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The improvement of water intake structures for energy and irrigation systems of mountainous and foothill rivers

Abstract: The purpose of this study is to solve the efficiency and reliability problems of upstream water intake structures for energy and irrigation systems in the region of the Republic of Azerbaijan. Among the methods used in the study, experimental, analytical, and modelling methods should be distinguished. During the study, analyses and field investigations of main structures, and energy and irrigation systems in the foothills were conducted to identify the reasons for the low efficiency and reliability of existing old water intake structures and reduce their negative impact on the environment. The results of the study showed that many water intake structures built on small rivers are not only in poor working condition but also do not meet modern environmental requirements. Many of these structures were built more than thirty years ago and have not been modernized or reconstructed in accordance with new technologies and requirements. As a result of the study, recommendations were prepared for the design of new water intake structures that meet all modern environmental requirements and guarantee the more efficient use of water resources. These new facilities will also help to reduce water losses during the overflow process, which will make the use of water more cost-effective. Additionally, one of the main outcomes is the developed useful model, which pertains to the field of hydroengineering construction for wa-

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ter intake from mountain and foothill rivers, serving as an additional barrier to reduce the influx of large sediment into the reservoir.

Keywords: water supply, hydroelectric structures, reconstruction, construction, system development

Introduction

Considering the specific relief of Azerbaijan, in many settlements, groundwater is used for domestic and drinking purposes. The quality and purity of the water there are quite high, so additional intensive purification is not usually required. However, in areas where there are mountain rivers and no other accessible sources of this important resource, it becomes necessary to utilize these water streams. Hydroengineering structures were constructed here as early as the mid-twentieth century, which are operated under quite challenging conditions. In many cases, their efficiency is low, both in terms of operation and the quality of the obtained water, due to the wear and tear of components. All this suggests that it is necessary to develop new hydraulic structures that could provide the population with water resources for domestic and drinking purposes. These structures play a vital role in the mountainous regions by enabling the utilization of abundant river resources for drinking water, irrigation, hydropower, and overall socioeconomic progress, as climate change impacts are exacerbating water stresses in the region. Increased variability in weather patterns, accelerated glacier melt, and changes in seasonal river flows are impacting the quantity and quality of water available from river sources. However, rising water demands from growing populations, expanding agriculture, and development needs are putting increasing pressure on water resources. During the design stage, it is essential to consider seasonal fluctuations in water levels, a large amount of sediment, suspended particles, and other foreign components that increase turbidity up to a level of 10.000 mg/L (Abilov 2023).

The construction of structures providing water to mountainous settlements is not properly regulated. This is due to the lack of necessary technical standards and rules during the design stage of water intake structures and facilities. As a result, most of these systems, especially in the mountainous regions of Azerbaijan, demonstrate unreliable operation. Many water intake systems built on small rivers in Soviet times have very low operational efficiency, are in poor operational condition, and require complete reconstruction (Koibakov and Umirkhanov 2013a). In addition, water intake facilities that are in normal operational condition require an increase in efficiency and reliability. These problems are particularly acute in energy and irrigation systems in mountainous and foothill regions, where sedimentation in small rivers considerably affects the efficiency of water intake points and structures (Abilov 2020).

According to Abilov (2023), the design of universal water intake structures on mountain rivers for settlement water supply systems is not regulated by specific norms and rules. Based on the analysis of the existing literature and operational experience on this issue, a general scheme of water intake structures on mountain rivers has been developed. The developed scheme is suitable for dammed water intake structures on mountain rivers, where the structure of the river flowing into the water intake basin and the purification of reserve water are regulated, thus improving the efficiency of reserve water purification and the operational reliability of the entire water supply system. According to Salokhiddinov and Ferreira Hoshimkhuzhaev (2020), development opportunities for the future are directly related to the level of protection and use of existing water resources, and society's attitude to water use. In the near future, increasing water demands can be met through improved water resource management, rational utilization, and the search for internal resources. According to Serikbaev et al. (2019), water measuring devices in hydraulic reclamation systems (used to create new land by applying hydraulic fill material) should operate at low pressures and head losses, without causing notable additional pressure losses or disrupting the normal flow of water bodies. They should allow the passage of sediments and floating debris and operate reliably under complex operating conditions.

The designs of water measuring devices should be quite simple and reliable, intended for serial production and mass use. Serikbaev et al. (2020) state that the measurement error of water flow is mainly determined by the accuracy of water metering structures, and improving the performance of water meters is necessary to increase the overall accuracy of water measurement in hydraulic reclamation systems. Bahretdinova et al. (2014) assert that water intakes in irrigation canals and losses in riverbeds cause a quantitative reduction in flow, while the discharge of collector and drainage water deteriorates its quality. According to Shukurlaev et al. (2007), the most advanced type of water intake structures are non-dam structures with head regulators. On the main sections of the main canals, settling basins and side outlets can be constructed upstream of the regulators. A large amount of sediment settles in the side outlet, so the side outlet can remove a considerable amount of sediment from the canal (Koybakov et al. 2020).

