CENTRAL ASIAN JOURNAL OF SUSTAINABILITY AND CLIMATE RESEARCH (2023) 2(2):69-84

https://doi.org/10.29258/CAJSCR/2023-R1.v2-2/69-84.eng

CAJSCR

Water resources and regional climate change: Almaty metropolis case

Saniya Akhmetova [a,b], **Svetlana Polyakova** [a], **Kassym Duskayev** [a], **Aleksandr Chigrinets** [a]

[a] Al-Farabi Kazakh National University, 71 Al-Farabi Ave., Almaty, 050040, Kazakhstan

[b] Kazakh-German University, 173 Nazarbayev St., Almaty, 050000, Kazakhstan

ABSTRACT

Water resource vulnerability in urbanized areas due to the impact of climatic factors manifests a complex and urgent challenge, assessing which is of great scientific, social, and applied significance. The intensity and changes of the hydrological characteristics of urban water objects differ significantly from these of natural water bodies. The condition of water objects is the most important indicator of the overall ecological well-being of a metropolis. This research aimed to evaluate the current (1971-2020) climate change and its influence on water resources during the warm period of the year based on the example of Almaty Metropolis. The study showed an increase of air temperature (from 0.17°C/10 years up to 0.41°C/10 years) at all target weather stations, with the greatest change observed in foothill areas (Almaty Joint Hydrometeorological Station). The observed precipitation change fell within the limits of mean multiyear values. The calculated basic hydrological characteristics of river runoff showed an increase since 1990s explained by air temperature and glacier melt trends. The article proposes certain recommendations on considering the influence of natural factors on Almaty's water resources, keeping in my mind that water management affects many areas of human activity.

ARTICLE HISTORY

Received: October 4, 2023
Accepted: November 16, 2023
Published: December 1, 2023

KEYWORDS

water resources, climate change, river runoff, air temperature, precipitation

CONTACT **AkhmetovaS.T.** akhmetova@dku.kz, Al-Farabi Kazakh National University, 71 Al-Farabi Ave., Almaty, 050040, Kazakhstan

Published by Kazakh German University, Almaty/Kazakhstan

1. Introduction

Recently, climate has been changing significantly, and these changes are world-spanning in nature. The rapid global trends propelling climate change include quick demographic growth, rising energy and food demands, fast development of new technologies, depletion of water and soil resources, urbanization, etc. (EEA, 2017). On the global scale, climate change can be traced to weather pattern fluctuations, as well as an increase in extreme weather events affecting many sectors of life. For example, 2017 saw multiple natural disasters with high economic impact, with the total losses estimated at $320 bln, and the largest total annual losses (WMO, 2018). Since the early 1980s, there has been an upsurge in heatrelated illnesses and deaths, with 20 days of extreme temperatures per year (WMO, 2018). Population migration associated with severe weather events constitutes one of the negative consequences of changing climatic conditions – for instance, 23.5 mln people were displaced due to the above reason in 2016 (IDMC, 2017). The disappointing forecasts of adverse climate change consequences encompass all regions of the world, and in this sense Central Asia (CA) is no exception. The Central Asian Region (CAR) includes Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, all highly dependent on and prioritizing exports in ensuring their food security, in turn directly related to water resources (Orlovsky et al., 2019).

Today, water serves the main factor determining the sustainability of any country's economy. Water scarcity is becoming more tangible every day. Even though Central Asia has substantial water resources, many experts predict their deficit in the next decades against the background of mounting water consumption and global climate change. The intensive use (80-90% of the total volume) of irrigation water in agriculture represents the main driver behind water depletion in the region. In addition, low efficiency of water management systems leads to huge and irretrievable water losses significantly complicating water relations and water resource management both across the CAR as a whole and inside individual countries (Orlovsky et al., 2019).

Based on the regional studies of temperature dynamics in CA and National Communications by CA states under the United Nations Framework Convention on Climate Change (UN FCCC), it is fair to say that the CAR is witnessing an overall warming trend. This is evidenced by the data showing an increase in temperatures in all five countries concerned. According to the IPCC reports, over the last century Central Asia has seen a 1-2°C growth in mean air temperatures (IPCC, 2007). Due to the fact that land temperatures in the Northern Hemisphere are higher than water surface temperatures in the Southern Hemisphere (IPCC, 2013; NEACC, 2018), in Central Asia the climate has been changing at a faster rate than globally. There is likewise a tendency of increasing number of warm winters and dry summers in most of the region leading to the degradation of glaciers and permafrost in the Pamir and Tien Shan Mountains. In fact, the area of mountain glaciation in CA has shrunk by almost one third due to the increase of mean annual atmospheric air temperature by less than 10°C over the last 100 years (Zholdosheva et al., 2017). Many researchers claim that in Kazakhstan temperature growth is much more intensive than in other countries.

The risks of heavy precipitation, increased aridity, flooding, and mudslides are also growing. There is no doubt that climate change imposes adverse impacts on the quantity, quality and seasonal dynamics of water resources, agriculture, and human health, and further exacerbates current challenges such as desertification and degradation of ecosystems and natural resources. Climate change and water resource depletion are of key importance for the economic development and future livelihoods of the countries sharing the Aral Sea Basin subject to everescalating water scarcity (Salnikov et al., 2023; Salnikov et al., 2018; Salnikov et al., 2015; Genina et al., 2011).

2. Study area

Almaty, Astana and Shymkent are Kazakhstan's largest urban communities holding the status of the "cities of national significance". Geographically, Almaty is located in the Balkhash-Alakol Water Basin. It is the country's largest metropolis and the center of urban agglomeration.

