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Long-term dynamics of the hydrological regime of the chirchik river

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Abstract: In this article, the long-term dynamics of the water regime of the Chirchik River at the Gazalkent hydrological station in northeastern Uzbekistan were analyzed based on average monthly discharge data for the period 1900–2022. The results show that the average annual discharge of the Chirchik River at Gazalkent is approximately 217–228 m³/s, with a strong seasonal variability — the highest flows occur in the spring–summer months. The multi-year analysis identified extreme years, with 1969 being the wettest year (average 459 m³/s) and 1917 the driest (133 m³/s). Linear regression results indicate a slight decreasing trend, though it is not statistically significant. The impact of climate change and anthropogenic factors on variations in the water regime was also analyzed.

Keyword: chirchik river basin; climate change; water discharge; Gazalkent hydrological station; multi-year river flow; hydrological regime; extreme water events.

Introduction

The Chirchik River is one of the major strategically important water bodies located in the northeastern part of the Republic of Uzbekistan. The river is approximately 155 km long, while its catchment area covers nearly 14,900 km². The Chirchik River basin mainly encompasses mountainous and foothill regions and is characterized by a complex hydrographic network. The river flow is formed by water originating in high-mountain areas and eventually joins the Syr Darya basin in its lower reaches. According to long-term hydrological observations near the city of Gazalkent, the mean annual discharge of the river is approximately 220 m³/s [1]. The natural and geographical conditions of the Chirchik River basin directly influence the formation of its hydrological regime. The upper part of the basin consists mainly of high-mountain areas where considerable snow reserves accumulate during the winter season. Mountain glaciers and seasonal snow cover in high-altitude zones are the principal natural sources feeding the river [2]. As air temperatures rise during spring and summer, snow and glacier melting intensifies, resulting in a substantial increase in the amount of water entering the river.

The hydrological regime of the river is characterized by pronounced seasonal variability. The highest discharge values are generally observed in late spring and early summer, particularly from April to June. During this period, intensive snowmelt in the mountains and increased precipitation contribute to a rise in river flow. In autumn and winter, the natural discharge decreases as snow and glacier melting slows. Consequently, substantial fluctuations in water discharge occur throughout the annual flow cycle of the Chirchik River. The water resources formed within the Chirchik River basin are regulated not only by natural factors but also by reservoirs, hydraulic structures, and irrigation systems. Reservoirs located in the upper and middle reaches of the river play an important role in regulating seasonal flow, preventing floods, ensuring the required water supply during the irrigation period, and generating hydroelectric power [3].

In particular, the Charvak Reservoir is one of the largest hydraulic structures regulating the flow of the Chirchik River. Water stored in this reservoir is distributed throughout the year according to the demands of irrigation, energy generation, and public water supply. Hydraulic structures located in the Khodjikent and Gazalkent areas also form an important part of the Chirchik–Bozsuv energy

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and irrigation system. These facilities make it possible to use the hydropower potential of the river and regulate the seasonal distribution of water resources [4].

The Chirchik River has particular importance for the socio-economic development of Tashkent Region and the city of Tashkent. Numerous settlements, industrial enterprises, agricultural lands, and transport and communication infrastructure are located in the middle and lower parts of the basin. Therefore, river water is widely used for drinking and domestic water supply, industrial needs, irrigation, energy production, and recreational purposes [5].

Agriculture is one of the main consumers of the Chirchik River's water resources. River water is used to irrigate large areas of agricultural land in Tashkent Region. Cotton, cereals, vegetables, fruits, and other agricultural crops are cultivated in these areas. Through the Chirchik–Bozsuv, Karasu, and associated main and inter-farm canals, water is supplied to more than one hundred thousand hectares of irrigated land [6].

The withdrawal of large volumes of water during the irrigation season may significantly affect the hydrological conditions in the lower reaches of the river. Particularly during the summer months, when water demand is high, reductions in discharge, alteration of the natural flow regime, and insufficient provision of environmental flows may occur in certain sections of the river. These conditions may negatively affect river ecosystems, aquatic organisms, and riparian landscapes.

The Chirchik River is also an important source of water supply for Tashkent and nearby areas. As the population grows, urban areas expand, and industrial activities develop, demand for river water continues to increase. At the same time, the discharge of wastewater into the river, return flows from agricultural drainage systems, and industrial effluents may affect water quality.

