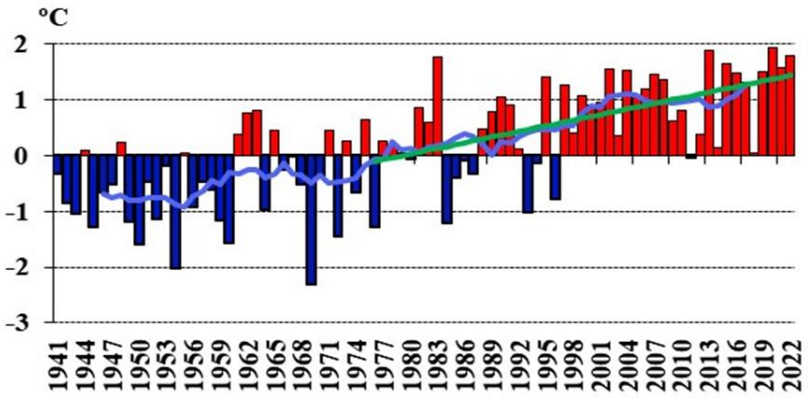
MINISTRY OF ECOLOGY AND NATURAL
RESOURCES OF THE REPUBLIC OF KAZAKHSTAN

REPUBLICAN STATE ENTERPRISE
«KAZHYDROMET»

SCIENTIFIC RESEARCH CENTER

ANNUAL BULLETIN OF MONITORING OF THE CLIMATE STATE AND CLIMATE CHANGE IN KAZAKHSTAN: 2022



ASTANA, 2023

CONTENT

SHORT SUMMARY

Climate features in 2022

For the globe as a whole, 2022 was among the top five to six warmest years in the instrumental observation period. The global mean annual temperature in 2022 was about 1.15±0.13 ℃ above the 1850-1900 baseline used as an approximation of pre-industrial levels.

On average for Kazakhstan, the average annual air temperature in 2022 was 1.78 ℃ above the climatic norm for the period 1961-1990 and this is the third value in the ranked series of the warmest years for the period 1941-2022, the year was among the 5 % of extremely warm years. For five regions such as Karaganda, Zhetysu, Ulytau, Atyrau and Kyzylorda 2022 was among the 5 % of extremely warm years with anomalies ranging from +1.46 ℃ to +2.42 ℃, for four regions Zhambyl, Mangistau, Turkestan and Almaty the year became record warm - the average anomalies for the territory were +2.33 ℃, +2.21 ℃, +2.05 ℃, +2.03 ℃, respectively. Extremely high annual temperatures were recorded according to data from most meteorological stations in the western, south-western, southern, and south-eastern regions of the country. According to data from 29 meteorological stations in the western, southern, and eastern regions, 2022 was the warmest year since 1941, with record temperature anomalies ranging from +1.13 to +3.11 ℃.

In many regions of Kazakhstan, January, the period from April to June and September were extremely hot. The daily maximum temperature in 2022 exceeded 30 ℃ and even 35 ℃ over the entire territory of Kazakhstan (except for high mountainous areas). In 2022, absolute maximum values were updated at four meteorological stations involved in climate monitoring in Kazakhstan. In the western and southern regions, the total duration of all heat waves was more than 50, in some places more than 60 days. As a consequence of high air temperatures for a significant part of the warm period of the year, especially in the western and southern regions of Kazakhstan, there was an acute need for cooling of premises to maintain favorable temperatures.

The layer of precipitation for 2022 on average over the territory of Kazakhstan was 311 mm (98 % of the norm). On average over the territory of most regions annual precipitation totals were within ±20 % of the norm. A significant deficit of precipitation (up to 25-45 %) was observed in the south-eastern, southern, and central regions of the country.

The average precipitation over the territory of Kazakhstan was below the norm in February, April, from June to October and December. Two months were dry (10 % extremes): April, when average precipitation was about 52 % of the norm, and September, when 53 % of the norm fell. Significant precipitation deficits were also observed in February (probability of non-exceedance of 25 %), June (23 %) and August (11 %). March was the wettest March on record (209 % of the norm) and November was extremely wet (175 % of the norm, probability of non-exceedance 98 %). From April to October and December, most of the territory of Kazakhstan experienced precipitation deficit. At some stations monthly minimums of precipitation were updated, at others - monthly maximums. Based on data from many stations in western, central, and southern regions precipitation was absent for at least a month.

