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Article

Assessment of Hydrometeorological Impacts of Climate Change on Water Bodies in Northern Kazakhstan

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Abstract: This article examines the impact of climate change on the hydrometeorological indicators of some lakes and reservoirs in the Akmola and North Kazakhstan regions. Two meteorological variables' annual and seasonal trends at three weather stations in 1986–2023 were analyzed. The non-parametric Mann–Kendall and Sen's slope methods were used to determine the presence of a positive or negative trend in weather data and their statistical significance. Hydrometric indicators were studied using the ArcGIS 10.8 program from 1995 to 2023. The results indicate an increasing average spring air temperature, with an annual rise of 0.08–0.09 °C. A significant trend in increasing average annual precipitation was observed in Saumalkol, with a rise of 4.7 mm per year. In contrast, no significant trends were found in the annual and seasonal precipitation data for Sergeyevka. It was also found that the area of Lake Saumalkol increased by 1.6% due to a rise in annual precipitation. In contrast, the area of Lake Kopa decreased by 6.04% because of an increase in the annual average temperature.

Keywords: water resources; lakes; reservoirs; test trend; Sen's slope; Kazakhstan

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Citation: Yessenzholov, B.; Khussainov, A.; Kakabayev, A.; Plachinta, I.; Bayazitova, Z.; Kyzdarbekova, G.; Zhamkenov, U.; Ramazanova, M. Assessment of Hydrometeorological Impacts of Climate Change on Water Bodies in Northern Kazakhstan. *Water* **2024**, *16*, 2794. https://doi.org/10.3390/w16192794

Academic Editor: Achim A. Beylich

Received: 2 August 2024
Revised: 14 September 2024
Accepted: 23 September 2024
Published: 1 October 2024

1. Introduction

Kazakhstan's water resources are a strategic asset due to its geographical location and, especially, its continental climate. The country's total surface water resources are estimated at 100.08 km^3 per year, of which 56.89 km^3 is formed within the republic and 43.09 km^3 flows in from neighboring regions: China (Ili, Yertis), Uzbekistan (Syr Darya), Kyrgyzstan (Shu, Talas) and Russia (Ural, Tobol) [1]. Kazakhstan has significantly less water compared to the global average (approximately 6.000 m^3), with 37.000 m^3 per 1 km^2 and 3.650 m^3 per person annually [2]. However, by 2030, Kazakhstan's annual per capita water availability is projected to decline to 2.300 m^3 [3].

Currently, water intake includes 20.18 km^3 of renewable surface water [4]; it is estimated that total surface water abstraction will increase to 30.22 km^3 in 2040 [5]. Much of this increase is due to increased withdrawals from the agricultural sector [3]. Current water consumption for agriculture in the country is 13.4 km^3 per year (69.1%), of which 8.8 km^3 per year (65.6%) is lost during canal transportation, leaving only 3.8 km^3 per year available for irrigation purposes. The average efficiency of canal water supply systems is only 15–20%, compared to 70–90% in the most-developed countries [3]. Another issue affecting the use of available water resources is water pollution [6]. In fact, 50–70% of Kazakhstan's surface water resources are classified as "polluted" or "heavily polluted" in terms of environmental state [4,7]. Moreover, the country relies heavily on water resources from neighboring countries, and at the same time, it is highly vulnerable to the impacts of climate change, posing high risks to the stability and availability of its water resources. Global concerns such as climate change can increase the physical, chemical and biological mechanisms that lead to deterioration of water resources. Climate change can directly or indirectly alter water quality and even aquatic ecosystems through various biochemical processes [8,9]. In addition, its specific impacts vary depending on the region and type of water body [10].

Climate change occurs against the backdrop of several rapid global trends, including rapid population growth, an increasing demand for energy and food, the development of new technologies, declining water resources, groundwater depletion, soil depletion, urbanization and changing consumption patterns [11]. The Sixth Assessment Report developed by the Intergovernmental Panel on Climate Change provides a more comprehensive regional analysis of climate change. In the coming decades, all regions must expect worsening climate change. A 1.5 °C increase in global warming will lead to an increase in heatwaves, longer warm seasons and shorter cold seasons. According to the report, extreme heat is more likely to exceed critical tolerance levels by 2 °C for agriculture and public health as global warming increases [12]. This could create risks that have a negative impact on the Central Asian region [13], especially in Kazakhstan, as evidenced in previous studies, where a significant part of its water supply comes from neighboring countries. For example, the work carried out by Karataev et al. confirms that over the period 1950–2020, linear indicators of average surface air temperature increased at a rate of 0.31 °C per decade. All trends in the series of annual and seasonal values of surface air temperature are positive and statistically significant, indicating a steady increase in air temperature in Kazakhstan [14]. Another study conducted for the period 1941–2011 also notes that trends in increasing surface air temperatures were observed in all seasons in the territory of the country. The average annual air temperature across the country increased by 0.28 °C per 10 years [15]. A regional study of the Zhabay river basin predicts the highest temperature increase to 3.9 °C at Temperature Coefficient Difference (TCD) 4.5 and to 6.4 °C at TCD 8.5 by the end of the century. The projected changes in annual precipitation in the Zhabay river basin show a clear trend toward a moderate increase in all periods and TCD of up to 11.5% by the end of the century [16].

Climate change has significant and diverse impacts on water resources. This influence manifests differently in diverse water resources in different regions but is generally negative. According to Li et al., for example, the negative consequence of climate change in eutrophic inland lakes in China is the continuing expansion of algal blooms [17]. Previous studies show that the decrease in the surface area of lakes in Kazakhstan is explained by various environmental and socio-economic factors, such as climate change, land use, agriculture, human activities and tourism, which in turn threaten the sustainability of lakes [18,19]. Gyau-Boakye P. notes that from 1945 to 1993, a temperature increase of 1 °C in the upper Volta basin led to a decrease in water consumption in the White Volta by 23.1% and in the Oti by 32.5% [20]. Somayeh Shadkam et al. state that Lake Urmia in Iran has decreased by 48% from 1960 to 2010, and about three-fifths of this change is attributed to climate change [21]. Studies conducted in the Colorado River basin from 1950 to 1999 showed that the temperature became warmer by 0.5 °C, and the river's annual flow decreased by 10% [22].