Intensive use of river water resources has caused several ecological and hydrogeological problems within the basin. Inefficient water use and seepage losses in irrigation systems may lead to a rise in groundwater levels. Rising groundwater levels may intensify waterlogging and secondary soil salinization in certain irrigated areas [7]. In addition, artificial regulation of river flow affects its natural seasonal variability and the hydrodynamic processes occurring within the river channel.

In recent years, climate change has become one of the major factors affecting the hydrological regime of the Chirchik River. Rising air temperatures may lead to glacier retreat, changes in the timing of snowmelt, and increased evaporation. Although accelerated glacier melting may temporarily increase river flow during the initial period, the long-term depletion of glacier reserves may eventually result in reduced summer discharge[8].

Changes in precipitation patterns also influence the annual and seasonal flow of the river. Uneven precipitation distribution between years results in alternating high-flow and low-flow periods. During dry years, increasing water demand combined with declining natural inflow may intensify the risk of water scarcity. In wet years, higher discharges and flood events may occur.

From this perspective, studying the long-term dynamics of the Chirchik River's hydrological regime is of considerable scientific and practical importance[9]. Analysis of long-term hydrological observation records makes it possible to determine variations in river discharge over time, seasonal flow distribution, the recurrence of maximum and minimum values, and the influence of reservoir operation on the flow regime[10].

Statistical analysis of long-term observation series enables the identification of increasing or decreasing trends in river flow. Furthermore, determining the relationships between water discharge and meteorological factors, including air temperature, precipitation, snow cover, and glacier conditions, is essential for forecasting future water availability.

A comprehensive study of the hydrological regime of the Chirchik River is necessary for the rational management of water resources, the sustainable supply of irrigation systems, the improvement of hydropower facility operation, and the protection of ecological conditions. Such studies also contribute to the development of scientifically based adaptation measures addressing potential water scarcity and extreme hydrological events under changing climatic conditions.

The main objective of this study is to analyse the long-term variations in the hydrological regime of the Chirchik River, assess the seasonal and interannual dynamics of river discharge, and determine the influence of natural and anthropogenic factors on river flow. The results of the study may provide a basis for developing practical recommendations for the efficient use, long-term planning, and sustainable management of water resources within the Chirchik River basin.

Materials and Methods

The study area was the reach of the Chirchik River monitored at the Gazalkent hydrological station. The Chirchik River is located in northeastern Uzbekistan and is predominantly supplied by snowmelt and glacier meltwater. The Gazalkent station is an important long-term monitoring site for assessing seasonal, interannual, and multi-decadal variations in river discharge. The geographical location of the basin and its principal hydrographic network are shown in Figure **??**.

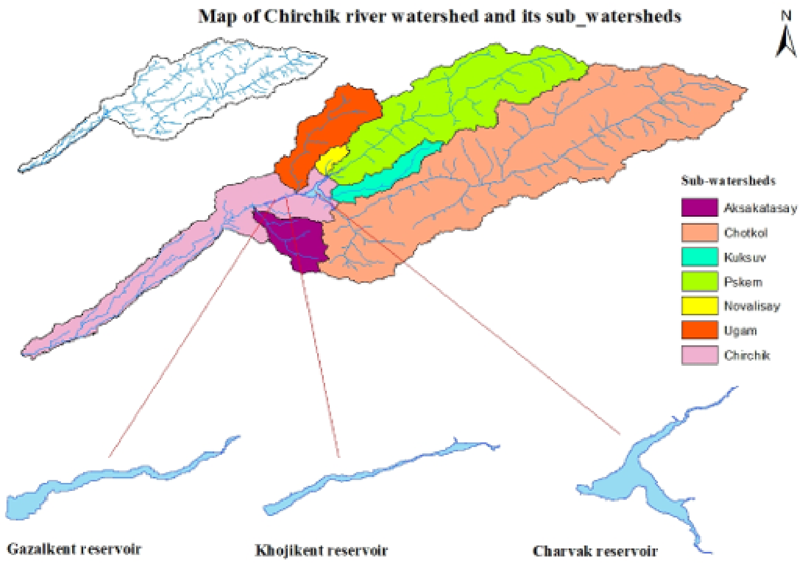

Figure 1. Location of the Chirchik River basin and its hydrographic network

The analysis used mean monthly discharge records from the Gazalkent hydrological station for the period 1900–2022. The dataset was compiled from statistical tables prepared from systematic observations by the Hydrometeorological Service of the Republic of Uzbekistan (Uzhydromet). All discharge values were expressed in cubic metres per second (m^3/s). The long observation period provided a suitable basis for identifying seasonal patterns, interannual variability, long-term tendencies, and extreme hydrological years.

