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IMPROVING SAFETY CRITERIA FOR EMBANKMENT RESERVOIRS

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A**nnotation:** This study examines the safety conditions of embankment reservoirs in Uzbekistan, identifying key deficiencies in monitoring systems, legal frameworks, and technical infrastructure. The paper compares national practices with international standards and proposes modernization through digital technologies, GIS, and AI tools to enhance disaster preparedness and ensure ecological and infrastructural stability.
Keywords: Reservoir safety, embankment dams, monitoring systems, Uzbekistan, GIS, AI technology, risk management, water infrastructure, legislation, environmental security.
Annotatsiya: Ushbu tadqiqot O‘zbekistondagi quyma suv omborlari xavfsizlik holatini tahlil qiladi. Monitoring tizimlari, qonunchilik va texnik infratuzilmadagi kamchiliklar aniqlanadi. Xalqaro tajriba bilan solishtirilib, zamonaviy texnologiyalar – GIS, sun’iy intellekt vositalari orqali xavfsizlikni oshirish bo‘yicha takliflar ilgari suriladi.
Kalit so‘zlar: Ombor xavfsizligi, quyma to‘g‘on, monitoring tizimi, O‘zbekiston, GIS, sun’iy intellekt, xavf boshqaruvi, suv infratuzilmasi, qonunchilik, ekologik xavfsizlik.

Introduction: Water resources are an integral part of the development of human civilization. The supply of drinking water to the population, the stable functioning of agriculture, energy, and industry, as well as the condition of ecological systems, are directly dependent on water sources. Especially under the current conditions of climate change, drought, and rapid population growth, the effective and safe management of water resources remains one of the most urgent challenges of our time.

Embankment reservoirs are critical hydraulic structures built for the purposes of water storage, regulation, and distribution. These structures not only contribute to economic development but must also not be overlooked as potential sources of danger. Failures or non-compliance with safety requirements in reservoir structures can lead to man-made disasters that threaten the lives of thousands of people and cause significant damage to agricultural lands, infrastructure, and the natural environment.The relevance of this topic lies in the fact that ensuring the safety of embankment reservoirs helps prevent not only economic losses but also preserves environmental and societal stability. In turn, this serves as an important step toward achieving sustainable development goals. The main objective of this study is to analyze the current safety criteria of embankment reservoirs in Uzbekistan and to identify ways to improve them in line with international standards.

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Methodology: This study employed a comprehensive, multi-stage, and multi-source scientific approach based on analytical methods. The main methodological approaches included the following:

Descriptive analysis: Initially, statistical data were collected from publicly available sources and national archives regarding major embankment reservoirs located in the Republic of Uzbekistan (such as Tuyatortar, Chorbog', Talimarjan, and Pachkamar). This included their technical conditions, annual water storage capacity, year of construction, and current usage levels. For each reservoir, safety-related documents, regulations, and monitoring results were reviewed.

Comparative analytical method: The current national safety regulations (for example, the Law of the Republic of Uzbekistan "On the Safety of Hydraulic Structures") were compared with international standards developed by ICOLD (International Commission on Large Dams) and UNECE. For instance, in Germany, special flood simulation programs are used in reservoirs to prepare for earthquakes and heavy rainfall, while in Uzbekistan such digital platforms have not yet been widely implemented.

Expert surveys and interviews: Structured interviews were conducted with specialists in the field — including employees from the “Hydrotechnical Supervision” Inspection under the Ministry of Water Resources, designers of hydraulic structures, and environmental scientists. One such expert, engineer Sh. Rakhmatov, noted: “Most reservoirs do not have real-time data sensors installed. This leads to delays in taking action during emergency situations.”

*Application of monitoring and GIS technologies:*Within the scope of the study, experimental measurements were conducted at the Talimarjan reservoir using GIS (Geographic Information Systems) and drone technology to assess changes in terrain and water levels. These technologies made it possible to determine the degree of soil erosion around the reservoir, identify subsidence zones in the dam, and map out high-risk areas. Based on this methodology, three critical points with potential flooding risks were identified.

Results: During the study, 15 major embankment reservoirs located in the territory of Uzbekistan were examined. Based on the data collected on each facility — including technical condition, safety level, the presence of monitoring systems, and risk probability — the following key findings were obtained:

1. Outdated and insufficient monitoring systems: It was found that 60% (9 out of 15) of the analyzed reservoirs lack automated safety monitoring systems. For example, in the Chorbog' reservoir, the sensors installed to monitor water pressure and deformations were last placed in 1998, and most of them are currently non-functional. Similarly, the Tuyatortar reservoir has no emergency alert system in place at all.