Freshwater availability is expected to decline in Central Asia. Water problems in transboundary rivers have expanded to the level of interregional water policies, with the Central Asian region currently facing major challenges related to the water security crisis [23].

Kazakhstan has limited water resources, which are unevenly distributed throughout the territory and are characterized by significant intra-annual and long-term fluctuations in water flow. These characteristics significantly complicate the management of the country's water resources, which averaged 91.3 km^3 per year during the observation period 1974–2008 [24]. However, Wang et al. note that Kazakhstan has reached a relatively safe level (level II), and the level of water security is high [25]. Another study shows that the river water resources of the Republic of Kazakhstan have decreased by 16.0 km^3. According to forecasts, due to the expected decrease in transboundary runoff, by 2030, there will be a further reduction in the republic's water resources to 87.1 km^3, and in dry years to less than 50.0 km^3 [22]. Thus, there is an urgent need to conduct studies on water resources, particularly in the northern part of the country, accounting for 45% of all lakes and currently facing environmental challenges [18].

In the case of Northern Kazakhstan, the main focus is on the endorheic lakes of the State National Nature Park (SNNP) "Burabay" and the Yesil River system [26–30]. There has been limited research on the geochemical, morphological and other indicators of the remaining lakes and reservoirs. Therefore, this work attempts to cover these gaps. This study aims to explore the impact of climate change on hydrometeorological indicators of water bodies in the Akmola and North Kazakhstan regions. In this context, the research objectives are as follows:

- To analyze climate change in the Akmola and North Kazakhstan regions in recent decades;
- To assess the impact of climate change on the surface of water bodies in the region.

In the present study, statistical data have been processed, including annual and seasonal indicators of average temperature and precipitation over the past 38 years. The results were verified using the trend test and Sen's slope. Using correlation analyses, their impact on the level and area of water bodies in the studied region has been assessed.

2. Materials and Methods

To study air temperature and precipitation in the Akmola and North Kazakhstan regions from 1986 to 2023, we used average daily data provided by the Kazhydromet organization. As part of the study, data from the Kokshetau, Sergeyevka and Saumalkol weather stations were analyzed (Table 1). Meteorological stations were selected to ensure coverage of the areas surrounding the studied water bodies. Monthly averages were calculated based on the average daily data. Statistical processing was used to compile seasonal trends in air temperature changes.

$$\text{average t} = \frac{\sum_{1986}^{2023} \text{seasonal t}}{\text{number of years}} \tag{1}$$

Table 1. Location of the weather stations used in this study.

Weather Station	Coordinates WGS84	Absolute Height, m
Kokshetau	53°17′30″ N, 69°23′30″ E	228
Sergeyevka	53°52′48″ N, 67°24′57″ E	153
Saumalkol	53°17′29″ N, 68°6′16″ E	385

To estimate the impacts of climate change on the water levels and surfaces of lakes and reservoirs, average annual climate data were collected for 10 years from 1986 to 1995, 1996 to 2005, 2006 to 2015 and 2016 to 2023.

The annual amount of precipitation was calculated by summing the amount of precipitation that had fallen for each month during the year. The following is the formula for calculating the annual amount of precipitation.

$$\text{Annual precipitation} = \sum_{i=1}^{12} P_i \tag{2}$$

where P_i is the amount of precipitation in the i-th month.

In this study, two non-parametric methods (Mann–Kendall and Sen's slope estimator) were used to detect the meteorological variables' trends.

The Mann–Kendall test statistic S is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgh(x_j - x_i) \tag{3}$$

where n is the number of data points, x_i and x_j are the data values in time series i and j (j > i), respectively, and $sgn(x_j - x_i)$ is the sign function as

$$sgh(x_j - x_i) = \begin{cases} +1, \text{ if } x_j - x_i > 0 \\ 0, \text{ if } x_j - x_i = 0 \\ -1, \text{ if } x_j - x_i < 0 \end{cases} \tag{4}$$

The variance is computed as

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \tag{5}$$

where n is the number of data points, q is the number of tied groups and t_p denotes the number of ties of extent p. A tied group is a set of sample data having the same value. In cases where the sample size n > 10, the standard normal test statistic Z_s is computed using Equation (4):

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}}, \text{ if } S > 0 \\ 0, \text{ if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}}, \text{ if } S < 0 \end{cases} \tag{6}$$

Positive values of Z_s indicate increasing trends, while negative Z_s values show decreasing trends. Testing trends is carried out at the specific α significance level. When $|Z_s| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, significance levels $\alpha = 0.01$ and $\alpha = 0.05$ were used. At the 5% significance level, the null hypothesis of no trend is rejected if $|Z_s| > 1.96$ and rejected if $|Z_s| > 2.576$ at the 1% significance level.

Sen developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, \ldots, N, \tag{7}$$

where x_j and x_k are the data values at times j and k (j > k), respectively.

If there is only one datum in each time period, then $N = \frac{n(n-1)}{2}$, where n is the number of time periods. If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$, where n is the total number of observations.

The N values of Q_i are ranked from smallest to largest, and the median of the slope or Sen's slope estimator is computed as

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]}, \text{ if N is odd} \\ \frac{Q_{[N/2]+[(N+2)/2]}}{2}, \text{ if N is even} \end{cases} \tag{8}$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at specific probability.

Table 2 below presents the average values of the meteorological variables used in this study for the period 1986–2023.

