

Ministry of Education and Science of Ukraine
Black Sea Universities Network

ODESA NATIONAL UNIVERSITY OF TECHNOLOGY

International Competition of
Student Scientific Works

BLACK SEA SCIENCE 2022 PROCEEDINGS



ODESA, ONUT 2022

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BLACK SEA SCIENCE 2022

Proceedings

Odesa, ONUT 2022

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INTRODUCTION

International Competition of Student Scientific Works “Black Sea Science” has been held annually since 2018 at the initiative of Odesa National University of Technology (formerly Odesa National Academy of Food Technologies) with the support of the Ministry of Education and Science of Ukraine. It has been supported by Black Sea Universities Network (the Association of 110 higher education institutions from 12 countries of the Black Sea Region) since 2019, and by Iseki-FOOD Association (European Integrating Food Science and Engineering Knowledge into the Food Chain Association) since 2020.

The goal of the competition is to expand international relations and attract students to research activities. It is held in the following fields:

- Food science and technologies
- Economics and administration
- Information technologies, automation and robotics
- Power engineering and energy efficiency
- Ecology and environmental protection

The jury includes both Ukrainian and foreign scientists. In the 4 years that the competition has been held, the jury included scientists from universities of 24 countries: Angola, Azerbaijan, Benin, Bulgaria, China, Czech Republic, France, Georgia, Germany, Greece, Israel, Italy, Kazakhstan, Latvia, Lithuania, Moldova, Pakistan, Poland, Romania, Serbia, Slovakia, Switzerland, Turkey, USA.

At the same time, every year the geography has expanded and the number of foreign jury members has increased: from 46 jury members representing 25 universities from 12 countries in 2018, to 73 jury members of the 46 universities from 19 countries in 2022.

More than a thousand student research papers have been submitted to the competition from both Ukrainian and foreign institutions from 25 countries: China, Poland, Mexico, USA, France, Greece, Germany, Canada, Costa Rica, Brazil, India, Pakistan, Israel, Macedonia, Lithuania, Latvia, Slovakia, Romania, Kyrgyzstan, Kazakhstan, Bulgaria, Moldova, Georgia, Turkey, Serbia.

The interest of foreign students in the competition grew every year. In 2018, the students representing 15 institutions from 7 countries have submitted 33 works. In 2021 the number of submitted works increased to 73, authored by the students of 40 institutions from 18 countries.

The competition is held in two stages. In the first stage, student research papers are reviewed by members of the jury who are experts in the relevant fields. In the second stage of the competition, the winners of the first stage have the opportunity to present their work to a wide audience in person or online.

All participants of the competition and their scientific supervisors are awarded appropriate certificates, and the scientific works of the winners are included in the electronic proceedings of the competition. Every year the competition receives a large number of positive responses from Ukrainian and foreign colleagues with the desire to participate in the coming years.

5. ECOLOGY AND **ENVIRONMENTAL** **PROTECTION**

THE IMPACT OF THE COMBAT ON THE ENVIRONMENT: THE EXPERIENCE OF THE WORLD AND UKRAINE

Authors: Natalia Bohach¹, Nana Labadze²

Advisor: Myroslav Malovanyy¹, Tsitsino Turkadze²

¹Lviv Polytechnic National University (Ukraine)

²Akaki Tsereteli State University (Georgia)

Abstract. *Despite all the achievements of progress, war remains an important means of resolving the contradictions of mankind. Moreover, the growth of the world's population and the large-scale level of industrialization have led to the fact that since the last century, wars have begun to cause significant damage to the environment. Despite the efforts of environmental scientists, the issue of environmental protection is still not given enough attention, while the issue of environmental security in the armed conflict is becoming increasingly important. The purpose of this work is to comprehensively assess the impact of wars and armed conflicts on the environment, both globally and in the context of the war caused by Russia's armed aggression against Ukraine. This work assessed the environmental impact of all modern wars and armed conflicts since the beginning of the XXI century, as well as a detailed analysis of the environmental aspects of the war that has been going on in the East of Ukraine since 2014 caused by Russia's armed aggression against our state. The study also provides a predictive assessment of the further nature of changes in the impact of wars on the environment and provides recommendations on ways to minimize them, both in Ukraine and internationally.*

Keywords: war, Russian aggression, East of Ukraine, African continent, Middle East, Afghanistan, Georgia, climate change, environmental impact, environmental security.

