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Climate Country Risk Profile: Kazakhstan

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Climate Country Risk Profile:
Kazakhstan

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Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

■ Summary

This profile provides an overview of projected climate parameters and related sectoral impacts in Kazakhstan until the end of the century under different climate change scenarios (Shared Socioeconomic Pathways, SSPs).

- **SSP1-2.6 “Sustainability”** represents a low-emissions pathway broadly consistent with the goals of the Paris Agreement, while **SSP5-8.5 “Fossil-Fueled Development”** represents a high-emissions pathway.
- The projections summarize **changes in key climate variables** (e.g., temperature and precipitation) and implications for sectors such as water resources, agriculture, health/labour productivity, and renewable energy.
- As with all climate-model-based assessments, **results are subject to uncertainty** and do not explicitly account for future socioeconomic development, policy changes, or adaptation measures, unless stated otherwise.

TEMPERATURE

By 2100, Kazakhstan’s average air temperature is projected to rise from 5 to 9°C under SSP5-8.5 and from 2.2 to 3.8°C under SSP1-2.6 with modest regional variation and largely uniform warming nationwide. Under SSP5-8.5, examples show ~+7.23°C in Pavlodar versus ~+5.94°C in Mangystau.

AGRICULTURE

Spring wheat is the dominant crop in the region, contributing roughly 80% of total production. For 2071–2100, projected yeilds changes up to +27% (Akmola), +25% (Kostanay), and -3% (North Kazakhstan) depends on SSP.

PRECIPITATION

Average annual precipitation is projected to increase by 30–40 mm/year by 2100 in both scenarios, but uncertainty is high due to strong year-to-year variability; central/western dry regions show less change.

HEALTH AND LABOR

For high-intensity summer work, average productivity drops by 15% by 2100 under SSP5-8.5 (largest reductions in the west/southwest part of the country). Under SSP1-2.6, impacts are smaller and tend to stabilize after 2050s.

WATER

Overall increase in annual stream flow but with strong seasonal runoff shifts toward reduced summer flow and increased winter flow, with spring flood peaks ~1 month earlier in number of catchments, raising flood risk (notably in the north). SPEI falls to ~−1.2 (SSP1-2.6) and toward ~−3 (SSP5-8.5) by 2100 because potential evapotranspiration rises faster than precipitation. Overall, reduced snowmelt contribution and stronger flood–drought swings raise adaptation and infrastructure planning needs across basins and sectors.

RENEWABLE ENERGY

Solar PV potential increases under SSP1-2.6 (+13 to +33 kWh/m² by 2080s); under SSP5-8.5 it ranges from +5 to −28 kWh/m². Declines are plausibly linked to higher cloud cover/other stressors; however, West Kazakhstan, Atyrau, and Mangystau still show positive increase.

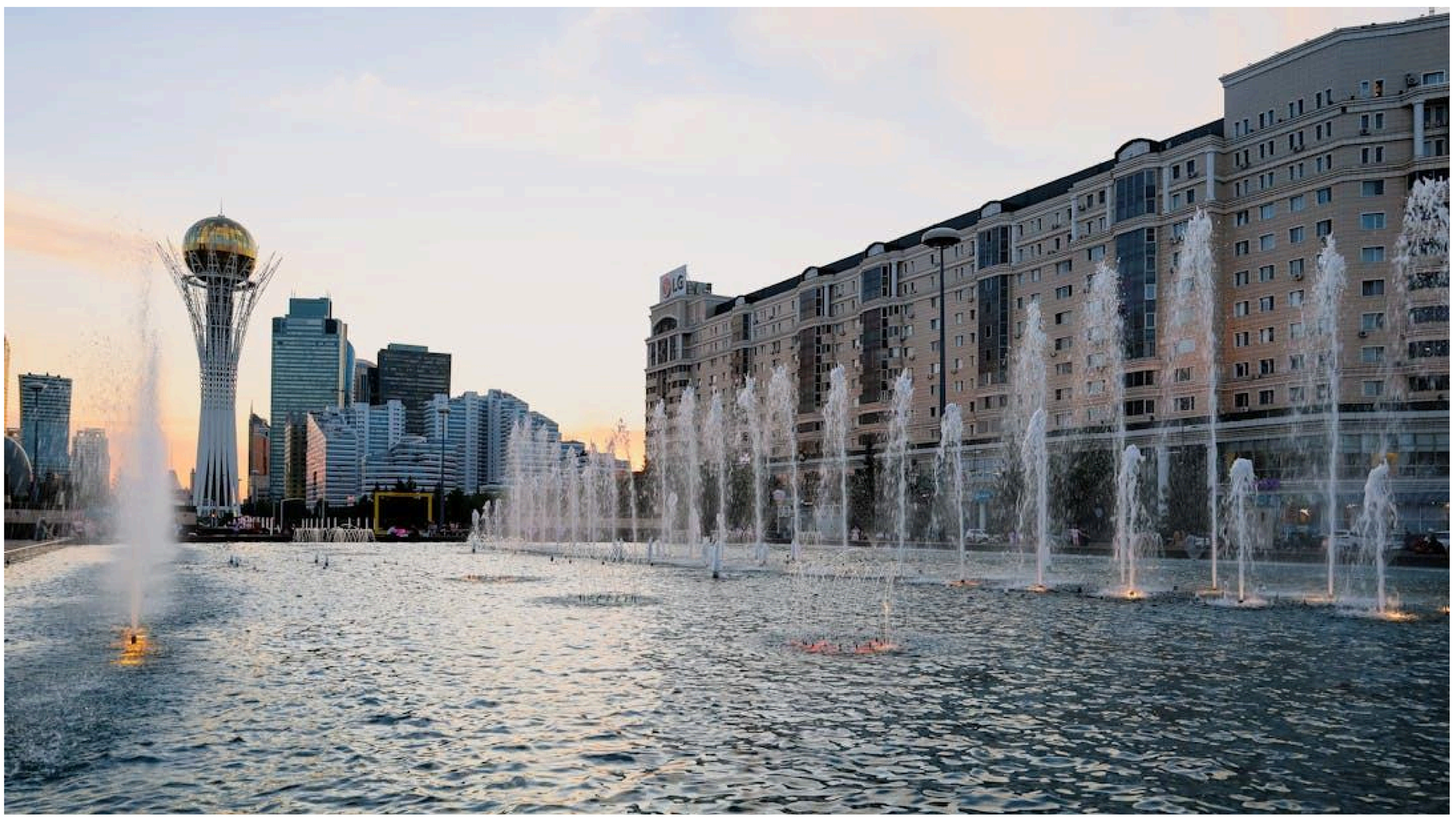
Introduction

Kazakhstan is the largest country in Central Asia with approximately 2,724,900 square kilometers. It is a landlocked country, bordered by Russia to the north and west, China to the east, Kyrgyzstan, Uzbekistan, and Turkmenistan to the south, and the Caspian Sea to the west.

The country's vast size results in a **variety of landscapes** across its territory. Hilly plateaus and expansive steppes cover much of Kazakhstan, including the Kazakh Steppe in the north. Mountains are predominantly located in the east and southeast, with the highest peak being Khan Tengri, reaching 7,010 meters. Additionally, large, semiarid and arid areas stretch across large parts of the country.

These diverse landscapes are highly sensitive to variations in **temperature** and **precipitation**, which are expected to be significantly influenced by climate change. Consequently, the country faces substantial land degradation challenges driven by a combination of agricultural expansion, deforestation, and climate change induced shifts in weather patterns. Kazakhstan’s extensive rangelands are particularly affected by **erosion**, resulting in significant vegetation loss. In addition, **desertification** represents a major concern, with at least two-thirds of the national territory considered susceptible to **aridization**[1],[2].

Kazakhstan experiences a **distinctly continental climate**, situated in the center of the Eurasian continent. It is characterized by the high continentality climate. Winters, from December to February, are typically cold, with average temperatures ranging from -9°C to -12°C. Summers, from June to August, are warmer, with average temperatures of 22°C to 23°C[3]. Extreme temperatures can reach –40°C in January and up to 40°C in July. Winter conditions often include snowstorms, blizzards, and freezing drizzle, whereas summers can be notably hot. Another feature of the region is that much of the country is classified as either **arid** or **semi-arid**. The mean annual precipitation of the country is 250-350 mm in the north, and only around 100-120 mm in the south[4].