Before the statistical analysis, the dataset was checked and prepared for processing. Duplicate records, blank cells, non-numeric entries, and possible inconsistencies in the time series were identified. Only years containing a complete set of 12 monthly observations within 1900–2022 were retained for the principal analyses. Missing or unreliable values were not included in the calculation of annual statistics. This procedure produced a temporally consistent hydrological series suitable for comparison across the entire study period.

Descriptive statistics were calculated for each month and each year. These included the arithmetic mean, median, minimum, maximum, standard deviation, and coefficient of variation. The coefficient of variation was used to express discharge variability relative to the mean and was calculated as follows:

$$C_v = \frac{\sigma}{\overline{Q}} \times 100\% \tag{1}$$

where C_v is the coefficient of variation (%), σ is the standard deviation (m^3/s), and $\overline{Q}$ is the mean discharge (m^3/s).

The mean annual discharge for each year was calculated from the corresponding 12 monthly values using:

$$\overline{Q} = \frac{1}{12}\sum_{i=1}^{12} Q_i \tag{2}$$

where $\overline{Q}_y$ is the mean annual discharge (m^3/s), and Q_i is the mean discharge for month i (m^3/s).

Time-series plots were prepared for both annual and monthly discharge. These graphs were used to visualize the alternation of high-flow and low-flow periods, the intra-annual distribution of runoff, and changes in the amplitude of discharge fluctuations over time. The long-term direction of annual discharge change was assessed using ordinary least-squares linear regression:

$$Q_t = a + bt \tag{3}$$

where Q_t is the estimated discharge at time t, a is the intercept, and b is the trend coefficient. A positive value of b indicates an increasing tendency, whereas a negative value indicates a decreasing tendency. The coefficient of determination (R^2) was used to describe the proportion of temporal variation explained by the fitted linear trend.

To reduce the influence of short-term fluctuations and more clearly reveal the underlying long-term pattern, a 12-month moving average was calculated for the monthly discharge series:

$$MA_t = \frac{1}{12}\sum_{j=0}^{11} Q_{t-j} \tag{4}$$

where MA_t is the 12-month moving average at time t, and Q_{t-j} represents the monthly discharge included in the moving window.

Discharge anomalies were determined by comparing each annual or monthly value with the corresponding long-term mean. Absolute anomalies were calculated as:

$$A_i = Q_i - \overline{Q} \tag{5}$$

where A_i is the discharge anomaly (m^3/s), Q_i is the observed annual or monthly discharge (m^3/s), and $\overline{Q}$ is the corresponding long-term mean discharge (m^3/s). Positive anomalies identify wetter-than-average periods, whereas negative anomalies indicate drier-than-average periods.

Extreme hydrological years were identified by ranking the mean annual discharge values in ascending and descending order. The years with the highest and lowest mean discharges were subsequently classified as the principal high-flow and low-flow years of the observation period. Their positions within the long-term series were assessed using descriptive statistics and time-series visualizations.

Microsoft Excel was used for the initial organization, screening, and tabulation of the data. Python was used for statistical calculations, time-series processing, linear regression, moving-average and anomaly analysis, identification of extreme years, and preparation of publication-quality graphics. The results were presented through statistical summaries, annual and monthly hydrographs, trend lines, moving-average curves, and anomaly plots. The selected procedures are consistent with commonly applied approaches for the analysis of long-term hydrological records and with methods used in previous studies [1].

Results and Discussion

Long-term monthly variability. The monthly discharge series for 1900–2022 demonstrates a pronounced seasonal pattern. River discharge generally increases during spring, reaches its highest values in late spring and early summer, and then gradually declines during late summer and autumn. The long-term mean monthly discharge peaks between April and June; although the exact timing and magnitude of the peak vary from year to year, consistently high flows are observed in May and June. In contrast, the lowest discharge values occur during the winter months Figura 2.

