

Assessment of Water Resources Formed in the Mountains of the Western Zarafshan Range and Issues of their Rational USE

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Abstract. This article examines the spatial and seasonal distribution of water resources formed in the mountains of the Western Zarafshan Range, the natural and climatic factors influencing their formation, and the current state of water resource utilization. In mountainous areas, precipitation, snow cover, glaciers, groundwater, and small river basins constitute the major sources of water resources. Climate change is significantly affecting the conditions of mountain river runoff formation through increasing air temperatures, decreasing snow and glacier reserves, increasing evaporation, and changes in the temporal distribution of precipitation. The study analyzes the hydrological characteristics of mountain rivers and streams of the Western Zarafshan Range, their flow regimes, seasonal distribution of runoff, and the use of water resources for agriculture, domestic water supply, and other economic sectors. Particular attention is given to integrated water resources management, the introduction of water-saving technologies, improvement of hydrological monitoring, and measures aimed at ensuring the sustainability of water resources under changing climatic conditions. Scientific and practical recommendations are proposed for the rational and sustainable use of water resources in the region.

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1. Introduction

Water resources in Central Asia are predominantly formed in mountainous areas. The formation of runoff in the basins of major rivers in the region is directly associated with snow and glacier accumulation in high mountain areas, atmospheric precipitation, and groundwater reserves. Therefore, the study of the hydrological characteristics of mountainous regions is of considerable importance not only from a physical-geographical perspective but also from economic, environmental, and social perspectives.

The Zarafshan River basin is one of the important water-management regions of Uzbekistan and Central Asia. The upper and middle reaches of the Zarafshan River are formed in mountainous areas and subsequently provide water for irrigated agriculture, domestic needs, industrial activities, and other sectors of the economy. In particular, the mountain and foothill areas of the western part of the Zarafshan Range play an important role in the formation of local water

resources.

The complex orographic structure of the Western Zarafshan Range, its altitudinal zonation, slope exposure, geological characteristics, and geomorphological conditions are important factors controlling runoff formation. Increasing precipitation with elevation, together with the accumulation and subsequent melting of snow, contributes to increased river discharge during spring and summer.

In recent decades, global climate change has increasingly affected hydrological processes in mountainous areas. Rising air temperatures influence the duration of snow cover, the timing of snowmelt, glacier mass balance, and the seasonal distribution of river runoff. In particular, increasing spring temperatures may result in earlier snowmelt. Consequently, runoff in some rivers may increase during the early part of the year, while water shortages may become more pronounced during the second half of summer.

Under these conditions, assessment of water

resources formed in the Western Zarafshan Range, identification of their spatial and temporal distribution, improvement of water-use efficiency, and evaluation of potential future changes represent important scientific and practical challenges.

2. Material and Methods

The main objective of this study is to assess the hydrological characteristics of water resources formed in the mountains of the Western Zarafshan Range, identify the factors controlling their formation, and develop scientific and practical recommendations for their rational use.

To achieve this objective, the following tasks were addressed:

1. To analyze the physical-geographical and hydrological characteristics of the Western Zarafshan Range;
2. To identify the major factors responsible for water-resource formation in the study area;
3. To assess the influence of atmospheric precipitation and air temperature on river runoff;
4. To investigate the hydrological regime and seasonal distribution of mountain river runoff;
5. To assess the role of snow cover and glaciers in water-resource formation;
6. To determine the importance of groundwater in hydrological processes;
7. To analyze the current use of water resources in different economic sectors;
8. To assess the potential impacts of climate change on future water availability;
9. To propose mechanisms for rational water use and integrated water resources management.

3. Results

The Western Zarafshan Range is an important part of the Zarafshan mountain system and is characterized by a complex geomorphological structure. Differences in elevation, slope orientation, valley morphology, and mountain relief contribute to substantial spatial variations in hydrological processes.

In mountainous regions, atmospheric precipitation generally increases with elevation, while air temperature decreases. This altitudinal pattern is one of the key factors controlling the distribution and storage of water resources. In high mountain zones, solid precipitation, particularly snow, contributes to the formation of natural water reserves.

Numerous small rivers and streams originating in the Western Zarafshan Range contribute to runoff toward downstream areas. Among the local watercourses, Urgutsoy, Amonqotonsay, Sazagonsay, and Tegirmonsay are important components of the local drainage system.

The formation of runoff in small mountain river basins is mainly associated with snowmelt, rainfall, and groundwater discharge into river channels. The discharge of some streams can change considerably within short periods of time. This creates challenges for hydrological monitoring and water-resource planning.

Water-resource formation in the Western Zarafshan Range is controlled by a combination of natural factors. These can be divided into several major groups:

- atmospheric precipitation;
- snow cover;
- glacier and snow-ice reserves;
- air temperature;
- evaporation;
- topography;
- geological and hydrogeological conditions;
- vegetation cover;
- soil characteristics.