Table 2. The average values of the meteorological variables.

Station	Meteorological Variables	Winter	Spring	Summer	Autumn	Annual
Kokshetau	T, °C	−13.0	4.2	18.9	3.6	3.4
	R, mm	39.6	57.5	154.9	63.9	316.0
Sergeyevka	T, °C	−11.5	3.7	18.7	3.0	3.5
	R, mm	63.8	80.1	165.1	88.1	396.9
Saumalkol	T, °C	−14.0	3.6	18.0	2.6	2.6
	R, mm	87.3	90.1	162.9	105.9	435.1

Note: T: temperature, R: precipitation in millimeters.

The monitoring of areas of the water surface of lakes and reservoirs was carried out based on 8-channel LandSat images (4–5 for 1995 data, 7 for 2005 data, and 8–9 for 2015 and 2023). The satellite images were selected from official US Geological Survey data and are georeferenced (earthexplorer.usgs.gov). The original satellite images are spatially linked. Prior to the digitization of water bodies, the satellite image was further processed. Firstly, the image quality was improved by mixing channels. In this case, channels 7 and 6 (infrared range) and 4 (red range) were used. Channel mixing was performed using the ArcToolbox toolkit in the ArcGIS environment through its Channel Mixing tools. This combination of channels is interesting because the infrared range absorbs radiation from the water, and the coastline has a clearer outline. The water surface of the lake is shown almost in black, and the flooded areas are dark blue. Secondly, it is a calculation based on satellite images of albedo. The studied area has good drainage, so the albedo ranges will allow the clear separation of the water surface from the surrounding fields. The albedo calculation was performed using the ArcToolbox toolkit in the ArcGIS environment through the Map Algebra tool. The following formula was used for the calculation for LandSat 4–7 images:

$$p = \frac{\pi R d^2}{E \cdot \sin\theta} \tag{9}$$

where p is the reflectivity (albedo); the albedo value ranges from 0 to 1; R—the intensity of radiation from an object that has reached the satellite's orbit (W/m^2); d—the distance from the Earth to the Sun (1 astronomical unit (AU)); E—the luminosity coefficient for each channel; and θ—the height of the Sun above the horizon (measured in degrees).

For LandSat 8–9 images, albedo was calculated using a different formula:

$$p = \frac{2 \cdot 10^{-5} \cdot Q - 0.1}{\sin\theta} \tag{10}$$

where p—the raster model of the image.

The contours of the water bodies were additionally checked using the Modified Normalized Difference Water Index (MNDWI) using the 3 and 7 channels of later image versions.

These operations identified and digitized bodies of water on satellite images. To calculate the metric parameters of the area, an equally large projection was set. After vectorizing a series of images of one object, its area was calculated using the "Field Calculator" function in the layer attribute table. The result of this calculation was a specific area of the reservoir in a certain period of time. The determination of the height of the water's edge was carried out on the basis of superimposing the contours of the lake on srtm images. To accomplish this, the contour of the lake was converted into points, and the points of the coastline were superimposed on the srtm model. The "Extract" tool from the ArcToolbox toolbox allowed us to calculate the height of each point. The average value of the points was taken as the average height of the water edge in the reservoir.

The influence of the average annual temperature and annual precipitation of 10 years of data on changes in the mirror area of lakes and reservoirs was calculated using Spearman's rank correlation (p):

$$p = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)} \quad (11)$$

where n is the number of pairs of observations.

3. Results

3.1. Weather Station Data Analysis

The results of the application of statistical tests to determine the average seasonal and annual air temperatures for the period 1986–2023 are presented in Table 3. The study results were presented based on data obtained from the Kokshetau, Sergeyevka and Saumalkol weather stations for the period 1986–2023. The average water temperature at the Sergeyevka station showed a negative trend of −0.03 °C/year; at the other stations, Kokshetau and Saumalkol, it was 0.03 °C/year and 0.02 °C/year, respectively. Thus, all three stations can be assessed as stable, since the Mann–Kendall test showed that there is no trend. Seasonal temperatures differ significantly; in all three stations, the average spring temperature increased significantly from 0.08 to 0.09 °C/year. It is also worth noting that winter in Sergeyevka is cooling by −0.13 °C/year. Winters in Kokshetau and Saumalkol are less variable, at 0.00 °C/year and 0.01 °C/year, respectively. The trend in the average summer temperature in all stations is very minimal at 0.00–0.01 °C/year, and the autumn temperature is also insignificant at 0.03–0.05 °C/year.

Table 3. The average air temperature by season and annual (°C) for 1986–2023.

Station	Test Trends	Winter	Spring	Summer	Autumn	Annual
Kokshetau	Z_s	0.18	2.74	0.45	1.04	1.91
	Q_{med}	0.00	0.09	0.01	0.03	0.03
Sergeyevka	Z_s	−3.46	2.29	0.73	1.53	−0.33
	Q_{med}	0.13	0.08	0.01	0.05	−0.01
Saumalkol	Z_s	0.35	2.33	−0.25	1.08	1.56
	Q_{med}	0.01	0.08	0.00	0.03	0.02

Note: Z_s: Mann–Kendall test, Q_{med}: Sen's slope estimator.

If we consider by month, in Kokshetau, a significant increase was detected in March and April of 0.1 °C/year and 0.09 °C/year, respectively. The results of the Mann–Kendall test in March amounted to 2.06, and in April 2.04. The trend at the 95% significance level showed a significant increase.

In the case of Sergeyevka, the results of the Mann–Kendall test and the Price differ significantly from the rest of the stations. Winter is becoming colder here; the average January temperature decreases annually by −0.44 °C, as the Mann–Kendall value showing −5.20 was estimated as Sig.Decreasing. The largest increases were recorded in May and August, at 0.08 °C/year and 0.06 °C/year, respectively. The analysis of the Mann–Kendall test in May was 2.46 and in August 2.25, and the trend can be interpreted as Sig.Increasing.