Climate change in Kazakhstan

A steady increase in the average annual air temperature is observed in all regions of Kazakhstan. On the territory of the country, the average annual air temperature increase is 0.33 ℃

every 10 years. For the territory of individual regions, the rate of increase ranges from 0.21 °C/10 years (Karagandy region) to 0.54 °C/10 years (West Kazakhstan region). In all seasons, except winter, the temperature increase is statistically significant.

All trends in the average annual and seasonal precipitation over the territory of Kazakhstan are statistically insignificant. There is a slight tendency to increase the annual precipitation amounts (by 0.8 mm/10 years), mainly due to the precipitation of the spring season, when the increase in some western, northern and central regions is 7-18 %/10 years. During the autumn period, precipitation decreases almost throughout Kazakhstan, in some western and southern regions by 4-12 %/10 years.

Analysis of trends in extremes of surface air temperature and precipitation showed that over the period 1961 to 2022:

- there is a steady increase in the number of summer days with temperatures above 25 °C and 30 °C, as well as tropical nights with temperatures above 20 °C, especially noticeable in the south, southwest and west of the republic;
- everywhere there is an increase in the number of heat waves in the warm season, the total and maximum duration of heat waves, as well as the duration of heat waves in general for the year increases;
- there is a reduction in heat deficit (the need for heating) in the cold period of the year and an increase in cold deficit in the warm period (the need for air conditioning), especially in the south-west and west of the republic;
- everywhere there is a steady increase in the period of active vegetation with an average daily temperature above 10 °C, as well as the sum of active temperatures for this period;
- the number of days with frosts and severe frosts below minus 20 °C is reduced;
- the characteristics of precipitation extremes did not change significantly over most of the Republic's territory.

The observed increase in the frequency and duration of periods with high air temperatures in the warm season leads to negative consequences not only for the human body and animals, but also for the transport infrastructure due to the deformation of the pavement, for the conditions of the urban environment and recreation areas, for the energy industry, as there is a need for additional energy generation for cooling the premises.

An increase in surface temperature leads to a reduction in the period with negative temperatures, as a result, precipitation is more likely to fall in liquid form. This, in turn, can affect snow accumulation during the cold season. In mountainous areas, both the area and the period of precipitation in solid form are reduced, which affects glacial systems.

An increase in surface temperature during the cold season leads to a decrease in the need for thermal energy generation. Reducing the number of days with frosts, on the one hand, leads to a positive effect for the health of the population, on the other hand, heat waves in the cold season can lead to the formation of ice on the roads when the cold weather returns.

An increase in the duration of the growing season in those areas where this is combined with an increase in precipitation and a reduction in the maximum duration of the rainless period (in some northern and southeastern regions) improves conditions for crop production.

In some areas, an increase in the maximum daily precipitation has been recorded, which may lead to an increased risk of destruction of the roadway and storm systems in settlements, landslides, and mudslides in mountainous areas.

INTRODUCTION

Climate is a natural resource that is vital for determining the development of many sectors of the economy and the health of the population of any country. Meteorological information collected, managed, and analyzed by national hydrometeorological services helps users of this information, including decision-makers, to plan any activity taking into account current climatic conditions and observed climate changes. The use of up-to-date meteorological and climate information helps to reduce risks and damages and optimize socio-economic benefits. The climate system is monitored by national, regional, and international organizations under the coordination of the World Meteorological Organization and in cooperation with other environmental programmes.

The study of regional climate and continuous monitoring of its change is one of the priority tasks of the national hydrometeorological service of Kazakhstan RSE "Kazhydromet". Since 2010 RSE "Kazhydromet" has been issuing annual bulletins to provide reliable scientific information on regional climate, its variability and change. Considering the geographical location of Kazakhstan and its vast territory, the observed changes in climatic conditions in different regions of the Republic can have both negative and positive impact on biophysical systems, economic activity, and social sphere. Consideration of climatic conditions and assessment of their changes are necessary to identify potential consequences and to take timely and adequate adaptation measures, ultimately to ensure sustainable development of Kazakhstan.