I. WARS OF THE XXI CENTURY: ASSESSING THE IMPACT ON THE ENVIRONMENT

Wars and armed conflicts have been an integral part of human existence throughout its history, from ancient times to the present day. Despite the destructive nature of the war and the awareness of all its negative consequences, the international community has failed to secure a peaceful settlement of the dispute. Moreover, any state that has succumbed to the illusions of pacifism and lost its military potential will sooner or later fall victim to armed aggression, which became especially familiar to Ukraine after Russia started the war in 2014.

At present, there are no signs that wars and armed conflicts will end in the foreseeable future. Moreover, the growth of the Earth's population, the gradual depletion of resources, the limitation of living space and the deterioration of the environment will be the causes of new wars. This is an objectively realistic scenario that cannot be prevented. At the same time, the awareness of the inevitability of such a forecast necessitates a comprehensive readiness for it, including in the field of ecology.

Scientists Rafael Reuveny, Andreea S. Mihalache-O'Keef, Quan Li in their

article «The effect of warfare on the environment» reviews theoretical studies of the possible effects of war on the environment and evaluates statistical models of these effects on air emissions per capita population, the rate of change in forest area and a composite indicator of environmental stress reduction [1].

It is generally assumed that war always harms the environment, but it is logical to say that this is not the only possible outcome. War can also disrupt and reduce harmful human activities. Another possibility is that war may not have a significant impact on the environment. Since all these possibilities are logically plausible, the net impact of the war on the environment is an empirical question (Table 1).

Table 1. Theoretical impact of warfare on the environment [1]

Effect	Direct/ Indirect	Mechanism	Examples
Harmful	Direct	Destruction as a winning strategy	Destruction of arable land, agricultural land, forests and lakes; flooding; burning of oil fields; destruction of mines; extermination of livestock
Harmful	Indirect	Side effects of war-related activities	Movement of armed forces; waste and pollution from military production; neglect of environmental standards; damage to the environment by refugees
Favorable	Direct	Destruction of normal economic activities that harm the environment	Destruction of environmentally harmful industries; destruction of vehicles and transport network that reduces emissions; destruction of fishing fleets
Favorable	Indirect	Side effects of war-related activities	Reduction of fishing in dangerous areas, reduction of activity in restricted areas, reduction of fuel used at home, as more is sent to the front, mobilization of workers from environmentally harmful sectors of the economy
No clear effect	Direct	Minor impacts	Point air/missile strikes, border skirmishes, low-tech armed conflicts
No clear effect	Indirect	Harmful and beneficial effects are offset	The growth of military production is balanced by the destruction of normal economic activities that harm the environment

The publication finds that the war has a significant impact on the environment, but the signs and magnitude of these consequences depend on the studied environmental indicator, the place of hostilities on its own territory or abroad, as well as the level of technological development of the studied state.

Scientists Michael J. Lawrence, Holly L.J. Stemberger, Aaron J. Zolderdo, Daniel P. Struthers, Steven J. Cooke with their study «The effects of modern war and military activities on biodiversity and the environment» conduct a detailed analysis of the impact of hostilities and armed forces on the environment. The article objectively

reveals the nature and features of different types of impact on the environment in the following areas (Fig. 1):

- by the nature of the weapons used (conventional or nuclear);
- by components of the armed forces involved (land, air, sea);
- by stages of war (preparatory period, active warfare, postwar period);
- by the nature of the armed forces (activity of military facilities, exercises, etc.)

[2].

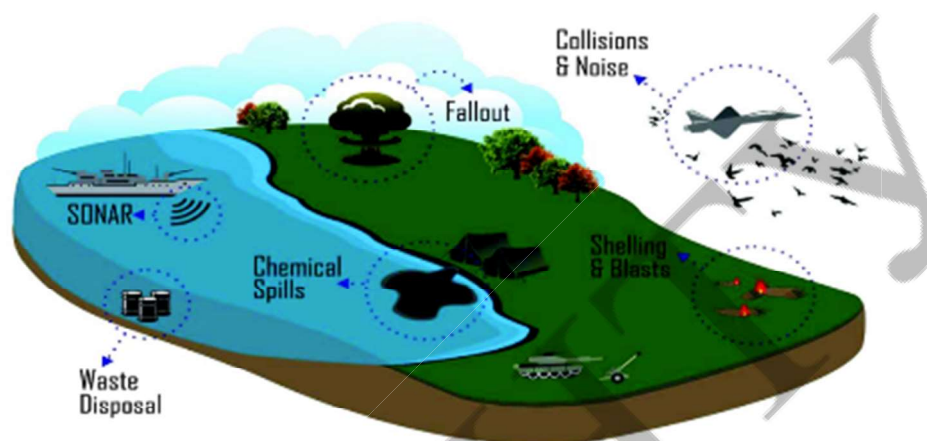


Fig. 1. Review of the potential adverse effects of war on the environment, including land, air and naval theaters of war [2]

The results of the study confirm that the impact of warfare on the environment is mostly negative. The authors of the publication claim that since war is an integral part of human activities, it is advisable to further deepen the level of study of the impact of war on the environmental situation in order to develop potential strategies to minimize the harmful effects.