The city's water objects – and, the same is true for the entire Kazakhstan – represent the central element of national and regional security, and play a key role in providing the population with food as well as supplying water for Almaty industry. Four water courses – the Kishi Almaty and Ulken Almaty, Aksai and Kargaly Rivers – flow through the city and are actively used for industrial and drinking water supply, irrigation, power generation, etc. River embankments host multiple leisure and recreational facilities attracting substantial number of domestic and foreign vacationers every day. Some of these sites like the Shymbulak Ski Resort and Medeo High-Altitude Skating Rink are widely known practically all over the world (Chigrinets, 2015; RCH, 2009; Chigrinets et al., 2019; Vilesov, 2010; Vilesov et al., 2013).

In addition to climate change, the pressure on water resources is growing due to rapid urbanization. Urban communities and their populations are expanding every year. The analysis of Almaty's demographics over the past decades shows a steady population growth bolstered by annual domestic migration. As of March 1, 2023, the population of the metropolitan area amounted to 2 170 869 people and continues to increase.

In 2030, the urban population due to migration may reach 3 million. This entails overloading the entire city infrastructure and leads to even greater pressure on its water resources. Along with demographic growth, the territory of the metropolis is undergoing active development imposing additional pressure on its water objects (Almaty City Akimat, 2019).

Thus, due to the expected growing water consumption in Almaty Region to meet the needs of the increasing population and economic activity, the pressure on river flow, climate and water rotation will escalate at a high rate (Almaty City Akimat, 2019).

The near-term prospect of expected runoff reduction due to climate change makes this challenge even more acute. Melting of glaciers poses additional risks to the sustainable development and food security of the country and the constituency. Glacier degradation will cause the risk of short-term flooding followed by a long-term decline in water availability (RCH, 2009).

Creation of ecologically safe water environment and effective development of the water sector of Kazakhstan's "Southern Capital" manifests one of the main conditions for improving the comfort of living and health of Almaty residents. Therefore, it is extremely important to study all types of impacts on the city's water objects in detail (Almaty City Akimat, 2019).

The assessment of the current state of water resources in Almaty against the background of ongoing climatic changes and determination of the process development trend represents a methodological and practical basis for achieving sustainable water resource management in Almaty Region as well as in the country (Chigrinets et al. 2019).

This research aimed to analyze river runoff dynamics based on the data of 4 (four) hydroposts in the Kishi Almaty and Ulken Almaty River Basins under the influence of changes in the main climatic parameters according to the data from 4 (four) meteorological stations located at different altitudes during 1971 and 2020. Fig. 1. shows the study area map.

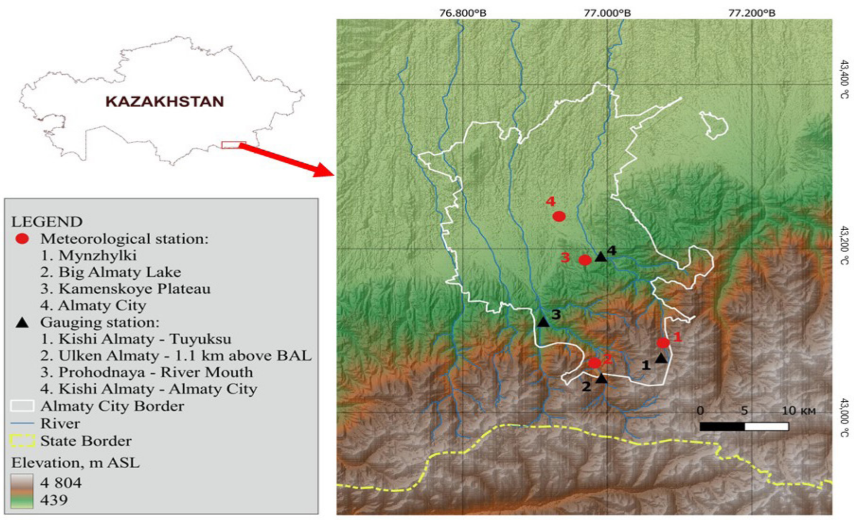


Figure 1. Study area.

3. Materials and methods

To analyze the current changes in climatic parameters and their impact on river flow fluctuations, the following mean monthly meteorological observations of Kazhydromet RSE (Republican State Enterprise) 4 weather stations in the study area (Almaty Joint Hydrometeorological Station (Almaty JHMS), Kamenskoye Plateau, Mynzhilki, Big Almaty Lake (BAL)) and annual data on the regime and resources of land surface water from the hydrological posts in the basins of the Kishi Almaty and Ulken Almaty Rivers for the warm period (April-October) during 1971-2020 were used as inputs:

Hydrological data - mean monthly discharge (1971-2020); climate data - monthly precipitation (1971-2020) and mean monthly air temperature (1971-2020); digital elevation model (DEM) - SRTM satellite imagery.

The study utilized the following methods: 1) spatial analysis – the research team created the study area map based on space imagery using QGIS 3.22 software; 2) statistical method –

• hydrological calculations were carried out as per the Code of Regulations (CR) 33-101-2003 Determination of Basic Design Hydrological Characteristics (SC for CHCS of the RF, 2004) and Methodological Recommendations for Determining Estimated Hydrological Characteristics in the Presence, Insufficiency, Absence of Hydrometric Observations and for Assessment of Homogeneity of Hydrological Characteristics and Determination of Their Values on the Basis of Dissimilar Data (SHI, 2009);

• runoff hydrographs (real year runoff method) were constructed for the altitudinally distributed hydroposts on the Kishi Almaty and Ulken Almaty Rivers. The actual years for building the hydrograph were determined based on the empirical curve of availability. Long-term mean values of Q, k modular index, dispersion, and Cv variation index were obtained based on the method of moments for the studied series. Consequently, the difference and total integral curves were constructed, from which the phases of low and high-water content were determined. Certain hydrological data series included gaps of several months that were restored using the method of correlation by year-analogue and river-analogue, which did not significantly affect the quality of outputs;

