CHAPTER 8

A decision-making system for managing the remediation of water resources in the Kherson region: agent-oriented modeling in the context of post-war economic recovery

Tetiana Cherniavska
Nataliya Tanklevska
Bohdan Cherniavskyi

Abstract

The study explores the theoretical and practical aspects of managing the remediation of territories in Ukraine affected by military activities. The authors argue for the necessity of employing unconventional scientific approaches to address military contamination, reconstruct and restore infrastructure following the largest war in Europe in terms of destruction and consequences since World War II. In the context of mitigating the environmental disaster caused by the destruction of the Kakhovka Hydroelectric Power Plant dam, the authors propose the implementation of a simulation-based agent-oriented model for remediating water resources in the Kherson region. This model integrates geographic information systems, artificial intelligence, machine learning, and the Agile approach. According to the authors, the use of agent-oriented modelling in designing a management system for remediating military contamination on affected territories is a promising direction that can significantly improve the efficiency and effectiveness of recovery efforts. The developed and implemented models are designed to account for the complex interactions and dynamics of events in the socio-economic and ecological systems during remediation efforts. This approach will contribute to the optimal decision-making process for effective management solutions. It is substantiated that the integration of the project with advanced technologies and innovative engineering solutions can minimize the time required for remediation and multiply the effects of the recovery efforts.

As a platform for effective project management, the authors propose using the Agile approach, which has already proven to be a highly efficient method of managing teams in conditions of uncertainty. Agile emphasizes flexibility, adaptability, and active collaboration. This method will facilitate the involvement of all key stakeholders at every stage of project implementation, including government authorities,

DOI: 10.21303/978-9916-9850-6-9.ch8

local administrations, public utilities, contractor companies performing remediation work, and international partners. This will help ensure transparency and synchronization of actions among all key agents, forming the basis of agent-oriented modelling. The implementation of the remediation and restoration project for water resources in the Kherson region is critically important to ensure water availability and restore the region's economic activities after the cessation of military operations.

Keywords

Agent-Oriented Modelling, remediation, water resources, Agile approach, Geographic Information Systems, Artificial Intelligence, Machine Learning, post-war recovery, management system, agricultural business, Ecosystem, economic benefit.

8.1 Introduction

The international community recognizes that the war in Ukraine, the second-largest in scale and destruction since World War II, has caused significant damage to the country's ecosystems and natural resources. According to the Ministry of Environmental Protection and Natural Resources of Ukraine, by early 2024, the total damage caused by the war amounted to 60 billion USD. This figure includes forest destruction, water resource contamination, and biodiversity loss. Approximately 9,300 square miles of forests were destroyed by fires ignited during combat, contributing to increased carbon emissions. Reports highlight that attacks on industrial facilities and water treatment plants have contaminated freshwater resources. Additionally, over 67,000 square miles of territory have been affected by landmines and unexploded ordnance. Irreparable harm to wildlife has also been observed, including the extinction of rare species in nature reserves and the loss of fauna. Particularly notable is the ecocide resulting from the destruction of fish in the Kakhovka Reservoir and the biocenosis damage to the Dnipro River's coastal zone [1].

The study highlights the urgent need for innovative strategies, particularly after the Kakhovka Hydroelectric Power Plant (HPP) dam's collapse, to manage ecological disasters and restore critical resources like water. Modern hybrid conflicts require advanced technologies such as Geographic Information Systems (GIS), Artificial Intelligence (AI), and Machine Learning (ML) to address contamination and socio-economic disruptions effectively. The proposed Agent-Oriented Modeling (AOM) project identifies key agents and integrates advanced technologies to optimize decision-making and enhance coordination among stakeholders.

Agile project management ensures flexibility, adaptability, and active collaboration, enabling iterative adjustments based on real-time feedback. The research aims to develop a decision-making system that integrates AOM, Information Technology (IT) solutions, Internet of Things (IoT) devices, and AI-driven analytics to enhance the efficiency of remediation efforts. This integration is expected to create a synergistic effect, addressing multifaceted challenges in post-conflict recovery and contributing to sustainable regional development.

The proposed system will expedite water resource restoration in the Kherson region, ensuring supply for agricultural, industrial, and domestic needs. It also aims to optimize resource allocation and improve transparency and accountability among stakeholders, offering a scalable model for managing ecological remediation in post-conflict regions globally.

8.2 The genesis of military contamination remediation: preconditions and reasons for the paradigm shift

The essence of the phenomenon under study is deemed expedient to be revealed by identification of the major aspects of the underlying cause, namely, of the consequences resulted from military activities. In the context of remediation of military contamination, the term "military activity", in the author's opinion, can be characterized as a totality of diverse activities and operations undertaken by the armed forces of a particular state or other paramilitary formations, involving various forms of combat operations, training maneuvers, testing and operation of military equipment and weapons, logistical operations, as well as construction and operation of military facilities. Significant environmental exposures often accompany such activities and can result in various levels of soil, water and air contamination, which require remediation activities to restore ecological balance and mitigate risks to human health and ecosystems.

Military activities, encompassing operations, training, and logistics, impose extensive environmental impacts that require a comprehensive understanding and mitigation approach. Explosive use, armored platforms, aviation, and large-scale maneuvers during military operations result in soil contamination with heavy metals, toxic chemicals, and unexploded ammunition. Water reservoirs are polluted by petroleum leaks and untreated wastewater, while air quality deteriorates due to emissions from fuel combustion and explosions, spreading toxic gases and aerosols. The destruction of infrastructure compounds these effects, releasing hazardous materials into ecosystems and severely disrupting environmental balance.

The health implications of military contamination are equally profound. Chemical weapons and toxic residues from ammunition exposure lead to acute and chronic illnesses, including cancer, neurological disorders, and respiratory conditions. Radioactive emissions from nuclear weapons testing and the use of depleted uranium in ammunition result in lasting health problems such as genetic mutations and kidney failure. Additionally, activities like armament testing and large-scale military training contribute to ecosystem disruption and the release of hazardous substances, further amplifying the ecological and human health crises associated with military actions.

Military logistics, including the transportation of equipment and construction of temporary and permanent facilities, add to the strain on the environment by degrading soil, water, and natural habitats. These diverse and interconnected impacts emphasize the necessity of an integrated strategy for remediation to address soil, water, and air contamination while safeguarding public health and restoring affected ecosystems.

Problems of environmental contamination resulting from military activities, as well as integrated mechanisms for remediation of the territory, will be addressed in the present research paper. However, military activities, apart from the negative consideration described above, result in much broader consequences, including genocide, ecocide, and urbicide.

Consequently, the recent events currently occurring in the world and in Ukraine enhance the relevance of the present research. In the context of the above, an analysis of historical data is deemed appropriate.

Thus, in the book J. Cummins "Why Some Wars Never End: The Stories of the Longest Conflicts in History", Swiss scholar J.-J. Babel cites a calculation stating that mankind has experienced only 292 years of peace over 5,500 years of the documented history. Wars, despite their apparent completeness, continue to be an enduring phenomenon, and multi-generational conflicts constitute complex historical processes involving multiple factors and consequences. In his book, J.-J. Babel studies such conflicts with special concern for their origins and pivotal episodes, as well as analyses the causes for their continuity and residual effects [2].

Periods of absolute peace amount to merely around 300 years in the entire history of the mankind. In accordance with Brockhaus and Ephron Encyclopaedia, the history of nations is presented in the form of a continuous war, where periods of peace are only temporary truces based on fear and distrust rather than on fraternal love and mutual trust [3].

One of the key factors underlying the relevance and significance of this research is that contemporary military conflicts introduce new types of contaminants and their combinations, which exacerbate their impact on ecosystems and biocenoses while also posing serious health risks to populations, including genetic health. In the 20th century, most scientific studies focused on eliminating specific pollutants associated with particular types of military activities. However, the global community now faces the increasing complexity of military conflicts and the consequent need to shift paradigms in managing their aftermath and recovery processes.

Summarizing the above, it can be concluded that military activities in the early 21st century have undergone radical changes, resulting in the emergence of new types of contamination. This has significantly complicated the processes of remediating contaminated territories. Contemporary contaminants, such as nanomaterials, advanced chemical and biological agents, require the development of new methods and approaches for remediation. Undoubtedly, the growing complexity of military operations' impacts on ecosystems and human health demands a comprehensive approach encompassing technological innovations, international cooperation, and socio-economic measures. Effective remediation of military contamination is only possible through a systemic approach involving active participation from all stakeholders.