Unlike their Western counterparts, Ukrainian scientists pay full attention to the environmental problems of Russia's armed aggression against Ukraine. Seven year of the war in eastern Ukraine has serious consequences for the biosphere of the entire planet, not just a particular region. Therefore, under the auspices of international organizations, namely the OSCE and UNEP, with the participation of numerous volunteer organizations and donors from European countries, domestic researchers are developing material to address the environmental crisis in the Donbass.

The International Charitable Organization «Environment People Law» (hereinafter EPL) is a pioneer among researchers of the impact of the war on the environment of Donetsk and Luhansk regions. They were the first to assess the damage caused by shellings, such as the battles for Savur-Mohyla mound (summer 2014), which is located within the Donetsk Kryaz Regional Landscape Park, which is a natural monument and has significant recreational potential. The use of artillery caused significant losses to the park's forest due to large-scale fires, as well as damage to large areas of soil cover (Fig. 2-3) [3].

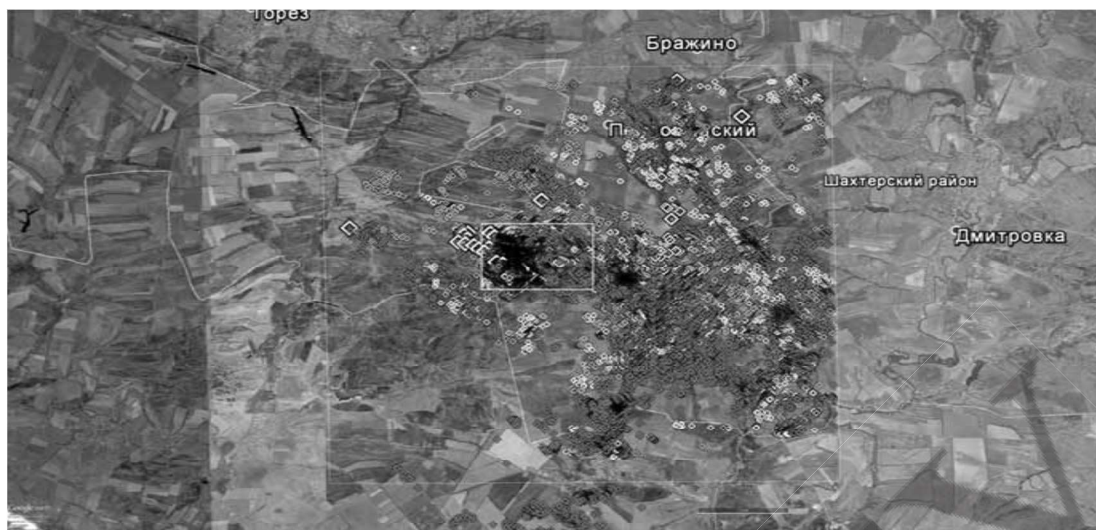


Fig. 2. The area of 225 km² with shells explosion craters

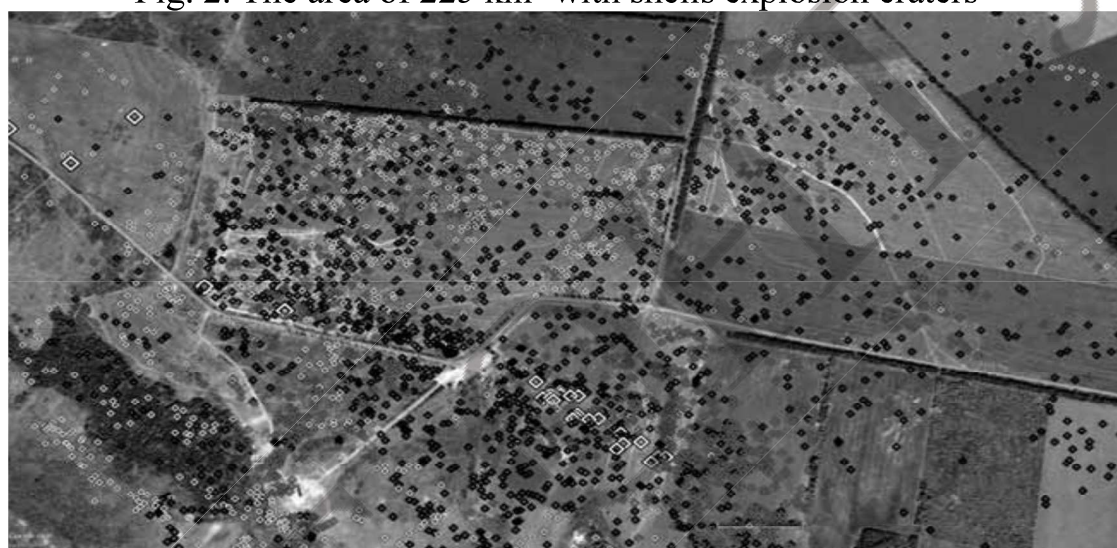
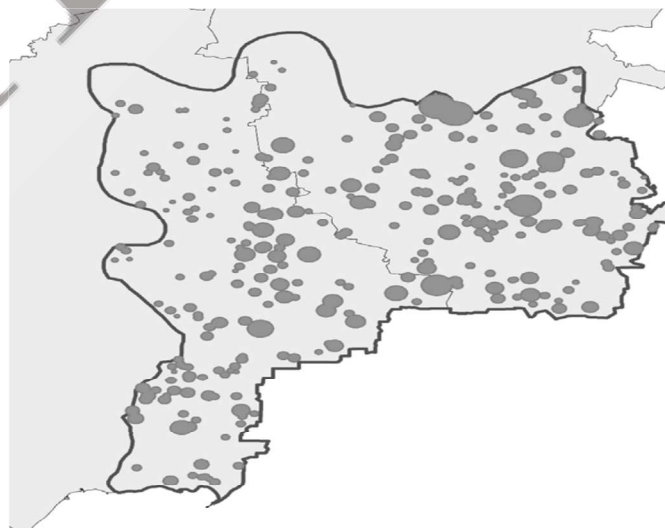


Fig. 3. Part of the craters in an enlarged format

Large-scale fires in the study area are one of the most significant factors in the impact of hostilities on the environment, which led to the choice of EPL for the next object of study. At the same time, information on this topic is relatively accessible, including in the temporarily occupied territories, which further contributes to research (Fig. 4) [3].



B. Babin, A. Chvalyuk, A. Plotnikov in their work reflect the main risks to the sea ecology of Ukraine, in particular uncontrolled fishing, ingress of wastewater from industrial facilities and coastal settlements, which in particular leads to the destruction of bottom ecosystems in Karkinitzka and Kalamitsky Bays, environmental threats arising from the actions of the Russian occupants in the Crimea (Russian Black Sea Fleet, illegal usage of captured drilling rigs, construction of desalination systems, etc.), as well as Russia's use of sea reserves adjacent to the occupied Crimea to create artificial pretexts to expand their territorial claims [4].