[Front cover image]
Big Almaty Lake, Almaty, Kazakhstan.
Source: unsplash.com

[1]
Mirzabaev, A., Oskenbayev, Y., Sansyzbayev, A. (2025). The role of land restoration for climate change mitigation and biodiversity conservation in Kazakhstan. Central Asian Journal of Sustainability and Climate Research

[2]
Encyclopedia Britannica Online (2025). Kazakhstan

[3]
World Bank. (2021). Current Climate > Climatology

[4]
Salnikov, V., Turulina, G., Polyakova, S., Petrova Y., Skakova, A. (2015). Climate change in Kazakhstan during the past 70 years. Quaternary International. 358: 77-82

[Image 1]
Astana, Kazakhstan.
Source: pexels.com

Driven by these high aridity levels, Kazakhstan's primary environmental challenge is **water scarcity**. Studies indicate that runoff-based water sources are declining and are expected to continue decreasing in the future. The country possesses approximately 90.1 km³/year of total renewable water resources in the form of runoff, of which about 95% is already utilized by the economy. This narrow margin between water availability and consumption has resulted in existing water stress, which is further exacerbated by ongoing reductions in water availability and may lead to more severe water shortages in the near future[5].

Kazakhstan's **population** is approximately 20.5 million, and its **GDP** per capita stands at 14,154 USD, making it the largest **economy** in Central Asia[6],[7]. The country's wealth in natural resources plays a vital role in its economic growth and strength in the global economy. Kazakhstan is the largest producer and exporter of grain in Central Asia, with approximately 12% of the population employed in the **agriculture sector**. The primary crops include **grains** and **legumes**, primarily **wheat**, and **oilseeds** that form a significant part of the agricultural industry[8],[9]. However, rising temperatures and changing rainfall patterns are expected to reduce agricultural productivity and increase the frequency of **droughts**. Studies linking drought indices to **wheat yields** in Kazakhstan suggest that these increasingly dry conditions will place substantial pressure on both domestic food availability and the country's agricultural export economy[10].

Understanding Kazakhstan's geography, economy, and climate highlights how closely the country's development is linked to its natural environment. As **climate change** intensifies existing pressures on water resources, agriculture, and ecosystems, these vulnerabilities are expected to deepen. A comparison of average temperatures between the periods 1871–1990 and 1994–2023 already indicates an observed increase of approximately 1.64 °C. This warming trend is expected to continue as climate change intensifies.

The following risk profile report provides a concise overview of the anticipated impacts of climate change on Kazakhstan's climate and key sectors.

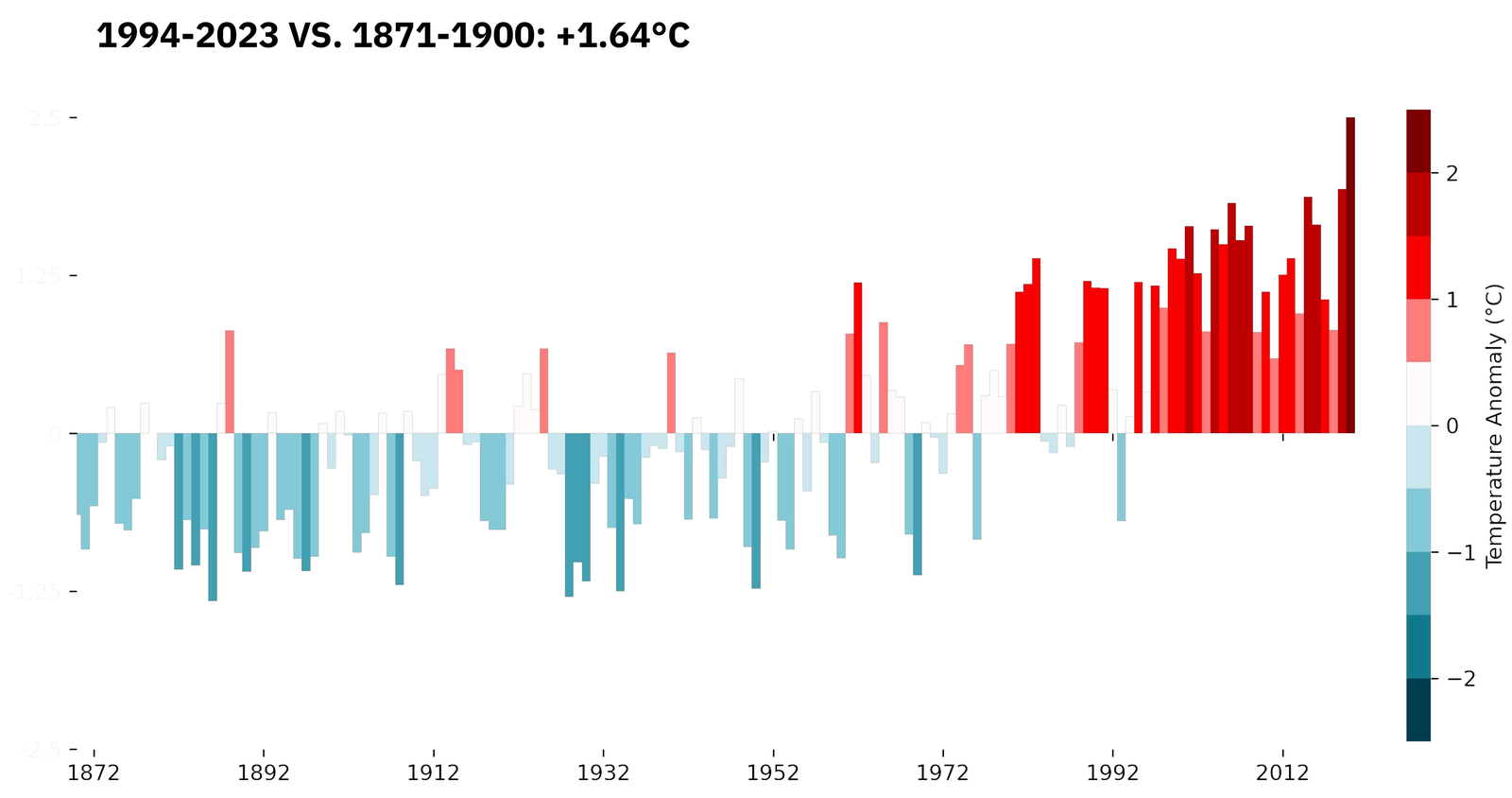


Figure 1.
Historical temperature anomalies in Kazakhstan, 1871–2023[11].

[5] Tursunova, A., Medeu, A., Alimkulov, S., Saparova, A., Baspakova, G. (2022). Water resources of Kazakhstan in conditions of uncertainty. Journal of Water and Land Development. 54 (7-9): 138-149

[6] Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan. (2026). Main.

[7] World Bank. (2026). World Bank national accounts data

[8] Agri-Food Trade Statistical Factsheet, European Union – Kazakhstan, 2024

[9] Press Service of the Government of the Republic of Kazakhstan. (2018, December 30). Agrarian year results: Yield growth and increased crop production. Official Information Source of the Prime Minister of the Republic of Kazakhstan.

[10] Karatayev, M., Clarke, M., Salnikov, V., Bekseitova, R., Nizamova, M. (2022). Monitoring climate change, drought conditions and wheat production in Eurasia: the case study of Kazakhstan. Heliyon. 8(1).

[11] Rohde, R., Muller, R. A., Jacobsen, R., Perlmutter, S., Urban, J., & Mosher, S. (2013). Berkeley Earth temperature data set.

Steppe
Kostanay, Kazakhstan
Source: unsplash.com

How to interpret the figures

The following pages present the projected development of various climate variables and additional indicators that illustrate the impacts of climate change. For each variable, results are shown using line plots, maps, bar plots, and bubble plots to convey changes across time and space. In all cases, the data represent either absolute or relative changes compared to a defined reference year or reference.

All figures use 1981–2010 as the reference period and compare two future scenarios and two future horizons.

FUTURE SCENARIOS

SSP1-2.6 **“Sustainability”**

SSP5-8.5 **“Fossil-Fueled Development”**

FUTURE HORIZONS

2041–2070

2071–2100

LINE PLOTS

Show 30-year running means of national averages over time; shaded bands indicate the “likely” (95th percentile) range. Values are plotted at the midpoint of each 30-year period: the value at 2085 represents the 2071–2100 average.

MAPS

Provide a spatial perspective, and present scenario–period combinations in a grid (rows = scenarios, columns = periods).

BAR PLOTS

Summarize the average subregional change for SSP5-8.5 in 2071–2100.

BUBBLE PLOTS

Compare subregions across all scenario–period combinations and represent the ensemble.

