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MAIN DIRECTIONS OF MODERN HYDROLOGICAL RESEARCH IN AZERBAIJAN

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ОСНОВНЫЕ НАПРАВЛЕНИЯ СОВРЕМЕННЫХ ГИДРОЛОГИЧЕСКИХ ИССЛЕДОВАНИЙ В АЗЕРБАЙДЖАНЕ

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Abstract. Modern hydrological research in Azerbaijan is primarily focused on the efficient management of water resources. Advanced equipment is being installed for monitoring water bodies, and the network of hydrological stations is expanding. These studies monitor the hydrology of rivers, lakes, and reservoirs, assessing both the quantity and quality of water. In recent years, automated hydrological stations equipped with sensors have been put into operation, especially in territories liberated from occupation, where monitoring activities have been restored. These efforts are important for the sustainable management of water resources and the preservation of ecological balance. Overall, hydrological research in Azerbaijan is developing through the application of modern technologies, providing valuable data for water resource planning. In recent years, hydrological research in Azerbaijan has been further developed through the application of modern technologies and is primarily focused on the efficient management of water resources. These studies aim to examine the regimes of rivers, lakes, reservoirs, and groundwater, assessing both the quantity and quality indicators of water. Hydrological observations are mainly carried out through automated stations in real time, which ensures greater accuracy and efficiency in monitoring and planning water resources. One of the main objectives of hydrological research is to identify climate and water balance changes occurring in different regions of the country and to forecast flood and drought risks in advance. This is of great importance for the population, as well as for sectors such as agriculture, industry, and energy. Additionally, aspects like the base flow of rivers, reservoir water levels, and the management of irrigation systems are also among the key directions of these studies.

Аннотация. Современные гидрологические исследования в Азербайджане в первую очередь направлены на эффективное управление водными ресурсами. Устанавливается передовое оборудование для мониторинга водных объектов, расширяется сеть гидрологических станций. В рамках этих исследований отслеживается гидрология рек, озёр и водохранилищ, оцениваются как количественные, так и качественные показатели воды. В последние годы особенно на территориях, освобождённых от оккупации, введены в эксплуатацию автоматизированные гидрологические станции, оснащённые датчиками, и восстановлена система наблюдений. Эти усилия имеют важное значение для устойчивого управления водными ресурсами и сохранения экологического баланса. В целом гидрологические исследования в Азербайджане развиваются за счёт применения современных технологий, что обеспечивает получение ценных данных для планирования водных ресурсов. В последние годы гидрологические исследования ещё больше продвинулись благодаря внедрению инновационных методов и в основном сосредоточены на изучении режимов рек, озёр, водохранилищ и подземных вод, а также на оценке их

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количественных и качественных показателей. Гидрологические наблюдения преимущественно осуществляются через автоматизированные станции в режиме реального времени, что обеспечивает более высокую точность и эффективность в мониторинге и планировании водных ресурсов. Одной из главных целей гидрологических исследований является выявление изменений климата и водного баланса в различных регионах страны, а также предварительное прогнозирование рисков наводнений и засух. Это особенно важно как для населения, так и для таких отраслей, как сельское хозяйство, промышленность и энергетика. Кроме того, ключевыми направлениями исследований являются изучение базового стока рек, уровней воды в водохранилищах и управление ирригационными системами.

Keywords: hydrology, research, Azerbaijan.

Ключевые слова: гидрология, исследование, Азербайджан.

Hydrological observations in Azerbaijan date back to 1880, when the first observations were conducted on the Salyan section of the Kura River. However, continuous and systematic monitoring of river flow began primarily after 1925. Since then, the number of hydrological stations has gradually increased, forming a comprehensive network. The expansion of the network of hydrological stations and observation points has created favorable conditions for more accurate and continuous monitoring of the country's water resources (https://clck.ru/3QymEb).

Currently, Azerbaijan has 87 hydrological observation points at various water bodies, including rivers, lakes, and reservoirs. Of these, 79 monitor rivers, six monitor reservoirs, and two monitor lakes. All are focused on monitoring water conditions (https://clck.ru/3QYmEb).

