ГІДРОТЕХНІЧНЕ БУДІВНИЦТВО, ВОДНА ІНЖЕНЕРІЯ ТА ВОДНІ ТЕХНОЛОГІЇ

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APPLICATION OF GABION-BASED BIOPLATEAUS FOR REDUCING EUTROPHICATION IN SURFACE WATER BODIES

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The article highlights the urgent problem of reducing the eutrophication of surface water bodies under the conditions of increasing biogenic loading and intensification of anthropogenic impact on water resources. The features of water quality formation in reservoirs and coastal water areas are considered, and the key factors that cause the accumulation of nitrogen and phosphorus compounds, the development of "algal blooms", deterioration of transparency and oxygen regime are identified. Attention is focused on the limitations of traditional technological methods of combating eutrophication, which require significant financial costs and do not always ensure a long-term environmental effect, which determines the feasibility of introducing nature-based and bio-engineering solutions.

Special attention is paid to gabion-based bio-platforms as a local bio-engineering structure that combines the functions of bank protection and a natural bio-filter. The structural features of gabion blocks with crushed stone filling, the filtration-sorption soil layer and emergent aquatic vegetation are considered, which ensure mechanical filtration, sorption and biochemical transformation of nitrogen and phosphorus compounds. The principle of operation of the bio-platform, the role of biofilms and the root zone in reducing the concentration of biogenic components, as well as the possibilities of integrating such structures into the coastal zones of reservoirs and recreational water bodies are analysed.

The paper presents the results of analytical and comparative assessment of the efficiency of gabion-based bio-platforms as a nature-based technology for reducing biogenic loading. It has been established that the use of such bio-engineering structures contributes to the improvement of water quality, stabilization of coastal ecosystems, reduction of the risk of eutrophication processes and at the same time is characterized by relatively low operational costs. It is concluded that gabion-based bio-platforms are expedient to be implemented in the water management practice

of Ukraine as an effective and durable solution for local purification of surface waters and increasing the ecological stability of water bodies.

Key words: *bio-platform, gabion structures, eutrophication, nutrients, bio-engineering structures, nature-based technologies, water quality, coastal zone, filtration, phytoremediation.*

Коваленко Р. Ю. Застосування біоплато на габіонній основі для зменшення евтрофікації поверхневих водойм

У статті висвітлено актуальну проблему зменшення евтрофікації поверхневих водойм в умовах зростання біогенного навантаження та інтенсифікації антропогенного впливу на водні ресурси. Розглянуто особливості формування якості води у водосховищах і прибережних акваторіях, визначено ключові чинники, що зумовлюють накопичення сполук азоту та фосфору, розвиток «цвітіння води», погіршення прозорості та кисневого режиму. Акцентовано на обмеженнях традиційних техногенних методів боротьби з евтрофікацією, які потребують значних фінансових витрат та не завжди забезпечують довготривалий екологічний ефект, що обумовлює доцільність впровадження природоорієнтованих та біоінженерних рішень.

Особливу увагу приділено біоплато на габіонній основі як біоінженерній споруді локальної дії, що поєднує функції берегоукріплення та природного біофільтра. Розглянуто конструктивні особливості габіонних блоків із щебеневим заповнювачем, фільтраційно-сорбційного ґрунтового шару та вищої водної рослинності, які забезпечують механічну фільтрацію, сорбцію та біохімічну трансформацію сполук азоту і фосфору. Проаналізовано принцип роботи біоплато, роль біоплівок і кореневої зони у зменшенні концентрації біогенних компонентів, а також можливості інтеграції таких споруд у прибережні зони водосховищ і рекреаційних водойм.

У роботі наведено результати аналітичної та порівняльної оцінки ефективності біоплато на габіонній основі як природоорієнтованої технології зменшення біогенного навантаження. Встановлено, що застосування біоінженерних споруд цього типу сприяє покращенню якості води, стабілізації прибережних екосистем, зменшенню ризиків розвитку евтрофікаційних процесів і водночас характеризується відносно невеликими експлуатаційними витратами. Зроблено висновок про доцільність впровадження біоплато на габіонній основі у водогосподарську практику України як ефективного та довговічного рішення для локального очищення поверхневих вод і підвищення екологічної стійкості водних об'єктів.