According to the calculations, the long-term mean discharge reached approximately 553 m³/s in June, with a standard deviation of about 175 m³/s, whereas the corresponding values in January and February were approximately 91 and 90 m³/s, respectively. Therefore, more than half of the annual flow is formed during spring and early summer, reflecting the snow- and glacier-fed character of the mountainous Chirchik River basin. Previous studies reported that 52.4 % of the annual flow occurred from March to June, 32.1 % from July to September, and the remaining 15.5 % during the colder part of the year [10].

The long-term monthly statistics indicate that winter discharge generally ranges from approximately 90 to 115 m³/s. The mean discharge increases to about 231 m³/s in April and reaches

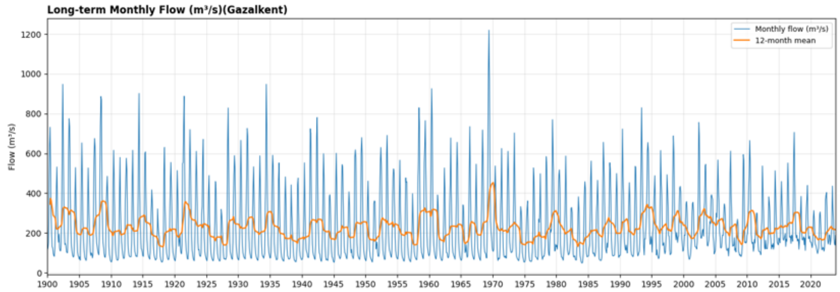

Figure 2. Figure 2. Long-term dynamics of monthly water discharge at the Gazalkent hydrological station. According to the calculations, the long-term mean discharge reached approximately 55

approximately 553 m³/s in June. Interannual variability also differs considerably among months. For example, the standard deviation is approximately ±175 m³/s in June, compared with only about ±32 m³/s in November. This contrast indicates that the high-flow season is substantially more variable than the low-flow season.

Annual flow statistics. For the 1900–2022 observation period, the overall mean of the annual average discharge was 228.2 m³/s, while the median was 221.4 m³/s. The standard deviation was 52.8 m³/s. The maximum annual average discharge, 449.5 m³/s, was recorded in 1969, whereas the minimum value, 133.0 m³/s, occurred in 1917 (Figure 3). The coefficient of variation of the annual discharge series was 0.23, indicating that annual values generally varied by approximately 20–25% around the long-term mean.

Figure 3. Figure 3. Long-term dynamics of annual water discharge at the Gazalkent hydrological station.

This degree of variability is characteristic of mountainous river basins whose runoff is strongly controlled by year-to-year differences in snow accumulation, glacier melt, precipitation, and air temperature. Consequently, substantial fluctuations were observed between wet and dry years throughout the study period.

Extreme years. The analysis identified several exceptionally wet and dry years. The wettest years were 1969, with an annual average discharge of 449.5 m³/s, followed by 1908 with 360.4 m³/s and 1921 with 349.4 m³/s. The driest years were 1917, 1927, and 1957, with annual average discharges of 133.0, 139.7, and 141.3 m³/s, respectively. The exceptionally high runoff observed in 1969 was likely associated with favourable snow accumulation and precipitation conditions, whereas the very low flow in 1917 reflects comparatively dry hydroclimatic conditions. Previous research also identified 2010 as a relatively high-flow year and 2020 as a lower-flow year [13], which is consistent with the recent portion of the long-term record.

Long-term trend. A linear regression model was applied to the annual discharge series for the entire 1900–2022 period. The estimated slope indicated a slight decrease of approximately 0.06 m³/s per year. However, the coefficient of determination was very low, showing that the trend was weak and not statistically significant. Thus, although the long-term series suggests a minor downward tendency, year-to-year natural variability remains much greater than the estimated linear change.

A modest decline was also observed between 2010 and 2020, with relatively high discharge at the beginning of the decade and lower discharge toward its end. This pattern is visible in the 12-month moving-average series and in the annual anomaly plots. Nevertheless, a short period such as one decade should not be interpreted independently of the full 123-year record. Reservoir regulation, irrigation withdrawals, climatic variability, changes in snow and glacier conditions, and possible changes in hydrological observations may all influence the recorded discharge. Therefore, the weak long-term trend should be interpreted cautiously and evaluated together with complementary meteorological and water-use data.

