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Management Theory and Studies for Rural Business and Infrastructure Development
eISSN 2345-0355. 2024. Vol. 46. No. 2: 229-239
Article DOI: https://doi.org/10.15544/mts.2024.24

ENVIRONMENTAL AND ECONOMIC DAMAGE TO AGRICULTURE AS A RESULT OF THE EXPLOSION OF THE KAHOVSKA HYDROELECTRICAL STATION

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Received 05 04 2024; Accepted 12 05 2024

Abstract
The explosion of the Kakhovka hydroelectric power station destroyed 350 pumping stations, the reclamation canals with a total length of more than 1,100 km were left without an irrigation source. The global problem arose due to the impossibility of irrigation in the Kherson region for 2-3 years, which will lead to the fact that the fields in the south of Ukraine will turn into a desert next year. In order to avoid the complete destruction of agriculture and colossal economic losses, it is necessary to study the damage caused in detail and develop ways to overcome it. The purpose of the work was to analyze the damage caused to agriculture after the explosion of the Kakhovka hydroelectric plant and to propose ways of its restoration.
According to preliminary calculations, losses from the death of all biological resources amount to about 10.5 billion hryvnias. The explosion of the Kakhovka hydroelectric power station caused a large-scale ecological disaster in the fishing industry: the aquatic biological resources of reservoirs in Kherson region, Dnipropetrovsk region, Mykolaiv region and other regions died without water. Without irrigation, it is impossible to grow corn, soy, oil and melon crops in the south.
To restore agriculture in the territory affected by the man-made disaster, we have proposed several ways, including the use of well technology; grow crops that do not need a lot of moisture - wheat, barley, winter crops, peas; develop a strategy for drip irrigation and drainage, carry out land reclamation and implement at the legislative level the right of water users to unite and jointly manage canals, pipelines, pumping stations that supply water to fields for irrigation.

Keywords: *agriculture, ecological consequences, explosion of the Kakhovka hydroelectric station, plague of fish.*
JEL Codes: *H56, H51.*

Introduction

On the night of June 6, 2023, the Russians blew up the Kakhovka hydroelectric station and caused a large-scale man-made disaster, the consequences of which are particularly catastrophic for the southern regions of Ukraine. These regions have historically been the main producers of vegetables and fruits in the country, the cultivation of which depends on irrigation

systems. At the same time, the reservoirs of the region are inhabited by various species of fish and other aquatic biological resources. Without water from the Kakhovsky Reservoir, the reclamation systems of the southern regions simply will not work.

In general, in Ukraine, 18.7 million hectares of arable land need permanent irrigation, 4.8 million hectares require periodic irrigation, and this amount, taking into account climate changes, will only increase. In the current season (2023), farms planned to irrigate only 147,000 hectares of agricultural land after the tragedy at the hydroelectric plant, the figure may be even lower.

A number of scientists were engaged in forecasting the consequences of the disaster at the Kakhovskaya hydroelectric station: P. Bremond, F. Grelot, A. Agenais (2013); M. Ladyka, V. Starodubtsev (2022); L. Khokhlova, D. Lukashov (2020); V. Vyshnevsky (2020); S. Pantazopoulos, (2023).

Researchers at the Agrocenter of the Kyiv School of Economics (Kyiv School of Economics, KSE) explain that irrigation systems do not necessarily have to be completely destroyed or damaged in order for them to be unusable. Due to the lack of water from the Kakhovsky Reservoir, the reclamation systems of the Kherson, Dnipropetrovsk, and Zaporizhia regions simply have nowhere to pump water for irrigation. According to them, the very infrastructure on the field and even pumping stations in Dnipropetrovsk, Zaporizhzhya and partly Kherson regions could not be affected at all, but if there is no water, they cannot be used.

The problem is that most agricultural products, especially fruits and vegetables, cannot be grown in this region without irrigation. The undermining of the dam of the Kakhovka hydroelectric power station actually turns the south of the country into a desert. If Ukrainian farmers, in the central regions of Ukraine, where there is access to water and irrigation systems, do not master the technology of growing and processing vegetables, such as onions, carrots, salads, green crops, Ukrainians will have to forget not only about exporting vegetables, but also about the possibility of vegetable self-sufficiency products of the population of Ukraine even in the summer period.