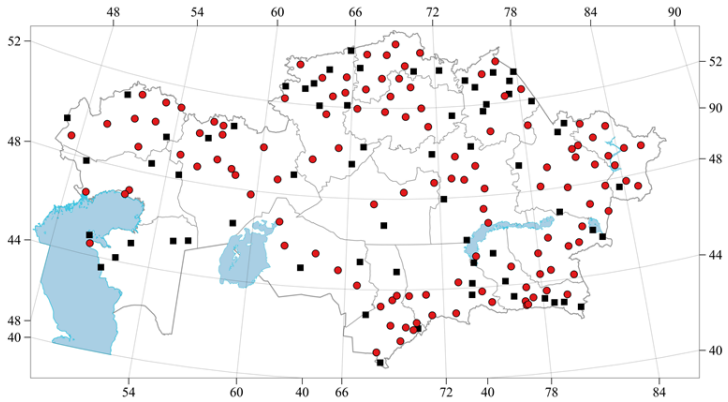
This edition of the Bulletin describes the climate conditions observed in 2022, including an assessment of extremes in temperature and precipitation regimes, and provides historical information on changes in surface air temperature and precipitation that have occurred since 1941. This Bulletin also includes estimates of climate change over a shorter period since the mid-1970s, when many experts believe global climate change intensified, particularly in the northern hemisphere. Appendices 2 and 3 contain maps showing the distribution of long-term mean air temperature and precipitation for the period 1961-1990, averaged by season and year.

Initial data. For preparation of the bulletin data of the Republican Hydrometeorological Fund of RSE "Kazhydromet" are used:

1) series of average monthly air temperatures and monthly precipitation totals, with about 120 meteorological stations having homogeneous series since 1941 and their data are involved in the generalization of information on the territory of the regions and Kazakhstan as a whole, since 1961 there are about 190 such stations, and their data were used to assess climatic norms for the period 1961-1990, to assess anomalies and trends in a particular point;

2) series of daily maximum and minimum air temperatures and daily precipitation since 1961 (about 190 meteorological stations).

The network of meteorological stations used for climate monitoring is shown on the map below.

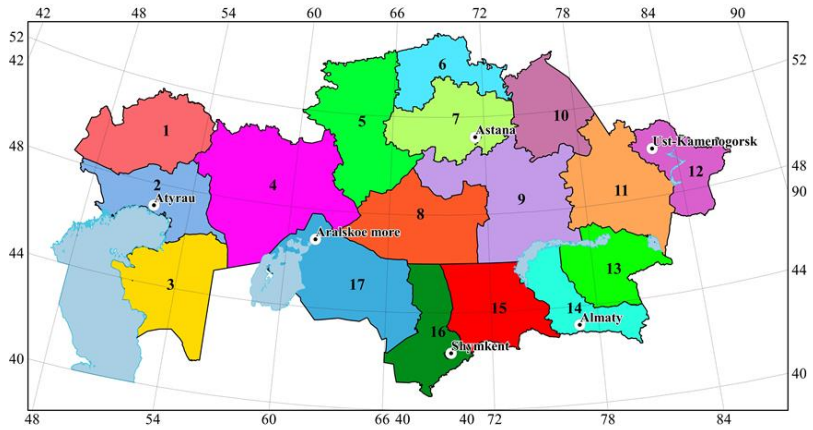


Meteorological station network in Kazakhstan used for climate monitoring
(stations used for averaging over the area of regions are shown in red circles)

Basic approaches and methods. The "norm" in the Bulletin is understood as the mean annual value of the climatic variable under consideration for the period 1961-1990. Temperature anomalies are calculated as deviations of the observed value from the norm. Precipitation anomalies are usually considered both in deviations from the norm (similar to air temperature) and in percent of the norm. As additional characteristics of anomalies, indicators based on the distribution function (probability of non-exceedance, which characterizes the frequency (in %) of occurrence of the corresponding anomaly value in a series of observations) and ordinal statistics (ranks, i.e. ordinal numbers in an ordered series of values relative to other numbers in the data set) are used; the periods for estimating these statistics are specifically specified in each case.

As an assessment of changes in climate characteristics over a certain time interval, linear trend coefficients determined by the least squares method are used. The measure of trend significance, the coefficient of determination (D), characterizes the contribution of the trend component to the total variance of a climatic variable over the time period under consideration (in percent).