The existing deficiency in well-defined technical standards and regulations for designing water intake structures in mountain settlements has led to the unreliability of these systems. There is a pressing need for comprehensive research into innovative and durable materials and components that can effectively enhance the longevity and cost-efficiency of water intake structures. A notable research gap pertains to the optimization of hydraulic characteristics in water intake structures, which could be addressed through rigorous mathematical modeling studies. Furthermore, a significant lack of detailed impact assessment studies hinders the understanding of how water intake systems in mountain rivers influence both the environment and ecosystems. In the realm of economic considerations, there is an evident dearth of insights into the potential costs and benefits associated with the implementation of new water intake infrastructure, particularly in remote mountainous areas. In-depth cost-effectiveness analyses are warranted to address this gap. The current absence of studies tracking the long-term performance and sustainability of newly implemented water intake structures necessitates further research, particularly focusing on the establishment of comprehensive follow-up monitoring mechanisms.

There is a need for completely new types and designs of water intake structures that would ensure the extraction and supply of the required quantity and quality of irrigation water with minimal material and energy costs, which is the main purpose of the study. Thus, the objective of the study is to develop effective and efficient technical solutions for the design and construction of water intake structures on mountain and foothill rivers that can provide the required quantity and quality of water for energy and irrigation systems while minimizing costs and negative environmental impacts. Specific goals related to this overall objective include:

- investigating sediment transportation, hydraulic patterns, and the effectiveness of existing water intake structures on mountain and foothill rivers;
- analyzing the reliability and operational efficiency challenges faced by current water intake structures;
- developing new technologies and optimized designs for water intake structures;
- carrying out laboratory testing and mathematical modelling to improve the hydraulic attributes of water intake structures;
- developing standardized projects, recommendations, and specifications for the establishment of water intake facilities;
- considering the ecological and hydrological characteristics of small streams into the design phase;
- decreasing the material and energy expenses associated with water intake structures;
- ensuring the water drawn meets the demands of energy and irrigation systems.

1. Materials and methods

Field and analytical studies on sediment transport during floods, the efficiency of reservoirs and water bodies, and the hydraulic regime of spillway structures were conducted on various rivers and in different regions, including occupied areas. To address the issues of operational reliability and efficiency of the existing small river water intake structures in mountainous and foothill areas, a methodology was developed, which included examining the sediment regimes of rivers by collecting information on hydrological regimes, precipitation, and water temperature during periods of peak and minimum flow. For this purpose, hydrological data from monitoring stations were used. The effectiveness of desilting and settling basins of the main water intake structures was also measured. Data from enterprise reports were utilized along with engineering-geological investigations to determine the impact of hydromechanical factors on the efficiency of desilting structures.

Furthermore, hydraulic regimes of spillway structures during flood periods were examined. For this purpose, modelling and calculations of hydraulic characteristics of spillway structures were conducted during the period of increased water consumption. The efficiency of water intake structures was also observed in accordance with the water consumption schedule of energy and irrigation systems using data on water consumption and the operational mode of the systems. Effective technical solutions were also developed for the design and construction of mountain and foothill water intake structures, including the creation of new structures and technologies for the construction of water intake structures. This involved laboratory testing of materials and components, and the development of new methods for calculating and modelling the hydraulic characteristics of structures.

During the study, data from monitoring stations, laboratory testing of materials and components, and enterprise reports were utilized. Experiments were conducted in the energy and irrigation systems of the Republic of Azerbaijan, particularly on rivers such as Lenkoranchay, Basharyuchay, Kudyalchay, Belokanchay, Ulumichay, and rivers in occupied zones. To examine sediment regimes of rivers, the monitoring of water levels and sediment deposits on riverbanks was performed. The efficiency of desilting and settling basins of main water intake structures was analyzed based on field trials, laboratory investigations of deposits, and the analysis of technical characteristics and operational modes of the structures. To examine the hydraulic regimes of spillway structures, field trials using hydrodynamic equipment and mathematical calculations of hydraulic characteristics during flood periods were conducted.

To assess the operational efficiency of water intake structures, data on the water consumption schedules of energy and irrigation systems were utilized. Field trials of main water intake structures and laboratory water analysis were conducted to evaluate water quality and its suitability for use in energy and irrigation systems. Analysis of existing technologies and materials was conducted to develop effective technical solutions for the design and construction of mountain and foothill water intake structures, new materials and components were also developed. Field and laboratory tests were performed on various water intake structure designs and mathematical calculations and modelling were employed to optimize and improve the design of the structures.