Delving deeper into the theoretical understanding of remediation as a scientific concept, it is worth noting that current scientific literature primarily focuses on narrowly defined studies, such as soil restoration or water remediation. There are also studies dedicated to remediating environments following specific large-scale military actions. However, the authors believe that military conflicts and their associated ecological catastrophes (as in the case of the Kakhovka Hydroelectric Power Plant dam destruction) act as catalysts for advancing comprehensive scientific research and development in the remediation field. The urgency of addressing complex environmental problems stimulates the application of unconventional approaches, as well as the development of technologies and innovations aimed at environmental protection and restoration. Moreover, the emergence of new contaminants and the increasing complexity of pollution require constant adaptation to conditions of uncertainty, as well as constraints in time and resources. Consequently, remediation strategies must become more comprehensive and interdisciplinary, uniting the efforts of economists, managers, engineers, ecologists, and safety experts. This integration is where the effectiveness and viability of management decision-making mechanisms at all levels of the territorial socio-economic system's hierarchy are realized.

The considerations outlined above underpin the hypothesis of this study: the nature of modern warfare manifests in the increasing complexity of technological and technical approaches to its conduct, ultimately influencing its consequences, including those for the environment and societal well-being in specific territories. Thus, the remediation of a particular socio-economic system (e.g., Ukraine) is inherently multi-level and multi-vector, with its effectiveness directly dependent on the functionality of management mechanisms at the macro, meso, and micro levels.

8.3 Comparative analysis of methodological approaches to the study of military contamination remediation

In the broadest accepted sense, comparative analysis (lat. *comparativus* – comparative) is the study of different objects or phenomena through comparison. It is employed across various fields of knowledge, helping to identify similarities and differences, uncover patterns, and develop universal approaches to addressing scientific challenges. Below, let's present an in-depth analysis of the methodological model architecture for remediation, viewed as a set of methods constituting its "core", along with complementary scientific methods and techniques suitable for solving specific tasks. It is possible to provide a general characterization, features, and applications in the context of the issues under investigation in remediation.

According to the authors, the "core" of the methodological model should primarily include an integrated and systemic approach. The integrated approach views the elimination of military contamination and subsequent remediation as interconnected tasks within a unified algorithm for restoring war-affected territories. This approach enables the identification of cause-and-effect relationships between actions and their outcomes, ensuring the adoption of well-founded, comprehensive solutions.

The systemic approach is essential due to the multi-component nature of military contamination. Territorial systems, as open systems, are influenced by both internal and external factors. Military activities disrupt these systems, destabilizing their functions. The systemic approach examines how changes in one subsystem affect others, allowing for consistent and coordinated decision-making at all levels of management.

The synergetic scientific approach examines the interactions of various factors and methods (in our case, traditional remediation methods and "green remediation" techniques) that collectively yield a greater effect than their individual application. In the context of remediation, the synergetic approach allows for identifying the most optimal combinations of methods that will best restore the ecosystem and provide impetus for the sustainable development of the territorial socio-economic system.

The adaptive approach emphasizes the dynamic nature of ecosystems and socio-economic systems, constantly influenced by anthropogenic factors. At the core of the adaptive approach lies the principle of continuous monitoring, analysis, and adjustment of management decisions and actions depending on changing situations, weather conditions, resource availability, and new incoming information. Hence, remediation approaches must be adaptive, enabling responses to emerging challenges as they arise.

The optimization approach in military contamination remediation involves applying mathematical methods and algorithms to find the best solutions for cleaning and restoring territories, considering multiple factors such as environmental, economic, and social aspects. Adaptive monitoring and management models are particularly considered by the authors for their application in adjusting strategic and tactical management decisions as new data on the contaminated territory's state become available.

This study explores the potential of the agent-oriented approach for identifying optimal remediation solutions. Agent-Oriented Modelling (AOM), a type of simulation modelling, operates at the micro-level (e.g., local territorial systems) by simulating system functionality through agents with unique attributes. This allows for the study of interactions within the system and the establishment of connections between micro- and macro-levels. A key advantage of AOM is its ability to closely replicate real-world systems. In socio-economic models, aggregated agents typically represent industries or regions [4, 5].

Scientific literature highlights AOM's extensive application in environmental studies and resource management, particularly for simulating ecosystems, managing resources, and analyzing pollution impacts. While many studies address socio-environmental management using AOM, its application in military contamination remediation remains limited [6–10]. The authors argue that employing AOM in this context holds significant potential to enhance the efficiency and effectiveness of remediation efforts.

Among relatively new yet well-established approaches, Agile stands out as highly suitable for achieving the goals of crisis management and rapid response (in our case, managing remediation efforts). The Agile methodology was introduced in 2001 when 17 software development professionals gathered in Utah, USA, to discuss and formulate the "Agile Manifesto". Dissatisfied with rigid traditional approaches like the waterfall model, the group proposed Agile, which is distinguished by its flexibility, ability to adapt to changes quickly, client orientation (in this case, stakeholders in remediation), and continuous improvement. These features make Agile indispensable for projects requiring flexibility, adaptability, and the ability to respond rapidly to changes, which is ideal for crisis management projects like the remediation of water resources in the Kherson region (**Fig. 8.1**).

Its "core" consists of a set of key scientific methodological approaches – seven methods: Agent-Oriented Modelling, the Agile Approach, the Systemic Approach, the Comprehensive Approach, the Synergetic Approach, the Adaptive Approach, and the Optimization Approach. The "periphery" of the methodological framework includes a collection of auxiliary, complementary, and specific research methods designed for scientific analysis and addressing particular problems and issues (12 methods).

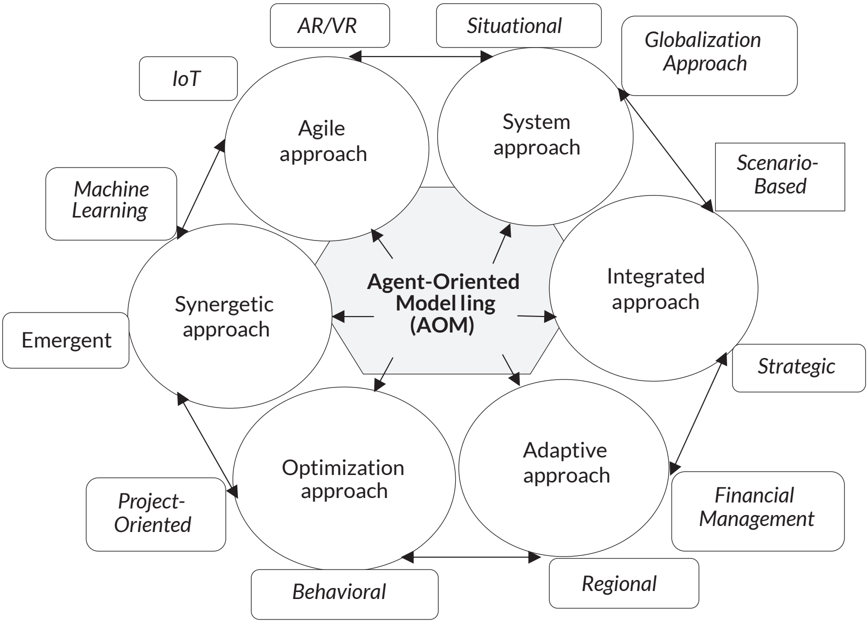

Fig. 8.1 Conceptual methodological model for managing the remediation of contaminated territories based on the agent-oriented approach

8.4 Project of a simulation-based agent-oriented model for remediation of water resources in the Kherson region

The inspiring impetus for developing a project on the remediation of water resources in the Kherson region based on agent-oriented modelling was a scientific study by E. Z. Berglund from North Carolina State University [11]. The author adheres to the idea that the concept of analyzing and understanding systems as complex emergent characteristics of adaptive structural elements offers a new and potentially revolutionary paradigm for a wide range of scientific disciplines. The nature of complex adaptive systems lies in studying their structures, composed of numerous active and interactive elements or actors (individual agents) with diverse capabilities and forms, which possess the ability to adapt through interaction with each other and the environment. The author's research focuses on agent-oriented modelling of such systems, which allows for designing the behavior of various agents and environments and then experimentally determining the type of complex dynamics that would be optimal for process management.