• series were tested for homogeneity based on Student's and Fisher's criteria. Student's test is used to check the homogeneity of hydrological series in terms of mathematical expectation. Fisher's criterion evaluates the homogeneity of series in terms of dispersion. The latter criterion is designed to analyze independent series obeying a normal distribution, the coefficients of skewness (Cs) and autocorrelation (r1) were taken into account during calculations (SC for CHCS of the RF, 2004);

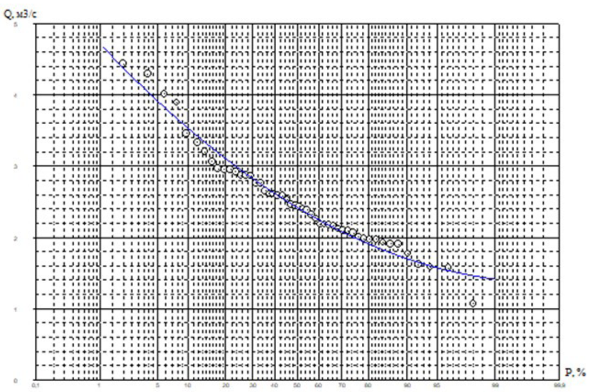
• significance of temperature and precipitation trends was assessed using the Mann-Kendall test. The Mann-Kendall test is used to determine whether a trend exists in time series data. It is a non-parametric test, meaning that no assumptions are made about data normality;

and 3) analytical methods: analysis of long-term runoff fluctuations, including the assessment of quasi-periodicity, trend, and statistical homogeneity of the series. Climatic series were analyzed by constructing time trends of changes in temperature and precipitation data averaged over the warm period.

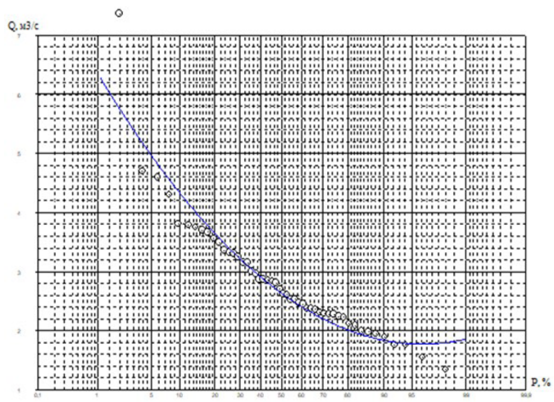
4. Results

4.1. Intra-annual runoff distribution

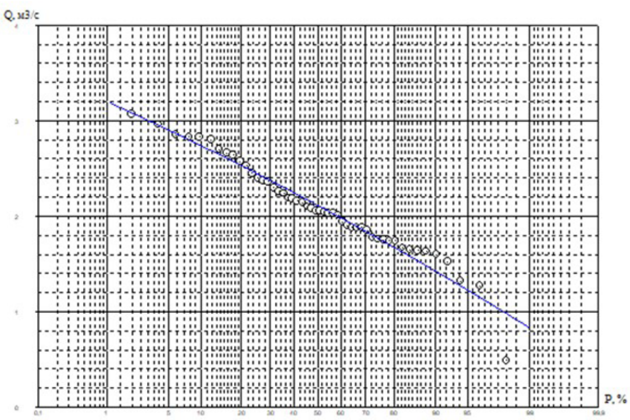
The rivers of the study area form their runoff on the northern slopes of the Ile Alatau Range. The predominant runoff of the Kishi Almaty River is spring-summer. The Ulken Almaty River is characterized by summer floods. The data of the supply curves in Fig. 2. demonstrate the closeness of the empirical points on the circumferential curves to the theoretical curve, as well as the fact that the theoretical curve almost completely covers the observed points.



a)



b)



c)

Figure 2. Water availability curves for the hydroposts of Kishi Almaty River - Almaty City (a), Ulken Almaty River - 1.1 km above BAL (b), and Prohodnaya River Mouth (c).

Table I. shows water discharge during periods of different water availability. The higher the latter, the lower the discharge. Based on the data of the table and curves, maximum discharge values are observed at the 5% level of water availability.

Table I. Water discharge (Q, m^3/s) during periods of different water availability at the Kishi Almaty and Ulken Almaty River hydroposts for the design warm period in 1971-2020.

Hydropost	Q_{max}	C_v	Availability, %				
			5	25	50	75	95
Kishi Almaty - Almaty City	4.43	0.27	4.01	2.87	2.43	2.06	1.58
Ulken Almaty - 1.1 km above BAL	4.7	0.35	4.59	3.32	2.65	2.28	1.69
Prohodnaya - River Mouth	3.07	0.23	2.9	2.4	2.06	1.76	1.29

Based on the availability curves in Fig. 3. and 4., 2001 (75% availability) and 2017 (5% availability) were selected as low- and high-water years with minimum and maximum observed discharge values, respectively.

For the hydroposts in the Kishi Almaty and Ulken Almaty River Basins located at different altitudes, annual runoff hydrographs were constructed for the above years.