In Saumalkol, the highest temperature increase was detected in April at 0.11 °C/year and in May at 0.06 °C/year. The value of the trend test in these months was 1.99 and 1.96, respectively. Thus, the results were evaluated as Sig.Increasing.

Figure 1 shows the data on trends in average annual temperature in the city of Kokshetau for 38 years (1986–2023). The average annual temperature for this period is 3.4 °C. There is a gradual increase in the average temperature. Over 38 years, the average temperature increased by 0.7 °C compared to the long-term annual average temperature of 2.7 °C. The linear trend shows that the average temperature in Kokshetau will continue to increase.

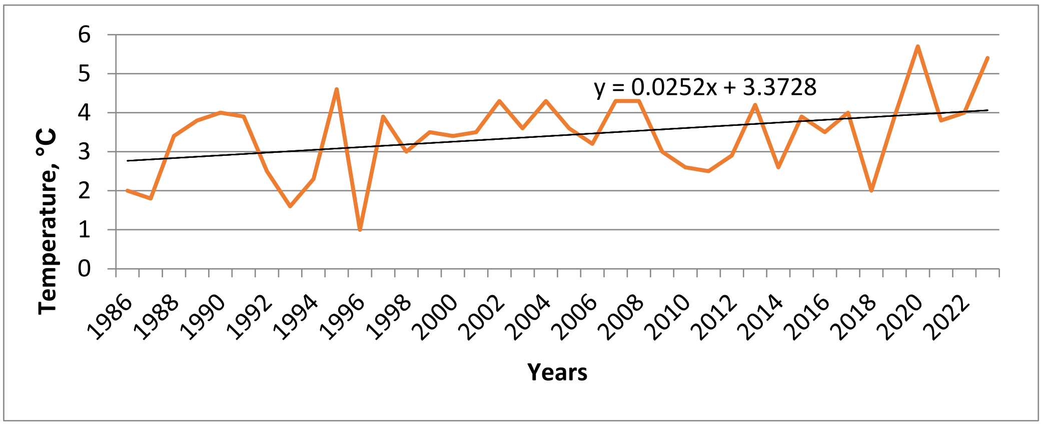

Figure 1. Trends in changes in average annual temperature in Kokshetau.

The average annual temperature in Sergeyevka has tended to decrease over the past 38 years. In 2023, the average annual temperature was 2.4 °C higher than in 1986. Over 38 years, the average temperature fluctuated between 1.4 °C (2011 and 2018) and 5.1 °C (1995). In 2020, there was an unusually high increase in the average annual temperature of up to 5.0 °C.

However, if we look at the trend in the data, we will notice that the average annual temperature fluctuates, with a significant increase of up to 4.6 degrees last year, suggesting that the actual data vary significantly and may deviate from the linear trend predicted by the equation. This may indicate the nonlinearity of climate change in Sergeyevka (Figure 2).

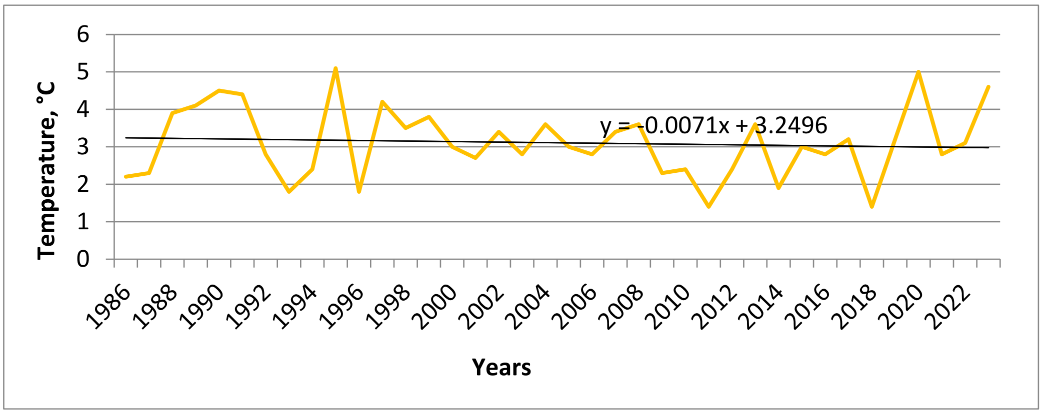

Figure 2. Trends in changes in average annual temperature in Sergeyevka.

From 1986 to 2023, the average temperature in Saumalkol ranged from 0.4 °C (1996) to 4.4 °C (2020). There is also a gradual increase in average temperature. The trend line shows the average temperature trend. The average temperature in 2023 is 3.1 °C higher than in 1986 (Figure 3).

The last 38 years have seen both record low and record high temperatures. The coolest years were 2011 and 2018, with annual average temperatures below 0.9 °C. At the same time, 2020 and 2023 were the hottest years, with temperatures exceeding 4 °C. Particularly noteworthy is the year 2020, when it was unusually hot; the average annual temperature exceeded 4 °C, which was the highest value for the entire observation period.