Ключові слова: *біоплато, габіонні конструкції, евтрофікація, біогенні елементи, біоінженерні споруди, природоорієнтовані технології, якість води, прибережна зона, фільтрація, фітоочищення.*

Introduction. Eutrophication of surface water bodies is one of the most pressing environmental problems, especially in Ukraine, where a significant part of the population is supplied with water from open sources [1, 2]. Excessive inputs of nitrogen and phosphorus compounds cause intensive development of phytoplankton, deterioration of water transparency, depletion of dissolved oxygen, and degradation of aquatic ecosystems. In the reservoirs of the Dnipro River basin, the phenomenon of "algal blooms" occurs on a regular basis, which complicates the treatment of water for domestic and drinking purposes [1].

The main sources of biogenic elements include agricultural runoff, municipal and industrial wastewater. Traditional technogenic methods of combating eutrophication are costly, energy-intensive and usually provide only short-term effect [2]. Therefore, increasing attention worldwide is being paid to nature-based water treatment technologies.

One of the promising solutions is the use of bio-platforms (bioplateaus) and gabion structures, which combine the functions of biofiltration and bank protection. Their integrated application makes it possible to reduce biogenic load, improve water quality and enhance the ecological stability of aquatic ecosystems. In this regard, the scientific justification of the design of a gabion-based bio-platform and the assessment of the effectiveness of its application for reducing eutrophication of surface water bodies are highly relevant.

Analysis of recent research and publications. The problem of eutrophication of surface water bodies and the influx of biogenic elements into aquatic ecosystems is widely covered in the works of Ukrainian and foreign researchers [2–4]. Scientific publications provide a detailed analysis of natural and anthropogenic factors influencing biogenic load formation, as well as the role of agricultural runoff, municipal and industrial wastewater, and atmospheric deposition in transforming the trophic status of rivers and reservoirs [3, 4]. Considerable attention is paid to the mechanisms of phytoplankton structure transformation, development of "algal blooms", depletion of dissolved oxygen, and degradation of aquatic communities under conditions of increased concentrations of nitrogen and phosphorus compounds [1, 5].

A number of studies have shown that traditional approaches to combating eutrophication–such as chemical precipitation of phosphates, advanced reagent-based wastewater treatment, dredging works, and bank stabilization using massive concrete structures–generally provide only short-term effects and require significant capital and operational expenditures [2, 6]. Against this background, nature-based technologies are rapidly developing. These are based on the application of phytoremediation, constructed or restored wetlands, riparian buffer zones, infiltration systems, etc. It has been demonstrated that such systems are capable of effectively reducing concentrations of nitrogen and phosphorus compounds, BOD and suspended solids due to the combined action of filtration, sorption and microbiological transformation processes [7, 8].

A separate line of research focuses on floating and shoreline bio-platforms, which are considered as bio-engineering facilities intended for polishing of surface runoff, stormwater and drainage waters, as well as for local renaturalization of degraded shoreline areas [7, 9]. It has been shown that the root zone of macrophytes and the filtration–sorption substrate ensure intensive removal of nitrogen and phosphorus compounds, development of biofilms, and stabilization of oxygen conditions in the littoral zone. At the same time, in most studies bio-platforms are considered mainly from an ecological perspective–as elements of natural purification–whereas the issues of their engineering design, structural reliability and long-term durability are insufficiently addressed.

Gabion structures are traditionally used as bank-protection and anti-erosion systems, as well as elements for regulating channel processes. Modern studies confirm their advantages over rigid concrete stabilisation works, including higher crack resistance, permeability, self-compaction capacity and the formation of coastal biotopes within the stone fill [10]. In research dedicated to infiltration and combined water-intake systems, gabions are considered as an efficient medium for biofilm development and preliminary water purification during filtration through a gravel-crushed stone backfill layer [10].