Atmospheric precipitation

Atmospheric precipitation is one of the major sources of water for mountain rivers. In mountainous areas, precipitation varies significantly with elevation. The increase in precipitation at higher elevations contributes to greater water storage within river basins.

The uneven seasonal distribution of precipitation determines the seasonal character of river runoff. During spring, the combined effects of rainfall and snowmelt can cause substantial increases in river discharge.

Snow cover

Snow cover functions as a natural reservoir in mountainous environments. Snow accumulated during winter melts during the warm season and contributes significantly to river runoff.

The amount of snow accumulation and the rate of snowmelt directly influence river discharge. Monitoring the thickness, duration, and timing of snow cover and snowmelt is therefore essential for water-resource assessment and forecasting.

Air temperature

Air temperature is one of the principal meteorological factors controlling the rate of snow and glacier melt. Increasing temperatures can cause earlier snowmelt. At the same time, higher temperatures intensify evaporation, resulting in a greater transfer of water back into the atmosphere.

Long-term increases in air temperature associated with climate change may alter the seasonal distribution of river runoff.

Mountain rivers of the Western Zarafshan Range exhibit considerable seasonal variations in discharge. Their hydrological regime is characterized by periods of high water, low water, rainfall-induced

floods, and, in some areas, freezing processes.

During spring, snowmelt combined with increased rainfall results in higher river discharge. In some rivers, the high-water period may occur mainly from April to June.

During summer, snow and glacier melt in high mountain areas contributes to maintaining river flow. However, during the second half of summer, depletion of snow reserves and high temperatures may cause declining discharge in some small rivers.

In autumn, decreasing precipitation and declining air temperatures generally lead to reduced runoff. During winter, freezing processes may occur in the upper reaches of mountain rivers.

These seasonal characteristics have direct implications for water-resource management. Water demand for irrigation is generally high during summer, while natural river discharge may decline during the same period, potentially intensifying water shortages.

Quantitative assessment of water resources is based on key hydrological indicators. These include mean annual discharge, maximum and minimum discharge, annual runoff volume, runoff depth or modulus, and runoff coefficient.

Annual runoff volume can be estimated using the following equation:

$$W = Q \times T$$

where:

W – annual runoff volume;

Q – mean discharge;

T – time period.

The runoff modulus can be calculated using:

$$M = Q / F$$

where:

M – runoff modulus;

Q – river discharge;

F – catchment area.

These indicators allow comparison of the water resources of different river basins.

For small rivers of the Western Zarafshan Range, analysis of long-term hydrological observation series is particularly important. Short observation periods are generally insufficient for reliable assessment of long-term trends in water resources.

Therefore, expansion of the hydrological monitoring network, installation of automated water-level and discharge measurement systems, and integration of remote sensing data with ground-based hydrological observations are recommended.

Climate change is one of the major threats to mountain water resources. Increasing air temperatures may accelerate snow and glacier melt processes.

The major potential impacts of climate change include:

1. shortening of the duration of snow cover;

2. earlier onset of snowmelt;

3. reduction in glacier area and volume;

4. changes in the seasonal distribution of river runoff;

5. increasing evaporation;

6. intensification of drought periods;

7. increasing risk of extreme precipitation and floods.

One of the major challenges for mountain rivers is the potential increase in the imbalance between short periods of high runoff and prolonged periods of water scarcity.

For example, earlier-than-normal snowmelt may increase river discharge during spring. However, reduced snow reserves may result in lower runoff during summer. At the same time, agricultural water demand is usually highest during the summer season.

Consequently, under changing climatic conditions, it is important to assess not only the annual volume of water resources but also their **seasonal distribution**.

Water resources formed in the mountains of the Western Zarafshan Range play an important role in the socio-economic development of the region. They are used for agriculture, domestic and municipal water supply, livestock production, industry, and recreational activities.

Agriculture is one of the major water-consuming sectors. Under irrigated agriculture, efficient allocation and conservation of water resources are particularly important.

Traditional irrigation methods may result in considerable water losses through infiltration, evaporation, and drainage. Therefore, the implementation of drip irrigation, sprinkler irrigation, and modernization of irrigation canals can substantially improve water-use efficiency.

In foothill areas, the use of small mountain streams should also take into account the ecological safety of water abstraction infrastructure and the need to maintain sufficient natural river flows.

Rational water use refers to the economically efficient, environmentally sustainable, and socially responsible management of available water resources while considering the needs of future generations.

For the Western Zarafshan Range, the main directions of rational water use include the following.

Introduction of water-saving technologies

The use of drip and sprinkler irrigation technologies in agriculture can significantly reduce water consumption.