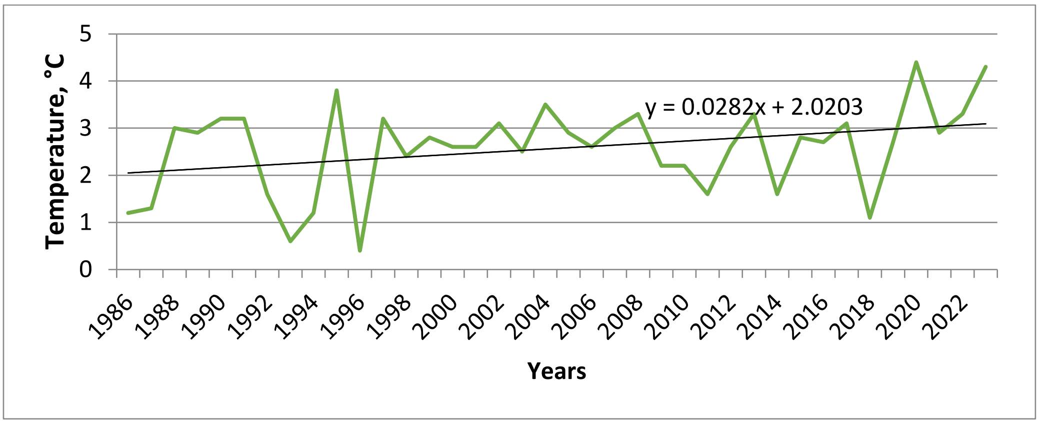

Figure 3. Trends in changes in average annual temperature in Saumalkol.

It should also be noted that there were changes in seasonal patterns. Winters are becoming shorter and less severe, with an increasing number of thawing days. Spring arrives earlier, with temperatures rising in March and April. Summers are becoming warmer, while autumns are shortening, accompanied by temperature increases in September and October.

To analyze climate data for precipitation in Kokshetau, Sergeyevka and Saumalkol from 1986 to 2023 (Figure 4), we can consider changes in average precipitation by season, as well as general changes in annual averages. This will allow us to identify trends and possible changes in the climate of these regions.

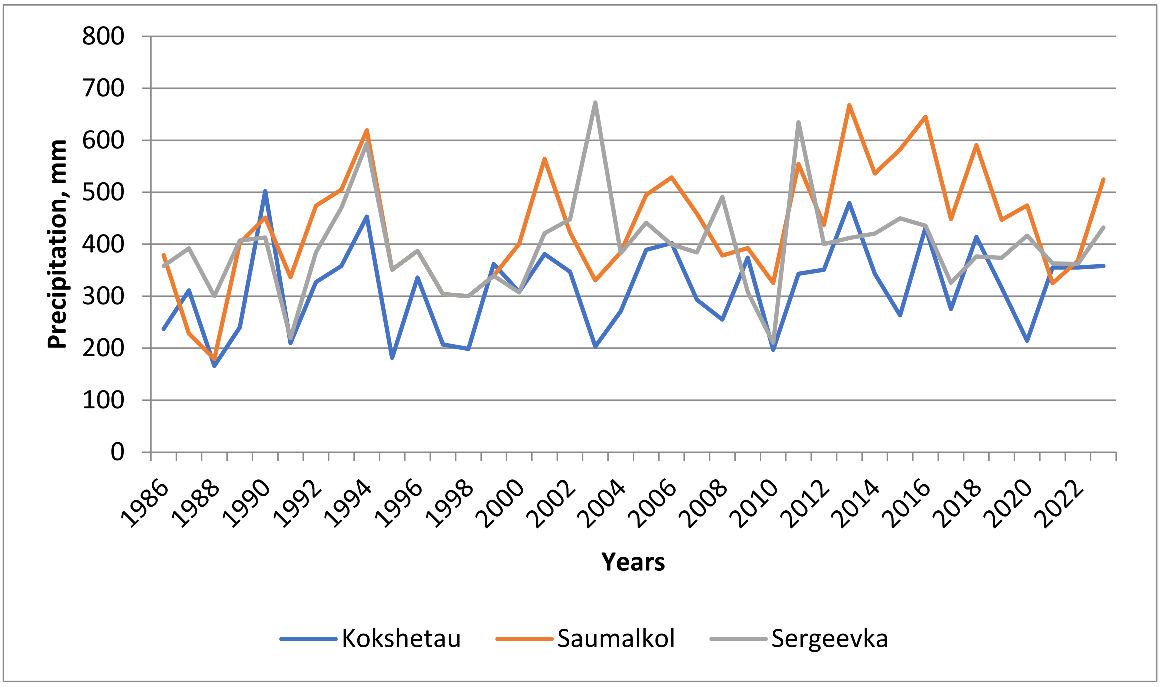

Figure 4. Annual precipitation from 1986 to 2023.

The analysis of the average annual indicators of atmospheric precipitation showed that in Saumalkol, it increases every year by 4.7 mm. The trend test coefficient was 2.34. This result is estimated as Sig.Increasing. There are no significant changes in Kokshetau and Sergeyevka. It is also worth noting that in Sergeyevka, the trend has not been detected by season or by month (Table 4).

Table 4. The average atmospheric precipitation by season and annually (mm) for 1986–2023.

Station	Test Trends	Winter	Spring	Summer	Autumn	Annual
Kokshetau	Z_s	0.05	0.15	1.07	2.61	1.57
	Q_{med}	0.00	0.00	1.21	1.13	1.92
Sergeyevka	Z_s	0.28	1.13	0.11	0.00	0.82
	Q_{med}	0.06	0.61	0.20	0.00	0.82
Saumalkol	Z_s	2.25	138	0.41	3.11	2.34
	Q_{med}	1.00	0.97	0.38	1.97	4.70

Note: Z_s: Mann–Kendall test, Q_{med}: Sen's slope estimator.

The results of seasonal trends showed that a significant increase was detected in Kokshetau in autumn. The Mann–Kendall test value was 2.61, and Sen's slope was 1.13 mm/year. In Saumalkol, an increase was detected in winter and autumn. The slope of the trend lines is 1.00 mm/year in winter and 1.97 mm/year in autumn. The coefficient of the trend test is 2.25 and 3.11, respectively. Upon interpretation, the significance of the test results increases.