The object of the study is the factors influencing environmental security caused by warfare during armed conflicts, their consequences in the post-conflict period, as well as the impact on the environment of military activities in peacetime.

The subject of the study is the peculiarities of the environmental situation in the war zone, taking into account regional features.

Due to the fact that the subject and object of research are directly related to war, the use of empirical methods, including field research and experiments, was objectively impossible. Therefore, in the framework of the project theoretical and complex research methods were used, in particular: analysis, synthesis, induction, deduction, comparison, abstraction, modeling.

1.1. Africa as the hottest spot on the planet

Climate change is often referred to as a «vulnerability enhancer» that can increase security risks and conflicts in fragile regions and hotspots where poverty, violence, injustice and social insecurity prevail. This is very important for the African continent due to the presence of both climate change and a large number of conflicts. Along with other factors, climate change can undermine human security and the livelihoods of vulnerable communities in Africa through a variety of components. These include:

- variability in temperature and precipitation;
- extreme weather and natural disasters such as floods and droughts;
- resource problems due to water scarcity, land degradation and food shortages;
- forced migration and farmer-herder conflict;
- infrastructure for transport, water and energy supply.

Because of these components, climate change can contribute to humanitarian crises and conflicts, depending on local conditions in different parts of Africa. While a number of statistical studies do not show a significant link between rainfall reduction and violent conflict in Africa, most studies do, mostly in conjunction with other issues. The impact of climate change on conflicts with resources is often indirect, complex, and linked to the political, economic, and social factors of conflict, including inequality, low economic development, and inefficient institutions.