The second most significant contribution to the formation of our conceptual framework was the publication by a team of scholars titled "Application of agent-based models as a powerful tool in water resource management". The authors highlight that human intervention often amplifies the complexity of water resource systems. In the context of military activities in Ukraine, these challenges become even more critical. Agent-Based Models (ABM) are recognized for effectively modelling complex systems, particularly water resources, by simulating the interactions of autonomous agents, such as agricultural, industrial, and domestic water users, as well as entities managing water resources. These agents, equipped with unique historical memory, interact with each other and their environment, collectively shaping the system's complexity. ABM provides realistic simulations, enabling policymakers at all levels to better understand the outcomes of their decisions, implement bottom-up approaches, devise effective strategies, and identify potential risks and consequences [12, 13].

A review of other authors' publications has further convinced us of the validity of this approach. Specifically, a study by a group of authors on developing the local water supply market using a multi-agent modelling approach was particularly useful in identifying key agents in the territory following the implementation of comprehensive remediation measures [14]. Another publication by a team of authors on data mining methods for water science modelling inspired us to explore the potential applications of advanced technologies such as AI, GIS technologies, drones, and robots in the remediation processes of contaminated territories [15].

In our opinion, after the conclusion of active military actions in Ukraine, particularly in its southern part – the Kherson region –a pressing need will arise to prioritize the restoration of water resources. Given the region's predominantly agricultural specialization, this necessity is primarily linked to the revival of economic activities. Before Russia's military aggression, the region had nearly 2 million hectares of agricultural land, Ukraine's largest area of arable land.

The "Kherson Chamber of Commerce and Industry" highlights the region's strategic location at the crossroads of transport routes in the lower Dnipro, with access to the Black and Azov Seas, favorable climate, and rich human resources, providing vast opportunities for trade, economic development, and investment. The region, situated on both banks of the Dnipro – the largest waterway in Ukraine – features 19 rivers, the Black and Azov Seas, the Kakhovka Reservoir, and Europe's largest irrigation system spanning 400 hectares [17]. The destruction of the Kakhovka Hydroelectric Dam and the near drying-up of the North Crimean Canal during the war already require reflection not only on the consequences for the ecosystem but also on the restoration of the socio-economic system [18]. In our view, it is imperative for the highest levels of state governance to initiate the search for optimal methods and the implementation of effective projects for the remediation of water resources in the Kherson region.

8.4.1 Project baseline data for remediation

The Kakhovka Hydroelectric Power Plant (HPP), named after P. S. Neporozhny, was located in southern Ukraine, 5 kilometers from the city of Nova Kakhovka in the Kherson region, on the Dnipro River. Its capacity was 334.8 MW.

The construction of the Kakhovka dam and hydroelectric station took four years, from 1950 to 1956. The dam complex rose 30 meters high, spanned 3.84 kilometers in length, and included both automobile and railway crossings. The construction required substantial investments and the relocation of approximately 50,000 people. Together, the Dnipro cascade of dams provided water supply for domestic, industrial, and irrigation purposes across more than half of Ukraine's territory, serving approximately 35 million people, including water-scarce regions such as Donbas, Kryvyi Rih, southern Ukraine, and, until 2014, Crimea [18–22].

The Kakhovka dam retained the waters of the expansive Kakhovka Reservoir, which performed multiple functions: supplying water to the hydroelectric power plant, industrial enterprises, and freshwater fish farms; protecting against floods; and supporting the Krasnoznamenka and Kakhovska irrigation systems as well as the Dnipro-Kryvyi Rih and North Crimean canals. Additionally, the reservoir created a deep-water route that allowed maritime vessels to travel upstream along the Dnipro. The outflow of the Kakhovka Reservoir was regulated seasonally and annually, with a standard headwater level of 16 meters.

On June 6, 2023, Russian forces destroyed the Kakhovka HPP. The station's turbines and generators were also blown up along with the dam. The resulting torrent swept away everything in its path, flooding several downstream towns and destroying residential, industrial, and commercial structures. The hydrological consequences of this event had to be assessed using numerous hydrodynamic models and satellite image analyses, as illustrated in **Fig. 8.2**.

As a result of the disaster, the water level also rose in the Inhulets River, a tributary of the Dnipro that flows from north to south and joins the Dnipro just upstream of Kherson, as clearly illustrated in the provided figure. As of June 9, 2023, approximately 620 km^2 of land within the analyzed satellite area of 19,000 km^2 were flooded according to hydrological analysis [20].

Fig. 8.2 Satellite image of the breached Kakhovka Dam
Source: [19]

These findings were further corroborated by the Ministry of Environmental Protection and Natural Resources of Ukraine, which estimated that the total flooded area during the peak flooding period exceeded 630 km^2 [19]. The decline in water levels was recorded by UNOSAT satellites between July 3 and July 5, 2023, when the flooded area decreased to approximately 40 km^2 [20].

The above map illustrates the satellite-detected flooding extending 90 km downstream of the damaged Kakhovka Dam wall to the Dnipro's mouth in the Rybalsche area of Kherson region, Ukraine. This was captured in ICEYE images acquired on June 7, 2023, at 12:18 UTC, 12:48 UTC, and 13:01 UTC [20] (**Fig. 8.3**).

A more in-depth analytical overview of this situation is presented in **Table 8.1**.

The primary purpose of creating the Kakhovka Reservoir was to provide irrigation water for the adjacent agricultural areas. Additionally, it served as an important source of drinking water, while energy production was secondary but still significant. Since its primary objective was to supply irrigation and drinking water, it can be assumed that potential contamination in the flooded area was not primarily caused by the reservoir water itself. However, as the terminal reservoir in the cascade, the Kakhovka Reservoir accumulated substantial runoff containing pollutants. As a result, the concentration of heavy metals in both water and bottom sediments was generally higher than in other reservoirs, such as the Kyiv Reservoir, which is less affected by negative impacts from surrounding territories [21].

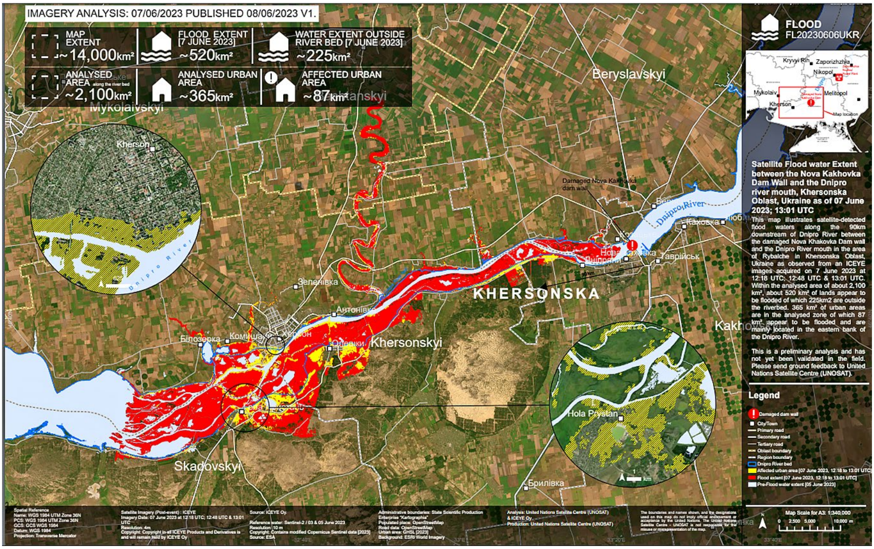

Fig. 8.3 Satellite Flood water Extent between the Kakhovka Dam Wall and the Dnipro river mouth, Kherson region
Source: [20]

Monitoring data from the Dnipro River, provided by the State Agency of Water Resources of Ukraine following the dam breach, indicate that overall ecological water quality met most criteria without exceeding regulatory limits [19].

The dam breach was a disaster for the aquatic flora and fauna, including marine species. According to national authorities, tens of thousands of tons of fish, including commercial species, were affected, with the majority lost due to the drying of the Kakhovka Reservoir. The Ukrainian government confirmed the loss of 11,388 tons of fish. As the breach occurred during the spawning period, it had a negative impact on the fishing industry in subsequent seasons [18].