- Modernization of irrigation infrastructure

It is necessary to reduce water losses in aging canals and hydraulic structures. Canal lining and the use of modern water-resistant materials can improve

water-delivery efficiency.

- Digitalization of water accounting

The introduction of modern automated water meters for water abstraction and consumption can improve the accuracy and transparency of water-resource management.

- Strengthening hydrological monitoring

Regular observations of river discharge, water levels, precipitation, temperature, and snow cover are essential for effective water-resource assessment.

- Application of GIS technologies

Geographic Information Systems can be used to analyze river basins, drainage networks, precipitation and snow cover, land-use patterns, and water consumption at different spatial scales.

- Integrated water resources management

An integrated basin-scale approach should be adopted to coordinate the interests of different water users and maintain the ecological sustainability of river systems.

GIS technologies have become essential tools in modern hydrological research. For assessment of water resources in the Western Zarafshan Range, digital elevation models, satellite imagery, meteorological observations, and hydrological data can be integrated into a unified analytical framework.

GIS technologies can be used to:

- delineate river basins;
- calculate catchment areas;
- map drainage networks;
- classify elevation zones;
- determine slope aspects;
- estimate snow and glacier areas;
- assess the spatial distribution of precipitation;
- identify areas vulnerable to water-related hazards.

Remote sensing data provide an effective means of monitoring changes in snow and glacier extent over time. This approach is particularly useful in mountainous and inaccessible areas.

For effective management of water resources in the Western Zarafshan Range, a basin-scale approach should be applied. Under this approach, the river basin is considered a unified natural and socio-economic system.

Integrated water resources management should be based on the following principles.

First, a balance should be maintained between natural water-resource formation processes and socio-economic water demand.

Second, the interests of upstream and downstream communities and economic sectors should be coordinated.

Third, environmental flows should be

maintained. Excessive abstraction from rivers can adversely affect aquatic ecosystems and downstream users.

Fourth, potential future impacts of climate change should be incorporated into water-management strategies and planning.

4. Discussions

Water-resource formation in the Western Zarafshan Range is the result of complex interactions among climatic, hydrological, geological, geomorphological, and ecological processes. The runoff of local rivers and streams is strongly influenced by seasonal variations in snowfall, rainfall, and temperature.

The analysis indicates that assessment of mountain water resources should not be based solely on mean annual discharge. The seasonal distribution of runoff, maximum and minimum discharge, and the timing and duration of high-water periods are also important indicators.

Under climate change, trend analysis of long-term hydrological series becomes particularly important. Statistical approaches such as the Mann–Kendall test, Sen’s slope estimator, regression analysis, and other statistical methods can be applied to identify long-term changes in hydrological variables.

The following relationships are particularly important for further investigation:

Atmospheric precipitation → snow accumulation → snowmelt → river runoff and

Air temperature → snow and glacier melt → evaporation → river runoff.

Statistical analysis and mathematical modeling of these relationships can be used to develop projections of future changes in river runoff.

Water resources formed in the mountains of the Western Zarafshan Range are of major importance for the natural environment and socio-economic development of the region. Mountain rivers and streams provide essential water resources for agriculture, domestic use, industry, and ecological systems.

The study leads to the following main conclusions:

1. Atmospheric precipitation, snow cover, glaciers, air temperature, topography, and hydrogeological conditions are the major factors controlling water-resource formation in the Western Zarafshan Range.

2. Mountain rivers have a strongly seasonal hydrological regime, with significant increases in runoff during spring and summer.

3. Climate change may alter the timing of snow and glacier melt and consequently modify the seasonal

distribution of river runoff.

4. Improvement of hydrological monitoring systems is necessary to ensure the long-term sustainability of water resources.

5. The application of GIS, remote sensing, and mathematical modeling provides significant scientific and practical benefits for water-resource assessment.

6. Wider adoption of water-saving technologies in agriculture can reduce pressure on available water resources.

7. Water resources should be managed through an integrated basin-scale approach rather than through isolated management of individual water bodies.

8. Development of hydrological forecasting models based on climate-change scenarios should be considered a priority for future research on the water resources of the Western Zarafshan Range.

The following measures are recommended to promote rational use of water resources in the Western Zarafshan Range:

expand automated hydrological monitoring stations on mountain rivers and streams;

establish systematic remote sensing monitoring of snow cover and glacier conditions;

develop an integrated GIS database of regional water resources;

expand the use of drip and sprinkler irrigation technologies in agriculture;

reconstruct canals with high levels of water loss;

digitalize water abstraction and consumption accounting;

maintain ecological flows in small mountain rivers;

develop adaptation strategies for areas exposed to high water-scarcity risks;

develop long-term water-resource projections based on climate-change scenarios;

strengthen economic incentives for water conservation among water users.

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