An intergovernmental panel on climate change has identified Africa's vulnerability as «vulnerable to climate change». Frequency and intensity of extreme weather events, as well as variability and long-term climate change (eg, temperature and precipitation, clouds and wind) [5-6]. They act as stressors for natural systems and human society, directly or indirectly affecting natural resources and related infrastructure (eg soil and water, ecosystems, agriculture and land use, forests and biodiversity, energy and economic systems and networks) that are important for the

existence, well-being and survival of people in Africa. The African environment is highly volatile and complex. Surface temperatures, together with irregular precipitation, increase land degradation, reduce water availability and food production, and increase the frequency and intensity of droughts, heat, floods, and other natural disasters.

Climate catastrophes can destabilize a society with weak economies, mixed political regimes, as well as contribute to conflicts arising from competition for limited resources, changes in power relations, and unequal distribution of resources.

1.2. Afghanistan is a country of continuous war

Afghanistan has been in a long-running conflict for more than forty years, facing a serious environmental crisis. Major environmental problems include depletion of aquifers, air and water pollution, soil degradation, deforestation, overgrazing, desertification, biodiversity loss, climate change and urban sprawl in environmentally fragile areas. In addition, the country often suffers from earthquakes, floods, droughts, landslides and avalanches. Approximately 400,000 people suffer from natural disasters each year (about half of Afghanistan's 400 districts are at risk), and 36% of the population lives below the poverty line.

Two-thirds of Afghanistan's landscape is occupied by mountainous terrain with little or no vegetation, which is typical of an arid country. For this reason, vegetation in these places plays a vital role in the ecosystem. For example, let's consider the role of pistachios among hundreds of other plants. This plant not only provides climate and environmental stabilization in growing areas, but facilitates the lives of thousands of families, providing them with a natural source of income.

Half of the rest of the country's landscape is desert, which is a hostile environment, and the other half is agricultural land and pastures. Currently, only six percent of Afghanistan's fifteen percent of agricultural land is cultivated. Over the past twenty-five years, agricultural land has declined sharply. Afghanistan is estimated to have lost 30 percent of its agricultural land and pastures, either through migrant farmers or degradation. Agricultural land in Kabul province has been lost due to degradation caused by the expansion of urban institutions. This has led to a drastic change in the previously dominant climatic and environmental factors in the region.

Compared to the twentieth century, agricultural production has declined by fifty percent. To compensate for this loss, villagers began to use the free natural resources of their environment. The end result of this process was a catastrophe for several natural forests that were cut down and smuggled out.

Deforestation, floods and avalanches caused greater destruction. Once forest productivity was reduced or monopolized by some military leaders, poor farmers sought another cheap and affordable alternative – opium cultivation. Afghan warlords and the growing international drug market have encouraged this. Thus, this has led to further degradation of Afghanistan's environment.

Many wooded areas and agricultural lands have been burned and degraded due to the use of heavy military technology and chemicals, ten thousand villages and a large number of landscapes have been destroyed. This continuous process is still doing damage to the environment. According to the World Bank for a Health Economics, the country must have at least 25% of the forest area, while in Afghanistan the forest area

is below 2%.

In Afghanistan, landmines are another worst environmental horror created by the ongoing war. The country's presence of more than ten million landmines makes it the deadliest minefield in the world. The daily death toll from these devices is between 20 and 30 people, mostly children and civilians.

The ecological structure of Afghanistan is very fragile and sensitive, with more than 60% of the area made up of highlands and mountains, while the climate is dry and the country is more prone to erosion and degradation. Therefore, due attention is needed, and due to the long war, this is not possible. That is why the environment in Afghanistan is in deep turmoil.

1.3. Syria as an example of a «dirty» war

Poor environmental conditions in Syria before the war were identified as the main contributors to the armed conflict, namely unprofessional management of natural resources and waste, inadequate government response to mining pollution and the severity of the drought from 2006 to 2010. This drought has damaged agriculture (25% of GDP), followed by rising unemployment, food insecurity and mass migration to urban centers. Combined with high population growth, water scarcity has created a greater risk of political instability.

Using satellite analysis of land in Deir ez-Zaur, the Dutch NGO PAX [8] has demonstrated the growth of improvised refineries. Tens of thousands of these refineries are currently in use in at least 37 locations in northeastern Syria, employing tens of thousands of civilians, including thousands of children, exposing their health to toxic fumes and hazardous substances on a daily basis. This practice has also affected local agricultural lands and water sources.

Syria suffered from high levels of air pollution before the conflict. In 2010, 69% of the population was contaminated with high levels of particulate matters (PM 2.5) [9].

This high level of air pollution was caused by industrial and vehicle emissions, waste incineration and seasonal pollution - hazardous particles contributed to chronic diseases, respiratory problems and hospitalization. Initially, the outbreak of the conflict reduced the percentage of the population affected by particulate matter (by 7% in 2011), as people fled cities en masse and industrial activity and energy consumption declined. However, since 2012, this trend has changed and reached a maximum of 72% in 2015.