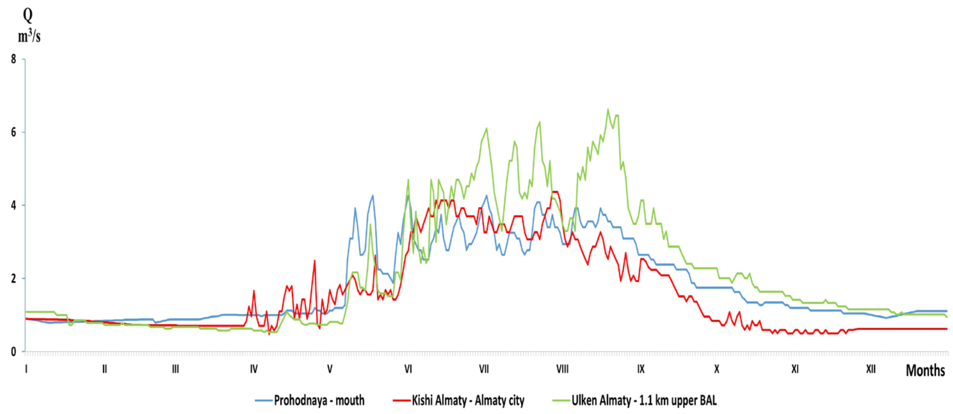


Figure 3. Low-water year (2001) runoff hydrograph at the Kishi Almaty River - Almaty City, Ulken Almaty River - 1.1 km above BAL, and Prohodnaya River Mouth.

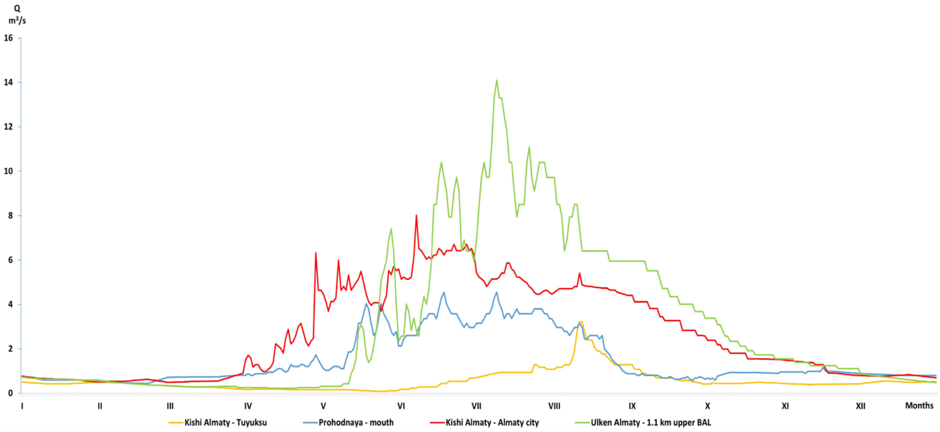


Figure 4. High-water year (2017) runoff hydrograph at the Kishi Almaty River - Almaty City, Ulken Almaty River – 1.1 km above BAL, Prohodnaya River Mouth, Kishi Almaty River – Tuyuksu Glacier.

The hydrographs in Fig. 3. and 4. allowed identifying a runoff increase at the hydroposts on the Kishi Almaty and Ulken Almaty Rivers starting in April and lasting until October. It should be noted that at the posts located at higher altitudes, the runoff increase is observed a month later. For instance, the Ulken Almaty River post located 1.1 km above BAL shows the runoff increase in May.

The flooding period from April to October (spring-summer) on average accounts for 80% of the annual runoff in the studied rivers, and thus is considered the flood period.

The highest monthly runoff during the flooding period at the surveyed posts is observed in July and August (16-20% of the annual runoff).

4.2. Changes in mean multiyear runoff for the warm period

The integral curves shown in Fig. 5-7. give a clear picture of the water regime changes for the studied rivers at the corresponding hydroposts. According to the averaged warm period flow data for 1971-2020, the integral flow curves were built for the Kishi Almaty – Almaty City, Ulken Almaty – 1.1 km above BAL, Prohodnaya – River Mouth posts.

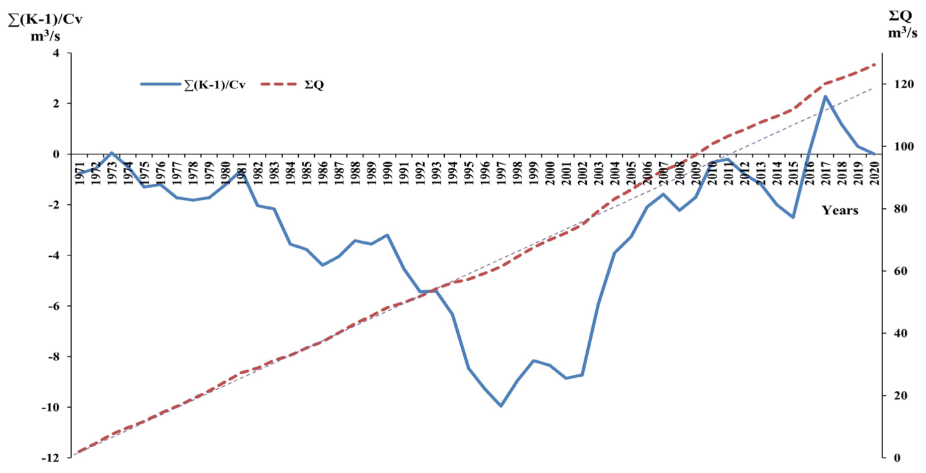


Figure 5. Integral flow curves for the Kishi Almaty – Almaty City hydropost (1971-2020).