However, the analysis of the available literature shows that the issues of integrated application of bio-platforms and gabion structures as a unified bio-engineering system for protecting water bodies from biogenic pollution remain insufficiently investigated. Most publications consider either phytoremediation systems or gabion bank-protection structures separately, without developing integrated schemes that would simultaneously perform functions of biofiltration, sediment accumulation, shoreline stabilization and landscape rehabilitation. The engineering and technological design principles of such systems, the assessment of their long-term effectiveness in reservoirs with different hydrological regimes, as well as generalized techno-economic comparison with traditional eutrophication-control methods remain poorly covered.

Therefore, there is a scientific and practical need for further research aimed at substantiating the design of gabion-based bio-platforms, assessing their impact on reducing biogenic load, and determining the economic feasibility of introducing such

bio-engineering systems into water-management practice in Ukraine. The present study is devoted to addressing this research gap.

The purpose of the research is to substantiate and evaluate the performance of a gabion-based bioplateau as a bio-engineering system intended to mitigate eutrophication of surface waters through the reduction of biogenic load and improvement of water quality.

Materials and methods of research. The materials of the study included data on the current state of surface water bodies in Ukraine, in particular the reservoirs of the Dnipro River basin, the level of biogenic load and manifestations of eutrophication, as well as analytical and calculation materials obtained during the author's qualification research devoted to the engineering and technological justification of bio-engineering measures aimed at reducing the inflow of nitrogen and phosphorus compounds into water bodies.

The study considered a structural scheme of a gabion-based bioplateau, which combines a gabion block filled with stone or crushed-stone material, a filtration – sorption soil layer and emergent aquatic vegetation. The gabion structure performs the functions of bank protection, stabilization of hydrodynamic conditions and creates a porous medium for filtration and development of biofilms. The filtration – sorption layer and the plant root zone ensure biochemical transformation and removal of nitrogen and phosphorus compounds, degradation of organic pollutants and deposition of suspended solids. The operating principle of the bioplateau involves slow filtration of water through the gabion structure followed by treatment within the plant root zone [11, 12].

The methodological basis of the research includes analytical, comparative and generalized engineering – calculation methods.

The analytical method was applied to summarize scientific sources regarding the mechanisms of eutrophication, biofiltration processes and the principles of operation of bioplateaus and gabion structures. Comparative analysis made it possible to compare the efficiency of bio-engineering systems with traditional technological approaches to eutrophication control according to environmental and economic criteria.

To assess the environmental efficiency of the bioplateau, the following water-quality indicators were considered: concentrations of nitrogen and phosphorus compounds, suspended solids content, indicators of organic pollution (BOD, COD), water transparency and the oxygen regime in the littoral zone. The assessment was carried out on the basis of generalized experimental data on the performance of bioplateaus and constructed wetlands presented in the scientific literature, as well as analytical calculations and modelling results obtained within the framework of the qualification research.

Special attention was paid to the techno-economic assessment of the application of gabion-based bioplateaus. For this purpose, generalized cost indicators for materials (gabion structures, vegetation, soil filling), construction and installation works and operational expenses were used. The economic efficiency was compared with alternative methods of reducing eutrophication (traditional hydraulic structures, reagent technologies, dredging, etc.) according to the indicators of initial capital investment, operating costs and duration of effect.

The study also took into account socio-ecological aspects of introducing bio-engineering facilities, in particular their influence on the recreational attractiveness of water bodies, the state of littoral ecosystems, landscape integration and environmental safety. The synthesis of results made it possible to develop a comprehensive assessment of the feasibility of using gabion-based bioplateaus as a nature-based technology for protecting water bodies from eutrophication.

Results of the research. As a result of the conducted research, a structural scheme of a gabion-based bioplateau was developed, which combines engineering and ecological

functions and is intended for local reduction of the biogenic load on surface water bodies. The scheme envisages the use of a gabion block filled with gravel – crushed stone material, a filtration – sorption soil layer and emergent aquatic vegetation with a well-developed root system. The structural model of the bioplateau is presented in Fig. 1.