1.4. Analysis of the impact of the Russian-Georgian war on the environment

The first large-scale Russian aggression in the 21st century against the post-Soviet countries that chose the Western path was the 2008 Russia-Georgia war. Except for the attack and destruction of military and civilian infrastructure (Georgia lost control of 189 villages, 125 of which remain under Russian occupation, nearly 150,000 people fled their homes after the war) the Russian military aggression caused an ecological disaster in Georgia - hundreds of hectares of unique forest in various regions of Georgia have been purposefully destroyed by the Russian military forces during the second half of August [10].

Smoke, high temperatures, fires and noise generated by firefighting have shaken the local fauna habitats and activities. They were under stress and may have migrated,

which may affect the spatial distribution of animals, leading to incredible habitat depletion and reduced reproduction. The forest fires in the Borjomi gorge have destroyed the forests, undergrowth, and topsoil. The fertile humus layer has been completely burned. Micro-biological processes required for maintaining soil functions have been stopped, and soil fertility has been destroyed.

The area directly affected by the fire is identified as a zone of high conservation value because it is characterized by the following characteristics:

- Biodiversity of global, regional, or national importance (endemism, endangered species).
- Conservation of important drinking water and control of soil erosion.
- Main resource to support the life of the local population.
- Substantial economic asset of the local population (tourism).

The environmental damage caused by forest fires includes the emission of greenhouse gases into the atmosphere. The burned forest was able to absorb 70,000 tons of carbon dioxide on average for 30 years. If considering it only from the climate change convention point of view, the damage is amount to at least EUR 7.2 million [11].

On August 13-14, 2008, the Russian occupation forces blew up and sunk 12 ships of Georgia. As a result, up to 50-70 tons of fuel oil, as well as engine and hydraulic oils were spilled into the sea. The bombs and ammunition stored on these ships also exploded, releasing an unknown mixture of chemicals into the sea. Such a large amount of oil spill in the coastal zone of Georgia is unprecedented. Spilled oil and oil products have severely polluted the Black Sea coastal zone and endangered the marine part of Kolkheti National Park and its biodiversity [10].

Consequently, because of the August 2008 war, Russian military strikes have caused significant damage to natural ecosystems in the Caucasus and Black Sea regions.

1.5. Analysis of the impact of hostilities in eastern Ukraine on the environment

Historically, Donetsk and Luhansk regions are one of the most industrialized areas of Ukraine, which has led to a critical situation in the field of environmental protection. Prior to the 2014 war, there were a total of about 4,500 industrial sites in these two regions that posed a potential environmental hazard. Russia's armed aggression against Ukraine has led to new risks and threats to environmental security, which could have catastrophic effect for both the region and Ukraine, and in the worst case scenario, in Eastern Europe.

War in eastern Ukraine could lead to disruptions in the security of enterprises, damage of infrastructure, or their destruction. In particular, among the most dangerous industries being damaged as a result of Russian aggression, it is worth noting the following:

- Alchevsk Metallurgical Plant;
- Gorlovka plant «Stirol»;
- Donetsk State Plant of Chemical Products;
- Yenakiyevo, Makeyevka and Donetsk metallurgical plants;
- Lysychansk Refinery;

- Severodonetsk plant «Azot»;
- Slovyansk, Luhansk, Uglehirsk and Myronivska thermal power plants;
- Toretsky Ferroalloy Plant;
- Yasynivsky, Avdiivsky and Yenakiyivo coke plants and many others.

In addition, a separate threat is damage of mining enterprises and their disconnection from the energy sources, which has repeatedly caused the shutdown of mine drainage systems and in some cases led to their complete flooding by mine waters. At present, there is a damage of drainage systems in almost the entire territory from Horlivka to Yenakiieve, in the Pervomaisk region, and partially in Donetsk, Makiyivka, Shakhtarsk and Toretsk. As a result, about 40 mines in the region are flooded or completely flooded and unfit for further use, some of them were illegally dismantled (Table 2).

Table 2. The state of mines in eastern Ukraine

Coal mines	Controlled territories	Temporarily occupied territories	Total
Mines in operation	29	75	104
In drainage mode	1	16	17
In the process of flooding	1	35	36
At the stage of liquidation	6	64	70
Total	37	190	227

Flooding of mines leads to pollution of groundwater and surface water with iron, chlorides, sulfates, other mineral salts and heavy metals. There is also a significant threat of flooding of mines used for waste disposal, in particular Oleksandr-Zakhid and Vuhlehirska. In addition, a special danger is the possible flooding of the mine «Young Communard», where in 1979 an underground nuclear explosion was carried out as part of the «Klivazh» project [12].