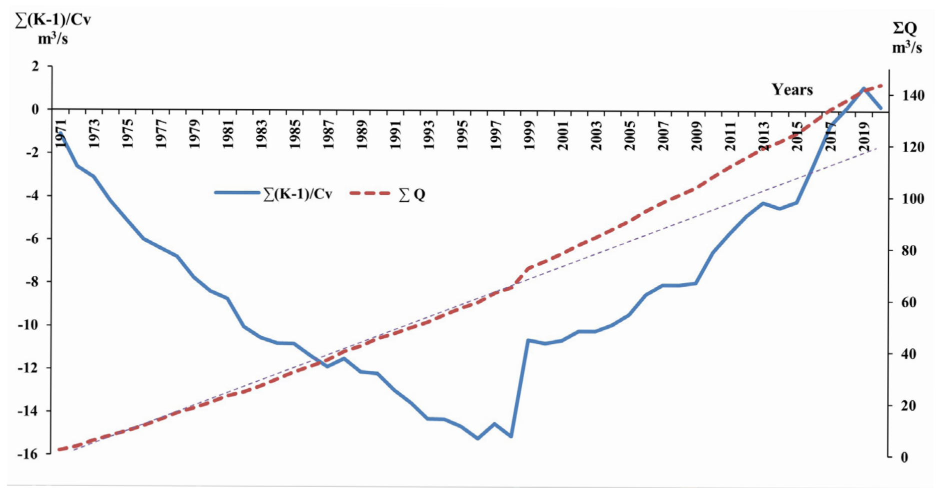


Figure 6. Integral flow curves for the Ulken Almaty - 1.1 km above BAL hydropost (1971-2020).

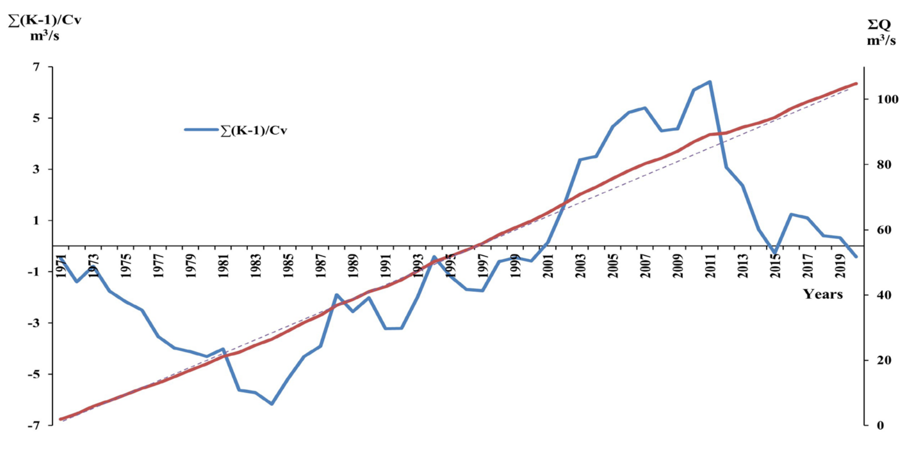


Figure 7. Integral flow curves for the Prohodnaya River Mouth hydropost (1971-2020).

The integral curves demonstrate an obvious trend of growing discharge at all the target hydroposts from the late 1990s till early 2000s, which can be explained by augmenting air temperature and subsequent melting of glaciers associated with the active positive climate change trend since 1990s. It is well-known that intra-annual river runoff variations are mainly driven by climatic factors.

4.3. Dynamics of main climatic parameters

The research team analyzed the peculiarities of climatic conditions in the study area by comparing the changes in the meteorological elements within the city limits based on the data of Almaty JHMS, Kamenskoye Plateau, BAL and Mynzhilki weather stations; and plotted the graphs of multiyear air temperature and precipitation sums at these sites (located at different altitudes) for the warm period from 1971 to 2020 (Fig. 8-11.).

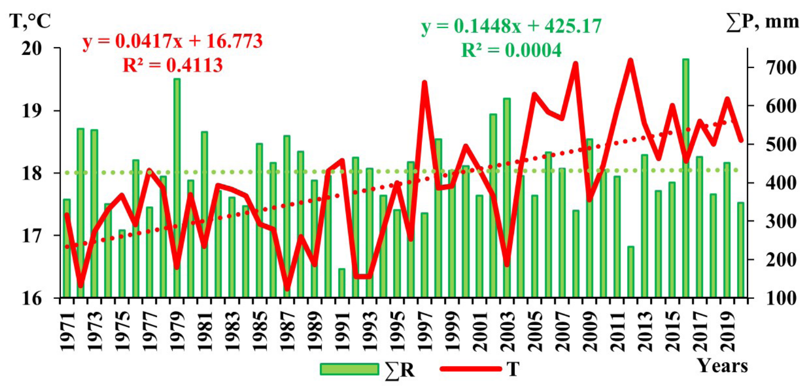


Figure 8. Multiyear (1971-2020) variations of mean air temperature and precipitation values during warm period (April-October) at Almaty JHMS Station.

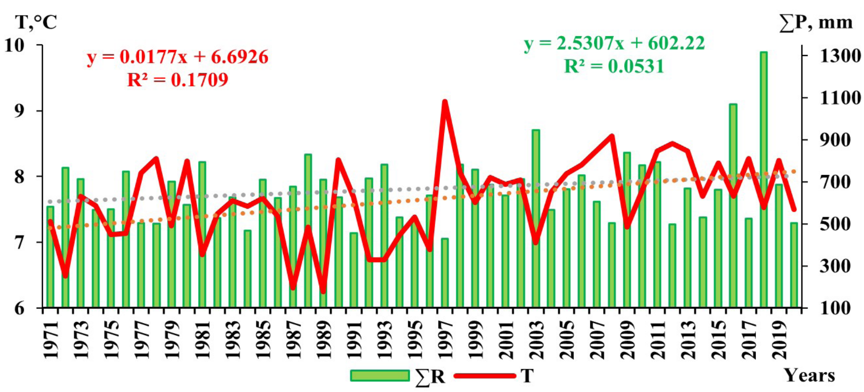


Figure 9. Multiyear (1971-2020) variations of mean air temperature and precipitation values during warm period (April-October) at BAL Station.