The question of the consequences of the cadastre was investigated: I.Kitowski, A. Sujak, M.Drygaś (2023); V. Pichura, L. Potravka, Y. Domaratskiy, N. Vdovenko, N. Stratichuk, K. Baysha, I. Pichura (2023); O. Shumilova, K. Tockner, A. Sukhodolov, V. Khilchevskyi, De Meester, S. Stepanenko, P. Gleick (2023); W. Post (2023); V. Yarmolenko (2023).

Analyzing the literature, it can be noted that some ecologists talk about the possibility of restoring the legendary Great Meadow with its forests, which was flooded by the Soviet authorities during the creation of the Kakhov reservoir, and call not to restore the dam. Meanwhile, others claim that there are no such chernozems, the Great Meadow and the Cossack steppe, and will not be in the near future. Stabilization of territories that have been under water for a long time takes place over millennia.

The authors claim that with the drying up of the Kakhovsky Reservoir, a huge area of fertile land will now be freed, while others claim that more than 200,000 hectares of sand, clay and silt with heavy metals will be freed. And there are 500,000 tons of dreisen on these bottom sediments. When dreisen, and other types of molluscs and fish, end up on land, they will begin to decompose. The water will start to rot and become a source of intestinal diseases. And when all this gets into the Dnipro river, the consequences can be catastrophic. A huge amount of rotting liquid will seep into the underground horizons as well. The quality of water from wells will deteriorate day by day.

Moiseyenko's research showed that the formation of vegetation on the territory of the Kakhovskaya HPP is extremely fast. This was facilitated by the presence of a seed bank and the relatively high humidity of the nutrient-rich substrate. The time of detonation of the dam at the beginning of June coincided with the ripening of willow seeds, which encouraged its mass distribution.

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Stone R states that it is possible to restore the vegetation that existed in this area prior to the filling of the reservoir known as the Great Meadow. The further development of biotopes at the bottom of the former reservoir will depend on various factors, primarily on weather conditions in winter and spring and the presence of spring floods.

However, for some reason, some ecologists today focus more attention on 150 tons of lubricant that got into the Dnipro from the destroyed engine room of the Kakhovka hydroelectric station. But this is such a big problem, considering the huge release of water in the first three days after the dam burst — about 90,000 tons per second. That is, this oil stain has dissolved so that no one will see it anymore. And the smelly slurry, saturated with organic matter and chemicals, will remain for centuries. The silt will dry, a film will form on top, on which you can even walk, but the equipment will not pass over it. Only foreign weeds will grow there, which will displace any willows or meadow grass planted by humans. Reclamation of such lands is impossible.

The only option is to cover the drained areas with water again, and for this it is necessary to build a bridge as soon as possible to stop the water leakage and restore the Kakhov reservoir to at least the so-called dead level, i.e. up to 12 meters.

The sooner Kherson region is de-occupied, the sooner it will be possible to minimize the catastrophic consequences that lie ahead.

In addition, after the dam was blown, a freshwater tsunami carried thousands of tons of phytoplankton and fish into the Black Sea. They will not survive long in salt water. Dead organic matter will settle to the bottom, and this will lead to an increase in the level of hydrogen sulfide, which will negatively affect the entire Black Sea basin. In addition, the Black Sea received approximately 100 times more fresh water than usual in the first three days. As a result, a huge number of marine inhabitants will also die.

The disaster will indirectly affect the entire cascade of Dnipro reservoirs, the usual functionality of which will be disrupted. We lost a huge amount of water accumulated during the spring flood.

Some scientists believe that it is possible to run pipes from the Dnipro or dig canals in order to save the agricultural sector of the Kherson region. They count kilometers, the required volume of water, but not its consumption. But we simply don't have that much water. The Dnieper cascade of artificial seas allows us to accumulate water during the spring flood. It is she who provides all our needs, and not the water that the main river of Ukraine carries at other times of the year.

If we do not catch the spring flood and accumulate water, not only the entire industry will stop, but also agriculture will completely collapse.

The explosion of the Kakhovka hydroelectric power station (HPP) became one of the largest environmental disasters in the history of Ukraine, which caused significant ecological and economic damage to the agriculture of the region. The Kakhov reservoir provided water supply for more than 500,000 hectares of irrigated land, which is vital for the agricultural sector of Southern Ukraine. Destruction of water supply infrastructure and flooding of agricultural lands led to large-scale crop losses, destruction of livestock and damage to infrastructure, which complicates agricultural activities.

