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IMPACT OF INNOVATIVE TECHNOLOGIES FOR THE MINED LAND RELEASE AND ECOSYSTEM RECOVERY: NEW LEGAL APPROACHES AND UKRAINIAN EXPERIENCE[1]

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Abstract. The article discusses new ways to effectively influence the release of mined land and restore its ecological use. The purpose of this article is to analyze Ukraine's experience in implementing innovative technologies at various stages of humanitarian demining (in particular, land release) and the potential restoration of ecosystems; to systematize key aspects of updating the legal framework for mine action and the emergence of the humanitarian demining market; and to attempt to identify new legal approaches. The research methodology is based on the use of a dialectical approach, abstraction, and methods of logical and comparative analysis.

Since Ukraine was subjected to large-scale armed aggression by the Russian Federation, which resulted in massive mining of large areas, including agricultural land, there is a need to survey and clear them of mines. However, with conservative methods, this can take decades and the cost of demining services is constantly rising. Ukraine's experience shows that innovative robotic and digital technologies can reduce labor costs, reduce environmental impact, and accelerate all stages of mine action, making it more efficient. The author analyzes Ukraine's legal approaches to improving the legal regulation of the relationships under study, revitalizing innovation, and restoring affected ecosystems.

Key Words: environmental law, land release, digitalization, machine learning, AI, digital farming, ecosystem recovery.

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INTRODUCTION

Ukraine has faced a complex problem of mined areas of varying density, which also negatively affects the inability to live safely, travel or pass through, and use these lands for various types of economic activity, primarily agriculture. Agricultural products are a significant part of the state's export earnings. Thus, according to rough estimates, Ukraine loses $11.2 billion every year (Tony Blair, 2024).

The ecology of Ukraine has undoubtedly suffered enormously, with entire ecosystems of seas, rivers, steppes, forests and even national reserves destroyed or severely damaged. 'According to the Ministry of Environmental Protection and Natural Resources of Ukraine, since the beginning of the war, 812 protected areas with different types of military impact have been affected'(Filho W. L., Fedoruk M. et al, 2024). For example, according to some eyewitness accounts from the occupation and satellite imagery, both the flora and fauna of the Askanyia Nova reserve in Kherson have been severely damaged. In particular, it has suffered many fires, during which both vegetation and some animals have

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disappeared, and more valuable animals have been actively exported by the Russian occupiers to the internationally recognized territories of the Russian Federation. Even the National Mine Action Strategy states: 'It is undeniable that there are both direct and indirect negative effects of explosive remnants of war (ERW) contamination on the environment, including chemical contamination of land and crops grown on it, the state of local flora and fauna, impossibility of access to and proper maintenance of areas of environmental importance, damage to and destruction of flora and fauna as a result of mine action activities' (On approval of the National Mine Action Strategy, 2024).

This situation has forced Ukraine not only to unify its society, but also to rapidly develop scientific and technological progress, to invent innovative technologies and methods for modernising existing and foreign machines, mechanisms and equipment, as well as the latest ways of applying various technologies and developing new techniques, including mine clearance. Recently, the term 'digital agro-innovations' has been proposed in agrarian and environmental law science for such modern technologies as 'newly created (applied) and (or) improved competitive information technologies for the use of electronic and digital devices, tools, systems and the establishment of electronic communication exchange between them, which significantly improve the structure and quality of agricultural production, management of agricultural production and related processes and are aimed at increasing the competitiveness of the national agricultural sector and ensuring sustainable development of the agricultural sector'(Miroshnychenko O., 2024). The innovative process, which takes decades in peacetime to develop in the presence of huge resources, is developing in Ukraine during the war in three years under constant attacks, lack of resources and partial outflow of intellectual and human resources of the state.

Ukraine's legal regulation is also adapting to the new conditions, with an ambitious goal of ensuring humanitarian safety in the allegedly contaminated areas, the possibility of their economic use, and the ecological restoration of various damaged ecosystems of forests, water areas, and soils in the Ukrainian steppes and forest steppes.

The purpose of this article is to analyze Ukraine's experience in implementing innovative technologies at various stages of humanitarian demining (in particular, land release) and the potential restoration of ecosystems; to systematize key aspects of updating the legal framework for mine action and the emergence of the humanitarian demining market; and to attempt to identify new legal approaches.

THEORETICAL FRAMEWORK

According to the Law of Ukraine 'On mine action in Ukraine', mine action is a measure taken to ensure national security and to reduce the social, economic and environmental impact of explosive hazards on the life and activities of the population (On mine action in Ukraine). That is, it is a complex task assigned to the state. Let us try to establish the correlation between the concepts of 'mine action' and 'demining'.

Article 5 of this Law states that 'the main components of mine action in Ukraine are:

1) information on the dangers of explosive remnants of war and training in the prevention of the risks associated with ERW;

2) demining (humanitarian demining);

3) providing assistance to affected persons and taking measures for their rehabilitation;

4) destruction of surplus ammunition, ammunition unfit for further use and storage, and ammunition subject to destruction in accordance with international obligations;

5) campaigns and education on the non-use of anti-personnel mines'.