The results presented above make it possible to explain the observed changes in the hydrological regime of the Chirchik River through the combined influence of several natural and anthropogenic factors. Among these, climatic processes play a particularly important role. Over the past five decades, a consistent increase in air temperature has been observed across Uzbekistan and Central

Asia, as reported in both IPCC assessments and regional studies [2]. In the arid and semi-arid regions of Central Asia, the average rate of warming has been estimated at approximately 0.2–0.3°C per decade. This warming has been accompanied by an increase in the frequency and duration of extreme weather events, including prolonged heat waves, droughts, and periods of abnormally high summer temperatures.

Rising air temperatures directly affect the formation of river runoff in mountainous catchments. The flow of the Chirchik River largely depends on seasonal snow accumulation, snowmelt, and glacier melt in the western Tien Shan Mountains. Therefore, changes in temperature conditions may alter both the volume and timing of runoff. Under warmer climatic conditions, snow begins to melt earlier in spring, which can shift the seasonal flood peak toward earlier months. At the same time, reductions in snow cover and glacier storage may decrease the amount of water available during late spring and summer, when water demand for irrigation and domestic supply is highest.

Accelerated glacier retreat may initially increase meltwater contribution to rivers. However, this effect is generally temporary. As glacier area and ice volume continue to decline, the long-term contribution of glacier melt to river flow may also decrease. Consequently, the Chirchik River may experience higher flows during certain warm periods in the short term, followed by a gradual reduction in summer runoff over longer time scales. This process may increase the vulnerability of the basin to seasonal water scarcity.

Numerous studies conducted in Central Asia indicate that no uniform long-term trend in precipitation was observed throughout all arid areas between 1980 and 2020. Nevertheless, local increases or decreases may occur in high-altitude regions, including the Chirchik and Chatkal catchments. These differences are related to elevation, topography, atmospheric circulation, and the seasonal distribution of precipitation. In mountainous areas, even relatively small changes in winter precipitation may have a considerable influence on the accumulation of snow reserves and the subsequent formation of spring and summer runoff.

According to regional climate-model projections, winter precipitation in the Chirchik River basin may remain close to its long-term average, whereas summer precipitation may decrease slightly. Even where annual precipitation totals do not change significantly, changes in precipitation type and timing may still affect runoff generation. For example, a larger proportion of winter precipitation may fall as rain rather than snow under warmer conditions. This reduces the amount of water stored in the seasonal snowpack and may lead to earlier runoff, smaller spring flood peaks, and reduced water availability during the summer period.

An increase in air temperature, particularly a rise in the number of continuously hot days, also intensifies evaporation from reservoirs, river surfaces, soils, and irrigated agricultural areas. Higher evapotranspiration rates increase water losses within the basin and reduce the proportion of precipitation that contributes directly to river runoff. Therefore, even in the absence of a pronounced decrease in annual precipitation, warming alone may negatively affect the amount of water available in the Chirchik River system.

The second major group of factors consists of anthropogenic impacts. Since the 1970s, the natural flow regime of the Chirchik River has been substantially modified by the construction and operation of major reservoirs, dams, hydropower facilities, and diversion canals, including the Charvak, Khodjikent, and Gazalkent hydraulic structures. The Charvak Reservoir, with a storage capacity of approximately 2.2 billion m³, plays the principal role in regulating river flow. It stores a considerable portion of the high spring inflow and releases water according to irrigation, hydropower-generation, industrial, and municipal water-supply requirements.

The operation of reservoirs considerably changes the seasonal distribution of river discharge. During the natural high-flow period, reservoirs retain part of the snowmelt and glacier-melt runoff, thereby reducing the magnitude of spring flood peaks. During the summer irrigation period and low-flow seasons, stored water is released to maintain water supply and energy production. As a result, the regulated hydrograph becomes smoother than the natural hydrograph, with lower peak flows and relatively more stable discharge during the summer and winter months.

Although reservoir regulation improves the reliability of water supply and reduces the risk of extreme flooding, it may also alter the natural hydrological and ecological functioning of the river. Reduced flood peaks can influence sediment transport, channel-forming processes, floodplain inundation, aquatic habitats, and the seasonal renewal of riparian ecosystems. Consequently, changes observed in the long-term discharge series may reflect not only climate variability but also operational decisions associated with reservoir storage and water releases.

