in the legal aspects associated with environmental crimes[21], green criminology[22], and ecocide[23,24,25], which, despite their relevance, have yet to receive adequate attention at the international level. Additionally, the experience of foreign countries in addressing environmental challenges, particularly those arising from military actions, holds significant importance. For instance, U.S. programs like MEC HA (Munitions and Explosives of Concern Hazard Assessment)[26] and CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act)[27], better known as Superfund, are designed to effectively assess risks and mitigate the consequences of environmental disasters, including those of military origin. Implementing similar approaches in Ukraine could help optimize time and resource expenditures, which is critically important in the context of limited funding and the need for rapid responses to environmental crises.

The implementation of the concept of crisis environmental management is a logical next step in developing a strategy for partially mitigating environmental problems and restoring the environment in both the short and long term. Traditionally, environmental management is viewed as a long-

[21] Баїк О.І. Міжнародні та національні правові підходи щодо відшкодування екологічних збитків, завданих воєнними діями. Науковий вісник Ужгородського національного університету. Серія «Право». 2023. Т. 1, № 78. С. 338–344. DOI: https://doi.org/10.24144/2307-3322.2023.78.1.55

[22] Eman K., Meško G., Dobovšek B., Sotlar A. Environmental crime and green criminology in South Eastern Europe – practice and research. Crime Law Soc Change. 2013. Т. 59. С. 341–358. DOI: https://doi.org/10.1007/s10611-013-9419-0

[23] Flamm P., Kroll S. Environmental (in)security, peacebuilding and green economic recovery in the context of Russia's war against Ukraine. Environment and Security. 2024. Т. 2, № 1. С. 21–46. DOI: https://doi.org/10.1177/27538796241231332

[24] Cusato E., Jones E.E.C. The 'imbroglio' of ecocide: A political economic analysis. Leiden Journal of International Law. 2024. № 37(1). P. 42-61. DOI: https://doi.org/10.1017/s0922156523000468

[25] Kowalska S. ECOCIDE. Veredas do Direito – Direito Ambiental e Desenvolvimento Sustentável. 2023. Т. 20. DOI: https://doi.org/10.18623/rvd.v20.2416

[26] U.S. Environmental Protection Agency (EPA). Munitions and Explosives of Concern Hazard Assessment Methodology. 2008. URL: https://www.epa.gov/fedfac/munitions-and-explosives-concern-hazard-assessment-mec-ha-methodology-technical-work-group (дата звернення 15.09.2024)

[27] Congress of the United States. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Public Law 96-510. Vol. 42, United States Code. Washington, DC. 1980.

term process focused either on the state level[28,29,30] or specific enterprises[31]. It involves systematic management of organizations' interactions with the natural environment to preserve biodiversity, ensure the sustainable use of resources, and minimize negative impacts on ecosystems. An important component is the continuous improvement of environmental policies and practices aimed at integrating the economic, environmental, and social aspects of organizational activities.

Crisis management, on the other hand, is typically associated with economic issues and refers to the process of managing unforeseen events that may threaten the functioning of an organization or cause significant negative consequences. This involves developing strategies to prevent or mitigate the effects of such situations and coordinating communications with stakeholders. Crisis environmental management combines both approaches, focusing on managing environmental crises at various levels – from individual enterprises to the national scale. In the current context of war and post-war recovery, Ukraine must adopt a crisis management strategy across all sectors, not limited to environmental issues alone. This approach could form the foundation for the country's socio-economic development.

It is also essential to differentiate between crisis environmental management and disaster management[32,33,34]. The latter is a system for managing responses to emergencies aimed at minimizing harm to people,

[28] Бабчинська О. І. Формування механізму екологічного менеджменту в контексті концепції сталого розвитку. Економіка та держава. 2020. № 10. С. 140–143. DOI: https://doi.org/10.32702/2306-6806.2020.10.140

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[31] Луцяк В. В., Томашук І. В. Екологічний менеджмент потенціалу Вінницької області. Економіка. Фінанси. Менеджмент: актуальні питання науки і практики. 2019. № 1. С. 33–47.