Table 8.1 Assessment of flooding consequences following the destruction of the Kakhovka hydroelectric power plant

Oblast / Region / Hromada	Total analysed zone, km^2	Total water extent observed, km^2	Flood extent, km^2	Water extent outside river bed, km^2	Total urbanarea in analysed zone, km^2	Affected urban area, km^2
Khersonska	***1 828***	***675***	***499***	***200***	***345***	***85***
Beryslavskyi	***208***	***38***	***26***	***9***	***17***	***2***
Beryslavska	11	–	26	–	–	–
Tiahynska	197	38	–	9	16	2
Kakhovskyi	***183***	***37***	***22***	***11***	***55***	***7***
Kakhovska	19	–	–	–	4	–
Novokakhovska	151	37	22	11	42	7
Tavriiska	13	–	–	–	8	–
Khersonskyi	***1 104***	***413***	***317***	***124***	***219***	***54***
Bilozerska	133	65	42	5	17	3
Chornobaivska	24	1	1	1	9	–
Darivska	258	45	31	28	31	3
Khersonska	346	139	99	20	118	24
Muzykivska	9	–	–	–	2	–
Oleshkivska	292	160	143	69	42	23
Stanislavska	42	4	1	1	–	–
Skadovskyi	***333***	***187***	***134***	***56***	***55***	***23***
Chulakivska	80	10	5	3	6	1
Holoprystanska	253	177	130	53	49	22
Mykolaivska	***270***	***24***	***22***	***24***	***20***	***1***
Bashtanskyi	***270***	***24***	***22***	***24***	***20***	***1***
Horokhivska	164	15	13	15	13	1
Snihurivska	107	9	9	9	8	–
Total	**2 098**	**700**	**521**	**224**	**365**	**87**

Source: [20]

The spread of chemicals associated with the incident primarily originated from two sources: discharges from industrial facilities and infrastructure located in flooded zones and/or the migration of potentially contaminated sediments from the reservoir. The highest concentration of pollution occurred downstream from the breach site, where pollutants and sediments were transported. A list of chemical hazard hotspots was compiled by merging data from CEOBS, Ecodozor, and Reach, followed by cross-verification of object names and locations. According to this data, primary remediation should focus on the following:

1) cleaning facilities outside the flood zone (21 facilities);

2) cleaning damaged infrastructure and communications, such as bridges (56 facilities);

3) dismantling and initial remediation of specific facilities by type, size, and location, prioritizing small-scale objects such as kiosks, stalls, and garages, as well as:

- cemeteries (19 facilities);
- agricultural/livestock facilities (17 facilities);
- construction sites (28 facilities);
- stores/markets (7 facilities);
- ports[1] (2 facilities);
- small and medium enterprises (71 facilities);
- transportation enterprises (5 facilities);
- waste sites (5 facilities);
- other (1 facility) [18].

Although it is currently impossible to fully assess the environmental, economic, and social consequences of the Kakhovka HPP destruction, analytical evaluations of the damage indicate that it is both extensive and multifaceted (**Fig. 8.4**).

At present, it is not possible to determine which types of damage are irreversible and which can be at least partially mitigated through post-incident recovery measures and a comprehensive set of remediation efforts. It is evident that the choice of effective remediation methods (or a combination of selected methods) and the implemented model for managing the remediation process of the affected territory will primarily determine the final outcome [18, 21, 22].

Nevertheless, it can already be stated with full confidence that the objective assessment of the consequences and the full scale of the disaster will only become clear in decades to come.

The goal of the project is to develop and propose a decision-making system based on an agent-oriented model for managing the remediation of water resources in the

---

[1] *Companies handling chemicals, as well as oil and fuel storage facilities located within port areas, are still included*

Kherson region. The proposed decision-making system will be integrated with advanced IT technologies and will account for various scenarios of identifying and selecting optimal remediation measures for cleaning water resources and addressing military contamination. The optimization of resource management and the effective coordination of actions among all project participants will be implemented using the Agile approach.

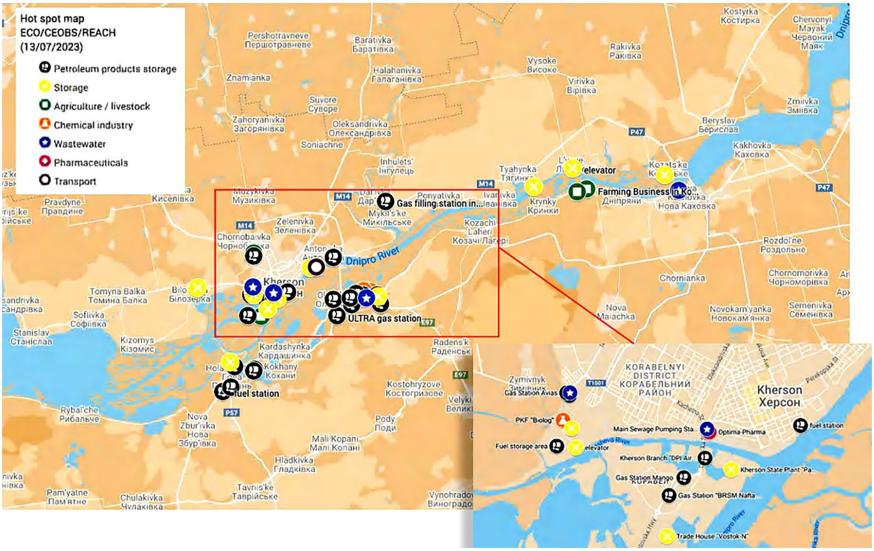

Fig. 8.4 Cartographic overview of 54 selected objects subject to primary remediation
Source: [18]

8.4.2 AOM model: identification of key agents and verification of their roles

One of the initial stages of agent-oriented modelling is the identification of key stakeholders, referred to as "agents". Each agent plays a specific role and contributes to the decision-making process (adjustments to tactical or operational decisions, as noted by the authors) within the framework of remediation activities and the effective allocation of water resources.

Six main groups of stakeholders are identified within the agent-oriented model, who will directly or indirectly influence the decision-making system (**Table 8.2**).

Table 8.2 Characteristics of key agents – stakeholders in the water resource remediation project for the Kherson region

Agent Group	Role in the Project	Significance
Agricultural business entities and farmers	Primary water consumers for agricultural land irrigation	Agricultural business entities and farmers play a key role in ensuring food security in the Kherson region, as the region's primary specialization is agro-industrial production. Their water needs significantly influence the overall allocation of water resources
Public utilities	Providing the population with clean drinking water and maintaining water supply and wastewater infrastructure	Public utilities are responsible for the health and well-being of the population, ensuring access to safe drinking water and proper sanitation
Government authorities	Government authorities regulate and coordinate remediation processes and the distribution of water resources	Government authorities develop regulatory acts that ensure the implementation and oversight of strategic remediation tasks, as well as mediate interests and resolve conflicts among various water users
Local self-government bodies	Local self-government bodies coordinate and implement remediation programs at the community level	Local self-government bodies ensure direct interaction with public utilities, contractors, and the local population, taking into account local needs and challenges while also facilitating the participation of public organizations and other stakeholders in remediation processes
Investors	Participation in project financing through financial and/or tangible investments; provision of equipment and machinery, and the implementation of advanced technologies and engineering solutions for remediation and water resource management	Domestic and international investors bring capital to the recovery and further development of war-affected territories, as well as expertise, which facilitates the acceleration and improvement of remediation processes, the introduction of new engineering solutions and technologies, and the implementation of advanced water resource management methods
Contractors for remediation work	Direct implementation of remediation processes and operations: elimination of military contamination, cleanup and restoration work, waste transportation, and other related activities	Contractor firms ensure the direct execution of remediation project tasks as well as the restoration of water supply and distribution systems

Implementation of agents in the Agent-Oriented Model:

1. *Description of identified agent groups.* Each agent i in the system can be described by the following characteristics:

– the agent's state $S_i(t)$ at a given time t;

– a set of behavioral rules R_i;

– the agent's location in the environment $P_i(t)$.

2. *Modelling the integration of agents into the environment.* The agent implementation environment is represented as a two-dimensional or three-dimensional space in which identified agent groups can move and interact. The 2D or 3D space can be divided into cells, each characterized by parameters $E_j(t)$, such as the level of resource contamination.

3. *Interaction among identified agent groups.* Interactions between the project's key agents can be described by a function $I_{ij}(t)$, which depends on their location and behavior at a given time:

$$I_{ij}(t)=f(S_i(t), S_j(t), P_i(t), P_j(t)). \tag{8.1}$$

4. *Behavioral changes during decision-making.* Agents' behavior changes over time in accordance with their rules of behavior and interactions with other agents involved in the remediation project:

$$S_i(t+1)=g(S_i(t), \sum j I_{ij}(t), E_j(t)). \tag{8.2}$$

5. *Integration of various stakeholders into the Agent-Oriented Model.* Integrating different agents into the agent-oriented model of water resource remediation ensures a comprehensive approach to water management and distribution. Each stakeholder contributes to the process, enabling the consideration of diverse interests and achieving more effective solutions.