MONTHLY GRID PLOTS

Show how the variable changes across months of the year for each scenario–period combination (rows = scenario–period combinations, columns = months).

DATA BASIS:

- The data used for the figures are derived from five bias-corrected CMIP6 models with daily climate forcing, obtained from the Inter-Sectoral Impact Model Intercomparison Project[12].
- The outputs of these five models were averaged to create a multi-model ensemble.
- The specific models used are: GFDL-ESM2M, IPSL-CM5A-LR, MPI-ESM1, MRI-ESM1-2-HR, UKESN1-0-LL.

[12]
Lange, S., Büchner, M. (2021). ISIMIP3b bias-adjusted climate input data (v1.1). ISIMIP Repository.

Climate

Temperature

The average annual temperature represents the average of daily temperature values over the course of a year. It is the most basic climatic measurement to assess the impact of climate change.

- In response to the rising greenhouse gas concentrations, for the **SSP5-8.5 "Fossil-Fueled Development"** scenario, air temperature in Kazakhstan is projected to rise between 5 to 9 °C by 2100.
- In comparison, in the **SSP1-2.6 "Sustainability"** scenario, air temperature is projected to rise between 2.2 and 3.8 °C by 2100.

When it comes to the regions, the air temperature increase in the future is expected to impact the whole country almost uniformly, without significant differences across regions.

- Under **SSP5-8.5 "Fossil-Fueled Development"**, the highest increase is expected in Pavlodar with an increase of +7.23 ºC. The lowest increase is Mangystau, with +5.94 ºC.

Changes in average annual temperature are expected to vary in intensity throughout the year. Across both scenarios and all time periods, the largest increases are projected for January, December, and August, while May consistently shows the smallest increase. Under the **SSP5-8.5 "Fossil-Fueled Development"** scenario, the particularly strong warming in December and January suggests substantially warmer winters, which could affect snow accumulation across the region.

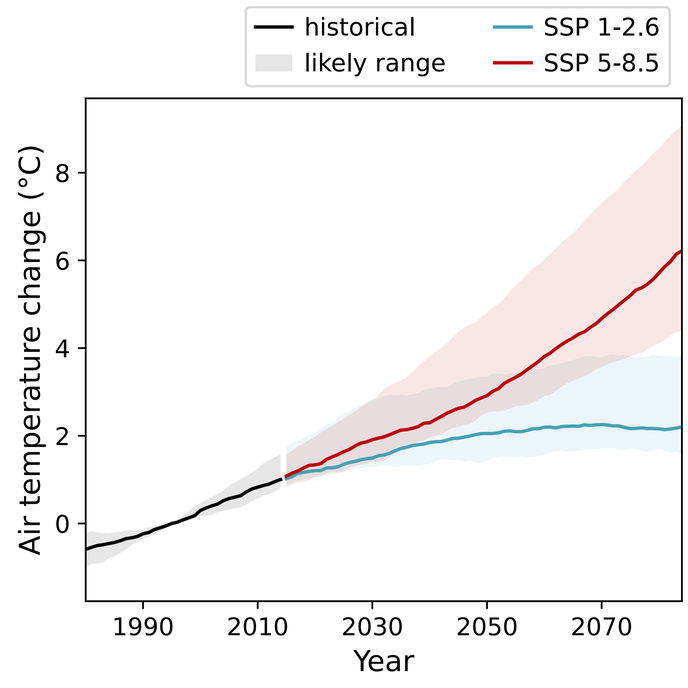


Figure 2.
Trends in annual temperature change.

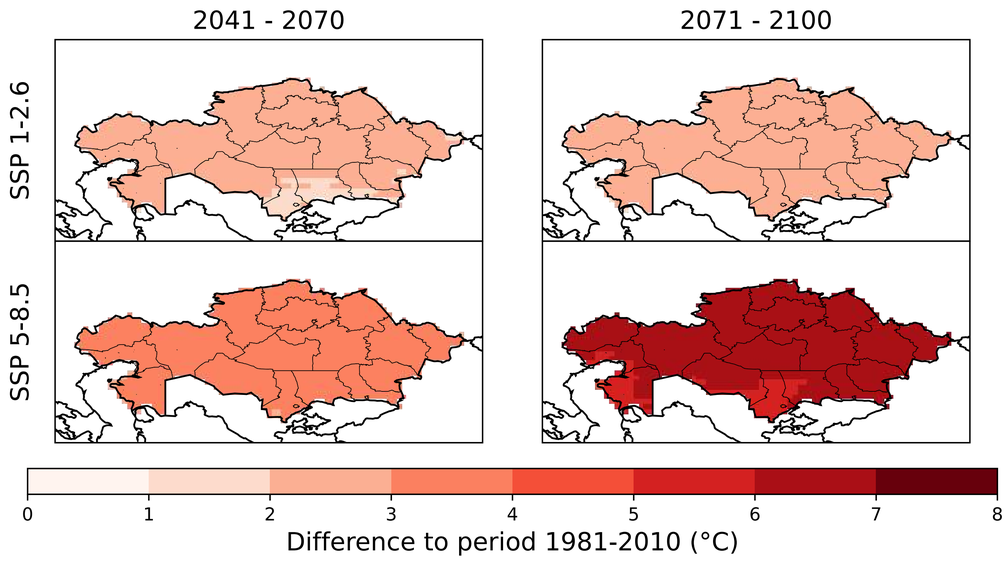


Figure 3.
Spatial distribution of temperature change.

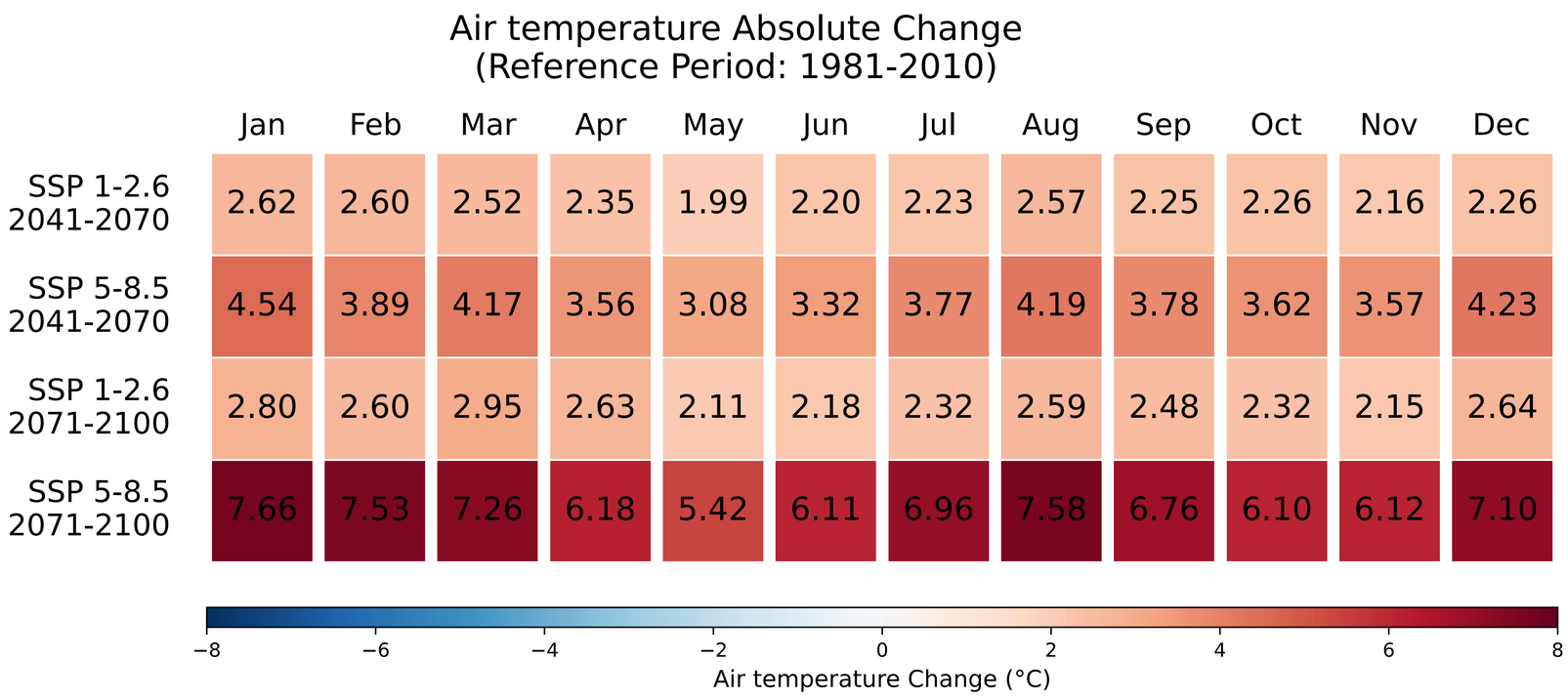


Figure 4.
Monthly temperature change patterns.