[32] Khan S.M., Shafi I., Butt W.H., Diez I.d.l.T., Flores M.A.L., Galán J.C., Ashraf I. A Systematic Review of Disaster Management Systems: Approaches, Challenges, and Future Directions. Land. 2023. Т. 12. С. 1514. DOI: https://doi.org/10.3390/land12081514

[33] Kirschenbaum A., Ed. Chaos Organization and Disaster Management. 1st ed. Routledge, 2003. DOI: https://doi.org/10.4324/9781482276398

[34] Local Disaster Management 1st ed. / ed. by G. Yannitell Reinhardt, L. Drennan. Routledge, 2020. URL: DOI: https://doi.org/10.4324/9781003036234

property, and the environment caused by disasters, encompassing not only environmental disasters. In a somewhat simplified understanding, it can be seen as just one component of crisis environmental management in cases of environmental disasters.

Examining environmental challenges in greater detail, climate change emerges as a primary issue, characterized by its complexity due to the synergy of various factors and emergent effects. In Ukraine, the impact of climate change is exacerbated by military actions, which intensify and modify existing environmental problems while also contributing to the emergence of new ones[35,36,37,38,39,40]. Consequently, this also affects the achievement of sustainable development goals, as both local and global challenges must be addressed simultaneously. Such multifaceted challenges require comprehensive solutions achievable only through the integration of knowledge across various fields. In Western Europe, multidisciplinary scientific projects are being actively implemented, bringing together different levels of biological organization and combining disciplines that might seem unrelated, such as microbiology, biotechnology, and informatics, or natural resource management, agriculture, and sociology. For Ukraine, it is crucial not only to focus on local issues but also to consider global

[35] Flamm P., Kroll S. Environmental (in)security, peacebuilding and green economic recovery in the context of Russia's war against Ukraine. Environment and Security. 2024. T. 2, № 1. C. 21–46. DOI: https://doi.org/10.1177/27538796241231332

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[37] Appiah-Otoo I., Chen X. Russian-Ukrainian war degrades the total environment. Letters in Spatial and Resource Sciences. 2023. T. 16. C. 32. DOI: https://doi.org/10.1007/s12076-023-00354-8

[38] Homanyuk M., Khodosovtsev O., Moysiyenko I., Ponomaryova O., Zharonkin V. Ukrainian facilities of the nature reserve fund in the conditions of war and Russian occupation. Ekonomichna ta Sotsialna Geografiya / Економічна та соціальна географія. 2023. № 89. С. 31–41. DOI: https://doi.org/10.17721/2413-7154/2023.89.31-41

[39] Tahmid A., Khanam S., Rashid Md. M., Ibnat A. Reviewing the Impact of Military Activities on Marine Biodiversity and Conservation: A Study of the Ukraine-Russia Conflict within the Framework of International Law. Grassroots Journal of Natural Resources. 2023. № 6(3). P. 15–31. DOI: https://doi.org/10.33002/nr2581.6853.060302

[40] Zwijnenburg W., Hochhauser D., Dewachi O., Sullivan R., Nguyen V.K. Solving the jigsaw of conflict-related environmental damage: Utilizing open-source analysis to improve research into environmental health risks. Journal of Public Health. 2019. Vol. 42, № 3. P. e352–e360. DOI: https://doi.org/10.1093/pubmed/fdz107

impacts. For instance, publications addressing the effects of military actions on global climate change began to emerge as early as 2022, emphasizing the need to integrate these factors into scientific research and strategic planning.