Modern science is faced with the need for a comprehensive analysis of ecological and economic damage, which includes the assessment of crop losses, infrastructure destruction, impacts on livestock, recovery costs, and socio-economic consequences for the local population. The lack of systematic data and methodical approaches to the assessment of such large-scale damages makes this problem scientifically unsolved and requires the development of new approaches to its analysis.

The relevance of this article is determined by a number of factors. First, agriculture is a key sector of Ukraine's economy, which

provides not only domestic food needs, but also a significant share of export earnings. Crop loss and the destruction of water supply infrastructure have a direct impact on the country's food security and the region's economic stability.

Secondly, the ecological consequences of the explosion of the Kakhovskaya HPP affect the quality of soils, water resources and biodiversity. Decreasing land fertility and water pollution can have long-term negative consequences for the region's ecosystems. Understanding and minimizing these environmental losses are important tasks for the sustainable development of agriculture.

Thirdly, the socio-economic consequences of the disaster require special attention. The loss of jobs, a decrease in the incomes of the local population and the need for significant costs for the restoration of infrastructure require the development of effective strategies to support the affected communities and restore the economic activity of the region.

The purpose of this article is to systematize the available data on ecological and economic damages caused by the explosion of the Kakhovskaya HPP, and to develop scientifically based recommendations for minimizing these damages and restoring agriculture in the affected region. This will create a basis for further research and practical measures aimed at the recovery and development of the agricultural sector of Ukraine in the face of environmental and economic challenges.

The purpose of the work is to conduct an analysis of the damage caused to agriculture after the explosion of the Kakhovka hydroelectric power station and to propose ways of its restoration.

Methodology

To study the negative consequences of the accident at the Kakhovskaya HPP for agriculture, we used the following methods of scientific research: analysis, synthesis, theoretical generalization, and system-functional analysis allowed us to summarize the available information about the ecological consequences of the explosion of the Kakhovskaya HPP dam and the scale of environmental disasters; the expedition method made it possible to determine the actual environmental consequences for agriculture in the controlled territories of Ukraine.

Research results and discussion

The destruction of the Kakhovka hydroelectric power station (Figure 1) led to flooding, damage and a complete stoppage of the reclamation infrastructure in the areas adjacent to the Kakhovka Reservoir. So, the main pumping station of the Lymanetska irrigation system of the Kakhovsky inter-district water management department was flooded. This system provided water for 1.5 thousand hectares of irrigated land. At the same time, the water level in the upper reaches of the Kakhov reservoir in the Zaporizhzhia region is dropping rapidly. Such levels of the reservoir do not allow water withdrawal from it by the Vilnia inter-district water management pumping stations, which provided water supply for the Zaporizhzhya, Rozumivska, Pershotravneva and Verkhnyo-Tarasivska irrigation systems on an area of more than 14,000 hectares of irrigated land. As of June 9, more than 1,100 km of reclamation canals in Ukraine remained without water.

As a result of the explosion of the Kakhovka hydroelectric station, the water supply to 31 field irrigation systems of the Dnipropetrovsk, Kherson, and Zaporizhia regions was stopped. In 2021, these systems provided irrigation for 584,000 hectares. from which Ukrainian farmers collected about 4 million tons of grain and oil crops, worth about 1.5 billion dollars.

Most of the irrigation systems are currently located in temporarily occupied territories. According to the ministry, only 13 irrigation systems are operating on the right bank of the Dnieper this year. As a result of the explosion of the hydroelectric station, 94% of the irrigation systems in the Kherson region, 74% in the Zaporizhia region, and 30% in the Dnipropetrovsk region were left without water.