In Azerbaijan, the Hydrological Service performs monitoring, analysis, and forecasting. Thanks to government investment in this area, collaboration with international projects, and the development of scientific potential, hydrological data collection has become more accurate and systematic. This significantly contributes to the development of sustainable development strategies for the country and the preservation of ecological balance. Farda Imanov is one of the prominent scientists who has made significant contributions to hydrological research in Azerbaijan. For many years, he has conducted valuable research on assessing the country's water resources, analyzing river flow characteristics, and introducing hydrological calculations based on scientific principles. His textbooks and scientific papers, including "River Runoff," "Applied Hydrology," and "Statistical Methods in Hydrometeorology," have played a significant role in shaping both academic knowledge and practical experience in this field. Farda Imanov's research primarily covers river flow modeling, flood and drought risk assessment, statistical analysis of hydrometeorological data, and water resources planning. He is also actively involved in training young researchers and strengthening national scientific potential in the field of hydrology. His contributions have had a significant impact on the development of modern hydrological science in Azerbaijan and laid the foundation for the introduction of several innovations in this field.

Magbet Mammadov is one of the researchers who played a significant role in the establishment and development of hydrological science in Azerbaijan. His research primarily focuses on the study of the country's hydrographic network—rivers, lakes, and other water bodies. Mammadov's research covers topics such as the distribution of water resources in Azerbaijan, their morphological characteristics, and the scientific principles of their management.

In his book "General Hydrology," he thoroughly expounds on the fundamental concepts of hydrology, the characteristics of surface and groundwater, and their role in natural systems. His

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monograph "Hydrography of Azerbaijan" provides a detailed analysis of the country's river systems, systematically describing their physical and geographical features and regimes. Makbet Mammadov's scientific contributions are not limited to theoretical knowledge; he is also known for his research focused on practical applications.

The following researchers conducted research in Azerbaijan:

1. Farda Imanov – in the field of hydrometeorology and hydrological modeling. He has published scientific papers on river runoff analysis and water resources management.

2. Magbet Mammadov – studies the country's hydrographic network, river and lake hydrology, and water resources management. He is the author of "General Hydrology" and "Hydrography of Azerbaijan."

3. Bahram Bayramov – studies organic pollution of river waters.

4. Magomed Magomamov – hydrological observations and river water quality assessment.

5. Rahim Aliyev – research on the ecology of water bodies and the study of hydrological regimes.

Many other scientists and specialists are actively involved in hydrological research in Azerbaijan, particularly at research centers such as the Research Institute of Water Resources and Land Reclamation and the Institute of Geography. In 2000, M. Mamedov, F. Imanova, and R. Mahmudov published a book, "Hydrometry," consisting of nine chapters. The research covered topics such as hydrometry and hydrometric networks, water level observations, depth measurements, river flow velocity measurements, methods for measuring and calculating water discharge, suspended sediment, specialized hydrometric studies and observations, state water resource accounting and water cadastre, and safety precautions during hydrometric work [8].

In 2002, the book "Thermodynamics of Seas and Oceans" (A. Khumbetov and N. Guseinova) was published. The first chapter, entitled "Some Concepts of Thermodynamics," introduces readers to basic thermodynamic terms, concepts, fundamental principles, and laws of thermodynamics, as well as explains the concept of a thermodynamic system. The second chapter, devoted to "Fundamentals of Ocean Thermodynamics," teaches the practical application of theoretical knowledge. The third chapter examines the laws of change and conservation of thermodynamic parameters, as well as the dynamics and thermodynamics of irreversible processes in the oceans [3].