But the most dangerous central element of these measures is demining. There are three types of demining: combat or military, operational and humanitarian. Military demining is carried out by the military, based on a decision made by the military command on the expediency of mining or demining

for certain operations or other military activities. Operational demining is also carried out by military engineers or specialists of the State Emergency Service at critical infrastructure facilities during de-occupation or when the front line is moved further away from a settlement. And it is humanitarian demining that accounts for the largest number of areas (vegetable gardens, household plots, fields, forests, pastures, etc.) that need to be inspected, made sure of the need for demining, demined and handed over the released land as really safe.

Land release is an evidence-based decision-making process that helps to determine with certainty which land requires further action and which does not. The legislation defines humanitarian demining as 'a set of activities carried out by mine action operators to eliminate the hazards associated with ERW, including non-technical and technical surveys of territories, mapping, detection, neutralisation and/or destruction of explosive remnants of war, marking, preparation of post-action documentation, provision of information to communities on mine action and handover of the cleared territory' (On mine action in Ukraine). The stages of the land release are: identification of hazardous areas, exclusion of suspected contaminated areas/contaminated territories through non-technical survey, reduction of suspected contaminated areas/contaminated territories through technical survey and clearance of these kinds of lands.

The application of the land release process is to use all reasonable endeavours to determine where ERW is and is not present until it can be reasonably demonstrated that ERW is either not present in the area or, if found, has been destroyed or removed from the area.

The entire land release process needs to be supported by an *effective information management system* to ensure that data is collected accurately and consistently, reported in accordance with formats and timelines, entered correctly into databases, and analysed to provide reliable support to decision-makers and other stakeholders. The whole maps can be created with a huge amount of data with different proofs: informants evidences, witness statements, documentations, visible material evidence, photos and video, including many options how explosive devices can be visible on images. All this quantity of information may serve as the modern food for the artificial intelligence (AI) neural networks. In particular, the Ukrainians have thousands of hours of real, not simulated, video flights of various types of unmanned aerial vehicles that can be reviewed, processed and analysed not only by human experts but also by specialised neural networks for machine learning. And on the basis of this analysis, certain patterns, algorithms, suggestions for improving standard demining operations, or even methods or certain standards in the field of demining, from non-technical surveys to the transfer of demined areas, can be identified. Let us look in more detail at the possibilities for improving the efficiency, speed, cost and safety of demining operations at various stages using modern innovative technologies.

METHODOLOGY

Author used a dialectical method as a base of vision to create this research. There were several supplementary methods such as logical analysis, abstraction and comparative analysis.

Logical analysis helped to reveal the specific features of current legislation and recently developed subordinate legislation and standards for mine action. Abstraction made it possible to identify the most important innovations and proven approaches in demining practice in Ukraine, without getting side-tracked by minor technical details. The comparative method allowed for identifying similarities and differences between international demining standards and practices and Ukrainian approaches.

RESULTS

Identification of hazardous areas and non-technical surveys

Ukraine has already taken some steps to improve its legislation, the training system for mine action specialists and mine action operators, attempts to regulate the humanitarian demining market, and

to modernize the entire national mine action system in Ukraine. International law places the bulk of responsibility on the national government, with some exceptions for UN assistance: 'The primary responsibility for mine action lies with the government of an affected state. This responsibility is normally vested in a NMAA which is charged with the regulation, management and coordination of a national mine action programme. The NMAA is responsible for establishing the national and local conditions, which enable the effective management of mine action. It is ultimately responsible for all phases and all facets of a mine action programme within its national boundaries, including the development of national mine action standards, in line with IMAS' (IMAS 01.10).

In particular, the Mine Action Centre of Ukraine has not only adopted the best international empirical practices and methodologies, implemented international standards of IMAS – International Mine Action Standards, that were designed by the United Nations Mine Action Service. However, Ukraine did not limit itself to old practices, but added to its standards the latest digital and machine technologies that it had successfully used in its own experience, without limiting its list and demining specialists in the choice of technologies or mine actions methods, as technologies are constantly evolving and only practice shows which are the most effective and fastest in optimising the necessary processes at different stages.

According to the State standard of Ukraine 8820-5:2025 'Mine Action. Fundamentals of management. Part 5. Land Release Processes', which comes into force on 1 April 2025 (does not apply to river and sea areas), 'The non-technical survey methodology may include, but *is not limited to*, the following uses:

– the results of reasonable analysis of satellite imagery to identify potential locations of evidence;

– indicators taken from sensors, sensors, high-resolution video cameras, including those installed on unmanned aerial vehicles (UAVs);

– data obtained from informants;

– existing minefield maps or records' (DP «UkrNDNC», 2024).

The annexes to this standard specify what data, under what circumstances, can be considered as direct and indirect evidence of possible or actual land contamination. Indeed, at the first stages of research and processing of available direct or indirect evidence, it can be used:

1. Analysis of satellite images and drones with AI processing

High-resolution satellite imagery can be used to identify damaged areas and suspicious anomalies. *Drones* equipped with visible spectrum cameras, thermal imagers and multi-spectral sensors can detect recently disturbed ground, remnants of explosive devices, human or animal remains or suspicious objects. Specialised *drones equipped with laser scanners* (LiDAR) can detect anomalies in the terrain that indicate possible hidden mines. *Artificial intelligence* (AI) and *machine learning* can process large amounts of imagery, identify potentially dangerous areas and create interactive maps of contamination. For example, satellite image analysis and unmanned aerial vehicles were recommended for use by the international community in 2011 in A Guide to Land Release: technical methods (GICHD, 2011).