Precipitation

The annual **precipitation**, in this case, the average total annual precipitation, represents the total sum of all precipitation events across a whole year. Average precipitation change across Kazakhstan shows larger uncertainty ranges due to the year-by-year variability.

- **Both future scenarios** show a similar average trend: an average increase in precipitation of around 30 to 40 mm/year by 2100. Suggesting a similar pattern on both possible futures: a positive increase in precipitation by the end of the century.

The central and western regions of Kazakhstan, which are already drier regions, will experience less changes by the end of the century, while the wetter regions will experience a precipitation increase already by the end of the period 2011-2040. The highest increase in average precipitation is Jetisu, while the lowest increase is West Kazakhstan.

Changes in average precipitation are expected to vary substantially across months.

- Under the **SSP1-2.6 “Sustainability”** scenario, the largest increases are projected for January and February, while the smallest increase occurs in September. No monthly decreases in precipitation are projected under this scenario.



Figure 5.
Change in average annual precipitation by region.

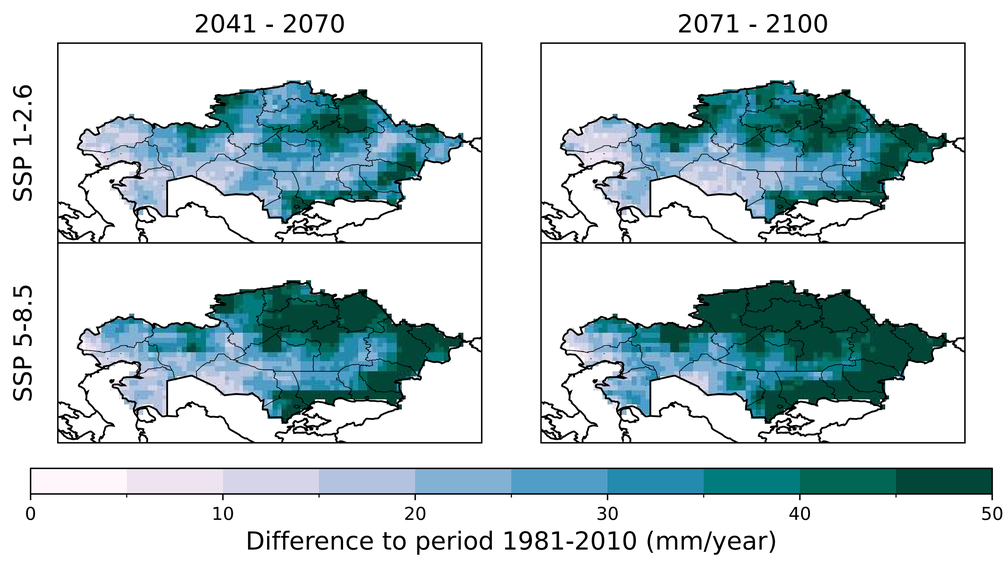


Figure 6.
Spatial distribution of precipitation change.

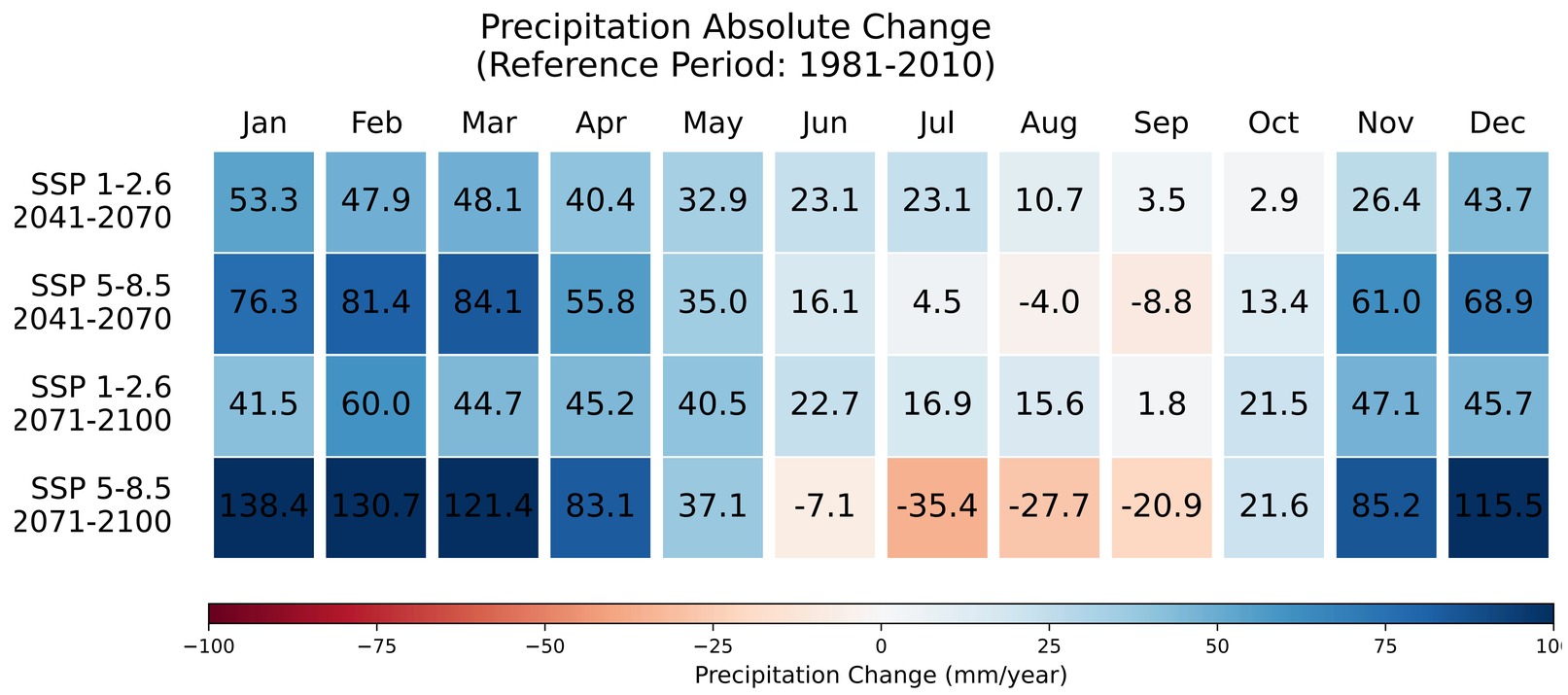


Figure 7.
Monthly precipitation change patterns.

Water

River discharge

Most parts of the country will experience an overall increase of **river streamflow** under climate change.

According to Didovets et al. (2026)[13] the northern and central catchments in Kazakhstan (including Shagan, Tobol, Derkul, Zhabay and Sarysu), as well as eastern Kazakhstan, are projected to experience:

- An increase in annual streamflow under both **SSP1-2.6 “Sustainability”** and **SSP5-8.5 “Fossil-Fueled Development”**, with a stronger and more robust increase under **SSP5-8.5 “Fossil-Fueled Development”** toward the end of the century.

The largest relative annual increase is reported for the Zhabay catchment, reaching up to ~50% by end-century under **SSP5-8.5** mainly due to strong spring floods. These changes are driven mainly by increase in total annual precipitation.

In terms of **seasonality**, a consistent shift toward higher streamflow in late autumn and the cold season (especially November and December–March) and early spring, alongside reduced summer flows (particularly July–September). This seasonal redistribution is attributed to earlier snowmelt (due to temperature rise), higher evapotranspiration, and seasonal precipitation shifts.

Snow Water Equivalent

The **snow water equivalent (SWE)** is another way to measure water availability in regions that depend on snow melt for freshwater. It represents the depth of water that would result in a complete melt of snow in a given snowpack. Lower levels of SWE would result in less water availability from snowmelt. Measuring SWE changes is important to help predict spring water runoff for drinking water or agriculture.

In the case of Kazakhstan, the SWE is expected to decrease for both future scenarios.

- In the **SSP1-2.6 “Sustainability”** scenario, SWE is expected to lower between 25% and 45%.
- In the **SSP5-8.5 “Fossil-Fueled Development”** scenario, SWE is expected to lower between 40% and 75%.