At present, a substantial share of the Chirchik River's water resources is diverted through the Chirchik–Bozsuv irrigation system to supply more than 100,000 hectares of irrigated agricultural land in Tashkent Region [4]. Large quantities of water are withdrawn during the vegetation period for the cultivation of cotton, cereals, vegetables, orchards, and other crops. These withdrawals may reduce the amount of water remaining in the main river channel, particularly in the lower reaches and during dry years.

Losses within irrigation canals, seepage, inefficient water distribution, and evaporation from agricultural fields may further reduce the volume of water returning to the river system. Return flows from irrigated areas may partially compensate for direct withdrawals, but their timing and quality differ considerably from those of natural river flow. Such return waters may contain dissolved salts, nutrients, pesticides, and other agricultural pollutants, which can affect the ecological condition of the river.

Other anthropogenic pressures include the discharge of municipal wastewater, industrial effluents, suspended solids, and chemical pollutants. Although these factors may have a relatively limited direct effect on the total volume of river discharge, they significantly influence water quality and the ecological status of the Chirchik River. Furthermore, urban expansion, industrial development, and increasing population density in the Tashkent region are expected to increase future demand for river water.

The weak long-term decreasing trend identified in the annual discharge series may therefore be associated with the combined effects of increasing air temperature, changes in snow and glacier accumulation, higher evaporation, reservoir regulation, and growing water withdrawals. However, the low statistical significance of the linear trend indicates that substantial natural interannual and multi-decadal variability remains present in the river-flow record. Wet and dry periods may alternate over several years or decades, making it difficult to attribute observed changes to a single factor.

In general, the variations observed in the hydrological regime of the Chirchik River are the result of a complex interaction between climate variability and human activity. Climate-related factors mainly affect the formation, seasonality, and long-term availability of runoff, whereas anthropogenic factors control its redistribution, storage, abstraction, and use within the basin. The effects of these factors may reinforce or partially compensate for one another depending on the season and hydrological conditions.

Among the anthropogenic factors, the construction and operation of reservoirs, dams, and diversion canals have had the greatest influence on the seasonal river-flow regime. Previous studies of mountainous basins in Central Asia have suggested that reservoir regulation and extensive water abstraction may reduce the average spring–summer flow in downstream river sections by approximately 20–30 %, depending on reservoir capacity, operational regime, climatic conditions, and irrigation demand. However, the magnitude of this impact may differ considerably between years and individual river basins.

Therefore, continuous hydrological and meteorological monitoring is essential for distinguishing natural climatic changes from the effects of river regulation and water consumption. Future studies should combine long-term discharge observations with data on air temperature, precipitation, snow cover, glacier area, reservoir inflow and outflow, and irrigation withdrawals. Such an integrated approach would allow a more accurate assessment of the relative contribution of each factor to changes in the Chirchik River's hydrological regime.

Understanding these interactions is particularly important for developing sustainable water-management strategies under changing climatic conditions. Improved reservoir-operation rules, reduced water losses in irrigation networks, modernized water-accounting systems, and the maintenance of minimum environmental flows may help reduce future water-scarcity risks. These measures would also support the long-term reliability of agricultural, hydropower, industrial, municipal, and ecological water uses within the Chirchik River basin.

Conclusions

Based on the continuous long-term dataset, the variations in river discharge at the Gazalkent hydrological station on the Chirchik River were comprehensively analysed. The results showed that the long-term mean discharge remained relatively stable throughout the study period, although considerable interannual and seasonal variability was observed. Distinct wet and dry years were identified, while the overall long-term trend indicated a weak decrease in annual discharge. Although this declining tendency was not statistically pronounced, it may become more important in the future under the combined effects of climate change, increasing water demand, reservoir regulation, and intensive irrigation development.

The study confirms that the hydrological regime of the Chirchik River is influenced by both natural and anthropogenic factors. Climatic conditions, particularly changes in air temperature, snow accumulation, glacier melt, and precipitation distribution, determine the formation and seasonal timing of river runoff. At the same time, reservoirs, irrigation canals, water abstractions, and hydropower operations substantially modify the natural flow regime. Therefore, the sustainable management of the Chirchik River requires an integrated approach that considers long-term hydrological variability, future climate scenarios, water-use efficiency, and ecosystem requirements.

The principal recommendations derived from the study are presented below.