Estimation of surface air temperature and precipitation trends, mean values of anomalies of meteorological variables are given both for data of individual stations and on average for the territory of Kazakhstan as a whole and for 17 of its administratively territorial regions. Mean values of anomalies of meteorological variables for the territory are calculated by averaging station data on anomalies. The boundaries of administrative territorial regions of Kazakhstan are presented on the map below.



1	West Kazakhstan region	10	Pavlodar region
2	Atyrau region	11	Abay region
3	Mangistau region	12	East Kazakhstan region
4	Aktobe region	13	Almaty region
5	Kostanay region	14	Zhetysu region
6	North Kazakhstan region	15	Zhambyl region
7	Akmola region	16	Turkestan region
8	Ulytau region	17	Kyzylorda region
9	Karagandy region		

Scheme of administrative-territorial division of the Republic of Kazakhstan

Climate indices, recommended by the World Meteorological Organization, are used to assess the temperature and precipitation regime in a particular year and its change since 1961, and help to "detect" (mathematically) significant climate change, including the characteristics of extremes. Some indices are based on fixed uniform thresholds for all stations, others on thresholds that may vary from station to station. In the latter case, the thresholds are defined as the corresponding percentiles of the data series. The indices also make it possible to assess the impact of the current climate and its changes on various aspects of socio-economic conditions in the study region. There are indices reflecting the potential impact on human health, on energy generation needs in different seasons, on agrometeorological conditions, on transport infrastructure, on extremity of hydrometeorological conditions, etc.

Responsible for the edition: Head of the Department of Climate Research Tillakarim T.A. In the preparation of the bulletin also participated: candidate of geography Dolgikh S.A., leading researchers Smirnova E.Y., Beldeubaev E.E., Kurmanova M.S., Aktayeva G.S., Medetova A.K., Abdolla N.S. and leading engineers Turumova G.E. and Karatay M.A..

1 OVERVIEW OF GLOBAL CLIMATE CHANGE AND ITS STATE IN 2022

It has been 30 years since the World Meteorological Organization issued its first State of the Climate Report in 1993 in response to concerns at that time about projected climate change. The annual State of the Global Climate Report identifies indicators of the climate system, including greenhouse gas concentrations, rising land and ocean temperatures, sea-level rise, ice melt and glacier retreat, and extreme weather events. It also highlights impacts on socio-economic development, migration and displacement, food security and terrestrial and marine ecosystems. Global climate indicators provide a broad view of climate change on a global scale, covering atmospheric composition, energy changes and the response of land, ocean, and ice. These indicators are closely interrelated. For example, increases in CO_2 and other greenhouse gases in the atmosphere lead to energy imbalances and thus atmospheric and ocean warming. Ocean warming, in turn, leads to sea level rise, to which is added the melting of land ice in response to rising atmospheric temperatures. Together, the indicators create a coherent picture of global warming that affects all parts of the Earth system.

Clear links can be seen between key climate indicators as a physical system and the cascading risks to most of the 17 Sustainable Development Goals. Monitoring global climate indicators and their associated risks and impacts is thus critical to achieving the Sustainable Development Goals by 2030.

Key messages on the state of the global climate in 2022:

The mean annual global temperature in 2022 was 1.15 ± 0.13 °C above the mean temperature for the pre-industrial period 1850-1900 (Figure 1.1). This is a less significant anomaly because the cooling effect of the La Niña phenomenon was observed for three consecutive years, such a prolonged effect of La Niña conditions has occurred only three times in the last 50 years. The six datasets used in the analysis place 2022 as the fifth or sixth warmest year on record globally, and all six datasets show that the last eight years, from 2015 to 2022, have been the warmest years in the history of instrumental observations since 1850 (Figure 1.1.).

In 2021, the molar fractions of **greenhouse gas concentrations** reached new highs: 149 % carbon dioxide (CO_2), 262 % methane (CH_4) and 124 % nitrous oxide (N_2O) from pre-industrial (1750) levels. The increase in carbon dioxide emissions from 2020 to 2021 was equal to that observed from 2019 to 2020 but exceeded the average annual growth rate over the past decade. The annual increase in methane concentrations from 2020 to 2021 was the highest ever observed. Real-time data from several specific locations show that concentration levels of the greenhouse gases, CO_2, CH_4, and N_2O, continued to increase in 2022.