As expected, snow water decrease will mainly affect the northern region and the southern mountainous regions of Kazakhstan, which will see a decrease in snow by the end of the period 2071-2100.

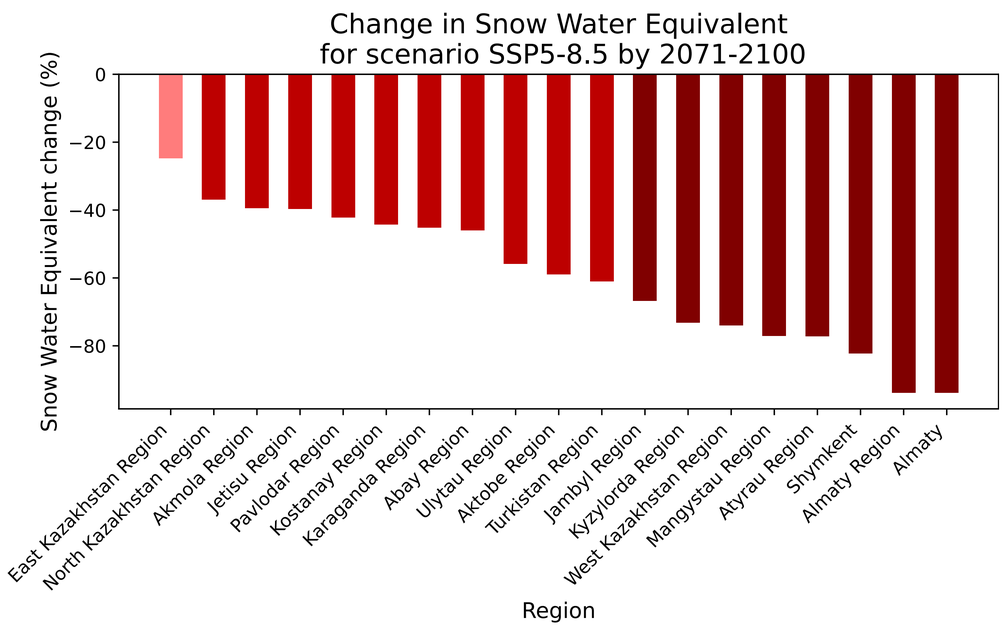


Figure 8.
Change in SWE by region.

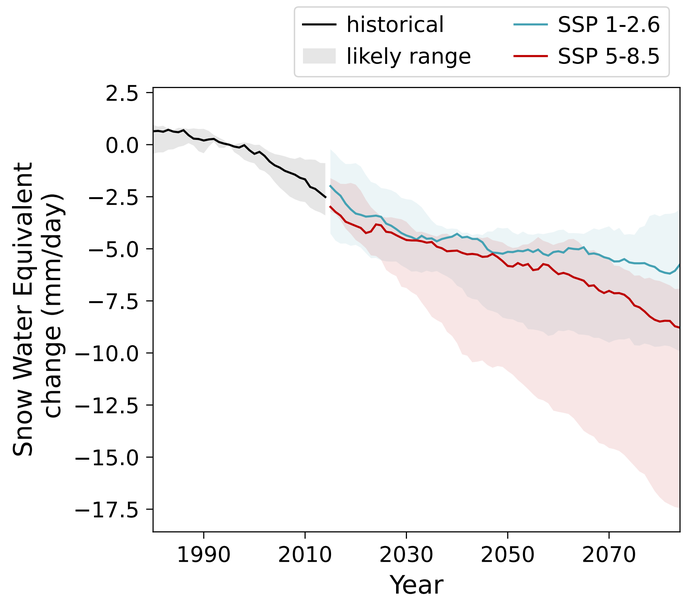


Figure 9.
Trends in SWE change.

[13]
Didovets I. et al. Central Asian Water Resources In The Face Of Climate Change: Shifting Seasonality And Diverse Impacts River Discharge (2026, in press) Springer Nature.

Standardized Precipitation Evaporation Index (SPEI)

The 12-month **Standardized Precipitation Evapotranspiration Index (SPEI)** describes the fluctuations of water availability based on monthly precipitation data, across a 12-month period. In essence, it gives an idea of water availability patterns across long term time periods. It is measured on a scale from -3 to 3, in which negative values indicate dry events, and positive values indicate wet events.

According to the models:

- the SPEI is expected to decrease by around -1.2 at the end of the year 2100 in the **SSP1-2.6 "Sustainability"** scenario.
- On the other hand, in the **SSP5-8.5 "Fossil-Fueled Development"** scenario, the decrease is expected to reach almost -3, indicating very intense dry events.

As seen in the maps, the regions primarily affected by the SPEI decrease are the south-west regions of the country: the regions that already are characteristically dry.

- In the **SSP5-8.5 "Fossil-Fueled Development"** scenario, most of the country reaches values of between -2.5 and -3, indicating the whole country is expected to experience intense droughts and dry events by the end of the century.

While the SPEI is expected to decline, the **annual precipitation** in Kazakhstan is expected to increase under the same future scenario and time periods. This apparent contradiction can be explained by the underlying components of the SPEI. The index is calculated based on both precipitation and **potential evapotranspiration (PET)**. While precipitation is projected to rise, PET is expected to increase even more significantly across the entire country, due to the higher temperatures. The magnitude of the PET increase outweighs the gains in precipitation, leading to a net decrease in SPEI. As a result, the frequency of drought events is projected to rise, despite the overall increase in precipitation.

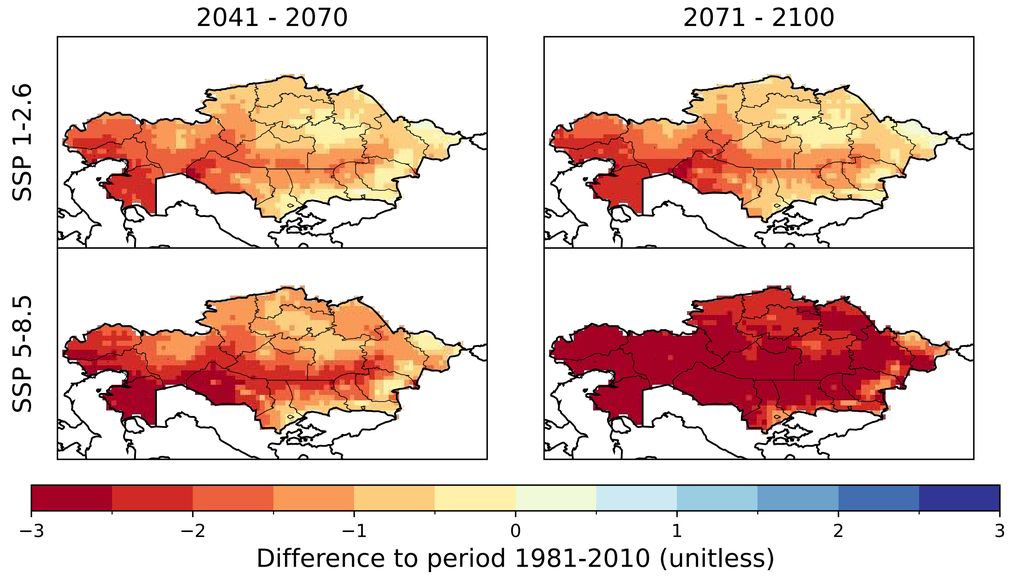


Figure 10.
Spatial distribution of SPEI change.

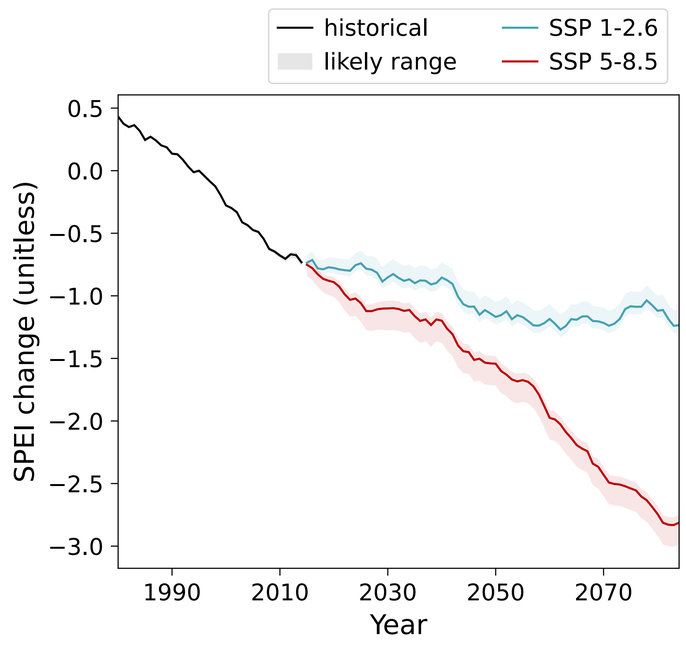


Figure 11.
Trends in SPEI change.