Monitoring stations, specialized hydrodynamic equipment, laboratory equipment for water and sediment analysis, and enterprise reports and data, were used to collect the necessary information. All experiments were conducted in accordance with international standards and protocols. It was also noted that the known technical solutions for the design and construction of water intake structures do not consider the ecological and hydrological characteristics of small streams, which is an important issue for future research and development in this field. Moreover, standardized projects, recommendations, and technical specifications were developed for the construction of small hydropower plants (HPPs) such as Belokan-1, Kusarskaya HPP, and Ulumskaya HPP. These projects can be used in future studies for the construction and reconstruction of water intake facilities in mountainous areas.

2. Results

Water intake stations are an important component of water supply and wastewater treatment infrastructure. Figures 1–4 allow the extraction of water from natural sources, purification of it, and distribution of it among consumers. However, the operation of such structures involves high costs for construction, maintenance, and repair (Abbasov et al. 2022).

Fig. 1. Water intake structure for small hydroelectric power plants of the Kalbajar district
Source: developed by the author

Rys. 1. Konstrukcja ujęcia wody dla małych elektrowni wodnych w okręgu Kalbajar

Fig. 2. Water intake structure for small hydroelectric power plants
Source: developed by the author

Rys. 2. Struktura ujęcia wody dla małych elektrowni wodnych

Fig. 3. Water intake structure for small hydroelectric power plants
Source: developed by the author

Rys. 3. Struktura ujęcia wody dla małych elektrowni wodnych

Fig. 4. Water intake structure for small hydroelectric power plants
Source: developed by the author

Rys. 4. Struktura ujęcia wody dla małych elektrowni wodnych

The study established the features of small rivers, changes in bottom sediments and velocities, and the technical condition of water intakes (Fig. 5).

(a)

(b)

Fig. 5. General view of the Belokan HPP water intake structure
Source: developed by the author

Rys. 5. Widok ogólny struktury wlotu wody HPP Belokan

Based on the results of analytical studies and field observations, a new type of highly efficient water intake system for energy and irrigation systems was proposed, including the design of a skirt-type water intake developed by the authors. Technical parameters and criteria for the effectiveness of the new water intakes were determined, and a comparison with existing technical solutions was conducted to select the most efficient option. Water intake stations have multiple components, including pumping stations, storage tanks, equipment for purification and disinfection, and flushing and settling tanks, all of which require special attention and maintenance. Natural conditions, such as pollution and changes in the water systems of rivers and lakes, also increase the operating costs of water intake facilities (Weerahewa et al. 2023). Fluctuations in water quantity and seasonal river flow demand adjustable extraction methods involving gates, pumps, and monitoring systems, thus increasing operational expenses. The sedimentation, turbidity during floods, and pollution from agriculture, industries, and urban areas require frequent cleaning, additional treatment for contaminants, and addressing algal blooms. Infrastructure faces accelerated corrosion and scaling due to polluted intake water, leading to quicker deterioration and replacement costs. Lower water quality mandates elevated chemical usage, energy consumption, and reduced process efficiency. Monitoring becomes complex, considering parameters like organic matter, bacteria, and heavy metals. Climate change adaptation necessitates upgrading infrastructure for intensified floods and droughts. Depletion or contamination of reliable water sources drives tapping distant alternatives, significantly amplifying pumping costs. Stricter regulations on intake water quality and environmental assessments further contribute to rising regulatory compliance expenses.

Thus, the high cost of water intake facilities for supplying water to the population and agriculture poses a challenge for the operating organization to optimize costs and increase the efficiency of water resource utilization. The maintenance of budget subsidies for the operating costs of the energy and irrigation systems cannot last long without taking measures to improve the efficiency of water resources use. Cost optimization may include the installation of modern equipment and monitoring systems to improve the efficiency of water intake stations. This will reduce water and energy losses, and improve water quality, which can lead to a reduction in equipment maintenance and repair costs (Crook et al. 2020). Modern equipment such as advanced pumps, valves and gates ensures efficient water intake and distribution, minimizing wastage. The provision of real-time monitoring furnishes essential data regarding water levels, flow rates, pressure, and quality. These systems detect leaks, thus preventing water loss, and promote energy efficiency by optimising equipment operation and using variable frequency drives (VFDs) for demand-based motor control. Automation and remote control adjust operations based on real-time data, reducing manual intervention. Predictive maintenance algorithms prevent downtime by anticipating equipment failures. In addition, it is necessary to take measures to reduce the pollution of water systems, which can help reduce the cost of the cleaning and disinfection of water at water intake stations (Tariq et al. 2021). This can be achieved through the use of modern technologies for wastewater and industrial emissions treatment and through the introduction of measures for the environmental control and sanitary cleaning of the territory around reservoirs (Fig. 6). Implementing stringent regulations on industrial and municipal wastewater treatment before discharge using technologies like membrane bioreactors can significantly reduce pollutant loads entering water bodies. This improves intake water quality, lowering chemical costs. Air pollution control systems (scrubbers, electrostatic precipitators etc.) in industries curb the atmospheric deposition of pollutants into water bodies, preventing intake quality issues. River zone protection via enforced buffer strips around intakes limits nearby pollution sources like farms. This secures intake water quality. The environmental monitoring and control measures aid regulatory compliance, helping avoid heavy non-compliance fines that increase operating costs.