The next logical step involves considering environmental policy and regulation in the context of sustainable development, as well as analyzing the impact of military actions on Ukraine's international environmental commitments. Ukraine has declared its intention to pursue green recovery and transformation[41], aiming to uphold its climate commitments despite wartime challenges. This is undoubtedly a commendable goal, but its realization requires clearly defined interim objectives and a specific plan focused on innovative technologies. Unfortunately, significant progress in this direction remains elusive. Plans for the urgent construction of nuclear power plants and the restoration of thermal power plants have been announced, yet funding for science as a source of innovation remains critically low. Consequently, while we aspire to innovation, outdated approaches and methods are still being applied. Businesses and civil society strive to introduce new ideas from the bottom up but often encounter bureaucratic obstacles. However, there is no alternative but to develop a system of crisis environmental management within the frameworks of sustainable development and the European Green Deal. It is necessary to objectively assess pre-war prospects, challenges, and obstacles, as well as the post-war reality, to achieve sustainable development in Ukraine.

Risk assessment is a key topic that must be an integral part of any planning and crisis management system. Unfortunately, it often receives insufficient attention in Ukraine. Effective risk assessment and emergency preparedness are critical elements that minimize damage from potential threats and ensure a prompt response to crises. The modern world offers numerous examples of successful risk assessment practices actively employed in various countries, such as Life Cycle Assessment (LCA)[42], Ecological Risk Assessment (ERA)[43], Quantitative Risk Assessment

[41] Міністерство економіки України. Україна та UNIDO підписали Програму зеленого відновлення промисловості України на 2024-2028 роки // Міністерство економіки України. 2024. URL: https://www.me.gov.ua/News/Detail?lang=uk-UA&id=0dc30b91-d3dd-476e-bb79-8eb317ed4d4f&title=UkrainaTaUnido (дата звернення 15.10.2024).

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(QRA)[44], Risk Matrix[45], and Predictive Theoretical Approaches[46]. Ukraine must study and adapt these approaches to its realities. It is important to understand that the risk assessment process follows a clear sequence: starting with threat identification, analyzing their potential consequences, and preparing response strategies for possible scenarios.

Risk communication becomes particularly relevant during wartime and will undoubtedly remain critical during the country's recovery. International experience shows that successful risk communication is based on a combination of factors, including expert involvement and the selection of appropriate tools and techniques. Among these tools are risk matrices[47], risk ladders[48], and visual materials[49], which simplify complex information for broader understanding.

Each communication channel, whether traditional media, social networks, or public forums, has its own advantages and disadvantages. To effectively convey risk-related information, messages must be adapted for different audiences. It is essential to consider the specific ways in which each audience perceives information, their mentality, cultural and informational context, and current interests.

Strategic planning and crisis environmental management are fundamental components of long-term environmental planning. Crisis environmental management should be an integral part of every strategy, as it accounts for risks and enables the creation of more resilient environmental management systems. During strategic planning, special attention must be paid to risk assessment, as it enhances the ability to respond to crises quickly and effectively. Strategic environmental thinking is equally important. It encompasses not only long-term planning but also preparation for complex crisis situations that may arise unexpectedly.

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4. The role of adaptive leadership and communication in crisis conditions

In times of crisis, leadership and decision-making are among the most critical aspects of effective crisis management. Experience shows that success largely depends on the ability of leaders to make decisions quickly, without waiting for instructions from higher authorities. In this context, the ability for adaptive leadership and strategic thinking is particularly important, as it allows leaders to consider not only current needs but also the long-term consequences of their actions. Adaptive leadership is especially useful in crisis situations, where circumstances change rapidly and demand a flexible and innovative approach. It enables a response to complex challenges that cannot be solved using standard technical methods. Key principles of adaptive leadership include the ability to assess a situation from the outside, clearly identify the main issues, regulate stress, mobilize the team, and create conditions for innovation, experimentation, and learning. The use of decentralized and participatory management models is particularly important as they allow for the effective involvement of various stakeholder groups in decision-making. This increases flexibility in responding to crises and facilitates faster problem-solving.

To assess leadership qualities and skills required for adaptive leadership, various tests can be applied, such as MBTI (for determining personality type)[50], DISC (for analyzing behavioral reactions)[51], and the GROW Model (for evaluating leadership abilities and development potential)[52].

Crisis communication and stakeholder interaction are integral parts of effective crisis management. However, in Ukraine, this topic often receives insufficient attention in environmental education and practice. Successful communication during crises is a key factor for achieving positive outcomes, and it is therefore important to consider the specifics of team management and stakeholder interaction in crisis situations.