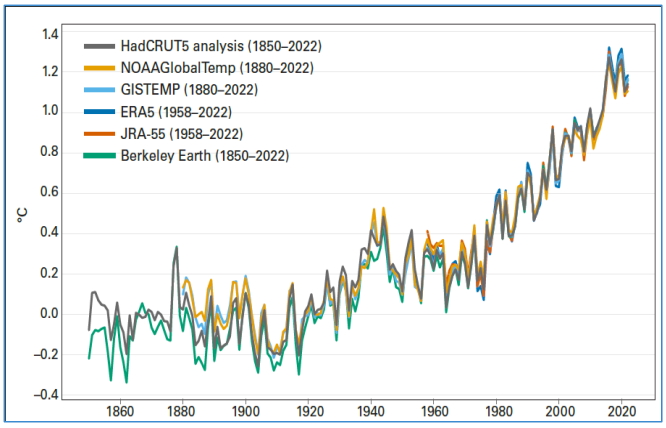


Figure 1.1 - Anomalies in global mean annual air temperature relative to pre-industrial conditions (1850 1900) across six global temperature datasets (1850-2022).

Source: Met Office, United Kingdom of Great Britain and Northern Ireland; Copernicus Climate Change Service (C3S); Climate Data Store (CDS), 2023.

Global mean sea level continued to rise in 2022, reaching a new all-time high for satellite altimetry (1993-2022). The rate of global mean sea level rise doubled between the first decade (1993-2002) of satellite observations, when sea level rose by an average of 2.27 mm per year, and the last decade (2013-2022), where global mean sea level rose by an average of 4.62 mm per year.

Ocean heat content in 2022 reached a new record high in the history of observations. Ocean warming rates have been particularly high over the past two decades. Despite the persistence of La Niña conditions over the past three years, 58 % of the ocean surface will be affected by at least one heat wave in 2022.

Glaciers. In Switzerland, for the first time in history, even at the highest measurement points, snow did not persist after the summer melting season and therefore no fresh ice accumulation occurred. On 25 July, the Swiss balloon probe recorded 0 °C at 5184 m, which was the highest zero line in the history of observations (69 years) and only the second time that the zero-line exceeded 5000 m in altitude.

Measurements on glaciers in high mountain Asia, western North America, South America, and parts of the Arctic also show loss of substantial glacier mass.

For the Greenland ice sheet, the 26th consecutive year ended with a negative total mass balance.

The evolution of **the ozone hole** in 2022 was similar to its evolution in 2021. The Antarctic ozone hole reached an area of 26 million km2, which is comparable to 2020 and 2021. This unusually deep and large ozone hole was caused by a strong and stable polar vortex and colder than normal conditions in the lower stratosphere.

Exceptional **heat waves** broke summer records in Europe and China. In parts of Europe, extremely high temperatures were combined with exceptionally dry conditions. In China, from mid-June to the end of August, the strongest and longest heat wave since national observations began was observed, resulting in the hottest summer on record, with temperatures exceeding 0.5 °C, while it was also the second driest summer on record.

In Pakistan, **flooding** due to record rainfall in July (181 % of normal) and August (243 % of normal) caused numerous casualties and economic losses of USD 30.0 billion.

Drought affected many parts of Europe and the Mediterranean, as well as East Africa. In Europe, drought conditions were most severe in August. West-central Germany recorded its

driest summer on record. Northern Italy and the Iberian Peninsula had an exceptionally dry winter in 2021/2022. In eastern Africa, rainfall has been below average for five consecutive rainy seasons, the longest such period in 40 years, with severe impacts on agriculture and food security. As in the previous prolonged drought of 2010-2012, La Niña conditions and the negative phase of the Indian Ocean Dipole (IOD) contributed significantly to the drought conditions.

2 AIR TEMPERATURE

In 2022, the average annual air temperature anomaly in Kazakhstan was +1.78 ℃ relative to the long-term average for the period 1961-1990 (5.4 ℃) and was 0.14 ℃ lower than in the record year 2020. Since the 1960s, each successive decade in Kazakhstan has been warmer than the previous one. The mean annual air temperature for the last decade 2013-2022 was +6.75 ℃ and exceeded the climatic norm by 1.33 ℃, this is a record value among positive decade anomalies, the previous warmest decade was in 2001-2010 with an anomaly of +1.09 ℃. The last five years 2018-2022 was also the warmest with a mean annual air temperature of +6.79 ℃, which exceeded the climatic norm by 1.36 ℃.