For them to enter into the market (economically justified) relations with farms, it is firstly necessary to sharply reduce the cost of supplied irrigation and energy water, and this can be achieved

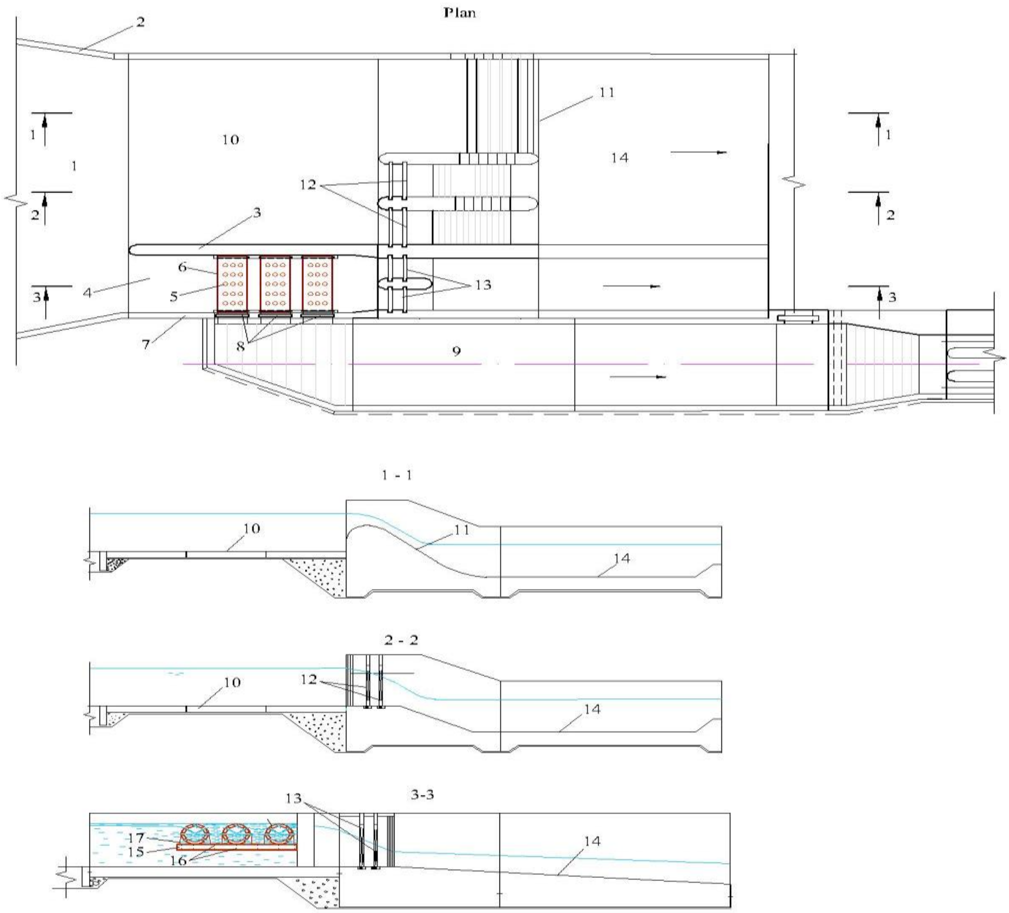

Fig. 6. Plans and sections of a frontal water intake structure with a pocket
Note: upper crest – 1; water diversion dam – 2; wall extended towards the upper crest – 3; side walls – 4; pocket – 5; attachment element – 6 to wall 3, extended towards the structure, and to side wall 4; channel beam – 7; clamp – 8; holes – 9; polyethene pipe – 10; on the side wall of the device – 4; inlet pipes – 11; settling basin – 12; plunge pool – 13; lower crest – 14; automatic spillway gates – 15; fasteners for washers in the upper crest – 16; and pocket weights, closures for passing floating objects – 17
Source: developed by the author

Rys. 6. Plany i przekroje konstrukcji czołowego ujęcia wody z kieszenią

by increasing the efficiency of water intake facilities. However, it is not possible to do this, since the designs of water intake structures are initially material and energy intensive. The analysis of the existing energy and irrigation water intake structures in small rivers on their foothill sections indicates that only about 30% of the structures are in a relatively satisfactory operational condition, while 70% are in an unsatisfactory state (even after overhaul and reconstruction). The structural and technical characteristics of the water intake structures do not contribute to effective sediment control, increases of the water intake coefficient, and the regulation of water flow in channels. All these factors reduce the efficiency of water intake facilities and complicate the task of reducing the cost of irrigation and energy water for the transition to market relations with farms.