6. *Modelling the remediation process.* Behavioral rules for the various agent groups, based on designed and implemented algorithms for each type of agent, optimize management and coordination of the territory's restoration process. For instance, agents directly implementing water resource remediation operations can follow specific algorithms for interacting with other agent groups according to routes and locations of primary or emergency remediation of contaminated areas. Meanwhile, the local population reacts to these activities and makes its own decisions in response.

7. *Analysis and evaluation of results.* The effectiveness of implementing the Agent-Oriented Model for water resource remediation in the Kherson region can be assessed using a set of parameters and indicators, including the efficiency

of management processes, interaction among participants, and resource utilization (e.g., financial, material, and labor resources) relative to the time and degree of task completion.

8. *Optimization.* Conducting a series of simulations during the early stages of project implementation can identify additional opportunities to improve the proposed model. This involves exploring the most promising integrations with advanced technologies, such as drones, robotics, GIS, and satellite systems. These integrations significantly enhance the overall effectiveness of strategies for remediation and monitoring, enabling efficient operational and tactical management of both remediation activities and social responses, as well as identifying optimal cleaning routes and methods [23].

9. *Technological advancements in Agent-Oriented Modelling.* The authors argue that modern technological advancements significantly expand the capabilities of agent-based modelling in the context of territory remediation. Robotics, artificial intelligence, GIS, drones, autonomous vehicles, recognition technologies, and others make the proposed model more precise, adaptive, and effective. Selective and comprehensive integration of these technologies enables the achievement of maximum results under time and resource constraints.

10. *Proposal for decision-making and implementation.* To support the adoption of the model presented in this monograph and its implementation, the authors propose an analysis of the integration of modern technologies into agent-based modelling of territory remediation, considering their functional roles and interactions within the system (**Table 8.3**).

Table 8.3 Implementation of modern IT technologies and IoT solutions in AOM

Implementation in the project	Functional roles and interaction within the decision-making system	Expanding agent-based modelling capabilities
1	2	3
Implementation of robotic technology		
Robots-agents, behavioral models, sensors, and actuators	Defining the types of robots required for the project based on the complexity and scale of remediation tasks they will perform (e.g., robots for drilling, transporting contaminated soil, or monitoring water quality)	Developing robotic behavioral models that include movement algorithms and interaction protocols with other agents during remediation tasks. Integrating data transmitted by robot sensors (e.g., pollution detectors) into the model for more precise monitoring and effective decision-making

Continuation of Table 8.3

1	2	3
GIS and satellite technologies		
Territorial modelling of remediation work, real-time monitoring, spatial analysis	Using GIS data to create more accurate territorial models as close to reality as possible	Enhancing real-time monitoring capabilities based on updated satellite data, thereby expanding the potential for rapid response and adjustments to strategies and plans for water resource remediation implementation
The use of drones		
Monitoring drones, spraying drones, delivery drones, analytical drones	Identifying the types of drones required for the project based on the tasks they can perform in remediation work (e.g., for collecting aerial imagery and data on territorial conditions, delivering equipment to hard-to-reach areas)	Used for collecting soil, water, or air samples in high-contamination zones; can also be employed for one-time spraying of chemicals or biopreparations on polluted areas to neutralize contamination or restore the ecosystem, as well as for monitoring emergency situations. Integrating data collected by drones into the project's agent-based model to reduce time and resource costs and minimize risks
Neural Networks, ML and Artificial Intelligence		
Intelligent agents, decision optimization, forecasting, and remediation scenario analysis (simulation of scenarios)	Incorporation into the project's integrated model with machine learning capabilities to analyze incoming data and adapt agent behavior for effective territorial remediation management	Optimization of remediation management decisions at macro, meso, and local levels, enabling forecasting of force majeure situations, assessment of selected remediation methods and strategies, risk minimization, and overall project efficiency enhancement

8.4.3 Project management model based on the implementation of the Agile approach

Effective project management at various stages of its implementation requires specific skills in using specialized tools and management methods to accomplish tasks such as planning, organizing remediation activities, monitoring the implementation of project objectives, and evaluating intermediate and final results to allow for adjustments and/or alternative replacements if necessary. It is crucial to clearly define goals, tasks, and roles, as well as to establish effective communication and control mechanisms to ensure the successful achievement of objectives. A project management algorithm is developed that outlines goals, key actions, and tools to maximize efficiency (**Table 8.4**).

Table 8.4 Project management algorithm by implementation stages

Goals	Key actions	Tools
1	2	3
Stage 1. Project initiation		
– defining the project's goals and objectives; – verifying stakeholders and key agent groups in the project; – developing a concept of tactical and strategic project goals, substantiating benefits for key participants	– diagnosing the situation, assessing key needs and challenges; – developing the project business plan; – forming the project team and assigning roles to working group leaders and executors; – defining the main stages and timelines for project implementation	– business plan; – SWOT analysis; – stakeholder diagrams; – project management platforms (e.g., Microsoft Project, Trello, Asana)
Stage 2. Planning		
– developing a detailed project plan, including an organizational plan, financial plan, and material and technical support plan; – identifying necessary resources and sources for their provision/expense coverage; – developing a risk management plan	– creating a detailed project schedule (Gantt Chart); – prioritizing tasks and subtasks; – analyzing and comparing resources and costs; – developing and organizing a communication system for receiving feedback from the team and key agents	– Gantt chart; – Critical Path Method (CPM); – risk management plan; – architecture-oriented agent-based interaction scheme for project participants
Stage 3. Implementation		
– evaluation and selection of the optimal scenario and action plan for project task implementation; – coordination and management of the project working groups' activities; – information and resource support for task execution	– allocation of tasks by responsibility centers, priorities, deadlines, and resource capabilities, and management of their implementation; – monitoring task progress, operational and final control over task execution; – ensuring effective team communication; – operational plan adjustments, adaptation, and change management	– task management platforms (e.g., Jira, Monday.com); – time management tools (e.g., Toggl); – document management systems (e.g., Google Drive, SharePoint); – communication and connectivity tools

Continuation of Table 8.4

1	2	3
Stage 4. Monitoring and control		
– interim evaluation of project task implementation; – identification and management of issues and risks; – oversight of project plan and budget compliance	– regular collection and analysis of aggregated information on task progress; – presentation and discussion of project status reports based on "milestone" dates; – conducting operational meetings during project implementation; – verification of "bottlenecks" in project execution; – quality control of completed remediation work	– monitoring and reporting tools (e.g., Microsoft Power BI, Tableau); – Earned Value Management (EVM) method; – control reports and checklists
Stage 5. Completion and evaluation		
– completion of project tasks; – evaluation of results and expectations of stakeholders and project partners; – audit and summarization of the project, with the transfer of results to stakeholders	– auditing results and providing a final overall evaluation of project task completion; – preparing reports and transferring the relevant documentation; – organizing a presentation of project results for stakeholders, partners, and the public; – conducting a project closure analysis (Lessons Learned)	– final project report; – surveys for feedback collection from the team and stakeholders; – tools for project closure analysis (e.g., Post-Project Review)

Our position is that an unconventional approach to implementing water resource remediation measures in Kherson region should be based on a modern and non-traditional management framework – specifically, the Agile methodology. As previously mentioned, it is possible to consider Agile to be a promising and highly effective approach for managing crisis operations, responding to constantly changing conditions during remediation activities, addressing the dynamic ecosystem situation influenced by weather and other factors, as well as ensuring operational team management and continuous communication to make effective decisions [16].

The rationale for adopting this approach is as follows:

1. *Flexibility over rigidity:* Agile allows for constant plan revisions and adaptations, in contrast to traditional methods. This flexibility is crucial in the context of uncertainty surrounding remediation activities, the coordinated actions of agents, and rapidly changing situations.

2. *Focus on people and their interactions:* Agile has proven highly effective in managing a large number of participants (as in our case – specific remediation activities conducted over a large area with numerous agent groups). It is particularly effective in complex coordination systems, facilitating decision-making processes and ensuring transparency and involvement of all stakeholders.

3. *Reduction of bureaucratic burden:* projects of this nature are typically associated with extensive documentation processes, including preparation, approval at various levels, and ongoing management of documentation throughout the hierarchy, culminating in reporting. Traditional approaches often require significant resources to manage this aspect. Agile, in contrast, reduces bureaucratic barriers, focusing on tangible results and progress [24].