In 2003, Esmiralda Mammadova published the textbook "Water Supply and Reclamation Hydrogeology" for undergraduate and graduate students at higher education institutions. The first part of the textbook briefly outlines the history of exploration and discovery of groundwater deposits for water supply purposes, substantiates promising areas for developing environmentally friendly drinking water, analyzes exploitable groundwater reserves and their use, describes groundwater deposits and their types, and addresses groundwater protection issues. The textbook also addresses monitoring of drinking groundwater deposits and their recharge zones. The second part examines the content and stages of development of reclamation hydrogeology, studies the natural and water management conditions of reclaimed areas, examines the regime and balance of groundwater on reclaimed lands, and presents methods for hydrogeological and reclamation research and forecasting [5].

In 2003, the book "General Hydrology" by Makbet Mammadov and Farda Imanov was published, which presents general information on hydrology, groundwater, rivers, lakes, swamps, glaciers and their hydrological role, oceanology, as well as research on pollution and protection of water bodies [6].

In 2008, E. Masimov wrote a monograph, "The Role of Water in Biological Systems. Hydrophobicity," which includes the following sections: Properties and Role of Water in Biological Systems; Two-Phase Systems; Distribution of Substances in Two-Phase Systems; Two-Phase Water-

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Polymer Systems; Relative Hydrophobicity of Solutions of Some Medical, Biological, Synthetic Polymers and Inorganic Salts; Relative Hydrophobicity of Biological and Synthetic Polymers for Medical Purposes; Two-Phase Polymer-Inorganic Electrolyte Systems; Influence of External Factors on the Characteristics of Two-Phase Aqueous Systems; Structural Temperature of Water and Aqueous Solutions [4].

The textbook "River Runoff," published by Farda Imanov in 2002, examines the main physical and geographical factors of river runoff, runoff losses, annual runoff, runoff distribution throughout the year, minimum runoff, runoff during flood periods, rainfall floods, groundwater runoff, and mudflows. The textbook was compiled using textbooks from the former USSR, monographs, and the results of experimental studies conducted in Western countries [9].

In his 2010 book "Applied Hydrology," Farda Imanov examines hydrometry, hydraulics, statistical methods in hydrology, river runoff, and hydrological calculations, conducting interdisciplinary research. The textbook's primary goal is to reinforce theoretical knowledge with case studies, combining the disciplines of "Hydrometry and Safety," "Statistical Methods in Hydrometeorology," "Hydraulics," and "River Runoff and Hydrological Calculations" [10].

In 2011, Farda Imanov published the textbook "Statistical Methods in Hydrometeorology", which provides extensive information on the application of statistical methods in hydrometeorology, taking into account international experience, including the history of their application, general information about mathematical statistics, methods of mathematical modeling of hydrometeorological series, statistical criteria and dependencies, probability theory, basic methods of analytical distribution, linear correlation and much more. The main sections of the textbook: 1. Brief history of the application of statistical methods in hydrometeorology; 2. General information about probability theory and mathematical statistics; 3. Empirical distribution curves and analytical distribution functions; 4. Methods for estimating the parameters of distribution curves; 5. Interval estimation of parameters and hypothesis testing; 6. Statistical dependencies and linear correlation in hydrometeorology; 7. Mathematical modeling of hydrometeorological series [11].

In 2011 was published as the first textbook written in Azerbaijani on this topic. The book covers the laws governing the hydrological regimes of lakes and reservoirs, the role of lake basins in the hydrosphere, their classification, development, morphometric features, feeding, levels, hydrological processes of reservoirs, hydrobiology, hydrochemistry, hydrodynamics, and the ecological status and classification of reservoirs in Azerbaijan. The textbook is structured as follows: 1. Morphometric features of lakes and reservoirs and their place in the hydrosphere; 2. Feeding, level regime, and water balance of lakes; 3. Dynamic processes in lakes; 4. Thermal and ice regimes of lakes; 5. Hydrochemical and gas regimes of lakes; 6. Hydrobiological characteristics, biological species, and productivity of lakes; 7. Sediments in lakes; 8. The role of reservoirs in the hydrosphere; 9. Hydrological regime characteristics of reservoirs; 10. Sedimentation and losses in reservoirs; 11. Reservoirs of Azerbaijan and their classification [2].