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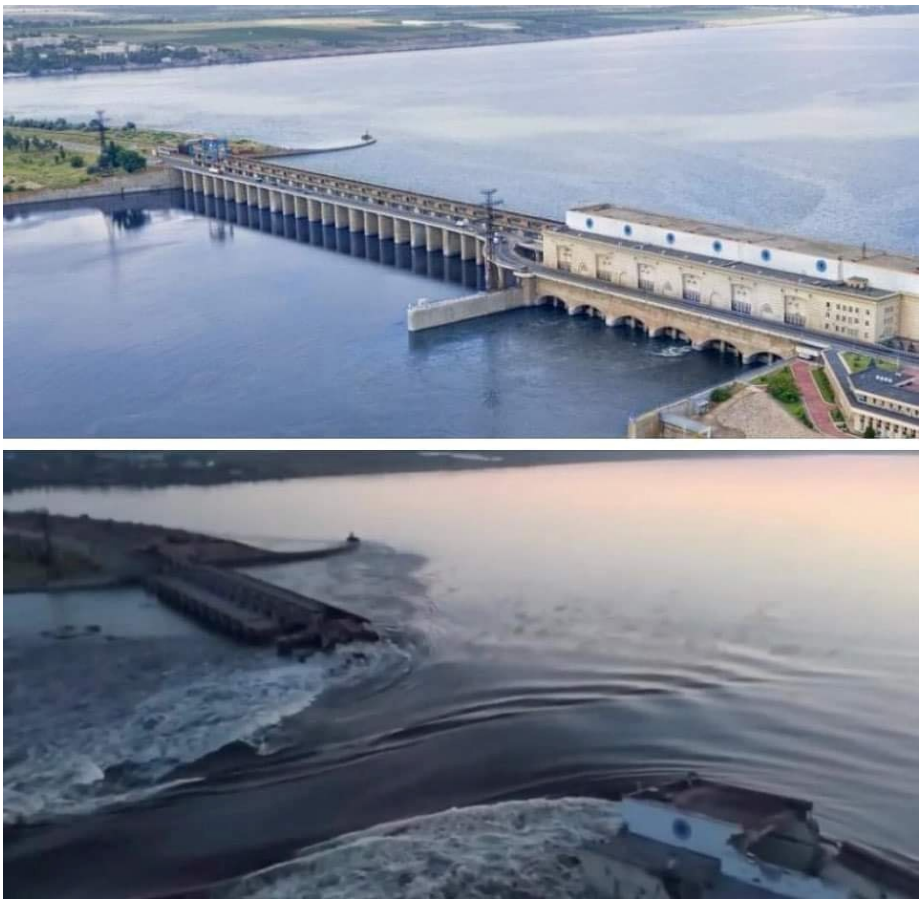

A

B

Figure 1. View of the Kakhovskaya hydroelectric dam: A – before destruction; B - after detonation

**(Photo: grivna.ua).*

The explosion of the Kakhovka hydroelectric station caused a large-scale ecological disaster in the fishery industry: the aquatic biological resources of reservoirs in Kherson region, Dnipropetrovsk region, Mykolaiv region, and other regions died without water.

At the beginning of the disaster in Ukraine, the spawning period had just ended, and as a result of the drop in the water level, the caviar had dried up in wet areas. In addition, the aquatic fauna carried away by the stream died, because the water receded and it ended up on dry land. As a result of the explosion of the Kakhovka hydroelectric station, the final spawning season in the lower Dnipro was practically disrupted, and the normal conditions for the existence of populations of valuable fish species were destroyed.

The only state-owned sturgeon farm in Ukraine "Production-experimental Dnipro Sturgeon Breeding Plant named after Academician S.T. Artyushchyka" is located in the village. Dniprovske, Bilozer district, Kherson region. It has been working since 1984 and compensated for the reproduction of sturgeon species of fish in Ukraine, which lost the possibility of natural reproduction. Every year, the plant provided housing for more than 1.5 million specimens of young sturgeons.

In addition, the Kherson production and experimental plant for breeding young fish, which is located in the temporarily occupied territory of the Kherson region, was under the threat of complete flooding. The plant annually introduced 13 million specimens of fish to the fishery water bodies of Ukraine.

The plant maintains valuable breeding stock of aquatic bioresources and grows carp,

pike, zander, catfish, bream, walleye, white carp for stocking natural reservoirs of national importance. The modern industrial herd of these fish species in the lower Dnieper and the Dnipro-Buzka estuary consists almost entirely of individuals that are products of this plant.

In the first days after the terrorist attack, almost 30,000 fish were destroyed (Figure 2), which caused losses of UAH 7.6 million to the Ukrainian fishery. According to the ministry's estimates, 95,000 tons of adults died as a result of the explosion of the Kakhovka hydroelectric station, which caused about UAH 4 billion in damages to the Ukrainian fishery.

Figure 2. A mass plague of fish after the explosion of the Kakhovskaya hydroelectric station
**(Photo: Ukrainian State Fisheries Agency).*

More than 70 species of fish lived in the lower reaches of the Dnipro and in the Dnipro-Buzka estuary, 18 of which are red-listed fish. At least one species of fish has already disappeared from the face of the Earth. This is a sea pike or pikeperch that lived in the Dnieper-Buzka estuary. For a long time it was considered extinct, but in 2016 we found out that it is alive.