Since the beginning of warfare, there has been a systematic disruption of water supply and sewerage systems [13]. Cases of damage to municipal sewerage and water supply networks were recorded in most settlements along the line of contact.

Since 2014 to 2019, as a result of warfare in the region, 366 cases of violations of regular activities were recorded at 63 water supply and sewerage facilities.

Among the main threats are high vulnerability of water supply to settlements during hostilities (including Mariupol, Krasnoarmiysk, Volnovakha, etc.) and increased risk of emergencies (eg, flooding of Kramatorsk) in case of emergency shutdown of pumping stations near the line of contact.

As a result of the Russian armed aggression in eastern Ukraine, a significant part of forest and forest protection plantations was lost: according to ForestWatch, in 2014 alone, 479 hectares of forest in the war zone were completely destroyed. The greatest threats to forest plantations in eastern Ukraine are forest fires [13] caused by explosions of ammunition or arsons related to Russian tactics of sabotage. As a result of fires caused by hostilities, plantations along the line of contact suffered the most.

In addition, the war has led to land pollution and disturbance of the nature reserve fund. Construction of fortifications, deforestation, spread of forest and steppe fires

damaged 78 reserves, nature reserves, landscape parks and other environmental facilities in Donetsk and Luhansk regions [13].

Violations of the nature reserve fund also occur due to lack of staff, cessation of funding and protection of territories in the Luhansk Nature Reserve, «Khomutovsky steppe», «Kalmiusky reserve», «Trokhizbensky steppe», «Pridintsivska floodplain» reserves, etc.

In general, there is currently a significant negative impact on the environment of hostilities caused by Russian armed aggression in eastern Ukraine. Analysis of research shows that during the war and the occupation by Russia, the ability to obtain objective information about the state of the environment is sharply reduced. Therefore, in order to improve the capability to monitor and analyze the situation, respond quickly to challenges and threats, prevent deterioration and create the conditions for future environmental recovery after the war, it is necessary, above all, to organize cooperation between agencies and international organizations.

II. DEVELOPMENT OF MILITARY TECHNOLOGIES AND THEIR IMPACT ON ENVIRONMENTAL ASPECTS IN THE FUTURE WARS

In fact, the whole history of mankind is a history of continuous wars. It is now clear that a world without war is an unrealistic utopia, and armed conflict will continue despite calls from pacifists. As the challenges and threats are constantly changing, the forms and methods of war, as well as military technology, are constantly being improved. So far, scientific and technological progress has reached an unprecedented level of development, which provides opportunities for the development of fundamentally new weapons systems and military equipment.

From the point of view of ecology, it is determined that the impact of hostilities on the environment is negative. If in the pre-industrial era armed conflicts were of low-tech nature and could not significantly affect the environment, then during the twentieth century the situation has changed radically. Significant damage to the environment began to cause not only by the actual fighting, but also combat training activities, daily activities of troops, as well as the work of numerous enterprises of the military-industrial complex.

A wide range of environmental scientists are paying attention to finding ways to reduce the military burden on the environment. At the same time, the proposals of some researchers are limited to calls for an end to wars or a significant reduction in armed forces and a reduction in military spending, which can be considered nothing more than a manifestation of pacifist idealism. In the case of Ukraine, the long-term reduction of the army and the reduction of defense spending have led to the armed aggression by Russia, so it is clear that none of the governments will risk the existence of their own state to solve environmental problems. At the same time, a significant number of experts recommend to develop and approve at the international level standards and rules for environmental protection during wars and armed conflicts, ie, in fact, an environmental analogue of the Geneva Convention. Also, it is proposed to develop and improve a set of technological standards in the framework of environmental safety of military production.

Given that the cessation of wars is an unrealistic scenario, and the harmonization of environmental standards for warfare at the international level is a difficult task due to significant contradictions between states, the most optimal is the environmental regulation of military and military-technical spheres at the national level. In addition, it is advisable to use modern technological advances to reduce the burden of the defense component on the environment.