Crisis communication has its own peculiarities that need to be taken into account. It is important to understand psychological biases[53,54,55,56], such as

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confirmation bias (when people tend to search for and interpret information that confirms their previous beliefs), the "firehose" effect (when an excessive amount of information in a short period makes it difficult to process and analyze, often used in information campaigns or propaganda), and the halo effect (when the perception of one characteristic of a person or object influences the evaluation of other traits). These biases can significantly impact decision-making, and methods such as critical thinking and feedback are used to overcome them.

Effective communication within a team is critically important during stressful situations as it ensures clear management of information flows. Stress management helps maintain focus and emotional stability during prolonged crises. Self-regulation methods and increasing team resilience contribute to leadership effectiveness.

Interaction with stakeholders, including government agencies, corporations, and communities, is critically important before, during, and after disasters. Special attention should be given to resolving conflicts that arise in these processes, as constructive interaction can significantly impact the success of crisis management.

5. Uncertainty and information challenges in crisis environmental management

In the context of a complex environmental crisis, one of the key management challenges is uncertainty, which arises from insufficient or inaccurate information. This can lead to critical decision-making errors and negatively impact the effectiveness of the response. Addressing this issue requires the implementation of specialized approaches and methods that allow for working with limited data and forecasting possible scenarios of event development.

One important topic is the role of disinformation, fake news, and rumors, which create additional difficulties in decision-making. Disinformation, spread both through social media and traditional communication channels, can significantly affect the perception of a crisis situation and the decisions made

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based on it. To counter such challenges, it is essential to develop media literacy, critical thinking, and fact-checking skills. In particular, attention should be given to methods of information verification, including the use of specialized resources for fact-checking and metadata analysis. Governments, public organizations, and social platforms play a crucial role in this process, as they can contribute to combating disinformation and spreading reliable information. However, even with advanced information verification mechanisms in place, managing uncertainty requires effective decision-making strategies. One such tool is Bayesian probabilistic modeling[57,58,59], which is based on Bayes' theorem and allows for updating the probabilities of various scenarios based on new data. This method is extremely useful in conditions of limited or incomplete information, as it enables adaptive response and course correction by incorporating changes in input data. Another important tool is pre-mortem analysis[60], which allows for predicting potential failures through an imagined retrospective analysis of the potential collapse of a decision or project. This approach helps identify weak points at early stages and implement measures to prevent errors.

Uncertainty demands adaptive planning and constant situation monitoring. Successful organizational experiences show that in crisis conditions, not only timely decision-making but also regular evaluation of their effectiveness and the implementation of necessary adjustments are critical.

6. Integrative approach to sustainable development and environmental policy

Ukrainian science and education traditionally focus on an in-depth study of individual details, yet lack a systemic approach and interdisciplinary analysis. Developing systems thinking is critically important for making effective decisions in today's context, where the complexity of environmental, social, economic, and technological processes demands an integrative approach. Fundamentals of systems theory help understand the interactions and interdependencies between system components, which is

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crucial for comprehensive crisis management[61]. Systems thinking involves analyzing concepts such as emergence, feedback loops, and leverage points. Emergence describes the phenomenon where a system exhibits properties that cannot be understood solely by examining its elements. For example, the complexity of an anthill's behavior as a whole cannot be explained by studying the behavior of a single ant. Feedback loops, both positive and negative, are key to understanding how systems change under the influence of external factors. Positive feedback loops amplify changes, while negative ones stabilize the system. Leverage points are critical junctures in a system where even minor changes can have significant effects on the system's overall state. Tools of systems analysis, such as input-output models and causal loop diagrams, allow for visualizing and evaluating the impacts of interventions within a system. These tools enable the analysis of cascading effects and both direct and indirect interactions among system elements, which is vital for understanding the bigger picture and making more informed decisions.