However, the freshwater tsunami led to the complete disappearance of the entire population of the red walleye. In addition, the sturgeon, which during the spawning migration just approached the dam and were swept away by the water hammer, were seriously affected.

Even if they could hide behind islands or rocks, they still died because of the high turbidity of the water. Bottom sediments, together with such heavy metals as cadmium, manganese, iron, which produce a colloidal solution, rose from the bottom of the Dnieper and clogged the fish's gills.

In total, from Kherson to the Dnipro-Buzka estuary, about eight thousand tons of marketable fish died from water hammer. All the youth died. In the south of Ukraine, we lost all of this year's spawn.

Birds, even waterfowl, were also affected as a result of the dam being blown up. All those who nested in grass or bushes. For example, the red-eared swamp owl makes nests exclusively on the ground. And now is the period of feeding the chicks. Therefore, all young birds died, except for those species that nest high in trees.

In total, more than 50 objects of the Nature Reserve Fund of Ukraine ended up in the flooded territory. Water flooded most of the habitat of such Red Book rodents as the sand

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fly, ground hare, Nordman's mouse...All of them did not survive.

Rare sand praying mantises that lived only in that flooded area, fragile Linden arrows, as well as incredibly wonderful, very large, but completely non-aggressive Kolp Kluge wasps, also called yellow-haired wasps, died. In general, we have already lost several dozen Red Book species of various animals, and it is still unclear what to do with it.

As a result of the Russian terrorist act, the entire agricultural sector of southern Ukraine was under threat. Vegetable growing and horticulture in the region is disappearing altogether. In addition, lands on which grain and oil crops were traditionally grown were also affected. According to preliminary estimates of the Ministry of Agrarian Policy, only on the right bank of the Kherson region, 10,000 hectares of agricultural land were flooded, while on the left bank the area of flooded land is several times larger (Figure 3).

Flooding and restriction of access to water due to the explosion of the Kakhovka hydroelectric station had an extremely negative impact on the production of grain and vegetables. In the conditions of closing access to water due to the destruction of the Kakhovskaya hydroelectric station, in the prevailing climatic conditions, it is impossible to ensure full-fledged cultivation of a number of crops.

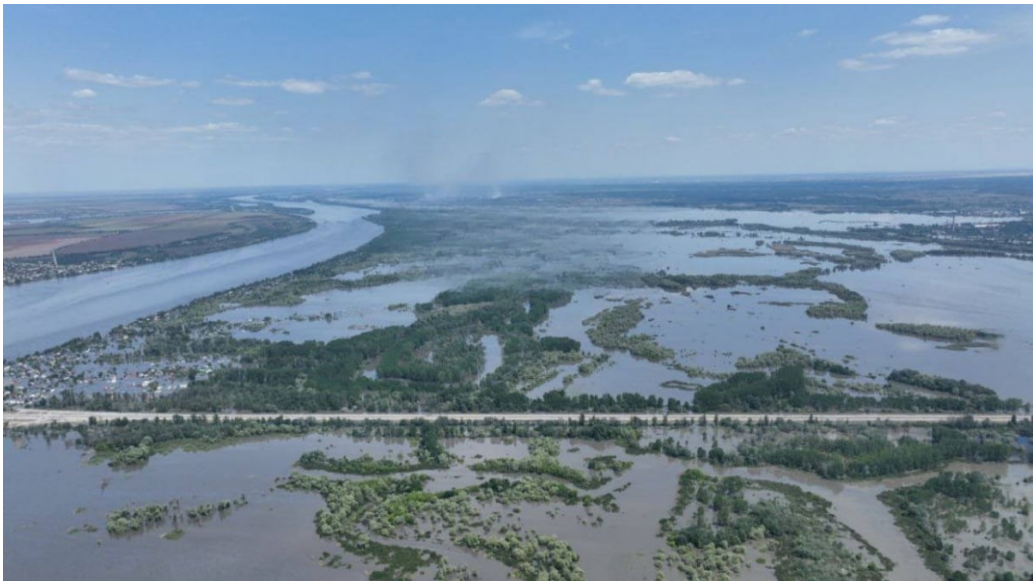

Figure 3. Flooded fields with crops as a result of the explosion of the Kakhovka hydroelectric station

**(Photo: 24tv).*

The explosion of the Kakhovka hydroelectric station is a special blow to the production of vegetables. The Kherson region has always specialized in the cultivation of vegetables, in particular, more than 35% of the vegetables of the borscht set before the war were supplied to the domestic market of Ukraine from this region. Vegetable cultivation is dependent on irrigation.