The analysis of air temperature trends shows a widespread positive trend of the parameter alteration. Mean multiyear temperatures during the warm period at all stations under consideration increased from 0.02°C/year (BAL) to 0.04°C/year (Almaty JHMS). The highest rate of temperature growth was observed at Almaty JHMS becoming less intense with altitude. The average anomaly for the last decade (2011-2020) in Almaty amounted to 1°C and exceeded the anomaly value of the previous decade (2001-2010) by 0.6°C. The mean anomaly value for the last decade exceeded the previous one by 0.4°C at the Kamenskoye Plateau station (Fig. 10.), and by 0.3°C and 0.2°C – at the Mynzhilki (Fig.11.) and BAL stations, respectively.

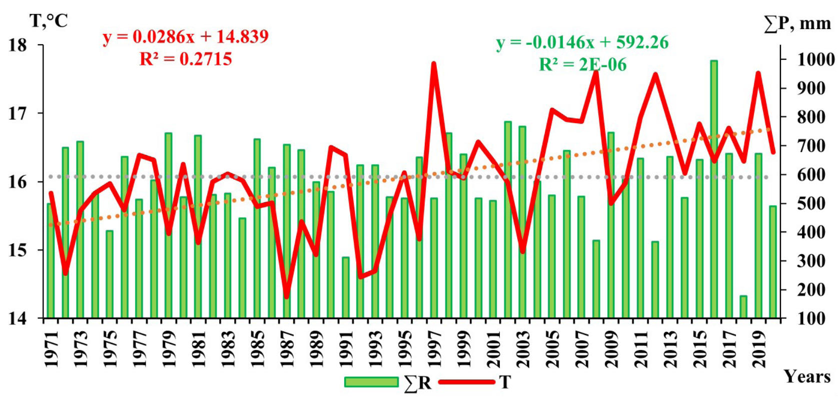


Figure 10. Multiyear (1971-2020) variations of mean air temperature and precipitation values during warm period (April-October) at Kamenskoye Plateau Station.

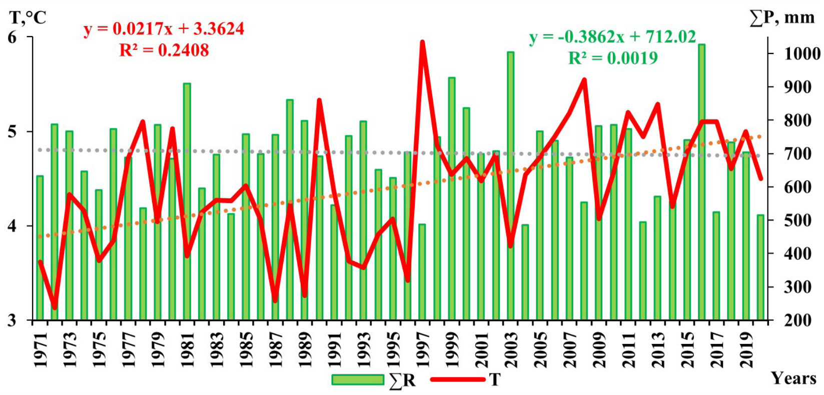


Figure 11. Multiyear (1971-2020) variations of mean air temperature and precipitation values during warm period (April-October) at Mynzhilki Station.

Contrast to air temperature, the assessment of linear precipitation trends showed weak negative dynamics at the Kamenskoye Plateau station, with the total warm period precipitation decreasing by 0.02 mm/year, as well as at the Mynzhilki station, with precipitation decreasing by 0.4 mm/year. It is worth noting that during the same period the amount of precipitation at the BAL station grew by 2.5 mm/year, and at the Almaty JHMS Station the trend line demonstrated an almost even course (0.1 mm/year). At the same time, during the last decade, an increase in precipitation was noted practically at all target weather stations except BAL, with the precipitation anomaly amounting to 58 mm (during 2011-2020) and 31 mm (during 2001-2011). At the stations of Kamenskoye Plateau and Almaty JHMS, the difference between the anomalies of the last and previous decades was 21 and 27 mm towards increase, respectively. The largest positive precipitation anomaly (approx. 58 mm) during the last 10 years was recorded at the Mynzhilki station.

The significance of the trends in air temperature and precipitation amounts was tested against the Mann-Kendal criterion (Table II.).

Table II. Significance of temperature and precipitation trends based on the Mann-Kendall Test.

Stations	Temperature		Precipitation	
	Z-Value	P-Value	Z-Value	P-Value
Almaty JHMS	4.66	0.000003	-0.13	0.90
Kamenskoye Plateau	3.67	0.0002	0.00	1.00
BAL	2.86	0.004	0.84	0.40
Mynzhilki	3.67	0.0002	-0.38	0.70

Whereas the Mann-Kendall test showed significance of the air temperature trends for all the target stations, the precipitation change trends, on the contrary, turned out to be insignificant.

5. Discussion

As a part of Central Asia, Kazakhstan – except for high-mountain areas – has insufficient moisture content, which is associated with its sparse hydrographic network. In terms of water availability, the country is one of the most water-deficient in Eurasia (RCH, 2009).

According to the study (Fazylov et al., 2017), in the next 30 years the volume of water resources in Kazakhstan’s highland basins will increase on average from 0.8-4.5% to 14.0-22.5%; and, will decrease by 7.0-10.3% in lowland watersheds, accordingly.

The data in the 8th National Communication and 5th Biennial Report of the

Republic of Kazakhstan to the UN FCCC point to a significant climate warming taking place in the country – the comparison of mean multiyear air temperatures for two consecutive periods (1961-1990 and 1991-2020) indicates an average 0.9°C growth in annual temperatures, with the most significant warming (by 2.0 and 1.7°C) registered in February and March, respectively. In July and December, the temperature did not change significantly (MEGNR of the RK, 2022).