A trend analysis of the monthly data revealed that, in Kokshetau, a significant increase in precipitation was noted in October, 0.50 mm/year, and February, 0.20 mm/year. The indicators of the trend test coefficient are 2.94 and 2.26, respectively. For the other months, this trend was not detected. In Saumalkol, precipitation increases are observed by 0.5 mm/year in March, by 0.89 mm/year in October, by 0.64 mm/year in November and by 0.37 mm/year in February. The results of the trend test were of 2.84 in March, 2.73 in October, 2.33 in November and 2.17 in February.

3.2. Analysis of Reservoir Surface Changes in the Context of Climate Change

We analyzed how air temperature and precipitation affect the area of water resources over a 10-year period from 1986 to 2023. By examining the data on changes in the area of Lake Kopa as a function of the amount of precipitation and average temperature for different years (1995, 2005, 2015, 2023), it is possible to analyze the influence of these factors and their correlation with the area of the lake. The area of the lake decreased from 14.4 km^2 in 1995 to 13.2 km^2 in 2015 and then increased slightly to 13.53 km^2 by 2023. The amount of precipitation tends to increase from 299 mm in 1995 to 327 mm in 2023. The average temperature shows an increase from 4.6 °C in 1995 to 5.4 °C in 2023 (Figure 5).

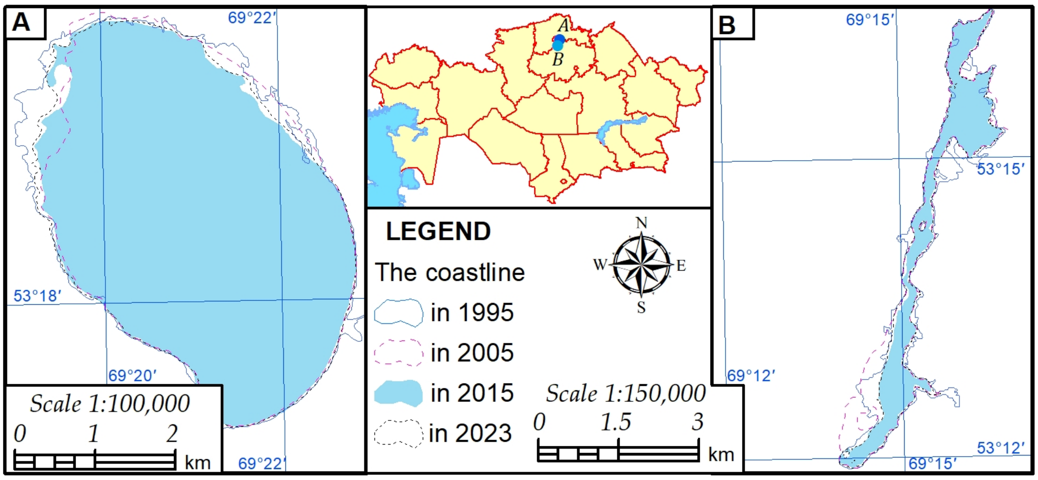

Figure 5. Map of changes in the shorelines of Lake Kopa (**A**) and Shagalaly reservoir (**B**).

Mathematical calculations of Spearman's rank correlation show that the correlation with lake area and precipitation is 0.6, indicating a moderate positive correlation. This means that with increasing rainfall, there is a slight, but not strong, increase in the lake area.

Spearman's correlation coefficient between the lake area and average temperature is −0.8, indicating a strong negative correlation. This indicates that as the average temperature increases, the lake area tends to decrease (Table 5).

Table 5. Climatic and hydrological indicators of Lake Kopa.

Years	Lake Area, km^2/mm	Annual Precipitation, km^2/mm	Average Annual Temperature, °C
1986–1995 y.	14.4	299	4.6
1996–2005 y.	13.38	300	3.6
2006–2015 y.	13.2	330	3.9
2016–2023 y.	13.53	327	5.4
Spearman's rank correlation		−0.8	0.6

Thus, the variation in the area of Lake Kopa is likely influenced by a combination of factors, with temperature and precipitation playing a significant role. The negative effect of temperature may outweigh the positive effect of precipitation and lead to an overall reduction in the lake area. The observed correlations indicate that climate changes, such as rising temperatures and changes in precipitation, may have significant impacts on water resources such as lakes, requiring further research and potential adaptive management strategies for water resources and ecosystems.

An analysis of data for Lake Saumalkol shows that the area of the lake changed from 21.1 km^2 in 1995 to 21.5 km^2 in 2023, with a slight decline and subsequent recovery over this period. Rainfall increased from 398 mm in 1995 to 478 mm in 2023, showing an overall upward trend. The average temperature also increased from 2.2 °C in 1995 to 3.1 °C in 2023 (Figure 6).

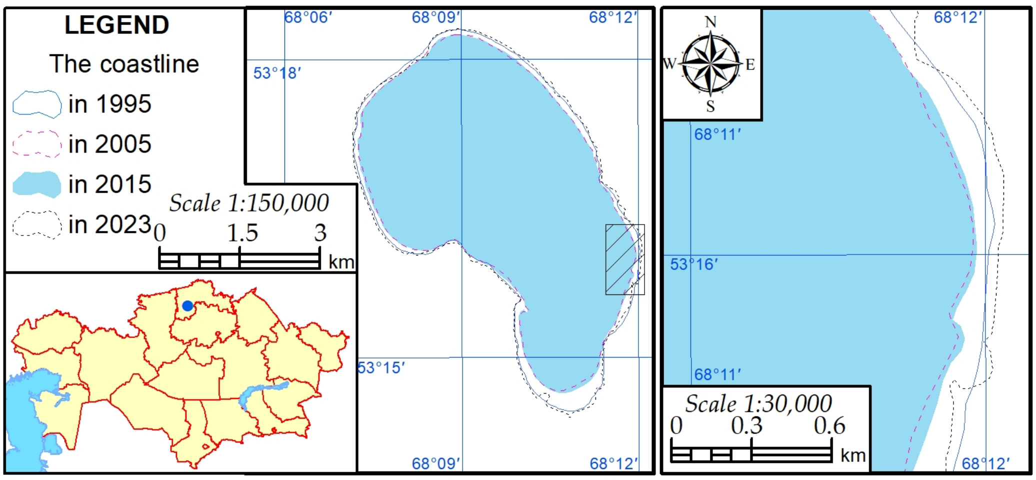

Figure 6. Map of changes in the shorelines of Lake Saumalkol.