In 2012, Makbet Mamedov published a monograph, “Hydrography of Azerbaijan,” which examined the rivers of Azerbaijan in detail [7].

In 2011, the book "Hydrometeorological Calculations" was published. This textbook presented for the first time methods for determining environmental flow. The textbook examines methods of analysis, systematization and calculation of the main hydrological indicators used in the design of water management structures and assessment of water resources, based on the volume of observation data and taking into account international experience in hydrological calculations. The principles of river runoff formation and the methods of genetic and statistical analysis widely used in hydrological calculations are presented in detail. The textbook consists of the following sections: Brief history of hydrological calculations; Methods of hydrological calculations and

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generalizations; Calculation of runoff characteristics in the presence of sufficient observation data; Estimation of runoff characteristics based on short series of observations; Calculation of runoff characteristics in the absence of observation data; Intra-annual runoff distribution; Calculation of flood hydrographs; Runoff transfer; Methods for determining environmental flow; Assessment of the impact of economic activity on river runoff [11].

In 2015, the book "Simple Methods of Biological Analysis of Organic Pollution in River Waters" was published by B. Bayramov, M. Maherremov and R. Aliev. This textbook is intended for biologists and hydrologists. It covers topics such as the hydrosphere, freshwater, organic pollution, biological self-purification processes, benthic organisms, collection of macrozoobenthos samples, and assessment of water quality in rivers [1-8, 12].

The main organizations and institutes conducting research on modern hydrological studies and current directions in Azerbaijan are as follows:

- The Scientific Research Institute of Water and Melioration, operating as a public legal entity, conducts fundamental and applied research in the fields of water and melioration.

- The Institute of Geography, especially the Department of Arid Hydrology and Water Resources, studies the condition of Azerbaijan's water resources and the flow of mountain rivers.

- The Hydrometeorology Center carries out work related to the monitoring of water bodies, calculation of water balance, and systematization of hydrometeorological data.

- Under hydrogeological and engineering-geological studies, exploratory works for the discovery and use of groundwater resources are carried out by amateur researchers.

Looking at recent research directions and results in Azerbaijan, they can be grouped as follows:

- Automation of stations nationwide for hydro-meteorological forecasts has been expanded, with the application of satellite and radar technologies.

- Hydrogeological research is conducted on groundwater status, mineral water reserves, and the potential of thermal waters.

- Hydrological companies, such as Caspian Geomatics, apply drone, aerospace, and hydrometric measurement methods to analyze the hydrobiological regime of rivers, lakes, and water bodies, including parameters like flow and volume (https://clck.ru/3QYny8).

In the Caspian Sea, issues such as water level fluctuations, changes in wind, and wave regimes are studied. For example, the Caspian Hydrometeorology Department examines changes in the sea regime from 1980 to 2023. Geological planning is conducted at a scale of 1:200,000, and hydrogeological mapping continues across the republic (https://clck.ru/3QYo2A).

In the Karabakh zone, new methods have been used to study the "flow regime" of rivers, and the region's water resources have been analyzed based on spatial statistics.

One of the main goals of the hydrological service in Azerbaijan is to provide government agencies, the public, and various economic sectors with accurate, timely, and forecasted information about the regime and condition of the country's water bodies. This is crucial for the proper management of water resources and the timely implementation of safety measures. At traditional hydrological stations, water level and temperature are measured twice daily. Water flow rates are determined twice every ten days, but during the spring-summer high-water period, these observations are made more frequently (https://clck.ru/3QYo2A).