Table 2.1 presents the lists and ranks of the ten warmest years on average for the globe and for Kazakhstan (based on ground network data). Each year, which is included in the 10 warmest years for the globe and for Kazakhstan is assigned a different color, which allows to judge about coincidences in the ranking of the warmest years in both lists. The six warmest years in Kazakhstan were included in the list of the ten warmest years for the globe. The year 2020 turned out to be record warm both in Kazakhstan and globally.

Table 2.1 - The warmest years in the history of observations on the globe (since 1850) and in Kazakhstan for the period 1941-2022 and the corresponding anomalies of mean annual surface air temperature averaged over the territory of Kazakhstan. Anomalies are calculated relative to the period 1961-1990

Rank	Globe	Kazakhstan	Anomaly of mean annual temperature (Jan-Dec) averaged over the territory of Kazakhstan, °C
1	**2020**	**2020**	1,92
2	2016	2013	1,89
3	2019	2022	1,78
4	2017	1983	1,76
5	2022	2015	1,64
6	2015	2021	1,58
7	2021	2002	1,55
8	2018	2004	1,53
9	2014	2019	1,50
10	2010	2016	1,48

Figure 2.1 – shows the ranked series of mean annual surface air temperature anomalies averaged over meteorological stations in Kazakhstan for the period from 1941 to 2022. Globally, all 10 extremely warm years occur in the current century. In Kazakhstan this peculiarity is also well traced, except for 1983, which ranks fourth in the ranking of the warmest years.

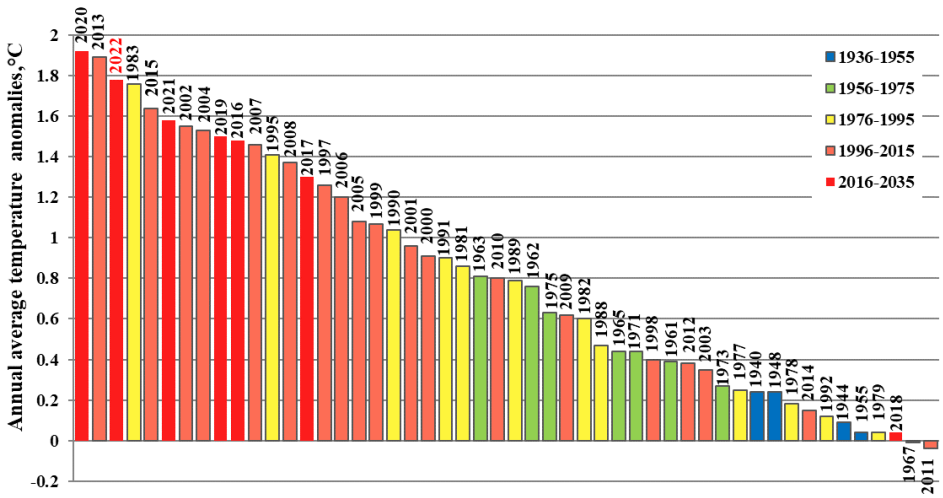


Figure 2.1 – Ranked series of positive anomalies of mean annual (January-December) surface air temperatures averaged over the territory of Kazakhstan (based on data from 121 meteorological stations) for the period 1941-2022. Anomalies are calculated relative to the base period 1961-1990

2.1 Anomalies of air temperature on the territory of Kazakhstan in 2022

The year 2022 in Kazakhstan took the 3rd place in the descending ranked series of mean annual temperatures since 1941 and was among the 5 % of extremely warm years (Figure 2.1).

Table 2.2 presents average annual and seasonal air temperature anomalies averaged by regions and for Kazakhstan as a whole, Table 2.3 presents average monthly air temperature anomalies. For each anomaly value, the probabilities of their non-exceedance, calculated from data for the period 1941-2022, as well as standard deviations for 1961-1990 are given (Table 2.2). In Tables 2.2 and 2.3, temperature values above the 95th or below the 5th percentile (warm and cold extremes, respectively) are shown in bold and color.