2. Warfare databases and historical maps

The use of *GIS* (geographic information systems) technologies to combine historical maps of warfare with modern data allows for the automatic prediction of possible minefields. Combining *Big Data* from various sources (drones, satellites, military maps, testimonies) into a GIS allows for the automatic identification of high-risk areas.

3. Since some modern ERW have electronic components (detonators, remote control), the use of specialised radio frequency scanners *(radio spectral analysis*) allows detecting such devices even without visual contact.

Analysis of military reports, satellite images of combat operations, and testimonies of local residents or other informants can help clarify whether a suspected contaminated area is actually contaminated. They can be processed by *AI* to create *predictive models* of contaminated areas.

The following technologies can theoretically help at this stage:

1. Magnetometric sensing

The use of magnetometers will help to detect metal objects under the soil at a depth of up to several metres. They can be used in combination with drones to quickly analyse large areas.

2. *Ground Penetrating Radar (GPR)* systems help to find mines and ammunition, even if they are made of plastic. The results can be processed by AI to improve the accuracy of object recognition.

3. *Thermal radiation analysis* (infrared cameras)

Mines can change the temperature of the ground due to the density of the material or heating by the sun. Drones with infrared cameras can detect such anomalies.

In addition, the number and professional qualifications of trained personnel for all stages of mine action are of great importance. For example, the use of *VR/AR* to train demining specialists allows for the creation of simulated scenarios in hazardous areas. This improves the skills of robotic system operators and reduces the risk of errors during actual work, which is especially valuable when the scope of work is large and there is a shortage of experienced specialists.

Technical survey

Ukrainian experience shows that the vast majority of land affected by the armed aggression of the Russian Federation is contaminated with shell casings, shell remnants and other ERW, rather than actually mined. Therefore, the return of most of the allegedly contaminated areas to productive use requires not direct demining, but the establishment of the true status of such lands through

1) primary non-technical survey,
2) if necessary, further repeated non-technical surveys,
3) technical surveys and
4) analytical evaluation of their results.

At this stage, experts can verify that the area is indeed contaminated and with what type of explosive remnants of war. The main objective of this important stage is to determine the exact coordinates of mines, the type of ERW and to plan for their effective and, if possible, rapid disposal. Technical survey work can be carried out using a single process (method), such as *manual demining, land clearance using mechanical means, mine detection systems using animals or a combination of several processes*.

For more than 15 years, international practices have recommended: manual inspection, using specially trained animals, flails, tillers, rollers or steel wheels, and a combination of different methods that have proven effective in different countries:

- ✓ Flail/tiller followed by visual inspection
- ✓ Flail /tiller followed by one animal
- ✓ Flail/tiller followed by low sensitivity detector
- ✓ One animal followed by targeted manual clearance (GICHD, 2011).

For modern safe and effective manual survey (and clearance) of mined land, specialists need reliable protection for their demining suits, auxiliary equipment such as metal detectors, mine detectors, and demining kits. Ukraine now produces both *sapper suits and complete sets*, as well as modern *mine detectors such as Aider*, numerous *metal detectors, professional sapper kits* and related products. For example, the Trembita metal detector, which finds mines in difficult conditions, is among several samples of domestically produced metal detectors that have been approved for use by the Security and Defence Forces of Ukraine and are not only as good as their foreign counterparts, but in some respects even better. In particular, Ukrainian mine detectors operate underwater or in other difficult conditions such as mineralized soils, and have Pinpoint technology, which is essential for determining the exact location of ERW (Ministry of Defence of Ukraine, 2025). Nevertheless, it is necessary to more systematically increase the production of goods for the 'whole cycle' of mine action It is advisable to involve the potential of domestic producers in the process of forming such a material and technical base in terms of manufacturing technical means for humanitarian demining, production of mechanized

demining machines (heavy class robotic complexes), pyrotechnic machines of heavy (light) type, which will help to reduce their costs. In addition, this will have an impact on the country's economic development and promote employment.

However, in order to facilitate the entry of Ukrainian-made goods into the market, it is necessary to simplify, accelerate and regulate the unified procedure for certification of mechanized demining (humanitarian demining), related products, components and other mine action equipment. And the cost of producing metal detectors and mine detectors, as well as the entire military-industrial complex, in Ukraine is significantly lower than in Europe and even more so in the United States. The existing capabilities of Ukrainian research institutions and the private sector make it possible to start developing prototypes of innovative technologies, but the process of scaling up production requires support from both the state and international partners. Receiving such support and scaling up the production of innovative technologies will help reduce the cost of humanitarian demining. Thus, with sufficient human resources, Ukraine can become a military forge in Europe, especially with foreign investment.

In more complex cases of contaminated land, the best option would be to clear it using mechanical means, either wheeled or tracked mine-detection systems. However, such specialized vehicles are not only expensive but also scarce. Special thanks to international donors, both private and foreign and international organisations. Thanks to international humanitarian assistance, Ukraine has received a range of different equipment and funding for various demining projects, usually addressing the local needs of individual communities. However, these are not always innovative technologies, as foreign partners often donate older equipment to Ukraine when they update their warehouses. In particular, Ukraine has received Ahlmann AS200 armoured demining excavators, Wisent-1 MS armoured demining vehicles based on the Leopard 1 tank hull, which has already been replaced by the Wisent-2 generation.