In our case, the project is divided into short cycles (or sprints), each concluding with a review of interim results. This allows for testing and implementing partial solutions (e.g., applying alternative remediation methods or replacing technical equipment), assessing their impact, and making real-time adjustments. This substantially increases the likelihood of success under complex and uncertain conditions. Tools like Jira and Asana help organize collaborative efforts among all project teams and stakeholders. Regular meetings allow for the identification of bottlenecks, discussion of potential problems, and exploration of solutions. Monitoring tools such as Power BI and Tableau provide visualizations of results and progress in cleaning and restoring the territory. These tools facilitate the evaluation of project task performance, effective risk management, and problem resolution.

Thus, the modified agent-based model for managing water resource remediation in Kherson region can be presented as a dynamic system in which agents interact with each other and external phenomena, making decisions based on localized information (**Table 8.5**). The integration of IT technologies, the Internet of Things (IoT), and machine learning (ML) significantly simplifies process management within this system, while the use of Agile enhances adaptability to changes and increases project management flexibility.

Table 8.5 Structure of the modified integrated AOM

Elements of the generalized AOM	Description
1	**2**
1. General variables of the mediation mana gement system	$W(t)$ – the total volume of water available for safe use at time t. $Z_i(t)$ – the contamination level of water resources at time t, specific to contaminant type i.

Continuation of Table 8.5

1	2
	$R(t)$ – the volume of water entering the system from natural or artificial sources (e.g., rainfall or resources purified through remediation systems). $L(t)$ – the volume of water lost due to infrastructure damage, leaks, or other inefficiencies. $P_i(t)$ – the consumption priority of agent *i* at a specific time *t*. $U_i(t)$ – the economic benefit derived from water consumption by agent *i*, where *i* represents key agents (e.g., agricultural entities, contractors, or public utilities). $C(t)$ – the volume of water purified using various remediation methods. $ML(t)$ – the machine learning model used to optimize water distribution based on real-time data and predictive analytics. $IoT(t)$ – data collected from sensors, drones, and monitoring devices, providing aggregated information on contamination levels and overall conditions in real time
2. Behavior of agents	*The economic utility function for agent water consumption.* Each agent *i* (e.g., agribusiness entities, farmers, utilities, contractors, etc.) seeks to maximize their utility $U_i(t)$, which depends on the volume of water allocated $W_i(t)$ and other factors, such as overall contamination levels $Z_i(t)$: $U_i(t)=f(W_i(t), Z_i(t), P_i(t)),$ where $W_i(t)$ – the volume of water received by agent *i* at time *t*; $Z_i(t)$ – the contamination level of the *i*-th contaminant, which can reduce the utility of each agent; $P_i(t)$ – the priority level of water consumption assigned to agent *i*, determined by government authorities or automated systems based on *ML* algorithms. *The water demand function for each agent i is described as:* $W_i(t)=f(N_i(t), A_i(t), weather(t), IoT(t)),$ where $N_i(t)$ – the number of users/area served by agent *i* (e.g., the size of the farm); $A_i(t)$ – the activity level of agent *i* (e.g., the area of cultivated land); *weather*(t) – climatic conditions affecting water needs (e.g., drought or precipitation); $IoT(t)$ – real-time data collected from IoT sensors, which provide a more accurate assessment of water requirements
3. Distribution of water among agents	The distribution of the total water volume $W(t)$ among agents during each remediation time period is determined using an *ML* model that incorporates various factors: consumption priorities, the pollution level by contaminant type *i*, and water demand based on real-time *IoT* data. The volume of water allocated to a specific agent *i* is determined as: $W_i(t)=ML(t, P_i(t), W_i(t), Z_i(t), IoT(t)),$ where $ML(t)$ – machine learning, which optimizes water distribution based on data about needs, contamination, weather conditions, and other factors

Continuation of Table 8.5

1	2
4. Dynamics of water pollution	The level of water resource pollution *Z* from the *i*-th type of contaminants at a given time *t* – $Z_i(t)$ – changes over time based on remediation factors and territorial pollution sources: $Z_i(t+1)=Z_i(t)-C(t)+P_{industry}(t)$, where $C(t)$ – the volume of pollutants removed as a result of water treatment using applied remediation methods; $P_{industry}(t)$ – the level of pollution generated by industrial entities and other contamination sources (e.g., cemeteries, waste dumps, etc.)
5. Remediation of water resources	The volume of treated water $C(t)$ depends on the investment in purification technologies and the implementation of a set of remediation measures, as well as the decisions made through the application of the Agile approach: $C(t)=f(investment(t), technology(t), remediation\_team(t), feedback\_loop(t))$, where *investment*(*t*) – the volume of investments in technologies, equipment, and materials for water remediation and purification; *technology*(*t*) – the effectiveness of implemented remediation technologies; *remediation_team*(*t*) – the efficiency of contractors and working groups executing the water resource remediation strategy; *feedback_loop*(*t*) – iterative improvements through the Agile approach, enabling rapid adaptation to changes during project implementation
6. Utilization of IT Technologies, IoT, and ML	*IoT.* The system utilizes sensors and drones for continuous monitoring of the territory's condition, water pollution levels, and water supply issues, transmitting data in real-time: $IoT(t)=\sum Sensor\ k(t)$, where *Sensor k*(*t*) – data from each IoT sensor *k* installed in the contaminated area. *ML* (*Machine Learning*). A machine learning model integrated into the system utilizes IoT data to predict water needs, assess pollution levels, and optimize resource distribution: $ML(t)=f(historical\_data, IoT(t), weather(t), priorities(t))$. *Agile Approach.* The implementation of the Agile approach will significantly enhance the efficiency of managing the remediation process and adapt solutions based on feedback: – iterations: the remediation project is divided into short iterations, each of which includes hypothesis testing and adaptation of optimal solutions to the conditions of the remediation activities (e.g., transport and logistics capabilities, financial resources, technical feasibility, weather conditions, etc.);

Continuation of Table 8.5

1	2
	– feedback: at each stage of the project, aggregated feedback is collected from remediation task performers, the operational management team, and incoming IoT data to identify bottlenecks and make adjustments to subsequent actions: $New\_strategy(t+1)=Agile\_feedback(t)$
7. Generalized system equation	The complete equation of the system, incorporating all the aforementioned components, can be expressed as follows: $W(t+1)=W(t)+R(t)-\Sigma_{[i=1;\,N]}-L(t),$ $W(t)=ML(t,\, P_i(t),\, W(t),\, W_i^{demand}(t),\, Z(t),\, IoT(t)),$ $Z(t+1)=Z(t)-C(t)+P_{industry}(t),$ $C(t)=f(investment(t),\ technology(t),\ remediation\_team(t),\ feedback\_loop(t))$

For the successful implementation of the decision-making system project based on an agent-based model for managing the remediation of water resources in Kherson region, integrating IT technologies, the Internet of Things (IoT), machine learning (ML), and the Agile approach, specific equipment, software (SW), and technologies are required. Below is a summarized analytical table outlining the key parameters of the necessary equipment, software, their purpose, quantity, and estimated cost (**Table 8.6**).

Table 8.6 Assessment of required software and other resources for project implementation

Resource name	Name	Purpose	Quantity	Price range (thousand USD)
1	2	3	4	5
Software, including:				
Agent-Based Modeling (ABM)	AnyLogic/ NetLogo	Modeling the behavior of key agents and simulating potential scenarios for the remediation of water resources	1 license	100–200
Machine Learning (ML)	TensorFlow, PyTorch	Optimization of resource allocation and forecasting outcomes	1 license	0–50
Geographic Information Systems (GIS)	ArcGIS/ QGIS	Spatial analysis of the territory and data visualization	5 licenses	30–60

Continuation of Table 8.6

1	2	3	4	5
IoT platform	AWS IoT, Azure IoT	Management of data transmitted from sensors and drones	1 platform	40–70
Data analytics	SAS, Tableau	Analysis of collected data, visualization of project outcomes, presentation of remediation results	1 license	70–150
Tools for Agile management	Trello, Jira	Team management and coordination of remediation tasks implementation based on the Agile approach	5 licenses	1–10
Technical equipment, including:				
Servers	HPE/Dell	Processing ABM, GIS, and IoT data	10 servers	40–60
IoT sensors and detectors	Senix, Siemens	Monitoring of the situation, territory, and pollution levels; inspection and control of facilities	100 sensors	2.5–5
Drones	DJI Phantom, Parrot	Controlling the state of water resources, water supply facilities, and related infrastructure	10 drones	20–40
Systems for machine learning	NVIDIA GPU/TPU	Processing received data and training ML models	5 GPUs	20–50
Infrastructure software, including:				
Project management systems	Microsoft Project, Asana	Management of project remediation implementation and coordination of team actions	1 license	30–70
DevOps tools	Docker, Kubernetes	Automation of system deployment and updates	1 license	5–15
Communication tools and instruments:				
Communication tools and instruments for integrating the joint efforts of project participants	Microsoft Teams/ Slack	Team interaction, remote work of project participants, idea generation, collaborative work, communication with key agents	10 licenses	5–15
		Total		**1,563–2,055**

The estimated total cost range for software (SW), technical, and infrastructure equipment, including communication tools for the effective implementation of the project, is approximately between 1,563 million and 2,055 million USD. This cost range accounts for potential price fluctuations in software and equipment, enabling more flexible budget planning for the project.