Improvement of water allocation and irrigation efficiency. Existing reservoirs, hydraulic structures, and irrigation canals should be modernized to improve the storage and regulation of spring and early summer runoff. Where technically and environmentally justified, additional regulating reservoirs or local water-storage facilities may be considered to reduce water shortages during dry periods. Particular attention should be given to the rehabilitation of ageing irrigation infrastructure, reduction of seepage and conveyance losses, and improvement of water-accounting systems [3]. The wider introduction of drip irrigation, sprinkler irrigation, and other water-saving technologies may substantially reduce agricultural water consumption. In addition, the use of treated wastewater, drainage water, and closed-loop water-reuse systems should be expanded in agriculture and industry where water-quality requirements permit.

Climate-adaptive water management. Reservoir operating regimes should be adjusted dynamically using climate-model projections, seasonal hydrological forecasts, and real-time monitoring data. Changes in snow accumulation, glacier melt, rainfall patterns, and the timing of spring runoff should be continuously assessed. During years with high spring inflow, a greater volume of water should be stored for use during the summer irrigation period. In dry years, reservoir releases should be carefully coordinated among irrigation, drinking-water supply, hydropower production, industrial use, and environmental needs. The technical condition and operational efficiency of dam facilities, hydropower structures, pumping stations, gates, and diversion canals should also be regularly inspected and improved.

Protection of river ecosystems. Water-management decisions should not be limited to economic water demand but should also maintain the ecological stability of the river system. Minimum environmental flows should be established for critical river sections to preserve aquatic habitats, riparian vegetation, sediment transport, and natural channel processes. During naturally high-flow periods, a proportion of the flood pulse should be allowed to pass downstream where possible, since seasonal high flows play an important role in maintaining river and floodplain ecosystems.

Water-quality monitoring should be strengthened along the entire river, particularly downstream of urban, industrial, and agricultural areas. Regular measurements of suspended sediments, salinity, nutrients, organic pollutants, heavy metals, and other contaminants are necessary to identify sources of pollution and prevent further degradation. New regulations and practical measures should be introduced to reduce untreated municipal wastewater, industrial discharges, and agricultural return flows entering the river.

Strengthening monitoring and data management. Long-term hydrological observations at the Gazalkent station and other monitoring points in the Chirchik basin should be continued without interruption. Hydrological data should be integrated with meteorological, glaciological, reservoir-operation, groundwater, irrigation-withdrawal, and water-quality information. The use of automated hydrological stations, remote sensing, geographic information systems, and digital water-accounting technologies would improve the accuracy, accessibility, and timeliness of water-resource assessments.

Future studies should examine not only annual mean discharge but also changes in seasonal flow distribution, maximum and minimum discharges, flood frequency, drought duration, and the timing of peak runoff. The application of non-parametric trend tests, change-point analysis, climate–runoff modelling, and scenario-based forecasting would provide a more detailed understanding of future changes in the Chirchik River regime.

Implementation of these recommendations would support the efficient, environmentally responsible, and climate-resilient management of water resources in the Chirchik River basin. Improved regulation and monitoring would help reduce the risks associated with drought, seasonal water shortages, and extreme hydrological events. In the long term, sustainable management of the Chirchik River will contribute to reliable water supply, agricultural productivity, hydropower generation, ecosystem conservation, and the social and economic well-being of the population living within the basin.

Authors' contribution

Conceptualization, D.K.R. and I.B.Z.; methodology, D.K.R. and I.B.Z.; validation, F.K.B.; formal analysis, F.K.B., D.K.R., and I.B.Z.; investigation, D.K.R. and I.B.Z.; resources, D.K.R. and I.B.Z.; data curation, F.K.B.; writing—original draft preparation, D.K.R. and I.B.Z.; writing—review and editing, F.K.B., D.K.R., and I.B.Z.; visualization, F.K.B., D.K.R., and I.B.Z.; supervision, F.K.B. All authors have read and agreed to the published version of the manuscript.

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Consent for publication.

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Data Availability Statement

The data supporting the findings of this study are presented within the article in the relevant tables and figures.

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Conflict of interest

The authors declare no conflicts of interest.

Abbreviations

GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
R^2	Coefficient of Determination
CV	Coefficient of Variation
MA	Moving Average
OLS	Ordinary Least Squares
m^3/s	Cubic Metres per Second
FAO	Food and Agriculture Organization of the United Nations
UNEP	United Nations Environment Programme

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