However, the more modernized Wisent 2 armored personnel carrier model (which can be modified as a repair and recovery vehicle, demining vehicle, and bridge paver) based on the Leopard 2 tank is made only to order and takes a long time to produce, which is why only a few NATO countries have these models or are waiting for them for a very long time. For example, Denmark had signed a contract with Flensburger Fahzeugbau Gesellshaft for the procurement of 3 Wisent 2 AEVs, but they will not be delivered until 2027. Therefore, at the moment, Denmark has leased three Wisent-2 (Fiorenza, N., 2024). Norway has ordered 8 Wisent 2s for 80 million euros, or 10 million euros per unit.

Unmanned mechanized systems are, of course, the safest for demining specialists. 'Currently, 62 GCS-200 mechanized demining vehicles manufactured by Global Clearance Solutions are operating in different regions of Ukraine. The *GCS-200 unmanned multi-purpose platform*, samples of which were handed over by our partners to a military unit of the Armed Forces Support Command last year, has a number of modifications. As a tracked vehicle, it is very maneuverable and can turn on the spot with a minimum radius of about four meters' (Mykhailov D., 2025). Another 26 such vehicles are scheduled to be delivered in 2025. Ukrainians have learned not only how to use foreign equipment, but also how to adapt it to different conditions and combine it with their own methods of technical survey and demining. Thanks to international cooperation, joint production of, for example, light MV-4 vehicles by a Ukrainian company that cooperates with the Croatian manufacturer DOK-ING has begun (Krasota I., 2025). Ukraine also revived its own research and development in this area and in October 2023 handed over to the State Emergency Service the first unmanned demining machine MR.3200, manufactured in Kharkiv, worth UAH 5.6 million (approximately 125 thousand euros). A year later, in 2024, Kharkiv designers presented a new, significantly improved Ukrainian mechanized demining machine MP.5100 (Cozatskii O., 2024) worth 450 thousand euros at the Demine Ukraine forum. In March 2025, the Germina URCM-3000 unmanned demining system worth €500,000 manufactured by the Kramatorsk Heavy Machine Tool Plant will be tested (Ministry of economy of Ukraine, 2025). With a government order and financial support, Ukraine could expand the supply of

its cheaper counterparts and not only cover its own needs, test them on different landscapes with different types of mines, but also export them abroad.

However, it is worth assessing the adequacy and effectiveness of the ratio of the level of contamination with ERW using the appropriate demining technique. It should also be remembered that the cost of demining will strongly depend on the chosen technology.

Today, the technologies and approaches that are best suited are:

1. Semi-autonomous reconnaissance drones

Drones with sensors (magnetometers, GPR, LIDAR) allow scanning the ground before the deminers start working. Infrared sensors help to detect mines whose temperature differs from the environment. Such drones can work even in hard-to-reach places (swamps, forests).

2. Demining robots

The use of robotic platforms, remotely operated (unmanned) vehicles, and specialized tracked robots for detailed probing reduces the risk to people. For example, Boston Dynamics-based platforms (such as Spot) can be equipped with metal detectors, X-ray scanners, and various sensors to search for ERW.

3. Biotechnology

Canine services have already been proven by the stable experience of using specially trained dogs. Experimentally, there is the potential to use rats, which were proposed in 2011 (GICHD, 2011) and bees trained to detect explosives, as they can effectively detect mines over large areas. As well as other animals smaller than humans, which reduces the risk of detonation. However, this methodology is only acceptable if the potential benefits clearly outweigh the small chances of endangering animals, and if all the principles of environmental safety of such operations are observed.

4. *AI and machine learning* for automatic identification of ERW

AI systems can analyze the shape, size and location of suspicious objects and determine the type of mines based on databases containing information about thousands of known ERW. Thanks to high-quality machine learning, specialized AI is able to offer the best options, tested by human experience of its predecessors, which technologies and machines are best used or in the most favorable combination for a given task on a certain terrain, taking into account the weather. However, in our opinion, this point *should limit AI's intervention* to suggesting different options with justification of these versions, but the decision should be made by a person – a responsible certified demining specialist. This is especially important when drones with trained AI will accompany specialists during demining operations and partially technical surveys. Both Ukrainian legislation and international guidelines need to explicitly state this point.

Using these technical survey methods, suspected contaminated and contaminated areas should be released through:

a) the complete or partial exclusion of previously documented suspected contaminated or contaminated areas if the non-technical survey has confirmed that there is no evidence of the presence of ERW;

b) full or partial reduction of suspected contaminated or contaminated areas if a technical survey confirms that there is no evidence of the presence of ERW;

c) clearance of the designated area to the specified depth.

Demining or clearance

Paragraph 11.2.9 establishes environmental requirements for conducting mine action operations with the use of machines, and most of them relate to the demining stage: 'The soil on which operations are carried out using machines and mechanisms must be left in a condition suitable for its intended use. If operations involve the removal of vegetation or are carried out in areas that may be prone to erosion, demining organizations should ensure that measures are in place to limit erosion. The operation, repair, and maintenance of demining machines should be carried out in an environmentally acceptable manner, preventing contamination of the ground from fuel and operating fluids' (DP

«UkrNDNC», 2023). In other words, the government sets minimum environmental standards to prevent potentially greater environmental damage from occurring.