The developed model is designed for efficient water intake from foothill rivers and is intended for use in hydraulic structures. Specifically, the model includes the design of a forebay (front water intake structure) with pockets that serve as an additional barrier against large sediment deposits. The water intake consists of several elements: a dam, a dividing wall, side walls of the water intake structure, a pocket, and finally, a siphon opening with a gate. An important feature of this model is the presence of a siphon opening between the dam and the pocket. Additionally, the pocket is equipped with a perforated polyethylene inlet pipe that is connected to the settling basin through siphon openings in the side and partition walls of the water intake structure. The advantage of this model is that it serves as an additional barrier against large sediment deposits, thus reducing their entry into the settling basin (Koibakov et al. 2015). The large sediment is transported within the pocket towards the flushing opening, where it is removed. Then, the clarified water enters the perforated inlet polyethene pipe and is directed to the inlet opening on the right wall of the settling basin. Therefore, the developed model serves as a useful tool in hydraulic construction aimed at reducing the amount of sediment deposits and improving the efficiency of the water intake process from the river (Fig. 7).

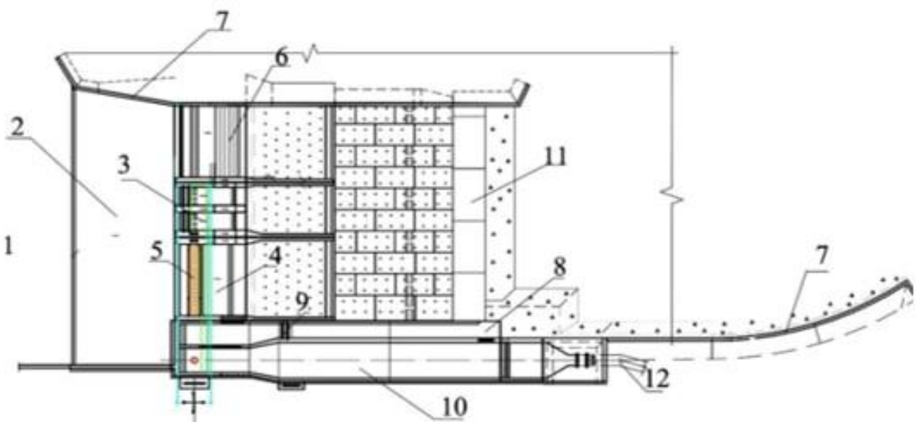

Fig. 7. Water intake structure plan
Note: Inlet channel – 1, ponur (impermeable layer) – 2, gate opening – 3, low-pressure dam – 4, steel grating – 5, automatic spillway dams – 6, retaining walls – 7, flushing collector – 8, gates – 9, settling tank – 10, lower pool – 11, derivation pipe – 12
Source: developed by the author

Rys. 7. Plan struktury ujęcia wody

Within the framework of this research area, a series of new structural and technological solutions have been prepared for the design and construction of water intake structures for mountainous and foothill rivers, and bio-positive structures that maximize the use of local and safe artificial materials. Several utility model patent applications are being developed for non-dam water intake structures, including protective-regulatory structures and fastenings for bio-positive construction. Ecological methods for regulating river channel sections have been developed, including projects for new types of water intake structures. In addition to the technical and functional characteristics of the developed model of a water intake structure, a number of problems related to the operation and construction of such structures can also be noted. Firstly, large sediment accumulated in the intake pockets can cause clogging of flushing openings and reduce the overall permeability of the system. As a result, the pockets and openings need to be regularly cleaned, which can lead to high operational costs (Ahmadi et al. 2023). Secondly, the construction of such structures can cause environmental problems, such as changes in the flow regime of rivers, disruption to the migration routes of fish and other aquatic organisms, and an increase in the risk of flooding in natural areas. Thirdly, the high cost of the construction and operation of water intake facilities raises the question of financing such projects. In conditions of limited budgets, this can become a serious obstacle to the implementation of the project (Evett et al. 2020).

Despite the above problems, the developed model of the water intake structure is beneficial in situations where there is a shortage of fresh water and efficient utilization is required. Proper operation and maintenance of the system can result in considerable water savings and reduced costs for water intake and treatment (Li et al. 2020). In pocket water intake structures that are part of hydropower projects, regular flushing provides a barrier against large sediment, reducing its deposition in sediment basins and improving operation. This is especially important for rivers with intensive sediment transport. As a result of this transfer, large, heavy particles are formed in the riverbed, which must be removed so that they do not fall into irrigation and energy systems. When developing new water intakes and protective equipment, natural materials are primarily used, which have a positive impact on river flows and riparian greenery. Such materials can be used in bio-positive structures, which are not only environmentally friendly and efficient but also help maintain the ecological balance of water bodies (Heiß et al. 2020). Designers of such structures consider not only technical but also environmental aspects, using materials that do not have a harmful effect on the environment. Lightweight and heavyweight forms and flexible rolls are used to create protective and regulatory structures that contribute to the efficient and sustainable operation of water intake structures (Juan et al. 2020).