2. Inadequate preparedness for seismic risks: At the Pachkamar and Guliston reservoirs, which are located in high seismic zones, no seismic assessment or reinforcement work has been carried out for the past 20 years. GIS analysis revealed that certain sections of the dam are experiencing subsidence of 2–3 cm annually. This situation significantly increases the risk of water instability during an earthquake.

3. Environmental hazards and weak infrastructure: Visual monitoring conducted with drone technology at the Talimarjan reservoir identified irregular water level fluctuations and eroded (porous) zones. These pose potential threats to surrounding infrastructure — especially roads and sewer networks.

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4. Lack of systematic maintenance and repairs: According to survey results, 75% of the organizations responsible for the reservoirs do not conduct regular technical inspections. This issue is particularly evident at smaller, regional-level reservoirs, such as those in Yangiariq and Zarafshon. In most cases, repair work is initiated only after emergencies occur.

5. Subjectivity in safety assessment criteria: The study revealed that current safety assessment methods are often based solely on visual inspections and official reports. For instance, although the 2023 official report rated the Qorasuv reservoir as "satisfactory," land monitoring conducted in May revealed a hidden water flow under the dam. This proves a lack of objective indicators and advanced technologies in the evaluation process.

Discussion: The findings show that safety issues in many embankment reservoirs across Uzbekistan have not received sufficient attention. In particular, the absence of automated monitoring systems, inadequate measures against seismic risks, and the continued use of outdated technical infrastructure significantly increase the level of danger. These problems are linked not only to technical shortcomings but also to inefficiencies in organizational and management mechanisms.

1. Technical and organizational inconsistency: The technical equipment used to ensure reservoir safety — such as water level gauges, deformation sensors, and warning systems — in many cases are either non-functional or entirely absent. This significantly limits the ability to detect hazards in real time and respond promptly. International experience, such as in Japan and the United States, demonstrates that AI-powered monitoring systems are used to predict risks in advance. The lack of such systems in Uzbekistan highlights a major gap in reservoir management.

2. Subjectivity in safety assessments: A major flaw in the current assessment methodology is its reliance on subjective judgments by oversight bodies rather than objective indicators. The study found that some reservoirs rated as "satisfactory" were, in fact, in hazardous condition when inspected using advanced technologies. This underlines the need to reform the evaluation system.

3. Gaps in legislation and their consequences: The Law of the Republic of Uzbekistan "On the Safety of Hydraulic Structures," adopted in 2010, includes many articles and clauses that are no longer aligned with the progress of modern technologies. For example, provisions for the use of digital control systems, drones, and geoscanner technologies are not reflected in the law, creating legal obstacles to the adoption of advanced solutions.

4. Inadequate focus on environmental safety: Analysis shows that the environmental impact of reservoirs — particularly on groundwater, nearby agricultural lands, and biocenoses — has not been sufficiently studied. Erosion processes occurring beneath the reservoirs, hidden flows caused by filtration, and structural deformations in dams negatively affect ecological balance. This highlights the need to incorporate environmental factors into the development of safety criteria.

In summary, the current system for ensuring the safety of embankment reservoirs must be reviewed comprehensively. The existing issues can be addressed by improving safety assessment standards in accordance with international guidelines, introducing modern monitoring technologies, updating legal frameworks, considering environmental factors, and strengthening the training of qualified personnel.

Conclusion and Recommendations: This study clearly revealed that there are pressing issues regarding the safety status, monitoring systems, environmental, and organizational aspects of

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embankment reservoirs. In most large reservoirs located in Uzbekistan, technical infrastructure is outdated, automated safety systems are lacking, and insufficient measures have been taken against earthquake and flood risks.

The absence of automatic sensors and real-time warning systems in many reservoirs results in delayed detection of hazardous situations. These systems must be upgraded using modern technologies — including artificial intelligence (AI), geographic information systems (GIS), and drones. The current legal framework is not aligned with modern technological conditions. In particular, the Law "On the Safety of Hydraulic Structures" should be amended to include regulations regarding the application of modern safety technologies. The impact of reservoirs on surrounding land, ecosystems, groundwater, and human life is not being assessed systematically. Therefore, it is necessary to implement a structured system for environmental monitoring. A large proportion of engineers working in the sector are at retirement age, while there is a shortage of new qualified specialists. Special scientific-practical centers should be established to train personnel in modern technologies. National safety standards must be updated and applied based on safety protocols developed by ICOLD, UNECE, and other international organizations.

Recommendations:

Gradually implement digital monitoring systems powered by artificial intelligence at each major reservoir.

Establish an independent national agency to monitor and audit the safety of reservoirs.

Develop and regularly update hazard maps for the lands and populated areas surrounding hydraulic structures.

Maintain all information related to the safety of hydraulic structures in an open-access database (to ensure transparency and public oversight).

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