The purpose of clearing areas is to remove or destroy ERW as safely as possible.

By 2025, the following technologies and approaches may be the most relevant to ensure maximum safety, efficiency, and cost-effectiveness of the process:

1. *Autonomous or Unmanned Ground Vehicles* for ERW clearance

The use of UGVs allows for the safe disposal of mines from a distance. Tracked systems with robotic manipulators can remotely defuse mines. Some robots are equipped with explosive water cannons that neutralize detonators.

2. *Drones*. Operators can remotely control robots from a safe distance using drones and AR glasses. Kamikaze drones equipped with small explosive charges can neutralize IEDs with pointed strikes, minimizing the risk to people.

3. *Electromagnetic pulses* to neutralize electronic mines. New types of mines may have electronic fuzes. The use of EMP guns can disable them without physical intervention.

4. Experimental demining methods, such as *laser vaporization* of mines using powerful lasers, are being tested as a rapid method of non-contact demining. The Ukrainian experience can demonstrate how effective and cheap this method can be. And if the tests are successful, the Ukrainian specialists who have tested it can be qualified instructors for international and foreign demining organizations.

Checking whether all ERW has been neutralized

Once the contaminated areas have been cleared, especially if the presence of UXO has been confirmed, it is necessary to make sure that there are no other UXOs and that the area is completely safe before handing it over to local communities. The same stage is also called the assessment of the status of surveys.

In this case, the following technologies can most effectively help to quickly review all previously surveyed and some neighboring areas:

1) *Drones and sensor grids*

The use of thermal imaging cameras and acoustic sensors allows you to check the area after demining. Deployment of sensor nets with vibration and magnetic sensors helps to detect residual explosive items.

2) *AI quality control* of demining. Analysis of the recorded data before and after demining allows you to refine maps and automatically compare the results and identify possible shortcomings.

Transfer of territories to local authorities

The final stage of mine action. 'Before an area can be accepted as excluded, reduced or cleared, it must be established with a sufficiently high level of confidence that there is no evidence of ERW contamination. This certainty can only be obtained after all reasonable efforts have been made to obtain information on the existence of ERW contamination and, if confirmed, to eliminate it' (DP «UkrNDNC», 2024).

The purpose of this stage is to officially certify the territories as safe for use by the residents of the respective community. We can optimize this process:

GIS and digital maps

The creation of 3D maps and interactive reports on demining allows you to control the process of transferring territories and will be most convenient for mine action specialists and change the legal status of different territories, which will give grounds for the return of safe productive use of the territories.

Blockchain for certification

Recording data on the work carried out in the blockchain can guarantee transparency and the impossibility of falsifying demining results. It can also potentially be used to certify goods in the field of mine action.

Recovery of agricultural land and ecosystems

This mine action is sufficient for safe use, but farmers need to use the land productively, which requires checking and analyzing the physical condition of the land and the chemical composition of the soil. Based on the results, they need to take measures to improve land fertility, if necessary.

Land affected by hostilities and where demining was carried out is considered disturbed land if it has lost its economic and environmental value due to soil disturbance, in accordance with Article 1 of the Law of Ukraine 'On Land Protection'. The need to return disturbed lands to economic use is stipulated by the Land Code of Ukraine, the Laws of Ukraine 'On Land Protection' and others. In such cases, Ukrainian legislation provides for such legal measures as improvement of agricultural land, land reclamation, reclamation, conservation, and monitoring of land and soil.

After the transfer of already released lands (or, if possible, at the same time as checking whether there is no remaining ERW), it is necessary to examine the soil quality of the site, whether there is sufficient humus, and the pH level. If there is minor damage to the soil cover, certain improvements to agricultural land can be applied, such as planting forest belts, loosening, distributing the humus layer, sowing certain plant varieties that can absorb heavy metals from the soil, but then the harvested crop must be utilized. Some experts consider such measures to be melioration or recultivation. On those land plots where the surface subsides, recultivation is not carried out until the underground voids are eliminated.

Recultivation is a set of organizational, technical and biotechnological measures aimed at restoring soil cover, improving the condition and productivity of disturbed lands in accordance with Article 166 of the Land Code of Ukraine.

Reclamation of disturbed lands is carried out in technical and biological stages. The technical stage of reclamation involves preparing the land for its further use and includes: Removal, storage and storage of fertile soil; selective formation of dumps, mining operations to level the surface of disturbed lands, leveling of dump slopes and excavations; covering the reclamation surface with fertile soil or soil suitable for creating a reclaimed soil layer; construction of access roads, if necessary; and carrying out erosion control, hydromelioration and cultural and technical measures, if necessary.

'The biological stage of reclamation includes measures to restore land productivity, which are carried out after technical reclamation. Biological reclamation includes a set of agrotechnical and other measures to restore soil fertility, increase the productivity of agricultural and forest lands, develop water bodies, restore flora and fauna, and eliminate the negative impact of disturbed lands on the environment' (On approval of the Rules for the development of working land management projects). According to the direction of further use of reclaimed land (creation of agricultural land, forests, water management facilities, etc.), the appropriate set of technical and biological stages is selected for a particular land plot.