8.4.4 Determining the comprehensive efficiency of implementing the water resource remediation management project in Kherson region

The water resource remediation management project in Kherson region, based on an Agent-Based Model (ABM) integrated with IT technologies, the Internet of Things (IoT), Machine Learning (ML), and the Agile management approach, holds critical importance in addressing the aftermath of the destruction of the Kakhovka Hydroelectric Power Plant (HPP). This project is not only a vital step towards the region's recovery after the active phase of military actions but also opens new opportunities for sustainable water resource management in the post-war recovery context.

I. Environmental significance and efficiency of the project.

The destruction of the Kakhovka HPP resulted in severe environmental consequences, including water resource contamination, ecosystem destruction, and threats to the potable water supply for the region's population. Implementing the ABM-based project will:

1. Effectively model and manage the region's complex water resource system, including restoring irrigation channels for agricultural lands.
2. Optimize the cleaning process of contaminated water by integrating advanced purification technologies and scenario-based modelling.
3. Enable real-time monitoring of the ecological state of water bodies using IoT technologies, allowing for timely responses to changes.

II. Social significance and efficiency.

The region's population faces threats of water shortages for household needs and deteriorating drinking water quality. The proposed integrated remediation project will:

1. Ensure sustainable water distribution among the population, agricultural, and industrial consumers based on priorities and real-time water supply data.
2. Reduce social tensions through fair resource distribution, especially in conditions of scarcity, by leveraging machine learning algorithms and IoT data.
3. Improve access to clean drinking water for the population and municipal services by implementing advanced technologies and purification methods.

III. Economic significance and efficiency.

As an agrarian region, Kherson region heavily relies on water resources for agricultural production. The destruction of hydroelectric and irrigation infrastructure has severely affected the region's economy. Implementing the proposed project will:

1. Coordinate the restoration and modernization of water and irrigation systems, ensuring sustainable water supply for all economic actors and the population.

2. Optimize the rational use of water resources, minimizing losses and increasing efficiency through IT technologies and machine learning.

3. Attract domestic and foreign investors to innovation-oriented projects to restore war-affected areas, creating economic incentives for accelerated recovery and development of the region [30].

IV. Technological significance and efficiency.

The integration of IT technologies, IoT, and ML into water resource management elevates remediation efforts to a new level. The use of technologies will:

1. Automate data collection and processing, real-time monitoring, and analysis of water bodies, enhancing decision-making and crisis management responsiveness.

2. Utilize machine learning to predict water supply needs for various agents and scenarios based on implemented decisions, allowing for swift responses to critical changes in the situation.

3. Apply the Agile approach to manage the project team flexibly, enabling iterative implementation of solutions and quick adaptation to changes based on continuous communication and feedback from all project participants [28].

V. Managerial significance and efficiency of the Agile approach.

The use of the Agile approach in managing the water resource remediation project will:

1. Enable flexible project management through iterations and feedback, which is crucial in the constantly changing post-war environment.

2. Coordinate the actions of all project participants across all levels of the management hierarchy – from top-level government bodies, specialized agencies, and ministries to local municipal services and contractors – under a unified remediation management strategy.

3. Ensure transparency and prompt decision-making at every stage of project implementation, contributing to the more efficient use of all types of resources [29].

This comprehensive approach ensures that the project not only addresses the critical challenges of recovery but also lays the groundwork for the region's long-term development, enhancing its resilience to future crises.

Below, let's present a summarized table of the potential effects of implementing the developed project (**Table 8.7**).

Table 8.7 Potential effects of implementing the water resource remediation project in the Kherson region

Parameter	Forecast value/Expected effect
Environmental effect	Reduction in pollution levels by 70–90 % (depending on types of contaminants); restoration of biodiversity up to 80 % within 5 years
Social effect	100 % provision of drinking water for the population of the region and 80 % of economic entities within the first 3 years of project implementation
Economic effect	Total required amount of external loans, investments, and funding: from 150 to 200 million USD, allocated as follows: – 80 million USD for modernization of the water supply system (pipelines, pumping stations, filtration); – 50 million USD for restoration of irrigation systems and infrastructure; – 20 million USD for the development and implementation of IT solutions, IoT, and ML for water resource management; – 10 million USD for the introduction of monitoring systems, state oversight, and regulation in compliance with international standards
Technological effect	Reduction in water supply system management costs by 50 % through project implementation and application of advanced technologies; increase in forecasting accuracy for water demand up to 95 %
Managerial effect	80 % of project tasks are expected to be completed within the established timeframe; reduction in administrative expenses by 40 %

Source: compiled by the authors based on consultations with specialists [25–27]

The final stage of the study involves an analytical assessment of the anticipated benefits for key agents across critical parameters (**Table 8.8**).

For key agents, including government bodies, local authorities, and private sector stakeholders, the project provides a structured framework for collaboration, transparency, and achieving common goals. The expected benefits extend beyond immediate remediation, encompassing socio-economic recovery, infrastructure modernization, and the promotion of innovative ecosystems. Key stakeholders, such as agricultural businesses, local communities, and investors, stand to gain significantly from enhanced water access, improved agricultural productivity, and increased trust in governance. The project's focus on agile management ensures adaptability to changing conditions, fostering cooperation and accountability among all participants. Ultimately, the remediation of water resources in the Kherson region will serve as a catalyst for regional renewal, contributing to national economic growth and setting a benchmark for sustainable post-conflict recovery [30].

Table 8.8 Potential benefits and opportunities for key agents from project implementation on remediation

Environmental effect	Social effect	Economic effect	Technological effect	Managerial effect
1	2	3	4	5
Key agent: agricultural sector and farmers				
Reduction in water pollution and salinity levels through the remediation of water resources and modernization of the water supply system, improvement of irrigated lands, and ecosystem restoration	Stable access to clean water for irrigation will ensure the region's food security	Increased crop yields and reduced overall costs, including those associated with water use for agricultural activities	Implementation of advanced technologies, real-time monitoring systems, and predictive analytics	Enhanced management efficiency and strengthened coordination between key agents and water resource management authorities through Agile methods
Key agent: public utilities				
Improved water quality through the application of advanced purification methods and modernization of the water supply system, reducing the overall negative impact of pollution	Reliable and safe water supply for the local population	Reduced costs for water purification processes, decreased water losses, and increased efficiency of infrastructure for providing high-quality services	Integration of IoT sensors for real-time monitoring of water quality and network conditions	Optimization of water supply system management through digital platforms and predictive analytics
Key agent: government bodies				
Compliance with national and European environmental protection standards and principles of ecological safety	Increased public trust and satisfaction through effective management and protection of national water resources	Focusing on all potential opportunities to restore the most vital resource – water – as a national asset, fostering the post-war revival of the region and economic recovery	Development of a unified centralized water resource monitoring system based on GIS, integrated with AI	Optimization of state governance and decision-making processes with transparent monitoring and reporting

Continuation of Table 8.8

1	2	3	4	5
Key agent: local self-government				
Gradual restoration of local ecosystems and reduction of environmental risks. Improved public health through better water quality and sanitation. Increased population density	Stimulation of the local economy through support for small-scale irrigation and infrastructure projects	Support for entrepreneurial projects of innovation-oriented small and medium-sized businesses	Utilization of advanced water supply technologies, drones, and IoT for monitoring and managing local water infrastructure	Strengthened collaboration with higher authorities and local stakeholders to optimize water resource management
Key agent: domestic and foreign investors				
Ensuring investor protection rights and creating opportunities for implementing and supporting sustainable development projects	Contribution to local community development and promotion of corporate socially responsible business practices	Benefits and incentives for implementing innovative environmental projects and initiatives aimed at restoring and developing priority sectors	Adoption of advanced technologies and fostering the region's innovation ecosystem	Clear structures of interconnection and management architecture based on Agile principles, ensuring transparency and accountability of all project participants
Key agent: contractor firms				
Application of advanced environmentally friendly technologies and remediation methods	Creation of jobs and opportunities for social housing and benefits for workers engaged in restoration activities	Increase in regional and business entity revenues through participation in large-scale remediation and infrastructure recovery projects	Utilization of cutting-edge technologies, equipment, machinery, and materials to effectively achieve remediation objectives	Optimization of the organizational and management mechanism through adaptive project management methods

8.5 Conclusion

The project developed by the authors for remediating military contamination and restoring the water resources of Kherson region holds extremely significant importance for the post-war revival of the region. The ecological disaster resulting from the destruction of the Kakhovka Dam necessitates the implementation of innovative solutions to address environmental, economic, and social problems. For these purposes, the management of water resource remediation is proposed through an agent-oriented model integrated with IT, IoT, machine learning, and the Agile methodology [28]. The project is aimed at restoring ecological balance, reducing water resource pollution, ensuring clean drinking water, and revitalizing agriculture as a strategically important sector of Ukraine's economic system. The project provides for the modernization of infrastructure in accordance with international standards, attracting investments to eliminate the consequences of war and reconstruct the water supply system, as well as integrating advanced technologies for adaptive and "transparent" management [29]. In addition to the immediate restoration of war-affected territories, the project lays the foundation for future resilience and long-term growth.