In the context of system resilience planning[62], key approaches include enhancing adaptability, transformation, redundancy, and rapid recovery. Adaptability refers to a system's ability to quickly respond to changes and adjust to new conditions. This is achieved through the implementation of new technologies, updates to management structures, and the development of flexibility in operational processes. Transformation, in turn, involves a radical shift in system functionality to improve its resilience, such as transitioning to new governance models or adopting renewable energy sources. Redundancy ensures the availability of reserves or duplication of critical elements, allowing the system to function even in the event of disruptions. Rapid recovery after catastrophic events requires the presence of effective response plans, quick-response teams, and technologies to restore system operations in the shortest possible time.

Scenario planning is a vital tool for assessing system resilience. It allows for modeling potential challenges and testing system robustness under various development scenarios. An important aspect is the assessment of natural capital, which includes analyzing ecosystem services and biodiversity that act as natural buffers and reserves.

Polycentric governance promotes coordination between different decision-making centers, enhancing the overall adaptability of the system. Complex adaptive systems, modeled through agent-based modeling and

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system dynamics, enable the simulation of actor and subsystem behavior in crisis conditions, providing tools for more precise resilience planning.

Comprehensive resilience assessment involves identifying potential risks and vulnerabilities within the system and developing strategies to improve its capacity for rapid adaptation and recovery under stress and shocks. Natural capital assessment is a critical element of this process and should be integrated into resilience policies to ensure long-term management effectiveness.

Toxicology is an integral component of systems thinking and sustainable planning as it helps predict the environmental consequences of pollutants from various sources. Modern toxicology encompasses key aspects such as pollutant identification, bioaccumulation and biomagnification, the synergistic effects of chemical substances, and their environmental transformation. These processes can have significant consequences for ecosystems and human health, making their prediction critically important. The ability to accurately foresee the behavior of pollutants after they enter the environment facilitates the development of effective strategies to minimize their harmful impacts. Understanding the biological effects of toxicants on both entire biological systems and their individual elements is key to choosing pollution control methods. Such methods include pollutant containment, ecosystem rehabilitation, pollution reduction, and the conservation of vulnerable areas. Moreover, it is essential to understand the specifics of pollution across various environmental media: water, soil, air, and biota. The migration of toxicants and critical links within these environments require thorough monitoring and forecasting, especially given the scale of environmental damage that can result from military actions. Modern monitoring and forecasting methods, such as GIS technologies and mathematical modeling, rely on processing large datasets, enabling real-time assessments and predictions of ecosystem states and their components.

However, certain challenges persist in Ukraine in this field. In addition to insufficient funding, there is often a mismatch between domestic scientific methods and international standards. The lack of information on modern foreign methodologies also hinders effective operations. Adapting international standards and methodologies to Ukrainian conditions can significantly accelerate monitoring and management processes, saving time, resources, and financial costs.

The primary decision-making models (Fig. 2) in the context of environmental crises encompass several important approaches, including rational choice theory, heuristic decision-making, recognition-based decisions, and evidence-based decisions. Each of these methods helps evaluate potential courses of action in situations of uncertainty or limited

information, which are typical of environmental crises. Rational choice theory assumes that individuals make decisions through logical analysis of available options, selecting the one that maximizes their benefit or utility. This approach is effective when there is sufficient time and resources to carefully consider all alternatives. Heuristic decision-making relies on simplified rules or "heuristics," enabling individuals to quickly arrive at satisfactory solutions. This method is particularly useful when information or time is limited, a common scenario during environmental crises. Recognition-based decision-making draws on prior experience or knowledge. People tend to choose options they have previously encountered or those recognized as effective. This approach simplifies decision-making, especially in complex situations. Evidence-based decision-making involves the use of scientific data and analysis to justify choices. It includes a systematic collection of information, making this approach the most substantiated but also demanding in terms of time and resources.