Both reclamation and conservation are considered natural forms of land restoration (Melnyk O., 2020). But conservation is the most radical method. According to T. Lisova, 'it is advisable to conserve these lands only if other measures aimed at restoring and improving their quality have not yielded the expected effect. Prior to the conservation of such lands, there is a need to apply nutrients, mineral fertilizers, and to land them by using soil removed during mining, geological exploration, construction, and other activities. The same chemical reclamation measures should be applied prior to land conservation, but not simultaneously, as this may prevent this process' (Lisova T., 2020). Unfortunately, it takes a lot of time, specialists, and technology to clear large areas of land in Ukraine. Therefore, in 2024, the legislation was amended to explicitly include among the grounds for conservation 'land plots contaminated with chemicals as a result of emergencies and/or armed aggression and hostilities during martial law; land plots on which military engineering and/or fortifications are located' (On approval of the procedure for land conservation). In general, the indicators characterizing soil properties and determining the need for land conservation by natural and agricultural zones are set out in the Annex to the Land Conservation Procedure. While the land is waiting for its turn to be demined, if there are

shells, mines, and other ERW in it, the soil may become contaminated with heavy metals, undergo pH changes, large animals may be tripped by mines, etc. At the same time, if no ERW is found on the allegedly contaminated land, the soils left under steam are capable of self-healing and improving their humus layer, so it is worth recording on the maps of the territories after at least non-technical surveys how long the land has not been used and the meaningful results of all surveys.

Modern technologies can contribute to a much faster restoration of contaminated land and prevent or reduce its conservation:

Integration of the Internet of Things (IoT) and sensor networks

Ecosystem monitoring systems:

After demining, IoT systems that include a network of sensors to monitor soil quality, moisture, pollution levels, and other environmental parameters can be used to restore agricultural land and ecosystems.

Real-time data analysis:

Data from the sensors is transmitted to a central system where AI algorithms analyze the condition of the soil and ecosystems, providing recommendations for optimizing agricultural or environmental restoration activities.

Systems for forecasting and planning restoration:

AI can be used to create models of ecosystem recovery after demining. This allows us to predict which rehabilitation measures (e.g., planting forests, restoring natural watercourses, transporting certain animals, sowing crops that are beneficial to the soil) will be most effective given the specifics of the local environment.

Optimization of agricultural practices:

By analyzing data on soil conditions, humidity, climate, and other parameters, AI can recommend optimal agricultural practices that will help return land to productive use faster.

Generally speaking, agricultural operations optimized with the help of various innovative technologies (including digital) can be considered digital farming. Only earlier it was perceived as a distant prospect for the development of the state's digital policy for large agricultural holdings in order to reduce costs, improve efficiency, monitor the condition of land, etc. But now it is a modern challenge with the first priority of security and the ability to conduct agribusiness in general, which is becoming a reality for ordinary farmers.

DISCUSSION

Unfortunately, pricing in 2025 for the provision of humanitarian demining is not transparent enough, that causes an unreasonable assessment of work by commercial mine action operators and does not contribute to the formation of an open service market. In 2022, at the beginning of the sowing season of winter crops, the situation was on the verge of catastrophic, many farmers lost significant sown areas. It was 2022 that turned out to be historically the most difficult, since Ukraine became heavily mined, was not ready for such aggression with a huge number of shells, bombs, guided bombs, mines, but insufficient material base and the number of sappers and mine operators. The fundamental foundations for the creation of a national mine action system were laid before the full-scale invasion of Russia, when the Law of Ukraine 'On Mine Action in Ukraine' was updated, the Procedure for keeping records of mine action operators, training and certification of their specialists was adopted, and the National Mine Action Authority and the Mine Action Center were established. Thus, due to a combination of both objective and subjective reasons, at the beginning of the full-scale invasion, mine action was somewhat unsystematic, with more survey and demining projects being implemented individually at the expense of donors or by uncertified specialists, but over time, in 2023-2024, Ukraine established its system, by updating the National Mine Action Authority, headed by the Minister of Defense of Ukraine, and the Mine Action Center, which was established in 2021,

and taking on new, much larger and more complex challenges, a legal mechanism for social security for victims and financial compensation for farmers was finally developed.

Most of the territories were liberated in the summer and fall of 2022, and large areas of allegedly mined land appeared, but some of them are close to the combat zone and it is more difficult, if not impossible, to demine them by the end of the war. All of these lands have been effectively withdrawn from productive use. Legally, they were included in the list of objects to be conserved.

Farmers were put in a risky, but also really difficult situation where they lost a sowing season, or maybe even several, with almost every month of land downtime, so they resorted to unregulated, often artisanal demining methods, some of which helped to improve and modernize drones and special demining vehicles. However, high demand and unofficial demining practices have created a market for "black deminers" who do not have certificates and do not guarantee the quality and safety of their work, but offer dumping prices for their dubious services.

Donor-funded demining, free of charge for landowners or land leaseholders, remained inaccessible for a long time due to long queues, and the private market offered too high prices, which is why a significant number of farmers decided to leave the land fallow for several more sowing seasons. In fact, the government civilized the procedure of state compensation for farmers only 2 years after the full-scale invasion of Russia by adopting the CMU Resolution 'On approval of the procedure for the use of funds provided for in the state budget for compensation of expenses for humanitarian demining of agricultural land' of March 12, 2024 № 284. Starting from April 15, 2024, farmers will be compensated 100 percent of the cost of demining services at the expense of budgetary funds; before that date, 80 percent of the cost is subject to compensation and only if the work is carried out by certified mine action operators.