The year was a record warm year (Table 2.2) for Zhambyl, Mangistau, Turkestan and Almaty regions (average anomalies for the territory were +2.33 ℃, +2.21 ℃, +2.05 ℃, +2.03 ℃, respectively). For Kyzylorda, Atyrau, Ulytau, Zhetysu and Karaganda regions, 2022 was among the 5 % of extremely warm years (with anomalies of +2.42, +2.33, +2.08, +1.91 and +1.46 ℃, respectively). The average air temperature anomalies over the territory of West Kazakhstan, East Kazakhstan, and Abay regions were included in the 10 % of extremely high anomalies: +2.12, +1.82 and 1.78 ℃, respectively. On the territory of the rest of the regions, the average air temperature anomalies were within the range of 1.20-1.60 ℃.

Table 2.2 – Regionally averaged mean annual (January-December) and seasonal air temperature anomalies in 2022: ***vT*** *- deviations from multiyear averages for 1961-1990, ℃;* ***P(t≤T$_{2022}$)*** *- probability of non-exceedance (in brackets) calculated from data for the period 1941-2022 in %;* ***s*** *- mean square deviation in ℃ for the period 1961-1990, in %.*

Region	Year		Winter		Spring		Summer		Autumn	
	vT (P)	**s**	**vT (P)**	**s**	**vT (P)**	**s**	**vT (P)**	**s**	**vT (P)**	**s**
Kazakhstan	**1,78 (98)**	**0,86**	4,17 (94)	2,44	2,43 (91)	1,28	1,09 (91)	0,65	1,50 (86)	1,16
Abay	1,78 (91)	1,07	3,54 (91)	2,74	**3,66 (96)**	**1,47**	1,04 (90)	0,77	1,40(77)	1,50
Almaty	**2,03 (100)**	**0,75**	**3,90 (99)**	**2,24**	**3,38 (99)**	**0,96**	1,34 (94)	0,66	1,65 (91)	1,02
Akmola	1,26 (86)	1,07	3,67 (91)	2,84	1,97 (78)	1,85	0,21 (62)	1,04	1,08 (69)	1,51
Aktobe	1,60 (89)	0,94	4,66 (91)	2,50	0,58 (63)	1,90	1,17 (80)	0,93	1,83 (89)	1,40
Atyrau	**2,33 (99)**	**0,82**	**5,74 (99)**	**2,40**	1,10 (68)	1,56	2,04 (94)	0,85	2,13 (94)	1,20
East Kazakhstan	1,82 (93)	1,11	3,30 (91)	2,72	**3,70 (96)**	**1,59**	0,72 (73)	0,84	1,59 (84)	1,52
Zhambyl	**2,33 (100)**	**0,87**	**5,54 (100)**	**2,87**	**3,22 (99)**	**1,00**	1,26 (91)	0,81	1,90 (91)	1,18
Zhetysu	**1,91 (99)**	**0,79**	**4,17 (99)**	**2,46**	**3,59 (100)**	**1,04**	1,05 (90)	0,63	1,42 (84)	1,13
West Kazakhstan	2,12 (94)	1,06	5,01 (93)	2,74	0,23 (48)	2,01	2,04 (90)	1,22	2,10 (91)	1,27
Karaganda	**1,46 (95)**	**0,85**	3,42 (94)	2,45	**3,32 (95)**	**1,31**	0,65 (74)	0,80	0,96 (72)	1,37
Kostanay	1,25 (83)	1,06	3,80 (91)	2,75	1,15 (67)	1,91	0,94 (78)	1,07	0,76 (65)	1,50
Kyzylorda	**2,42 (98)**	**0,91**	**5,09 (95)**	**2,85**	3,03 (88)	1,28	1,84 (94)	0,95	2,04 (91)	1,21
Mangistau	**2,21 (100)**	**0,75**	**4,42 (100)**	**1,88**	0,83 (68)	1,35	**2,67 (98)**	**0,86**	2,23 (94)	1,16
Pavlodar	1,20 (83)	1,16	3,78 (94)	3,15	2,81 (90)	1,73	0,16 (58)	0,94	0,89 (59)	1,62
North Kazakhstan	1,35 (88)	1,16	3,64 (91)	2,94	1,86 (80)	1,87	0,65 (77)	1,17	0,77 (62)	1,53
Turkestan	**2,05 (100)**	**0,79**	**4,51 (99)**	**2,60**	**2,61 (96)**	**0,86**	1,41 (94)	0,85	1,97 (94)	1,10
Ulytau	**2,08 (98)**	**0,97**	**4,53 (95)**	**2,71**	3,48 (93)	1,42	1,33 (90)	0,92	1,77 (89)	1,46