During the study, standard designs, recommendations, and technical requirements were prepared for small hydroelectric power plants, such as Belokan – 1, Kusarskaya HPP, and Ulum HPP, which can be used for the future design and construction of water intake facilities in mountainous areas. More importantly, the use of natural materials in the construction of water intake structures reduces the cost of materials and allows for the establishment of more economically advantageous market relations with farms. In addition, this approach reduces the negative impact on the environment and contributes to the efficient use of water resources (Jiaoyou 2019).

The results show that the existing water intake facilities are inefficient and consume too much energy and materials. Therefore, it is necessary to introduce new types of highly efficient water intake structures to considerably reduce the cost of irrigation water supply. Design and technical solutions have been developed to solve this problem. They allow effectively dealing with sediments, increasing the speed of water intake, regulating river flow, and improving the quality of the water taken. This will not only reduce the cost of water supply but also improve the environmental situation on the ground. The new water intake facilities will operate more efficiently and consume less energy, thereby reducing harmful emissions into the atmosphere and dependence upon petroleum products. The introduction of new technologies and materials can also help improve water quality, which is important for the health of the local population and the environment. An example of this is the fact that the use of modern cleaning and disinfection systems allows removing pollution from industrial and household emissions and controlling the concentration of chemicals in water (Bjornlund et al. 2019).

In addition, new types of water intake structures can operate in different climatic conditions, which can increase resistance to climate change. An example of this is that modern water intake structures can regulate water intake depending on the level of the river flow, which avoids overflow and flooding of territories during periods of heavy rains. Overall, the implementation of new and highly efficient water intake structures is an important step towards increasing water utilization efficiency and improving local environmental conditions. However, it is necessary to consider the individual characteristics of each region, and economic and environmental factors when choosing the right solution. One of the solutions to the problems mentioned above is a pocket water intake structure unit that regulates the flow of water in the form of a pocket and is used to control the water level and ensure a steady supply, and is part of a hydroelectric power plant with a regular flushing system. This serves as a barrier against large deposits in the bottom sediments and reduces the inflow into the sedimentation tanks, considerably increasing the structure's efficiency and uninterrupted operation.

When constructing new water intakes and protective structures, products made from natural materials are often used, which have a positive impact on river flow and riparian green belts. The use of such products, such as lightweight and heavyweight forms and flexible weirs, has led to the creation of efficient and biologically favorable water intake structures, protective and regulatory structures, which continue to be developed today. New types of highly efficient water intake structures greatly improve the quality and quantity of extracted water through the use of advanced technologies and materials. In particular, they feature a specialised filtration system capable of removing sediments, dirt, and other fine and coarse impurities from the water (Giri et al. 2022; Ostanin 2022).

New water intakes are also energy and material efficient and can considerably reduce the cost of supplied irrigation water. In particular, the use of modern pumping stations and automatic control systems optimizes the water intake process and minimizes energy losses. The developed design and technical solutions the creation of customized projects for water intake structures, considering the specific hydrological regime of the river and all factors influencing the quality and quantity of the extracted water. Thus, the introduction of new and highly efficient water intake facilities can noticeably improve the economic performance of farms using irrigation systems and ensure a more rational use of water resources while maintaining environmental safety and a green belt along the banks of the river.

3. Discussion

The development of water intake structures for hydropower and irrigation systems in foothill rivers is an important task that can enhance water utilization efficiency and reduce negative impacts on the natural environment. Hereafter, the results of studies conducted by other authors are presented and compared with the given study. The study analyzed the existing water intake structures on the rivers in the foothills and examined the possibilities for their improvement. It was established that existing water intake facilities often have limited capacity and do not meet the energy and irrigation needs of a growing economy. Moreover, the study showed that modern technologies and engineering solutions can help improve the operation of water intake facilities and increase their efficiency (Qu et al. 2020).

The study by Bazarov et al. (2021) presents the results of an analysis on the theory of cross circulation and the use of artificial and active methods for regulating water intake structures as a basis for the efficient design of frontal water intake structures and reliable protection against sedimentation in pumping stations and hydroelectric facilities. Based on a large amount of experimental data obtained in different countries of the world, the effectiveness and prospects of using frontal structures with an absorption coefficient of more than 50% are evident. The design of such water intake structures has been considerably improved and can be successfully used in various conditions, including on mountain rivers. The author highlights the development of new frontal ditch designs that effectively allow the downstream passage of bottom sediment to prevent excessive siltation of reservoirs and improve dam drainage efficiency. These results confirm the above findings and show that the use of filters can significantly improve the quality of water entering water intake facilities.