As of the beginning of 2025, there are more than 70 mine action operators in Ukraine who can provide relevant paid services and make a significant contribution to the clearance of Ukrainian land from ERW. Demining is an expensive service, so to stimulate the market, the state budget of Ukraine for 2024 allocated UAH 3 billion to compensate farmers for humanitarian demining of agricultural land, and the budget for 2025 allocated only UAH 1 billion, despite the fact that more than 139,000 km^2 of land and 14,000 km^2 of water remain mined (UA National Mine Action Center). Reduced state funding will lead to an increase in the gray unofficial demining market.

Currently, Ukraine has the following procedure for compensating for the cost of demining agricultural land:

A farmer submits an application to the State Agrarian Register, where an initial check is made to determine whether the land really belongs to the farmer, whether it has undergone a non-technical survey and whether contamination has indeed been found.

The Center for Humanitarian Demining carries out additional verification of the submitted documents. This Center determines the expected cost of demining the agricultural land and procures such services, informs the farmer about the completed bidding and the winning operator. The Center transfers 100% of the cost of the work to a special account.

The mine action operator starts demining the site after reserving the entire amount. The operator completes the demining of the site and sends the Center documents confirming the demining: a certificate of completion, an inspection report of the cleared/cleared land. The Humanitarian Demining Center checks the documents and sends them to the bank. The bank transfers funds for demining to the operator.

Also, farmers whose land has already been demined by certified mine action operators between February 24, 2022 and April 15, 2024 can apply for compensation, but in an amount not exceeding 80 percent of such services.

In a *difficult economic environment*, the capacity of customers of humanitarian demining services, who are often agricultural producers and landowners, is limited. The return of land to productive use will not provide farmers or landowners with profits (less than agroholdings) that can compensate for

the costs incurred in the short and medium term. This situation created the preconditions for the following negative scenarios, which were the most popular in 2022-2023:

– the customer turns to illegal humanitarian demining service providers who do not have a certificate of conformity of mine action processes and are not included in the list of mine action operators maintained in accordance with the law. 'This poses a danger to people and the state, which negatively affects the recovery of the national economy;

– the customer accepts the fact that the relevant land has been withdrawn from productive use, but does not take actions aimed at returning it;

– the contracting authority applies to non-profit mine action operators who can provide relevant services at the expense of donor support, but the donors' capacity is limited, and therefore only a small number of beneficiaries can access such services and in an uncertain timeframe' (On approval of the National Mine Action Strategy). The adoption of compensation to farmers can significantly reduce the demand for "black" deminers, but it requires urgent stable funding by the state or donors.

So, now, to overcome the "black deminers" it is necessary:

– increase the number of certified mine operators who have as many specialists as possible and the necessary means for the rapid release of mined areas that still remain;

– improve the methodology and means for faster non-technical examination with the help of the above-mentioned innovative technologies, since this is most of the work.

Both tasks can be facilitated by machine learning, AI and drone augmentation, especially with AI.

Ukraine signs a partnership agreement with AI tech company Palantir Technologies Inc. (Automation of demining). This agreement can be considered broader than a memorandum of understanding, as it contains specific provisions on the mutual rights and obligations of the parties in the following areas:

– Digitization of humanitarian demining operations, automation of a number of processes envisaged in the National Mine Action Strategy of Ukraine for the period up to 2033;

– Expansion of digital capabilities to coordinate clearance and assessment, prioritise mined areas for targeted activities, and manage risks in mine action;

– Use of a special assistant based on the Palantir Artificial Intelligence Platform (AIP) to make informed and most effective decisions in mine action.

The platform is able to work with large databases generated by stakeholders involved in a range of mine action activities, from local governments, regional government representatives, ministries and mine action operators. It is envisaged that AIP databases will contain both permanent information, such as an assessment of the economic efficiency of agricultural land, the proximity of areas contaminated with ERW to communication lines, etc., and operational information that will be regularly updated. For example, this may include data from surveys of the territories by the SES, SSTS, non-governmental operators, the number and condition of various equipment, the availability of pyrotechnic units in the required areas, etc.

'Thanks to the capabilities of Palantir AIP, the platform will analyse the information and provide recommendations for process optimisation. For example, it will provide advice, taking into account all the data, on how to most effectively clear a particular area - using new demining methods, such as drones, or traditional methods. The ultimate goal is to demine territories faster and at a lower cost' (Automation of demining).

The governments of the United Kingdom and Switzerland will support the priority project in humanitarian demining. It is based on the platform of the technology company Palantir, specializing in big data analytics. This was announced at the Mine Action Conference in Ukraine (UMAC-2024), which was held in Lausanne (Switzerland) in October 2024.

The allocated money will be used to implement a pilot project for 3 months in the Kharkiv region. This project will allow to check the general logic and the prioritization algorithm developed by the team of Ukrainians within one region.