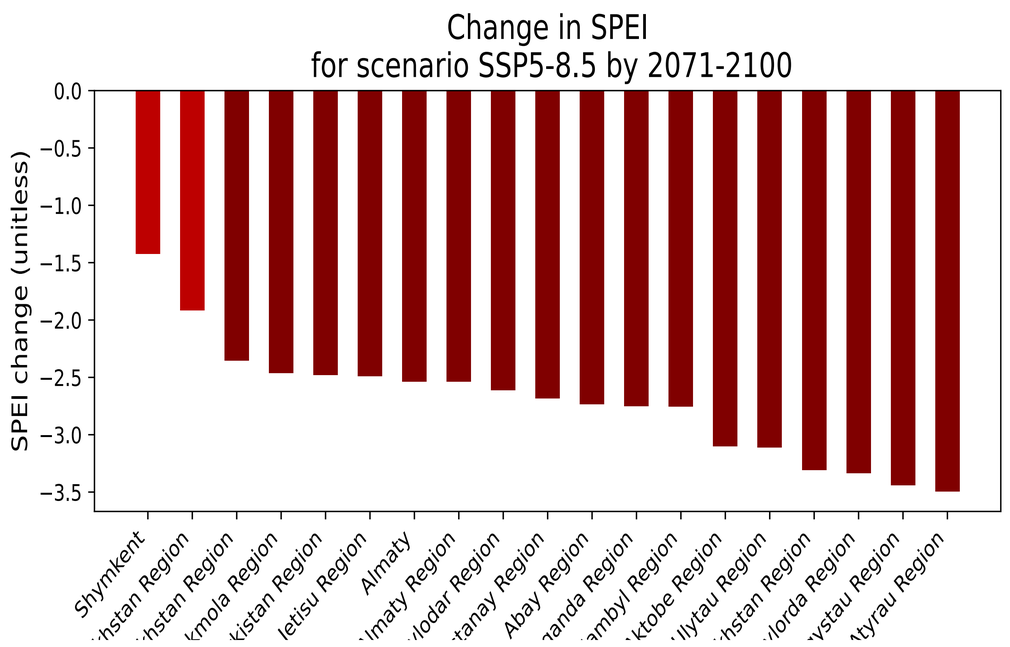


Figure 12.
Change in SPEI by region.

Agriculture

Crop Yield: Summer Wheat

Kazakhstan's most important crop is **wheat**. It ranks as the 11th largest wheat producer in the world, with approximately 18,577,000 metric tons produced in 2024. Wheat has historically played a key role in the country's agriculture, especially due to Soviet-era campaigns that promoted its cultivation. Today, it remains major component of Kazakhstan's economy, both domestically and in terms of exports. Around 8,000,000 metric tons are consumed within the country, while the remaining 10,000,000 metric tons are exported[14].

Although Kazakhstan also grows winter wheat and durum wheat, spring wheat is by far the most important type, accounting for about 80% of the country's total wheat production. Data was analyzed for spring wheat yield for the regions of Akmola, Kostanay, and North Kazakhstan between 2071 and 2100, for two future climate scenarios: the SSP1-2.6 "Sustainability" scenario and the **SSP5-8.5 "Fossil-Fueled Development"** scenario.

The projections indicate distinct regional patterns in late-century changes in spring wheat yields.

- Under the **SSP1-2.6 "Sustainability"** scenario, Akmola shows the largest projected increase, with yields rising by approximately 27%, whereas Kostanay exhibits a more moderate increase of about 13%.
- In contrast, under **SSP5-8.5 "Fossil-Fueled Development"**, Kostanay displays the largest projected change, with yields increasing by nearly 25%, while Akmola shows a smaller increase of around 13%.
- **Under both scenarios**, North Kazakhstan is projected to experience a slight decline, with yields decreasing by approximately 3%.

These projected **yield changes** are likely associated with increasing temperatures and shifts in precipitation across key crop growth stages, which can alter the crop's thermal conditions and water balance. In regions where yields increase, the projections are consistent with more suitable thermal conditions and/or reduced water, depending on the timing and magnitude of precipitation changes.

However, these projections do not account for other limiting factors (e.g., pests, diseases, or management changes). Effective adaptation strategies will therefore be important to help realize potential yield gains.

Projected yield increases should be taken with understanding of some limitation e.g. short-term extreme heat damage during critical crop stages and assume irrigation capacity improvements that may be unrealistic under worsening drought conditions and Kazakhstan's current water-management constraints.

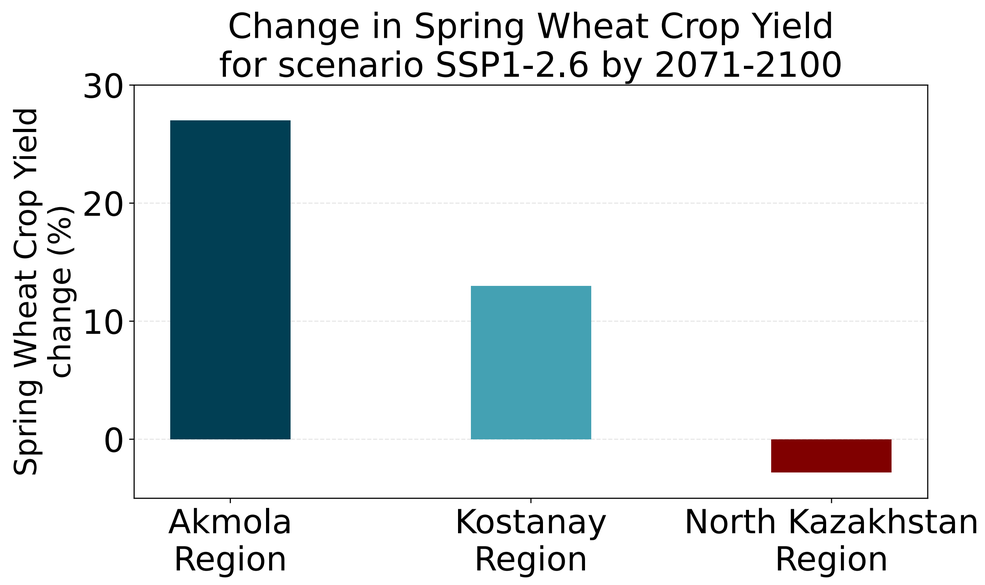


Figure 13.
Change in spring wheat yield (SSP1-2.6).

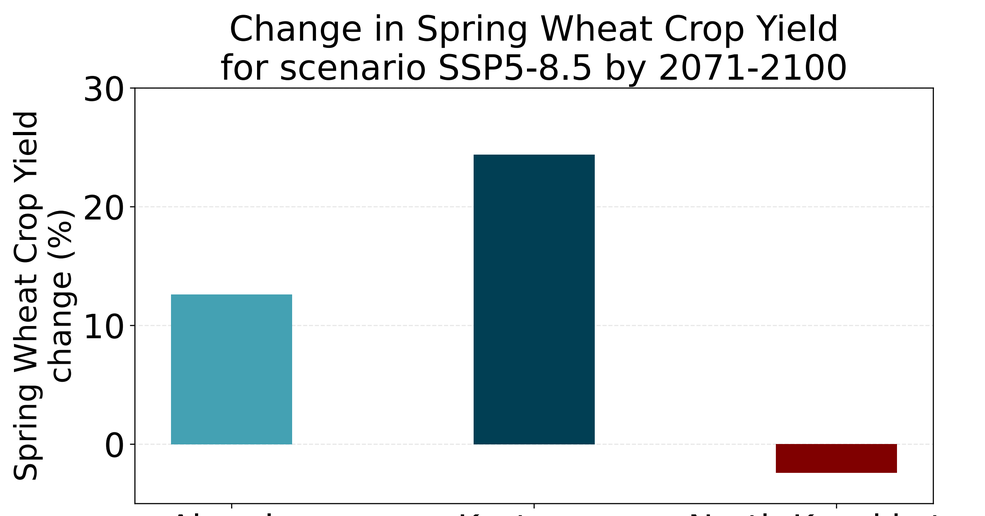


Figure 14.
Change in spring wheat yield (SSP5-8.5).