As for precipitation, its mean annual value over the territory almost did not change, with certain months showing an increase (maximum in February (by 15.6%)) or a decrease (in September and October by 10.8% and 14.8%, respectively) (MEGNR of the RK, 2022).

This study assessed the condition and trends of Almaty City (southern part of the country located in the mountainto-plain transition zone) water resources in the context of regional climatic changes. The research outcomes confirm that intra-annual river runoff alterations are driven by climatic factors, especially air temperature, with the latter demonstrating a growing trend since the end of the 1990s.

As per the data of the MEGNR of the RK, all 10 extremely warm years have occurred in the course of the current century. This trend is well traced in Kazakhstan, with the exception of 1983 that ranked the third among the hottest years) (MEGNR of the RK, 2022).

The air temperature in Almaty City also continues to rise. The highest growth (0.41°C/10 years inside the city limits) is observed in the foothills. With altitude, the rate of air temperature increase slows down (0.17°C/10 years at Big Almaty Lake). During the period under consideration, the amount of precipitation varied within the limits of mean multi-year values (the trend line is not significant). Thus, it can be alleged that river runoff directly depends on temperature.

Mounting air temperature stimulates the melting of glaciers, which in the future may lead to irreversible consequences – lack of drinking water, reduction of river flow and irrigation resources, desertification, land degradation, as well as higher cost of energy and food-stuffs – exacerbated by the growing risk of hazardous hydrometeorological phenomena like floods, mudflows, high waters, droughts, dry winds, and sandstorms.

6. Conclusion

Air temperature is a key factor affecting water resources of Almaty City. Higher temperatures lead to the reduction of surface water reserves, droughts and intensive desertification, depletion of watersheds and rapid melting of glaciers. It is therefore necessary to design adaptation measures and recommendations to consider the impacts of natural factors on the hydrological characteristics of water objects (IPCC, 2015).

The research team proposes the following recommendations on water resource conservation and climate change adaptation:

1) enhance irrigation technologies and infrastructure in Almaty City and adjacent areas;

2) improve the hydrometeorological monitoring systems in high-mountain areas;

3) upgrade water use schemes;

4) strengthen or establish international strategic partnerships to develop joint climate change mitigation plans by supporting joint initiatives at national and regional levels.

Monitoring of regional climate indicators affecting river flows and the associated risks and impacts is essential for the Central Asian Region to achieve its sustainable development goals.

References

Almaty City Akimat (2019). Almaty City Development Strategy until 2050 [Strategiya razvitiya goroda Almaty do 2050 goda]. https://www.gov.kz/memleket/entities/almaty/documents/details/344101?lang=ru. (in Russian)

Chigrinets, A.G. (2015). Surface water resources of the territory of Almaty City [Poverkhnostnyye vodnyye resursy territorii goroda Almaty]. Hydrometeorology and Ecology [*Gidrometeorologiya i ekologiya]* 2, 66-78 (in Russian)

Chigrinets, A.G., Mazur, L.P., Duskayev, K.K., Chigrinets, L.Yu., Akhmetova, S.T. (2019). Water Economy Balance of Almaty City. *Journal of Ecological Engineering* 3(20), 194-203. http://www.jeeng.net/Water-Economy-Balance-of-the-Almaty-City,99783,0,2.html

European Environmental Agency, EEA (2017). Annual Report 2010 and Environmental Statement 2011 (ISSN 1561-2120). *Copenhagen*. https://www.eea.europa.eu/publications/annual-report-2010/download

Fazylov, A.R., Yergeshov, A.A., Kobuliyev, Z.V. (2017). The influence of climate change on the formation of river flow in the mountain-foothill zones of Central Asia [Vliyaniye izmeneniya klimata na formirovaniye stoka rek gorno-predgornykh zon Tsentral'noy Azii]. Water and Environmental Issues of Siberia and Central Asia. Water Resource Management Issues in Siberia and the Far East [*Vodnyye i ekologicheskiye problemy Sibiri i Tsentral'noy Azii. Problemy upravleniya vodnymi resursami Sibiri i Dal'nego Vostoka]* 4, 216-224. https://ecogosfond.kz/wp-content/uploads/2019/07/CA.D.241-Vlijanie-izmenenija-klimata-na-formirovanie-stoka.pdf. (in Russian)

Genina, M., Breitner Zuma, L., Umirbekov, A., Isayeva, G., Musagazhinova, A. (2011). Analysis of climate change adaptation activities in Central Asia. Needs, recommendations, practices [Analiz deyatel'nosti v oblasti adaptatsii k izmeneniyu klimata v Tsentral'noy Azii. Potrebnosti, rekomendatsii, praktiki]. Climate Change and Energy Efficiency Programme of the Central Asia Regional Environmental Centre (CAREC). https://carececo.org/upload/27.pdf. (in Russian)

Internal Displacement Monitoring Centre, IDMC (2017). Global Report on Internal Displacement (GRID 2017), *Norwegian Refugee Council*. http://www.internal-displacement.org/global-report/grid2017/pdfs/2017-GRID.pdf

Intergovernmental Panel on Climate Change, IPPC (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability, contribution of Working Group II to the 4th IPCC Assessment Report. https://

www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

IPCC (2015). Climate Change 2014: Impacts, Adaptation and Vulnerability, contribution of Working Group II to the 5th IPCC Assessment Report. World Meteorological Organization, *WMO*. https://www.ipcc.ch/site/assets/uploads/2018/03/WGIIAR5-IntegrationBrochure_ru-1.pdf. (in Russian)

IPCC (2013). Climate Change 2013: The Physical Science Basis, contribution of Working Group I to the 5th IPCC Assessment Report. https://www.ipcc.ch/site/assets/uploads/2017/09/WG1AR5_Frontmatter_FINAL.pdf

Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan, MEGNR of the RK (2022). 8th National Communication and 5th Biennial Report of the Republic of Kazakhstan to the UN Framework Convention on Climate Change. United Nations Development Programme (UNDP) in Kazakhstan, Global Environmental Facility. https://www.undp.org/kazakhstan/publications/8th-national-communication-and-5th-biennial-report-republic-kazakhstan-un-framework-convention-climate-change

North Eurasia Climate Centre, NEACC (2018). Annual Summary Report on Climate Features and Change in 2017 for the Territory of the Commonwealth of Independent States. Institute of the Global Climate and Ecology under the Russian Federal Service on Hydrometeorology and Environmental Monitoring and Russian Academy of Sciences. *WMO's NEACC*. http://seakc-old.meteoinfo.ru/images/seakc/monitoring/cis-climate-2017.pdf

Orlovsky, N.S., Sonn, I.S., Kostyanoi, A.G., Zhiltsov, S.S. (2019). Climate change and water resources of Central Asia [Izmeneniye klimata i vodnyye resursy Tsentral'noy Azii]. Bulletin of the Diplomatic Academy of the MFA of Russia. Russia and the World [*Vestnik Diplomaticheskoy Akademii MID Rossii. Rossiya i mir*] 1(19), 56-79. https://ecogosfond.kz/wp-content/uploads/2019/09/CA.D.255-Izmenenie-klimata-i-vodnye-resursy-Centralnoj-Azii.pdf. (in Russian)

Regional Centre of Hydrology, RCH (2009). The impact of climate change on water resources in Central Asia. Industry overview [Vliyaniye izmeneniya klimata na vodnyye resursy v Tsentral'noy Azii. Otraslevoy obzor]. *Sector Report No. 6, Eurasian Development Bank*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4107899. (in Russian)

Salnikov, V., Turulina, G., Polyakova, S., Petrova, Y., Skakova, A. (2015). Climate change in Ka-zakhstan during the past 70 years. *Quaternary International*, 358, 77-82. https://www.sciencedirect.com/science/article/abs/pii/S1040618214006557

Salnikov, V.G., Turulina, G.K., Talanov, E.A., Polyakova, S.E. (2018). Analysis of climate change in Kazakhstan over the past 75 years (Analiz izmeneniya klimata v Kazakhstane za posledniye 75 let). New Methods and Results of Landscape Research in Europe, Central Asia Asia and Siberia [*Novyye metody i rezul'taty issledovaniy landshaftov v Yevrope, Tsentral'noy Azii i Sibiri*] 1, 247-252 (in Russian)

Salnikov, V., Talanov, Y., Polyakova, S., Assylbekova, A., Kauazov, A., Bultekov, N., Musralinova, G., Kissebayev, D., Beldeubayev, Y. (2023). An Assessment of the Present Trends in Temperature and Precipitation Extremes in Kazakhstan. *Climate* 11(2), 33. https://doi.org/10.3390/cli11020033

State Committee for Construction and Housing and Communal Sector of the Russian Federation, SC CHCS RF (2004). CR 33-101-2003 Determination of the main calculated hydrological characteristics [SP 33-101-2003 Opredeleniye osnovnykh raschetnykh gidrologicheskikh kharakteristik]. https://files.stroyinf.ru/Data2/1/4294815/4294815038.pdf. (in Russian)

State Hydrological Institute, SHI (2009). Methodological recommendations for determining the cal-culated hydrological characteristics in the absence of hydrometric observations [Metodicheskiye rekomendatsii po opredeleniyu raschetnykh gidrologicheskikh kharakteristik pri otsutstvii dannykh gidrometricheskikh nablyudeniy]. Ministry of Natural Resources and Ecology of the Russian Federation, Federal Service of Russia for Hydrometeorology and Environmental Monitoring. http://www.hydrology.ru/sites/default/files/Books/gidro-2.pdf. (in Russian)

Vilesov, E.N. (2010). Climatic conditions of the city of Almaty [Klimaticheskiye usloviya goroda Almaty]. Almaty: LEM (in Russian)

Vilesov, E. N., Cherednichenko, V. S., Cherednichenko, Alexey V., Cherednichenko, Alexander V. (2013). Climate change in Almaty over the past 130 years [Izmeneniye klimata goroda

Almaty za posledniye 130 let]. KazNU Bulletin. Ecological series [*Vestnik KazNU. Seriya ekologicheskaya*], 2/2(38), 74-83. https://pps.kaznu.kz/2/Main/FileShow2/8646/101/%20359/750/%D0%A7%D0%B5%D1%80%D0%B5%D0%B4%D0%BD%D0%B8%D1%87%D0%20%B5%D0%BD%D0%BA%D0%BE%D0%92%D0%BB%D0%B0%D0%B4%D0%B8%D0%BC%D0%B8%D1%80%D0%A1%D0%B5%D1%80%D0%B3%D0%B5%D0%B5%D0%B2%D0%B8%D1%87/2014/2. (in Russian)

World Meteorological Organization, WMO (2018). WMO Statement on the State of the Global Climate in 2017, *WMO-No*. 1212. https://library.wmo.int/idurl/4/56119

Zholdosheva, E. et al. (2017). Adaptation to climate change in mountainous areas of Central Asia [Adaptatsiya k izmeneniyu klimata v gornykh rayonakh Tsentral'noy Azii]. Series of reviews on adaptation in mountainous areas. UN – Environment [*Seriya obzorov po adaptatsii v gornykh rayonakh. OON – okruzhayushchaya sreda*]. https://www.weadapt.org/sites/weadapt.org/files/centralasia_rus.pdf. (in Russian)