In addition, the condition of ice cover on water bodies is monitored during autumn, winter, and spring. During the winter months, ice thickness is also specifically measured and recorded. These studies provide a solid database for forecasting floods and preventing them. On July 27, 2020, following an order approved by the country's leadership, important steps were taken to implement the "Action Plan for Ensuring Efficient Use of Water Resources for 2020–2022." As part

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of these measures, in 2021, new technologies were introduced to improve water resource management and increase the accuracy of hydrological observations. With state investments, 17 automatic hydrological stations equipped with sensors and capable of real-time data transmission were installed on the country's major rivers: 6 on the Kura, 3 on the Aras, as well as on the Qanix, Qabirri, Agstafachay, Shamkirchay, Tartar, Qusarchay, Vileshchay, and Lankaran rivers. Additionally, within the framework of the EU-supported Water Initiative project, 6 more modern automatic monitoring stations were set up on the Asrikchay, Zayemchay, Ganjachay, Kurekchay, Katekhchay, and Eyrichay rivers. These innovations enable more effective and prompt monitoring of water bodies (https://clck.ru/3QYo2A).

In 2022, thanks to state investments, significant work was carried out to restore hydrological observations in the liberated territories. Within this framework, 11 modern automatic hydrological stations were installed on 10 rivers located in these areas: Tartar, Tutgun, Kondelen, Kuruchay, Hekeri, Zabukh, Bergushad, Okhchu, Basitchay, and Aras (https://clck.ru/3QYo2A).

At the same time, 6 automatic monitoring stations were put into operation on the Alicanchay, Turyanchay, Qarachay, Velvelechay, and Gudyalchay rivers flowing from the Greater Caucasus mountain range. Thanks to these technological innovations, it has become possible to collect accurate and continuous data on the state of water flows, achieving significant progress in monitoring and managing the region's water resources. As a result, the total number of automated hydrological stations across the country has increased to 40, allowing approximately 45 percent of the overall hydrological observation network to be automated. Thus, the monitoring and analysis of water resources can be carried out more promptly and accurately. Hydrological services in Azerbaijan are carried out along several key directions. These activities include the preparation of hydrological forecasts, analysis of annual hydrological data and monitoring results, as well as field expeditions. At the same time, the current state of water bodies is assessed operationally, various hydrological regime indicators are prepared and analyzed, and short-term forecasts are made. A "Daily Hydrological Bulletin" is prepared based on the assessment of the conditions in major domestic and transit rivers, as well as large reservoirs. This document reflects current and expected water levels, river flow indicators, and forecasts of possible inflow to reservoirs (Azerbaijan Ecology Ministry, n.d.). The hydrological forecasts prepared are available in various formats: Warnings; Two-day water level forecast for two points on the lower course of the Kura River; Daily inflow forecast for reservoirs (Shamkir, Mingachevir); Spring-summer (April-June) high-water period forecast; Ten-day forecast; Monthly forecast; Quarterly inflow forecast for reservoirs (Shamkir, Mingachevir) (https://clck.ru/3QYo2A).

As a result, long-term research conducted will contribute to achieving more effective outcomes and advancing the science of hydrology. There are several important advantages to conducting hydrological research in Azerbaijan, which can be summarized as follows:

Basis for scientific research and planning: The collected data provides a scientific foundation for water management projects, engineering structures design, and regional development.

Proper management of water resources: Accurate hydrological data enables the efficient use of water resources, optimal operation of reservoirs, and planning of irrigation systems.

Support for sustainable development: Hydrological monitoring results aid in adapting to climate change, long-term resource use, and developing regional development strategies.

Reduction of flood and drought risks: Prepared forecasts and warnings are crucial for preventing or mitigating the effects of natural disasters such as floods, landslides, and droughts.

Preservation of ecological balance: Monitoring the regime of rivers, lakes, and other water bodies ensures the protection of ecosystems and supports maintaining suitable conditions for flora and fauna.

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The modern phase of hydrological research in Azerbaijan serves the purpose of efficient and sustainable management of water resources. In recent years, the implementation of technological innovations — such as automated monitoring stations, satellite and radar systems, and real-time data transmission — has significantly increased the accuracy and efficiency of observing hydrological processes. Through hydrological studies, key factors such as the dynamics of river flows, the capacity of reservoirs, groundwater reserves, and the impacts of climate change are analyzed on a scientific basis. The data collected in this field serve as a foundation for decision-making by government bodies, planning in the agricultural and industrial sectors, and reducing the risks of floods and droughts. The expansion of hydrological research also plays a vital role in maintaining ecological balance and ensuring the availability of water resources for future generations. As a result, this area of study has become an essential part of shaping the country's water policy based on scientific evidence and supporting sustainable development goals.