[14]
U.S. Department of Agriculture, Foreign Agricultural Service. (2023). Production – Wheat

Health

Summer Daytime Outdoor Productivity (HIGH INTENSITY WORK)

The **Summer Daytime Productivity** describes the daily average potential work output achievable by an individual in a single day. In this dataset, it is averaged out for the summer period of Kazakhstan (June - August). In this case, we focus on High Intensity Work, which encompasses work from the agriculture and construction sectors, such as work in farmland, animal husbandry, construction, and infrastructure maintenance.

For high intensity work, which demands substantial energy:

- the expected average productivity decrease is approximately 15% by 2080 under the **SSP5-8.5 "Fossil-Fueled Development"** scenario.
- Under the **SSP1-2.6 "Sustainability"** scenario, the decrease is much less severe and stabilizes after 2050.

The maps show that productivity loss at this intensity affects a large area of the country, extending beyond the south-west to encompass much of the western region. The regions with the highest decrease in high intensity work productivity are Shymkent, Kyzylorda, and Mangystau.

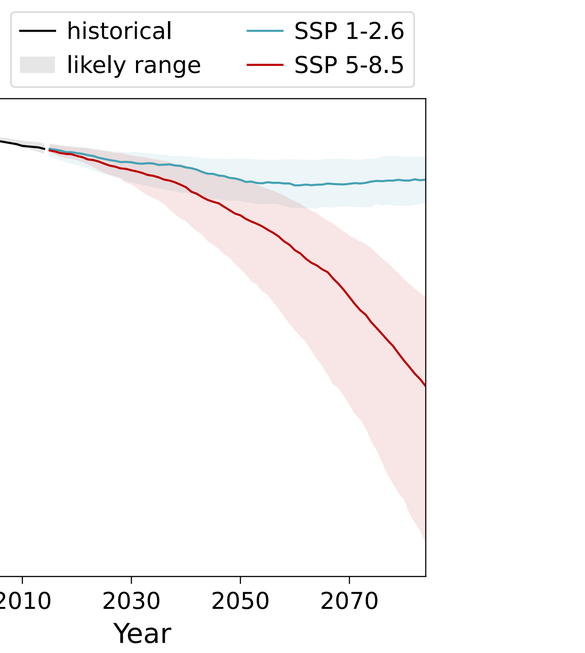


Figure 15.
Trends in summer daytime productivity.

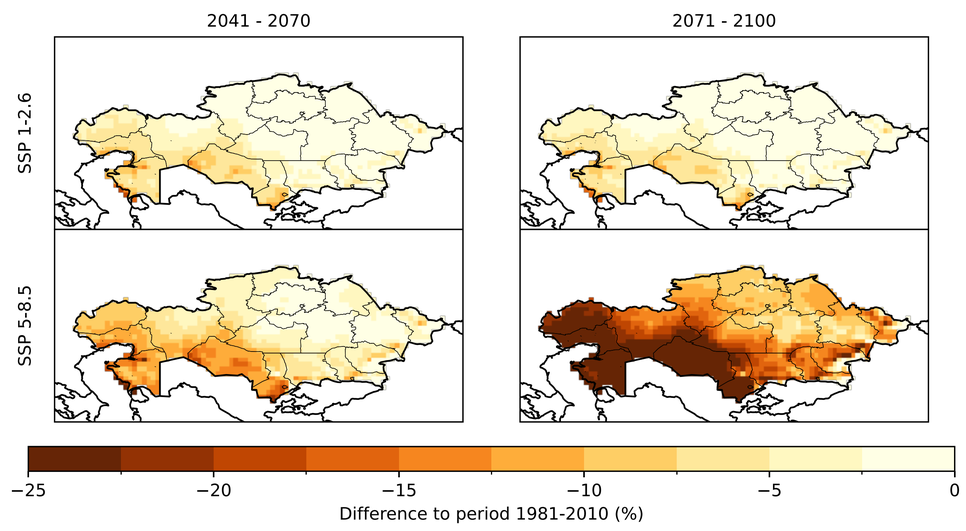


Figure 16.
Spatial distribution of productivity change.



[Image 2]
Nikolayevka, Kazakhstan. Source: unsplash.com

Tropical Nights

The term **tropical nights** refers to the nights where the minimum temperature does not go below 20 ºC, which indicates warm nighttime conditions that can possibly negatively impact sleeping conditions.

For Kazakhstan, the number of tropical nights per year is expected to increase:

- in the **SSP1-2.6 "Sustainability"** scenario, the number of tropical nights will increase between 8 to 24 nights by the end of 2100.
- In contrast, in the **SSP5-8.5 "Fossil-Fueled Development"** scenario, the number of tropical nights will increase between 35 and 70 nights per year.

The drier regions of Kazakhstan, mainly the west and southern regions, will experience the most impact:

these are the regions expected to reach up to 80 tropical nights per year in the **SSP5-8.5 "Fossil-Fueled Development"** scenario, and the regions with more than 10 tropical nights per year increase in the **SSP1-2.6 "Sustainability"** scenario.

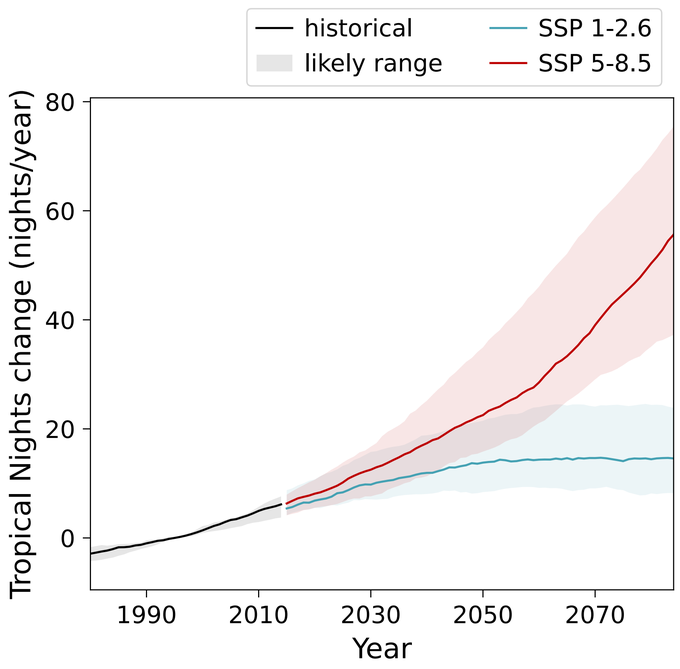


Figure 17.
Trends in tropical nights.