In the study by Abbasov et al. (2022), it was established that in recent years, projects have been developed to restore many lakes, but these efforts have not yet yielded positive results. Climate change appears to be the main factor affecting water resources. According to various forecasts, Azerbaijan's water resources may decrease by 15–25% by 2070, and rivers and lakes may dry up completely due to increased water intake. Meanwhile, the risks associated with pollution are also increasing, since pollution substantially reduces the ecological value of water resources, making them unsuitable for any use (Bagasharova et al. 2015). In this context, lakes in the vicinity of Baku can be mentioned as an example. Currently, the lakes on the Absheron Peninsula cannot be used for any purpose due to pollution. To overcome the current situation, water management activities in the country should be primarily aimed at reducing pollution and introducing new technologies that will allow the more efficient use of water. Such an approach will help reduce the water intake from rivers and ensure ecological flows (Imanaliyev et al. 2022). These results partially coincide with the study conducted above and confirm the threat to the ecological value of the waters, which in turn negatively affects the environment. In addition, it should be noted that environmental problems related to water resources can have a serious impact on the economy and the well-being of the population. For example, a reduction in the amount of available freshwater can lead to a decrease in the production of food and other goods, which in turn affects the standard of living of the population (Buktukov et al. 2020).

The results of the study by Ashraf and Batool (2019) showed that regular monitoring of glacier resources and the use of advanced water collection technologies will help mitigate the negative consequences of glacier depletion and ensure the long-term sustainability of the Kula irrigation system in the Himalayas. The above approach to the problem was not considered in this study but should definitely be considered in the following investigations. In a recent study by Bokiev et al. (2023), a physical model of a mobile solar and garland micro-hydro power station for mountainous areas was developed. The use of flexible cables ensures that the power output remains constant even when the water level drops. The garland arrangement of underwater wings enables the full utilization of the water flow section safely and conveniently, and the use of a generator to provide a large number of power sources is economically advantageous. By contrast, the study presented earlier focused on the low efficiency of water intake structures as well as energy and irrigation systems in foothills due to high energy and material density. The study proposed the development of new dam and non-dam water intake structures and conducted a scientific analysis of these structures. However, in the study above, several patents and recommended projects and technical conditions for the construction of small hydroelectric power plants were also obtained, which could be used in future studies on the construction or reconstruction of water intake facilities in the foothills. The recommended designs and specifications can also be applied to energy and irrigation systems on occupied rivers. A comparison of new and existing water intake facilities showed that the new design greatly increased the capacity and efficiency of water intake facilities while reducing operating costs and increasing reliability (Mustafayeva et al. 2022; Tu et al. 2023). The study also examined the environmental consequences of operating water intake structures and energy systems in mountainous areas and showed that they can have negative ecological impacts, including changes in river hydrology, degradation of river and lake ecosystems, and threats to aquatic biodiversity. In general, this study and the study written above provide valuable information about the management of water resources in mountainous regions, offering new physical models, designs, and technical conditions that can improve the efficiency, reliability and environmental sustainability of water intake structures, energy and irrigation systems.

Singh et al. (2021) examined the issue of water intake structures from an energy and economic perspective, specifically highlighting the key role of hydropower as a substantial portion of arable land relies on precipitation. Various countries have implemented numerous schemes aimed at increasing agricultural production with a low contribution to farmers' GDP. One such example is that the Indian government has focused on doubling the income of farmers from the same land area. Consequently, governments should focus on minimizing the cost of electricity to farmers in different countries by utilizing renewable hydropower and increasing the use of renewable energy, which currently accounts for approximately 5% worldwide. Therefore, when selecting the location of water intake structures for energy and irrigation systems in foothill rivers, it is necessary to consider not only hydrological and topographical characteristics but also local ecological features (Koibakov and Umirkhanov 2013b). Attention should also be paid to the interaction of water intake facilities with the environment and the possibility of using innovative technologies and methods to reduce the negative impact on the environment.

This study has potential limitations. The research was constrained to particular rivers and areas, so the results may not be generalizable to all mountainous and foothill zones. More extensive data gathering across diverse regions is required. Furthermore, the proposed technical solutions might not be ideal for every locale owing to variances in climate, topography, sediment volumes, etc. Thus, more exact designs adapted to specific locations are necessary. Long-term studies, evaluating the efficiency and environmental consequences of the new water intake structures over time, were not performed. Follow-up monitoring on a prolonged basis is imperative to fully assess the sustainability of these systems.

Furthermore, it is important to conduct further studies for the development of new technologies to enhance the water intake process and improve the efficiency and ecological safety of water intake structures. Such studies may involve the development of new materials for water intake structures, the investigation of the interaction of hazardous substances with water, and the development of methods for the purification of hazardous substances. Thus, the improvement of water intake structures for energy and irrigation systems in foothill rivers is an important task that requires the integration of various aspects, such as local hydrological, topographical, and ecological characteristics, and the application of innovative technologies and methods to ensure the environmental safety of water intake structures.