'Prioritization is one of the important processes in building an integrated system of mine action. Based on a large amount of data processed by AI, we will be able to determine which areas should be cleared first. And I am glad that we are moving quite quickly in building this process: we recently signed a memorandum with Palantir, and today we are launching a pilot project. I thank the partners for their support and I am convinced that this is a two-way movement - the technology we have developed and improved will be able to be used by other countries for which the problem of mining territories is relevant' (Ministry of economy of Ukraine, 2024) considers Yulia Svyrydenko, Minister of Economy of Ukraine.

After signing the project financing contract, Ukrainian teams will have three months to test the proposed prioritization system and if inconsistencies are found, correct them. In the case of a successful test, the project is scaled to all 10 areas that have been affected by hostilities.

In early 2025, Ukraine announced the creation of a mine range, where 'they are going to introduce new approaches to the analysis of satellite and aerial photographs for mapping mined areas, as well as the use of neural networks for automatic recognition of minefields and the integration of modern artificial intelligence algorithms into the processes of planning and safe mine clearance' (Kazancev D., 2025).

The updated legal regulation of Ukraine, the practice of contracting, the approved legal mechanism for compensating farmers for demining costs emphasize the need for (and with the help of innovative technologies - a real opportunity) to take into account more during all stages of mine action the environmental requirements for the preservation and restoration of the environment, the efficiency of using and combining various methods and techniques of inspection, demining, land monitoring, improving the safety of all processes, the reliability of services provided by certified operators. Such moments and the results of generalizations of Ukrainian practice can serve as a modern basis for updating and international approaches.

Thus, digital farming is becoming not only an innovation, but rather a necessity, to make use of natural resources more productively and in line with environmental safety, and to do business more efficiently in the face of unusual challenges such as martial law, contamination of large areas with explosives, and overcoming the consequences of hostilities. For Ukraine, digital farming as a direction of modern state policy (Strizhkova, A., Tokarieva, K. et al., 2020) has now become particularly relevant as a way for farmers to survive, modernize their business, taking into account the need to restore ecosystems, and become more profitable faster. As noted by V. Bredikhina, 'the use of digital technologies in the natural resource sector will open up new opportunities for economic development and efficient management of natural resources, will contribute to the modernisation of economic activity and its further transition to a closed, waste-free production cycle with the preservation of natural resources' (Bredikhina V., 2023).

CONCLUSIONS

Ukraine is going through an incredibly intense, stressful, but also enormously stimulating stage of its innovation development. Foreign technologies have been transferred to Ukraine in the form of non-innovative or so-called secondary innovations, when states gave away their older equipment, which was in greater quantity than the minority of innovative developments. On the one hand, this is a pragmatic approach, because the older generation of equipment performs its functions well, and we need a lot of it for such a long frontline and the territories of territorial communities contaminated with ERW. On the other hand, more advanced technologies could give an even more intense impetus to the development of the Ukrainian military-industrial complex, including demining. For the time being, however, Ukraine has also done a good job of inventing and modernizing both domestic and foreign technologies, even better than could be expected given the current level of funding and lack of professional staff. By streamlining legal regulation, adopting a national strategy, creating a working,

albeit imperfect, mine action system, and certifying mine action specialists, operators and items, it has managed to establish a market for mine action services that is gaining momentum.

Ukraine can offer the world its own forge of metal detectors, all kinds of drones, special armored unmanned demining vehicles, and other mine action equipment, as well as the improvement of the latest ways to apply various technologies and develop new techniques, including demining. At the international level, these improvements may be a proposal to update international standards of IMAS, EU and NATO countries, taking into account the Ukrainian experience.

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ВПЛИВ ІННОВАЦІЙНИХ ТЕХНОЛОГІЙ НА ВИВІЛЬНЕННЯ ЗАМІНОВАНИХ ЗЕМЕЛЬ ТА ВІДНОВЛЕННЯ ЕКОСИСТЕМ: НОВІ ПРАВОВІ ПІДХОДИ ТА УКРАЇНСЬКИЙ ДОСВІД

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Анотація. У статті розглядаються нові способи ефективно впливати на вивільнення замінованих земель та відновлення їх екологічного використання. Мета статті – проаналізувати український досвід впровадження інноваційних технологій у різні стадії гуманітарного розмінування (зокрема, ленд-реліз) та можливе відновлення екосистем, систематизувати ключові моменти оновлення правового регулювання протимінної діяльності, зародження ринку гуманітарного розмінування, спробувати виділити нові правові

підходи. Методологія дослідження побудована на використанні діалектичного підходу, абстрагування, методів логічного та компаративного аналізу.

Оскільки Україна зазнала масштабної збройної агресії РФ, наслідком якої стало масове мінування великих площ, у тому числі сільськогосподарських угідь, виникла потреба їх обстежити та розмінувати. Проте, консервативними методами досягнути цього можна десятиліттями з постійним здорожчанням послуг саперів. А досвід України показує, що інноваційні роботизовані та цифрові технології дозволяють знизити вартість робіт, зменшити шкідливий вплив на довкілля, прискорити усі стадії протимінної діяльності, дозволяючи досягнути усіх її цілей ефективніше. Проаналізовано правові підходи України до удосконалення правового регулювання досліджених відносин, пожвавлення інноваційної діяльності та відновлення постраждалих екосистем.

Ключові слова: екологічне право, розмінування земель, діджиталізація, машинне навчання, штучний інтелект, цифрове фермерство, відновлення екосистем.

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