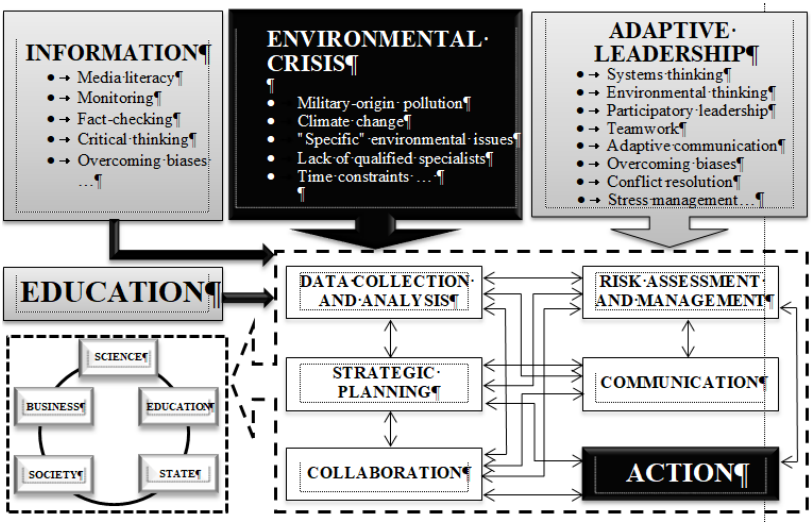

Fig. 2. Decision-making framework in conditions of a complex environmental crisis

One of the key aspects of decision-making approaches is the emphasis on humans as the primary criterion for assessing environmental risks. However, over time, comparative risk assessment methods have evolved towards less anthropocentric approaches, aiming to more accurately determine the prioritization of environmental threats.

For Ukraine, during wartime and in the context of future recovery, proper prioritization of threats and identification of critical environmental components are particularly crucial. This will enable the rational allocation of limited resources to minimize risks and maintain ecosystem stability. Integrating ecological, managerial, sociological, psychological, and other forms of knowledge and skills will facilitate the implementation of an adaptive leadership and management model under conditions of a complex environmental crisis. The adoption of this model will ensure effective responses to crises and support the development of resilient environmental policies in both the short and long term.

CONCLUSION

Ukraine is currently facing unprecedented environmental challenges that complicate the country's recovery during and after the war. Infrastructure destruction, soil contamination, threats to protected areas, and the critical issue of landmines present the state and society with the urgent task of implementing effective crisis environmental management strategies. Military actions significantly exacerbate global environmental issues such as climate change, necessitating a multidisciplinary approach that integrates the efforts of scientific institutions, businesses, governmental bodies, and the public. Adaptive leadership, strategic planning, and risk communication play a crucial role in enabling rapid responses to threats and minimizing their impacts.

Effectively addressing environmental challenges requires the integration of international expertise, including risk assessment, the adoption of innovative technologies, and the enhancement of legislation related to environmental crimes. Special attention should be given to training specialists capable of operating under environmental crisis conditions and to developing interdisciplinary educational programs that foster comprehensive thinking.

Ukraine's sustainable development demands the restoration of natural capital, the advancement of a "green" economy, and the creation of conditions for long-term ecological recovery. The crisis caused by the war also presents an opportunity to rethink the country's environmental policy and transform it in line with contemporary challenges and needs. Successfully implementing crisis environmental management will not only enable Ukraine to overcome the consequences of the war but also lay the foundation for resilient development in the future.

SUMMARY

In the current context of environmental challenges caused by military actions in Ukraine, systemic and integrated crisis management focused on multilevel stakeholder interaction becomes essential. This necessitates the development of crisis environmental management tools capable of

effectively addressing complex environmental situations while considering both local and global consequences. Special attention is given to adaptive leadership, strategic planning, and innovative technologies that enable swift and high-quality decision-making in crisis conditions.

The war has intensified the need for new approaches to environmental education, specialist training, and the development of interdisciplinary collaboration, allowing for the consideration of the interdependence of various fields of knowledge. Leveraging international expertise, particularly in risk assessment and sustainable recovery, contributes to the formation of a comprehensive strategy to address the consequences of environmental disasters. This highlights the importance of integrating social, economic, and environmental aspects into Ukraine's recovery and development processes.

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