In the modern era, there is a growing need to use Geographic Information Systems (GIS) in Azerbaijan for the study and efficient use of water resources. The integrated management of Azerbaijan's water resources through GIS allows for more efficient and sustainable utilization of these resources. Primarily, GIS ensures the collection and analysis of data reflecting the geographical location, volume, and usage of water sources (rivers, lakes, groundwater). Using this system, water balance is calculated, and the demand and supply across different regions are compared. The advantages of integrated water resource management through GIS in Azerbaijan include:

- Accurate mapping and visualization – The geographic distribution, spread, and condition of water resources can be visually analyzed through GIS.
- Real-time monitoring – Changes in rainfall, groundwater, and water bodies can be tracked and assessed instantly.
- Efficient use of resources – Accurate decisions can be made regarding where and how water resources should be directed, reducing waste.
- Risk prediction – Risks such as droughts, floods, and pollution can be identified in advance, allowing for preventive measures.
- Improved decision-making process – Management bodies gain access to a broader database and analytical tools.
- Adaptation to climate change – GIS allows for future forecasting of water resource changes based on climate scenarios.
- Environmental protection – Ensures sustainable and balanced use of water resources.
- Integrated planning – Enables coordinated management of water resources with other sectors such as agriculture, industry, and public consumption.
- Centralized data management – Information from various sources is consolidated and analyzed within a unified system.

The integrated management of water resources in Azerbaijan through Geographic Information Systems (GIS) can be implemented in several stages:

- Data collection and mapping – Using GIS technologies, information about river networks, reservoirs, groundwater, precipitation, and evaporation is collected and placed on digital maps.
- Monitoring and analysis – The volume, quality, and usage of water resources can be monitored in real time. This helps to identify water losses, pollution, and risk zones.
- Efficient planning – Water distribution for irrigation, industrial, and domestic use is planned more optimally.
- Risk assessment – GIS data can be integrated with climate and soil information to forecast situations such as floods, droughts, and water scarcity.

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- Support in decision-making – Government bodies and local administrations can make more informed decisions regarding water resource management.

Hydrological research in Azerbaijan is focused on the efficient and sustainable management of water resources. The application of modern technologies increases the accuracy and timeliness of observations. These studies examine the regimes of rivers, lakes, reservoirs, and groundwater. The collected data is used to forecast climate change impacts and natural disaster risks, such as floods and droughts. State support and international cooperation have facilitated the expansion of the monitoring network. Hydrological data plays a vital role in planning for agriculture, industry, and energy sectors. At the same time, it helps protect ecosystems. Research conducted in Azerbaijan is based on both scientific principles and practical applications. In the future, more advanced methods will be implemented, and research will expand further. This will ensure the sustainable use of the country's water resources and improve the well-being of the population.

The integrated management of water resources in Azerbaijan using Geographic Information Systems (GIS) is one of the effective approaches that meets the requirements of the modern era. Through this integration, precise geographical data on water sources across various regions of the country can be obtained and analyzed in real time. GIS technology allows for the visualization of the current state and usage of water resources, while also providing a scientific basis for their sustainable management. The application of GIS increases efficiency in management, as data is collected, stored, and analyzed more quickly. This plays a significant role in the proper allocation of water resources and the prevention of waste. Risks such as droughts and floods can be modeled and predicted in advance, enabling timely decision-making. Moreover, GIS technology allows water resources to be managed in coordination with other sectors — agriculture, industry, urban planning, and environmental protection. As a result, the distribution of resources is carried out in a more balanced manner. This approach contributes both to the conservation of natural resources and to the more efficient fulfillment of the population's water needs.

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