The rank correlation r = 0 between the lake area and precipitation indicates the absence of any correlation. This may seem counterintuitive, as increased rainfall due to higher water levels is generally expected to increase the area of bodies of water. However, a lack of correlation suggests that other factors may play a more important role in changing the Saumalkol Lake area, especially groundwater, as groundwater sources used to be involved in feeding the lake. However, under the influence of anthropogenic influences, these springs became clogged. In recent years, underground springs have begun to burst through and fill the lake (Table 6).

Table 6. Climatic and hydrological indicators of Saumalkol Lake.

Years	Lake Area, km^2/mm	Annual Precipitation, km^2/mm	Average Annual Temperature, °C
1986–1995 y.	21.16	397	2.2
1996–2005 y.	19.19	433	2.6
2006–2015 y.	19.46	526	2.5
2016–2023 y.	21.50	478	3.1
Spearman's rank correlation		0	0.2

Given that Spearman's correlation coefficient between the lake area and average temperature is 0.2, this indicates a weak positive correlation. This means that as the average temperature increases, there is a slight increase in lake area, which may be due to various climatic and hydrological processes, including changes in evaporation and precipitation.

Thus, changes in the area of Lake Saumalkol are weakly correlated with both precipitation and average temperature, indicating the complex nature of interactions within the aquatic ecosystem. To gain a deep understanding of the processes affecting the lake area, it is necessary to take into account other factors, such as geological, hydrological and anthropogenic changes.

The area of the Sergeyevka reservoir fluctuates with slight changes between the maximum value in 2005 (94.84 km^2) and the minimum in 2015 (93.33 km^2). The latest data for 2023 show a slight increase compared to 2015 to 93.4 km^2. These changes may indicate small natural fluctuations in water levels or the result of human influence (Figure 7).

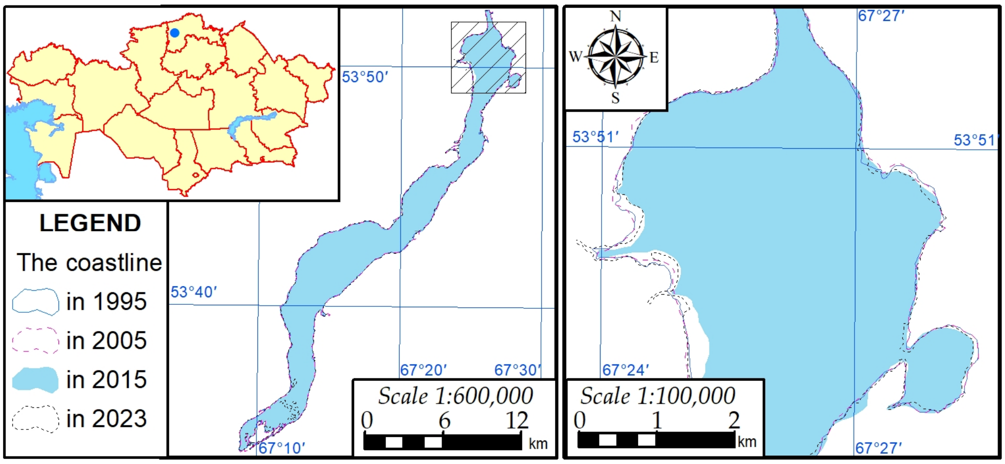

Figure 7. Map of changes in the shorelines of the Sergeyevka reservoir.

To estimate the impact of climate change on the Sergeyevka area, mathematical calculations were carried out. Thus, the value of Spearman's correlations between the reservoir area and precipitation was −0.4, which indicates a moderate dependence of the area on precipitation. This confirms the assumption that fluctuations in reservoir area are not directly related to precipitation. The rank correlation between area and mean annual temperature is above 0.4, indicating a moderate positive correlation (Table 7).

Table 7. Climatic and hydrological indicators of the Sergeyevka reservoir.

Years	Reservoir Area, km^2/mm	Annual Precipitation, km^2/mm	Average Annual Temperature, °C
1986–1995 y.	93.91	352	3.3
1996–2005 y.	94.84	396	3.7
2006–2015 y.	93.33	401	3.5
2016–2023 y.	93.40	388	3.2
Spearman's rank correlation		−0.4	0.4

4. Discussion

Our results were derived from historical data on precipitation and air temperature in three regions: Kokshetau, Sergeyevka and Saumalkol, spanning the years 1986 to 2023. Studies were conducted on temperature change trends over time. In addition, images of lakes and reservoirs were selected using remote sensing to assess changes in water areas during the low-water period using GIS technologies. Subsequently, correlations between the area of water resources and the average annual temperature and total precipitation were calculated. This analysis enabled us to evaluate the impact of a decade of climatic data on variations in the surface area of lakes and reservoirs.

It was found that the average air temperature of Kokshetau and the surroundings of Lake Kopa were negatively correlated with each other. This suggests that rising temperatures may lead to greater evaporation, which may reduce the lake's water volume and, therefore, its area. This connection appears to be stronger than that with precipitation, which could explain the trend in shrinking lake area despite increasing precipitation. Precipitation and lake area have a positive relationship, which could be explained by the fact that more precipitation causes the lake's water level to rise, thereby increasing its surface area. However, the weak correlation suggests that precipitation is not the only or dominant factor affecting the lake area.