References

1. After two years of war, Ukraine sees deepening environmental wound (2024). Yale Environment 360. Available at: https://e360.yale.edu/digest/ukraine-war-environment-2024
2. Cummins, J. (2010). Why Some Wars Never End: The Stories of the Longest Conflicts in History. Fair Winds Press, 280.
3. Brokhauz, F. A., Efron, Y. A. (1890–1907). Entciklopedicheskii slovar. Saint-Petersburg. Available at: https://rus-brokgauz-efron.slovaronline.com/
4. Méndez-Fajardo, S., Gonzalez, R. A., Barros-Castro, R. A. (2017). Using Actor-Network Theory in Agent-Based Modelling. Social Systems Engineering. John Wiley & Sons, 157–177. https://doi.org/10.1002/9781118974414.ch8
5. Ellers, J., Hoogendoorn, M., Wendt, D. (2010). An Agent-Based Modeling Approach to Investigate Emergent Patterns in Ecological Systems. 2010 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology, 6–13. https://doi.org/10.1109/wi-iat.2010.200
6. Radosavljevic, S., Sanga, U., Schlüter, M. (2024). Navigating simplicity and complexity of social-ecological systems through a dialogue between dynamical systems and agent-based models. Ecological Modelling, 495, 110788. https://doi.org/10.1016/j.ecolmodel.2024.110788
7. Sibertin-Blanc, C., Therond, O., Monteil, C., Mazzega, P. (2019). The Entity-Process Framework for Integrated Agent-Based Modeling of Social-Ecological Systems. Law, Public Policies and Complex Systems: Networks in Action, 57–86. https://doi.org/10.1007/978-3-030-11506-7_4

8. Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences, 99, 7280–7287. https://doi.org/10.1073/pnas.082080899
9. Yang, Y.-C. (2010). Modeling watershed management with an ecological objective – a multi-agent system based approach. Available at: https://typeset.io/papers/modeling-watershed-management-with-an-ecological-objective-a-3ozd9t5ntw
10. Martin, R., Schlüter, M. (2015). Combining system dynamics and agent-based modeling to analyze social-ecological interactions – an example from modeling restoration of a shallow lake. Frontiers in Environmental Science, 3. https://doi.org/10.3389/fenvs.2015.00066
11. Berglund, E. Z. (2015). Using Agent-Based Modeling for Water Resources Planning and Management. Journal of Water Resources Planning and Management, 141 (11). https://doi.org/10.1061/(asce)wr.1943-5452.0000544
12. Bahrami, N., Sadr, S. M. K., Afshar, A., Afshar, M. H. (2022). Application of Agent Based Models as a Powerful Tool in the Field of Water Resources Management. Computational Intelligence for Water and Environmental Sciences, 491–506. https://doi.org/10.1007/978-981-19-2519-1_23
13. Nouri, A., Saghafian, B., Bazargan-Lari, M. R., Delavar, M. (2022). Local water market development based on multi-agent based simulation approach. Groundwater for Sustainable Development, 19, 100826. https://doi.org/10.1016/j.gsd.2022.100826
14. Shirvani-Hosseini, S., Samadi-Koucheksaraee, A., Ahmadianfar, I., Gharabaghi, B. (2022). Data Mining Methods for Modeling in Water Science. Computational Intelligence for Water and Environmental Sciences, 157–178. https://doi.org/10.1007/978-981-19-2519-1_8
15. Gwapedza, D., Barreteau, O., Mantel, S., Paxton, B., Bonte, B., Tholanah, R. et al. (2024). Engaging stakeholders to address a complex water resource management issue in the Western Cape, South Africa. Journal of Hydrology, 639, 131522. https://doi.org/10.1016/j.jhydrol.2024.131522
16. Dong, H., Dacre, N., Baxter, D., Ceylan, S. (2024). What is Agile Project Management? Developing a New Definition Following a Systematic Literature Review. Project Management Journal, 55 (6), 668–688. https://doi.org/10.1177/87569728241254095
17. Khersonska torgovo-promislova palata. Zagalna Informatsiya pro region. Geografichne polozhennya i prirodni resursi. Available at: https://www.tpp.ks.ua/khersonskij-region.html
18. Rapid Environmental Assessment of Kakhovka Dam Breach Ukraine, 2023 (2023). United Nations Environment Programme. https://doi.org/10.59117/20.500.11822/43696

19. EkoZagroza. Official resource of the Ministry of Environmental Protection and Natural Resources of Ukraine. Available at: https://ecozagroza.gov.ua/
20. Satellite Detected Waters Evolution over Khersonska, Dnipropetrovska, Mykolaivska, Odeska and Zaporizka Oblasts in Ukraine as of 03 and 05 July 2023 (2023). United Nations Satellite Office. Available at: https://unosat.org/products/3636
21. Study of the Destruction of the Kakhovka Dam and Its Impacts on Ecosystems, Agrarians, Other Civilians, and International Justice (2024). Truth Hounds. Available at: https://truth-hounds.org/en/cases/submerged-study-of-the-destruction-of-the-kakhovka-dam-and-its-impacts-on-ecosystems-agrarians-other-civilians-and-international-justice/
22. Khoriev, M., Karamushka, V., Huliaieva, O., Kuns, B. (2024). Assessment of water needs in the lower Dnipro sub-basin following the destruction of the Kakhovka Reservoir. https://doi.org/10.21203/rs.3.rs-4480879/v1o
23. Quamar, M. M., Al-Ramadan, B., Khan, K., Shafiullah, M., El Ferik, S. (2023). Advancements and Applications of Drone-Integrated Geographic Information System Technology – A Review. Remote Sensing, 15 (20), 5039. https://doi.org/10.3390/rs15205039
24. Palopak, Y., Huang, S.-J. (2024). Perceived impact of agile principles: Insights from a survey-based study on agile software development project success. Information and Software Technology, 176, 107552. https://doi.org/10.1016/j.infsof.2024.107552
25. Konsultatsii z hromadskistiu. Ministerstvo zakhystu dovkillia ta pryrodnykh resursiv Ukrainy. Available at: https://mepr.gov.ua/topics/ogoloshennya/konsultatsiyi-z-gromadskistyu/
26. Konsultatsii z hromadskistiu. Derzhavne ahentstvo vodnykh resursiv Ukrainy. Available at: https://www.davr.gov.ua/konsultacii-z-gromadskistyu
27. Elektronni konsultatsii z hromadskistiu. Ministerstvo rozvytku hromad ta terytorii Ukrainy. Available at: https://mtu.gov.ua/timeline/Proekti-normativno-pravovih-aktiv.html
28. Cherniavskyi, B. (2024). Digital Technologies as an Accelerator of Remediation: a Strategic Vector for the Post-War Revitalization of Ukraine's Territory. Transformational economy: theoretical and practical aspects. Riga: Baltija Publishing, 653–675.
29. Britchenko, I., Cherniavska, T. (2019). Blockchain technology in the fiscal process of Ukraine. Economic Studies, 28 (5), 134–148.
30. Tanklevska, N., Cherniavska, T., Skrypnyk, S., Boiko, V., Karnaushenko, A. (2023). Financing of Ukrainian agricultural enterprises: Correlation-regression analysis. Scientific Horizons, 26 (8), 127–139. https://doi.org/10.48077/scihor8.2023.127