Practically all heat-loving fruits of Ukraine were grown precisely on the basis of irrigation from the Kakhov reservoir. The main capacities of summer greenhouses, providing the population of Ukraine and Moldova with cheap tomatoes, eggplants, cucumbers and peppers, were also located along the branches of the Kakhov irrigation system.

Without irrigation, it is impossible to grow corn and soybeans in the south. In the record year of 2021, the Kherson, Zaporizhzhya, and Dnipropetrovsk regions collected a total of 12 million tons of grain.

Southern farmers cannot fully use 1-1.5 million hectares of land. the cultivation of some types of oil and grain crops, as well as vegetables in the region can be forgotten for several years.

to obtain the planned corn harvest at the level of 11 tons per hectare, 570 mm of productive moisture is required in clearly defined periods of growth and ripening. Cultivation of corn requires 8–10 irrigations, which is a colossal amount of water.

The lack of irrigation in the first place means a decrease in productivity. In particular, the yield of oilseed crops with irrigation is approximately 2 times greater than the yield of a hectare without irrigation, and of grain - 2.5 times. Given the forecast of the grain and oilseed crop yield by the Ukrainian Grain Association for 2023 (68 million tons), due to the lack of land reclamation, Ukraine may lose from 0.5 million tons to slightly more than 1 million grains. This is a fairly significant reduction that will take place in the medium term.

In Zaporizhzhia, Kherson and Dnipropetrovsk regions, it will be possible to grow crops that do not require a lot of moisture - wheat, barley, winter crops, peas, while vegetables and industrial crops will not have such an opportunity.

The restoration of the Kakhovskaya HPP may cause a significant negative impact on the ecosystem of the Dnipro and surrounding areas. The reconstruction of the dam and the creation of a reservoir can disrupt natural waterways, cause bank erosion and the death of fish resources. The hydroelectric plant was built during the Soviet era, and its design may not meet modern safety and efficiency standards. Investing significant funds in the reconstruction of outdated infrastructure may not be economically feasible compared to the development of new, more efficient and environmentally friendly technologies. The restoration of hydroelectric power plants requires significant financial investments, which can be more effectively used for the development of other sectors, such as the modernization of water supply and irrigation systems, infrastructure development or support for local farmers. Taking into account the unstable geopolitical situation in the region, there is a risk of repeated destruction of the HPP in the future. Investing significant funds in the restoration of an object that can be destroyed again is risky.

In our opinion, the impact of the decision to cancel the restoration of the HPP will have the following consequences on agriculture:

1. The refusal to restore the Kakhovskaya HPP encourages the search for alternative sources of water supply for irrigation of agricultural land. This may include the development of artesian wells, rainwater harvesting and the introduction of modern irrigation technologies, which will help increase the efficiency of water use.
2. Investments in the modernization of existing irrigation systems, the use of drip irrigation and other effective methods will reduce water consumption and increase the yield of agricultural crops.
3. Abandoning a large-scale reservoir can contribute to the development of ecological agriculture, which uses natural resources more rationally and contributes to the preservation of biodiversity.
4. Focus on sustainable agricultural practices, such as crop rotation, use of organic fertilizers and reduction of chemical pollution, will ensure long-term soil fertility and sustainable development of agriculture.
5. The development of renewable energy sources, such as solar and wind farms, will ensure the energy independence of farmers and reduce energy costs, which will positively affect the economic stability of agriculture.
6. Funds saved from the refusal to restore hydroelectric power plants can be directed to support farmers through microcredit programs, crop insurance and grant support, which will contribute to the restoration of the agricultural sector and increase its competitiveness.

Recommendations for minimizing losses and improving the situation

1. Development of a comprehensive recovery program. It is necessary to create a state

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program for the restoration of agriculture in the affected regions, which will include measures for the reconstruction of infrastructure, support for farmers and ecological restoration. The program must be financially supported and have clearly defined terms of implementation.