2.1. High-precision weapons

The first high-precision weapons (HPW) were designed by Nazi Germany during World War II, but have not been widely used for a long time. Since the US Armed Forces operation in Iraq, Desert Storm (1991), where unmanned bombs were the norm, there has been a significant acceleration in the use of high-precision weapons. Subsequently, NATO members increased the use of precision ammunition in Bosnia and Herzegovina, Kosovo, and later in Afghanistan. More recently, HPW employment has risen sharply during the last operation in Libya, where almost all combat sorties were carried out using «smart» bombs, providing the Alliance with positive and significant results in terms of accuracy and minimization of collateral damage. Developments in areas such as aerodynamics, laser technology and electronics have brought us closer to the possibility of surgical accuracy, which is considered important for modern warfare [14]. In 2012, a study commissioned by the European Defense Agency stressed that the demand for accuracy had increased both to increase the effect against the opponent and to avoid casualties among friendly forces and non-warring third parties.

Future high-tech high-precision weapons systems are likely to have versatile characteristics and be used in several variants and platforms. The next generation of the HPW is likely to be delivered and operated by both conventional manned aircraft and autonomous unmanned aerial vehicles (UAVs). These weapons must have both lethal and non-lethal capabilities and be able to operate in a physical environment, guided in the virtual. The HPW of the future can be released in cooperation with other platforms and weapons systems, while maintaining the possibility of use in certain modes, will also increase their range, maneuverability and accuracy.

Examples of this concept can be seen in the new air-to-air missiles, including the AIM-120D air-to-air missile [15] (15) (Fig. 5), which has a much longer range than the already expanded version of the AIM-120C, and multinational European METEOR missile with a range of more than 300 km. It is noteworthy that METEOR can also receive mid-course manual updates from other aircraft and control-command units (C2) participating in the mission, providing an increased degree of maneuverability and accuracy.

Defense companies in cooperation with the countries have already started projects to develop a new generation of HPW. Recent examples include the Raytheon Industry version of Excalibur S [16] and the Israel Aerospace Industries HARPY NG [17]. This new generation of weapons is becoming more accurate, but at the same time universal.

Subsequent high-precision weapons, such as hypersonic weapons and powerful laser systems, are already becoming a reality.



Fig. 5. Air-to-air missile AIM-120D

In terms of environmental impact, the development of precision weapons has several important aspects. In particular, the accuracy of weapons can significantly reduce the use of ammunition and significantly reduce the mass of explosives required to hit the target. Thus, several dozens of tons of «ordinary» bombs or shells are replaced by a surgical strike of one high-precision ammunition, which creates much less burden on the environment.

2.2. Railgun

Railgun is a promising weapon, a gun that uses electricity instead of chemical fuels (ie gunpowder charges) to fire. Magnetic fields created by high-voltage electric currents accelerate the sliding of a metal conductor or armature between two rails to launch steel shells weighing about 10.4 kg. at speeds from 7250 to 9000 km/h. The US Navy has developed several prototypes for further installation on ships for the use of rails instead of artillery and / or air defense (Fig. 6) [18].



Fig. 6. Prototype of the railgun, US Navy, 2014

The environmental aspect of this type of weapon is primarily the absence of emissions of harmful substances during firing, as the projectile itself is all-metal and is driven by an electromagnetic pulse without the use of explosives.

2.3. Combat laser systems

Laser Weapon System (LaWS) - a promising system of directed weapons, based on a solid-state laser. The development was created by the Naval Surface Warfare Center Dahlgren Division of the US Navy Naval Systems Command. Development of the system began in 2007. The weapon was installed on the US Navy ship USS Ponce in 2014, for field tests (Fig. 7) [19].



Fig. 7. Combat laser system on board the USS Ponce

The system is designed to destroy unmanned aerial vehicles, manned aircraft and small ships, suppressing electronic air target systems. In terms of accuracy, speed and cost, it is much ahead of similar missile weapons. Among the advantages of this device against projectile weapons is the low cost per shot, as each firing from the weapon requires only a minimum cost of generating energy momentum; on the contrary, munitions for shells must be designed, manufactured, processed, transported and maintained, and occupy storage space.

Thus, the combat laser is a relatively environmentally friendly example of advanced weapons, which doesn't need to use shells and explosives. In addition, a significant number of other weapons and military equipment are being developed, the main common features of which are increasing the technological level of components, the use of artificial intelligence, minimizing human participation in functioning, and the application of new physical principles.

Reducing the level of damage to the environment during warfare as well as daily activities of the armed forces is one of the main tasks of mankind. Therefore, further forecasts of changes in the impact of military confrontation on the environment based on the analysis of promising trends in the development of the art of war and defense technologies will be significant. According to the results of the study, there is a relative

reduction in the impact of war on the environment due to the refusal of conducting warfare by mass conscripts armies, reduction of collateral destruction due to the development of high-precision weapons, and the emergence of relatively environmentally friendly weapons based on new physical principles.

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