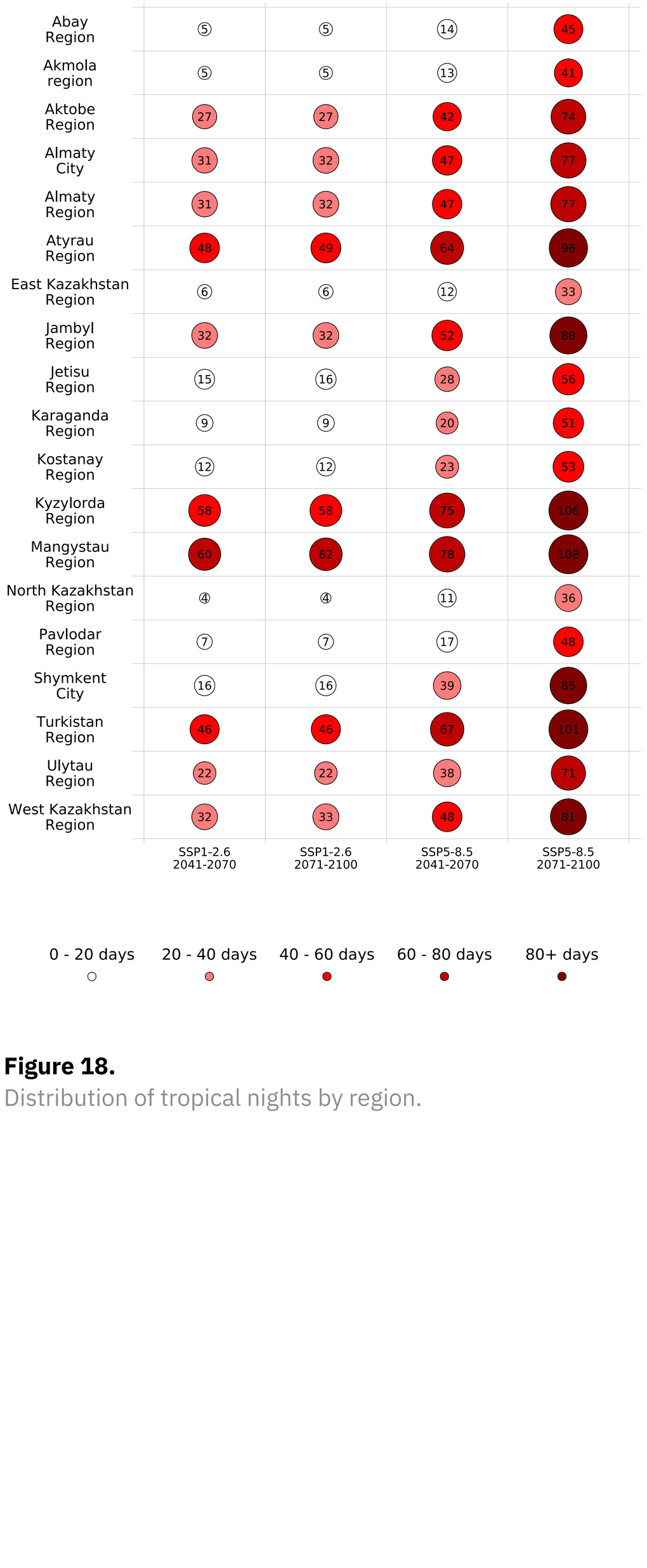


Figure 18.
Distribution of tropical nights by region.

Energy

Photovoltaic Potential

The **photovoltaic potential** describes the potential energy production of a photovoltaic solar panel. The greater the value, the greater the amount of electrical energy that can be produced by photovoltaic panels.

According to the models:

- the **SSP1-2.6 "Sustainability"** scenario shows a larger increase in photovoltaics potential, with a 13 to 33 kWh/m2 increase by the end of 2100.
- While the **SSP5-8.5 "Fossil-Fueled Development"** scenario shows a decrease in photovoltaics potential, with a change of between +5 to -28 in kWh/m2.

According to the maps:

- the **SSP1-2.6 "Sustainability"** scenario shows an increase of potential in the western and northern regions of Kazakhstan,
- while the **SSP5-8.5 "Fossil-Fueled Development"** scenario shows a decrease of potential in the central and eastern regions of Kazakhstan. There are only 3 regions where the photovoltaic potential will increase in the **SSP5-8.5** scenario: West Kazakhstan, Atyrau, and Mangystau.

A possible explanation for how most regions experience a decrease in photovoltaic potential under **SSP5-8.5** is that the higher precipitation causes increased cloud cover, reducing the exposure to sunlight. Other factors such as extreme weather events might also limit the potential of solar panels in the future due to maintenance costs.

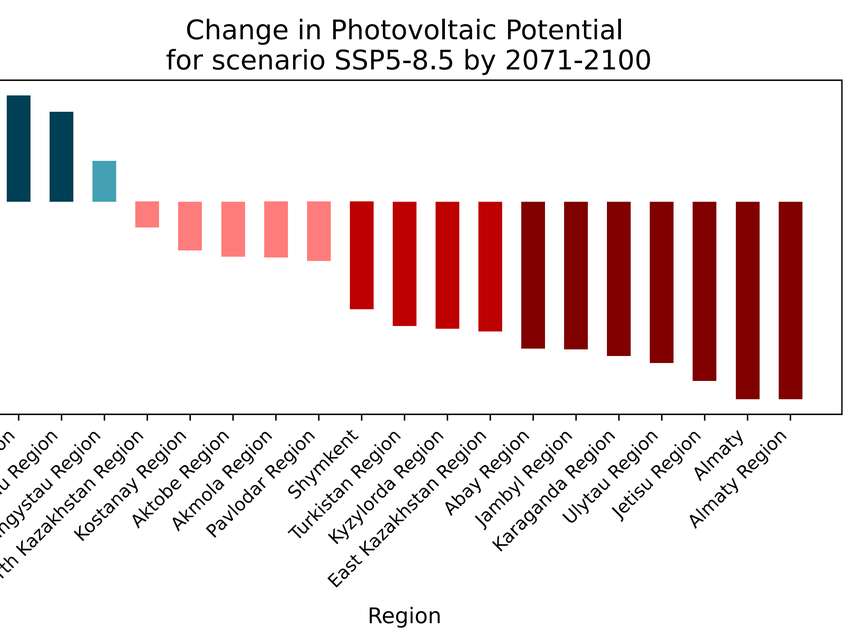


Figure 20.
Trends in photovoltaic potential.

Figure 21.
Change in photovoltaic potential by region.

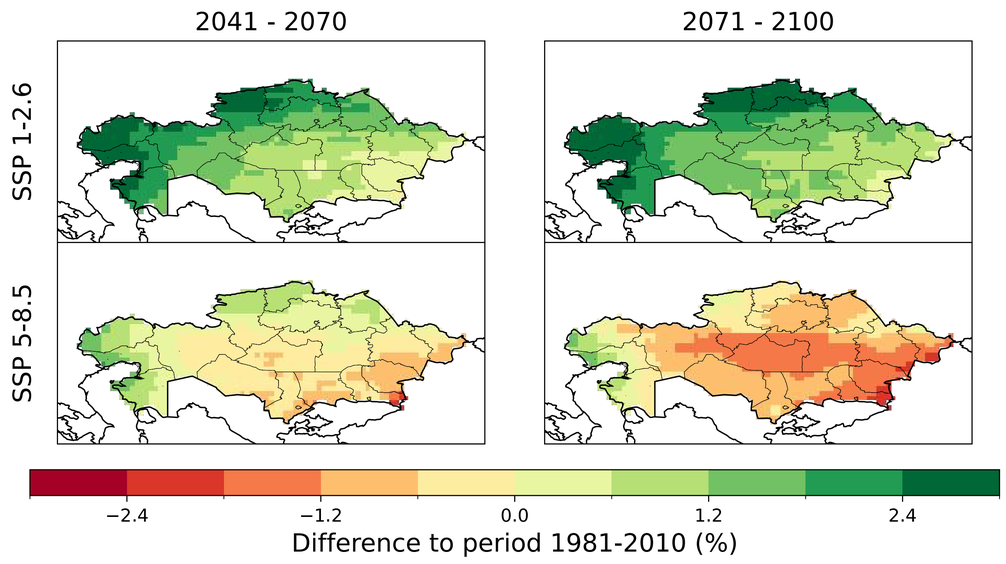


Figure 19.
Spatial distribution of photovoltaic potential change.



Koksu valley
Dzungarian Alatau, Kazakhstan
Source: unsplash.com

Conclusions

The projected future data shows that climate change will significantly alter Kazakhstan's climate and its key economic sectors over the coming decades.

Rising temperatures are projected to affect the entire country uniformly, with increases of up to 9°C under the high-emission SSP5-8.5 scenario. Even under the more sustainable SSP1-2.6 pathway, warming of more than 2°C is expected, which will still reshape ecosystems and patterns of human activity.

Although precipitation is projected to increase slightly on average and lead to general increase in streamflow, the combined effect of rising evapotranspiration and decreasing snow water would drive seasonal changes including more droughts and floods.

The impacts of climate change on wheat production, labor productivity, and overall human well-being highlight the broader socioeconomic risks. As Kazakhstan is both a major grain exporter and a country with a large rural population, any potential gains in wheat production can be taken advantage of, as long as water resources are also managed effectively.

The increase in tropical nights and more frequent extreme events such as droughts and floods will further challenge the public health, infrastructure, and energy systems. At the same time, opportunities such as the growth of photovoltaic potential under low-emission pathways show that mitigation and adaptation strategies can help offset some of the negative consequences.

Ultimately, the comparison between SSP1-2.6 and SSP5-8.5 demonstrates the critical importance of global and national action. A sustainable, low-emission pathway would significantly reduce the scale of climate risks for Kazakhstan, while continued reliance on fossil-fueled development would expose the country to severe and widespread challenges.

Strengthening adaptive capacity, investing in resilient infrastructure, and supporting sustainable agriculture practices will be essential to safeguard Kazakhstan's long-term stability in the face of climate change.



[Image 3]
Almaty, Kazakhstan.
Source: unsplash.com

[Back cover image]
Gorodetsky Glacier,
Almaty region,
Kazakhstan.
Source: unsplash.com



Charyn Canyon
Almaty region, Kazakhstan
Source: unsplash.com

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