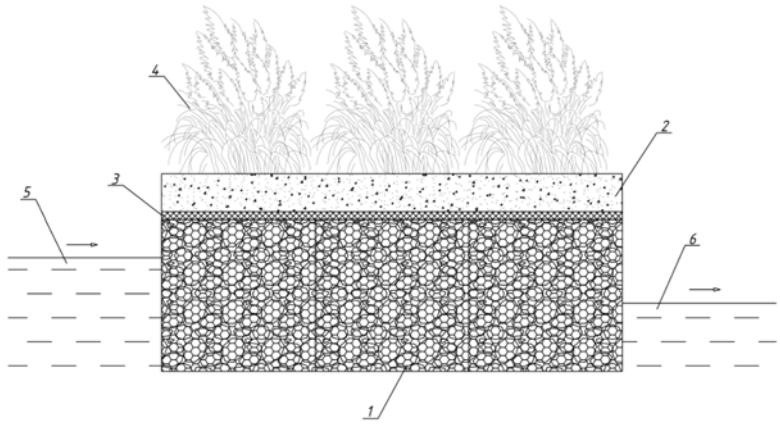

Fig. 1. Structural scheme of a gabion-based bioplateau: 1 – gabion block; 2 – geotextile or separation layer; 3 – filtration–sorption soil layer; 4 – emergent aquatic vegetation; 5 – incoming water flow; 6 – outgoing treated water flow.

The structure operates on the principle of slow filtration of water through a porous medium. At the first stage, the gabion block performs the function of a mechanical filter, retaining a part of suspended solids and promoting the formation of biofilms on the surface of the crushed-stone filling. Further filtration through the soil layer and the plant root zone ensures biosorption, nitrification–denitrification processes and biochemical transformation of nitrogen and phosphorus compounds, which contributes to the reduction of the biogenic load in the littoral zone of the water body [13, 14].

The obtained analytical and comparative assessment results indicate that a gabion-based bioplateau can ensure a decrease in the concentrations of nitrogen and phosphorus compounds as well as suspended solids in surface water due to the combined action of mechanical filtration, sorption and biological transformation [13]. At the same time, the gabion structure acts as a reliable load-bearing and protective framework, which increases the durability of the facility compared with traditional soil– or wood-based bioplateau platforms. An additional advantage is the resistance of gabions to deformation, erosion processes and ice loads, as well as their ability to integrate into the natural landscape without significant disturbance of the hydrological regime.

Particular attention was paid to assessing the ecological effect of applying bioplateaus in the littoral zone of reservoirs. It was established that the implementation of such a bio-engineering facility contributes to:

– reducing the inflow of biogenic elements into the water column, which in turn restrains the development of eutrophication processes;

– improving water transparency and the oxygen regime in the littoral zone;

– forming stable biotopes, which increases the ecological resilience of aquatic ecosystems;

– restoring the recreational and landscape attractiveness of shoreline areas.

Within the framework of a generalized techno-economic assessment, it was determined that the cost of construction and operation of a gabion-based bioplateau is significantly lower compared with traditional technological methods (reagent phosphorus removal, large-scale hydraulic reconstruction or dredging). In addition, the ecological effect of the bioplateau is preserved over a long period under conditions of minimal technical maintenance, which increases the overall economic feasibility of the proposed solution.

Thus, the results of the conducted research confirm the prospects of using gabion-based bioplateaus as a nature-based bio-engineering technology for reducing eutrophication in surface water bodies and allow recommending such systems for further practical implementation in the water-management sector of Ukraine.

Conclusions. The conducted research has confirmed the effectiveness of using a gabion-based bioplateau as a locally acting bio-engineering structure for reducing the biogenic load on surface water bodies. The combination of a gabion structure with a filtration–sorption soil layer and emergent aquatic vegetation ensures mechanical filtration, sorption and biochemical transformation of nitrogen and phosphorus compounds, which contributes to the improvement of water quality in the littoral zone.

The analytical assessment of the bioplateau performance has shown that the use of gabion structures increases the reliability and durability of the facility, ensures stable operation under conditions of water-level fluctuations and reduces the risk of shoreline destruction. The application of bioplateaus contributes to improving water transparency, stabilizing the oxygen regime and forming natural biotopes, which positively affects the ecological state of aquatic ecosystems.

The obtained results indicate the feasibility of introducing gabion-based bioplateaus into the water-management practice of Ukraine as a nature-based technology for mitigating eutrophication. The use of such bio-engineering structures ensures environmental efficiency at relatively low operational costs and may be recommended for application in the littoral zones of reservoirs and recreational water bodies.

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