2. Attracting international aid. Cooperation with international organizations and donors can significantly contribute to the financing and technical support of recovery measures. Using the experience of other countries that have faced similar disasters will help to develop effective strategies to overcome the consequences.
3. Improving the qualifications of agrarians. The organization of trainings and educational programs for farmers on the use of modern technologies, methods of ecological farming and effective management of resources will contribute to increasing the productivity and sustainability of the agricultural sector.
4. Creation of a reserve fund. It is important to establish a reserve fund for rapid response to emergency situations, which will be used to provide financial assistance to affected farmers and to restore infrastructure.
5. Monitoring and damage assessment. Regular monitoring of the environmental condition and economic losses will allow prompt response to new challenges and adaptation of restorative measures. The use of modern monitoring technologies will help to obtain accurate data on the condition of soils, water resources and agricultural land.

We offer several options to agricultural producers in the affected regions:

1. For example, those who are lucky enough to farm near the Dnipro River will be able to use well technology. At the same time, the state should develop a special support program for farmers in the south, which agricultural producers could use to continue their activities.
2. Implement drip irrigation technologies.
3. It is necessary to develop an irrigation and drainage strategy, to conduct an inventory of reclaimed land and engineering infrastructure systems.
4. Create an appropriate legislative framework and form transparent tariffs for irrigation services.
5. Unite water users to jointly manage canals, pipelines, pumping stations supplying water to fields for irrigation.
6. Reorientate on planting other agricultural crops that do not require irrigation.

The cost of restoring and modernizing the irrigation system in the south is several billion dollars.

Conclusions

Damage to the environment as a result of Russia's detonation of the Kakhovskaya HPP dam amounted to more than 146 billion hryvnias. More than 14 cubic km of water or 72.5% of the total volume of the reservoir was lost. 600 km2 of territories were flooded. 64 thousand hectares of forests were flooded. Unique types of biodiversity have been destroyed. The waters of the Black Sea were significantly polluted. In the first days after the disaster, excess concentrations of oil products, copper, zinc, arsenic and cobalt were recorded in sea waters. The salinity in the Dnipro-Buzka estuary decreased to the level of 0.2 ‰, which led to undesirable changes in the ecosystems of the estuary and the sea.

Catastrophic changes in the ecosystem and hydrogeological environment will reverberate for Ukraine for years. In total, according to preliminary calculations, losses from the death of all biological resources amount to UAH 10.5 billion. the Russians actually destroyed vegetable growing and horticulture in the south of Ukraine. Kakhov reservoir was the main supplier of water for one of the largest irrigation systems in Europe. Water from this irrigation system made it possible to grow up to 80% of all vegetables in Ukraine and a significant percentage of fruits and grapes.

One of the key tasks is the restoration of water supply systems for irrigation of agricultural lands. Investments in the

reconstruction of the Kakhovskaya HPP and other water intake structures, as well as the modernization of irrigation systems, will contribute to the restoration of agricultural production in the affected areas. Alternative sources of water supply, such as artesian wells and rainwater harvesting, can also be used to meet agricultural needs.

As long as Ukraine has not made a decision to rebuild the Kakhovskaya HPP, Kherson region, Zaporizhzhia and partially Dnipropetrovsk region will suffer huge losses, because there is no other way to supply water to these regions. We propose to apply a number of measures that will help agriculture to survive and partially reorient itself to the cultivation of crops that do not require irrigation.

The use of modern technologies, such as drone field surveys, precision agriculture and automatic irrigation systems, will help to optimize water consumption and increase the productivity of agricultural lands. Innovative approaches can also be used to restore soil fertility and reduce environmental impact.

The implementation of ecological restoration programs aimed at improving the quality of soils, restoring biodiversity and rehabilitating water resources will be an important step for the sustainable development of agriculture. The development and implementation of biomelioration measures and the restoration of natural ecosystems will help minimize the negative consequences of the disaster.

Provision of financial assistance and advisory services to farmers and rural communities affected by the disaster is necessary to restore their economic activity. Special programs of microcredit, crop insurance and grant support will help restore production and raise the standard of living of the local population.

In conditions of limited water supply, it is important to develop alternative branches of agriculture, such as the cultivation of drought-resistant crops, horticulture and animal husbandry. This will reduce dependence on irrigation and provide stable income for farmers.

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Management Theory and Studies for Rural Business and Infrastructure Development
eISSN 2345-0355. 2024. Vol. 46. No. 2: 229-239
Article DOI: https://doi.org/10.15544/mts.2024.24

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