The data for Saumalkol Lake indicate no significant correlation between lake area and the studied climate factors. This suggests that changes in the area of Saumalkol Lake cannot be attributed solely to precipitation or average temperature. The lake area may also be influenced by factors such as seasonal fluctuations in water levels and changes in groundwater. These weak correlations highlight the complexity of the interactions between climate variables and the hydrological properties of the lake. This confirms the need for an integrated approach to the study of aquatic ecosystems that takes into account a variety of factors.

Vadim Yapiyev et al. find that the area of endorheic lakes in SNNP "Burabay" is mainly regulated by climate variability. Evaporation from lakes dominated the water balance of lakes during the period 2000–2013. During most of the period, evaporation from the lakes increased, resulting in a steady decline in the levels of Lakes Shortandy and Ulken Shabakty. After the last drought in 2012, lake levels began to recover due to above-average rainfall [29].

Studies on climate change in Kazakhstan primarily confirm an increase in the average annual temperature. Salnikov et al. argue that during the study period (1941–2011), increasing trends in surface air temperatures were observed across all seasons in Kazakhstan. The average annual air temperature across the country increased by 0.28 C/10 years. The greatest warming occurred in winter, at a rate of 0.35 C/10 years, and the least warming occurred in summer, at a rate of 0.18 C/10 years [15].

The apparent increase in air temperature in the region, especially in winter, spring and autumn, led to increased evaporation and changes in freeze–thaw cycles. One noticeable effect was a decrease in winter precipitation in the form of snow and an increase in rainfall. This is accompanied by a general decrease in the total amount of annual precipitation. There is no consensus among researchers about changes in total precipitation. However, the observations of many authors do not show a significant trend toward a decrease in annual precipitation [31].

Kazakhstan is making efforts to combat climate change and adapt to its consequences. In this context, several strategic documents, such as the Strategy of Kazakhstan for the transition to a "green" economy until 2050 and the National Plan to Combat Climate Change have been developed [32,33]. These initiatives aim to reduce greenhouse gas emissions, improve energy efficiency and develop renewable energy sources. In 2016, Kazakhstan was among the first countries to ratify the Paris Agreement. The country should reduce greenhouse gas emissions by 15% by 2030 compared to the level of emissions in 1990 [34]. The announcement of carbon neutrality by 2060 was made in 2020 as a long-term objective.

Presently, Kazakhstan participates in the generally accepted international climate approach and is a rightful member of the global climate regulation.

5. Conclusions

For regions with limited water resources, such as the North Kazakhstan and Akmola regions, examining the impact of climate change on water availability is crucial. The studies employed an analysis of temporal trends in temperature and precipitation. Additionally, remote sensing images of the water bodies under examination were processed using GIS technologies.

The average annual temperature change in Kokshetau and Saumalkol indicates a small but steady increase of 0.03 °C per year and 0.02 °C per year, respectively. Despite this, the results of the Mann–Kendall test (statistics 1.91; 1.56) do not confirm the presence of a statistically significant trend. In Sergeyevka, the average annual temperature decreases by −0.01 °C every year. The results of the Mann–Kendall test show that there is no statistically significant trend.

At all three stations, Kokshetau (0.09 °C per year), Saumalkol (0.08 °C per year) and Sergeyevka (0.08 °C per year), a significant increase in temperature was detected in the spring period. Statistically significant results of the Mann–Kendall test confirm the presence of a steady warming trend. This may indicate the beginning of significant climate changes in the region that require further monitoring and adaptation measures.

The average annual precipitation also shows an increasing trend in all localities. But the results of the Mann–Kendall test (2.34) only confirm the presence of a steady-increase trend in Saumalkol. There is no statistically significant trend in Kokshetau and Sergeyevka.

The mathematical calculations of Spearman's rank correlation matrix between the area and the average annual temperature in the Sergeyevka reservoir and Lake Kopa showed a moderate correlation. For Lake Saumalkol, it was found that there is no significant correlation. However, a weak correlation exists between the amount of precipitation and the area of water bodies.

The research results will aid in the future development of adaptation measures for water bodies in the context of climate change. A methodological limitation of this study is the lack of long-term time series data on seasonal fluctuations in water levels, which hampers the analysis of long-term trends.

Given the identified impacts of climate change on water resources in the North Kazakhstan and Akmola regions, it is crucial to implement forward-looking responses to ensure the sustainability of these resources. Additionally, considering that water in this region is used for various purposes, including agriculture, tourism and household consumption, it is important to note that tourism, as a growing sector, is one of the highest water consumers [35,36]. Thus, promoting the conservation of water resources is fundamental considering the study results. Efforts to promote efficient agricultural, industrial and urban water use can help reduce pressure on water resources. It will also be necessary to encourage a change in public behavior using a combination of public awareness and educational efforts. Of course, continuous monitoring of hydrometeorological data by the responsible authorities is essential, which will guarantee the accessibility of robust data for informed decision-making.

Author Contributions: Conceptualization, B.Y., A.K. (Anuarbek Kakabayev) and A.K. (Abilzhan Khussainov); methodology, I.P. and Z.B.; software, I.P.; validation, B.Y., A.K. (Anuarbek Kakabayev) and A.K. (Abilzhan Khussainov); formal analysis, G.K. and U.Z.; investigation, B.Y. and A.K. (Anuarbek Kakabayev); resources, G.K. and Z.B.; data curation, B.Y. and I.P.; writing—original draft preparation, B.Y.; writing—review and editing, A.K. (Abilzhan Khussainov) and M.R.; visualization, Z.B. and M.R.; supervision, A.K. (Abilzhan Khussainov); project administration, B.Y.; funding acquisition, B.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research work was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP13268760). This work was supported by the UIDB/05105/2020 Program Contract, funded by national funds through the FCT I.P.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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