Conclusions

This study on water intake structures, energy, and irrigation systems in the foothill zone identified low operational efficiency due to high energy and material density. Therefore, it is necessary to develop new designs for dam and damless water intake structures and conduct scientific analysis. New construction and technical solutions were investigated, and several patent applications for inventions and utility models have been filed in the Republic of Azerbaijan. The research results confirm the high efficiency, reliability, and structural feasibility of the proposed water intake structures in mountainous areas and foothills. Notably, these model projects and recommendations can also be applied to energy and irrigation systems in the occupied zones of rivers. The development of these projects is of great importance for the preservation of water resources and the improvement of local environmental conditions. Therefore, through scientific analysis of operational experience, reliability and efficiency of water intake structures, energy, and irrigation systems in the foothills, new design and technical solutions were developed, along with standardized projects and recommendations that can be used in the design and construction of water intake structures in the foothills and rivers. The proposed designs help to reduce environmental problems through the well-thought-out integration of environmental factors. By considering river hydrology, seasonal variations, and impacts on native species, the solutions limit ecosystem degradation and threats to biodiversity and the use of natural building materials reduces negative impacts. It was established that the new designs considerably increased the capacity and efficiency of water intake facilities, reduced operating costs and increased reliability. Optimized and sustainable water intake structures ensure the modernization of infrastructure and preserve water resources and ecology. Wide implementation will lead to significant improvements in water management and local environmental conditions.

The environmental consequences of operating water intake structures and energy systems in mountainous areas were also evaluated. The results showed that their operation can have negative environmental impacts, including changes in the hydrological structure of rivers, the degradation of river and lake ecosystems, and a threat to aquatic biodiversity. Based on this study, some areas of further research can be identified, namely the investigation of the impact of new water intake facilities on the environment. Such investigation should encompass an evaluation of alterations in river hydrology and an in-depth analysis of their repercussions on ecosystems and aquatic biodiversity. Moreover, there is a need to scrutinize the adaptability of these innovative water intake structures across diverse contexts. This involves a comprehensive inquiry into their feasibility in regions characterized by water scarcity, such as arid or desert areas. In addition, an imperative area for further investigation pertains to the economic implications of the newly proposed water intake structures. Such inquiries should entail a thorough examination of the economic advantages and potential cost efficiencies associated with the operation of these facilities. Furthermore, there is a pressing requirement to probe the efficacy of these advanced structures in the face of climate change dynamics. This entails a comprehensive exploration of how these novel designs can effectively mitigate the impact of climate change on water availability and ecosystem sustainability. Thus, these areas provide many opportunities for the further exploration of water extraction, energy, and irrigation systems in the foothills. The development of new designs and engineering solutions can lead to improved environmental conditions and increased efficiency and reliability of water supply systems.

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Rashad Saffan oqlu Abilov

Ulepszenie struktur ujęcia wody dla systemów energetycznych i nawadniających rzek górskich i podgórskich

Abstract

Celem niniejszego artykułu jest rozwiązanie problemów związanych z wydajnością i niezawodnością struktur poboru wody dla systemów energetycznych i irygacyjnych w regionie Azerbejdżanu. Wśród metod wykorzystanych w badaniu należy wyróżnić metody eksperymentalne, analityczne i modelowania. Podczas badania przeprowadzono analizy i badania terenowe głównych struktur oraz systemów energetycznych i nawadniających na pogórzu w celu zidentyfikowania przyczyn małej wydajności istniejących starych struktur poboru wody oraz zmniejszenia ich negatywnego wpływu na środowisko. Wyniki badań wykazały, że wiele budowli hydrotechnicznych wybudowanych na małych rzekach jest nie tylko w złym stanie technicznym, ale również nie spełnia współczesnych wymogów środowiskowych. wymogów środowiskowych. Wiele z tych obiektów zostało wybudowanych ponad trzydzieści lat temu i nie zostało zmodernizowanych lub przebudowanych zgodnie z nowymi technologiami i wymogami. W wyniku przeprowadzonych badań opracowano zalecenia dotyczące projektowania nowych ujęć wody, które spełniają wszystkie współczesne wymogi środowiskowe i gwarantują bardziej efektywne wykorzystanie zasobów wodnych. Nowe obiekty przyczynią się również do zmniejszenia strat wody podczas procesu przelewania, co sprawi, że korzystanie z wody będzie bardziej opłacalne. Ponadto jednym z głównych rezultatów jest opracowany użyteczny model, który odnosi się do dziedziny budownictwa hydrotechnicznego dla poboru wody z rzek górskich i podgórskich, służąc jako dodatkowa bariera ograniczająca napływ dużych osadów do zbiornika.

Słowa kluczowe: zaopatrzenie w wodę, budowle hydroelektryczne, odbudowa, budowa, rozwój systemu