Notes: 1. For Mangistau region the assessment was carried out only by MS Fort Shevchenko;
2. values above the 95th or below the 5th percentile (warm and cold extremes, respectively) are highlighted in bold and bright color;
3. values above the 90th or below the 10th percentile are highlighted in pale color;
4. mean temperature anomalies over the territory of Kazakhstan were obtained by averaging data from 121 stations.

Anomalies of mean annual air temperature in 2022 were positive over the entire territory of Kazakhstan (Figure 2.2, top). In the northern, north-eastern, central parts and mountainous areas of the country, temperatures exceeded the norm by 1.0-2.0 ℃, and only in some central areas small pockets - by 0.6-0.9 ℃. In the western, south-western, southern, and south-eastern regions, air temperature anomalies were in the range of 2.0-3.1 ℃. Extremely high annual temperatures were recorded at 75 meteorological stations in these regions (probability of non-exceedance of anomalies exceeding 95 %). According to data from 29 meteorological stations in the western, southern, and eastern regions, 2022 was the warmest year since 1941, with record anomalies ranging from +1.13 to +3.11 ℃ (Figure 2.2, bottom).

Year

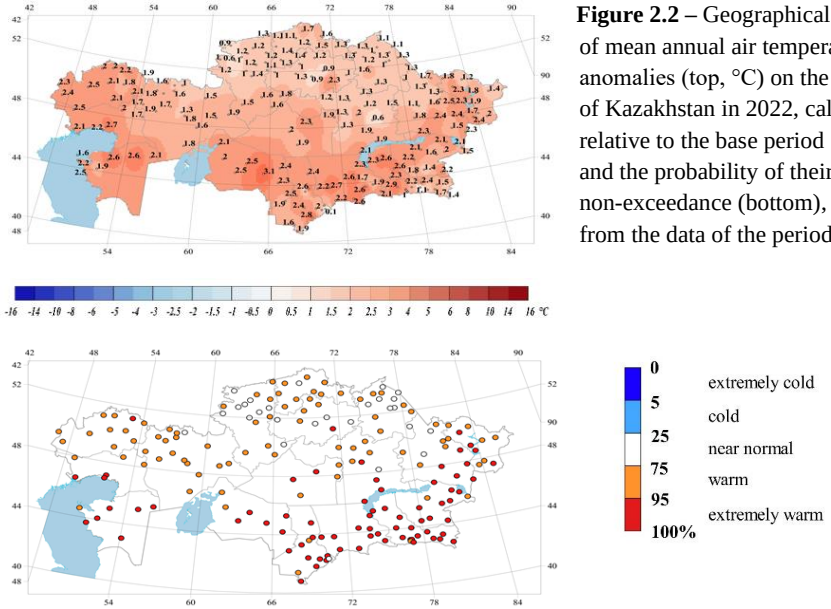


Figure 2.2 – Geographical distribution of mean annual air temperature anomalies (top, °C) on the territory of Kazakhstan in 2022, calculated relative to the base period 1961-1990, and the probability of their non-exceedance (bottom), calculated from the data of the period 1961-2022

In 2022, average monthly temperatures for the territory of Kazakhstan were above the norm for the period 1961-1990, except for December with a significant negative anomaly of 2.75 °C (Figure 2.3). Extremely warm April and September were the second warmest months since 1941, with anomalies of 4.29 ºC and 2.46 ºC, respectively. The warmest April was in 2012 with an anomaly of 5.70 ºC. The record September temperature was set in 1957 with an anomaly of 2.69 ºC. The month of January was also warm (anomaly 4.21 ºC), it was among the 10 % of the warmest months since 1941. In other months of the year, the positive air temperature anomaly ranged from +0.29 °C in November to 4.84 °C in February (Table 2.3).

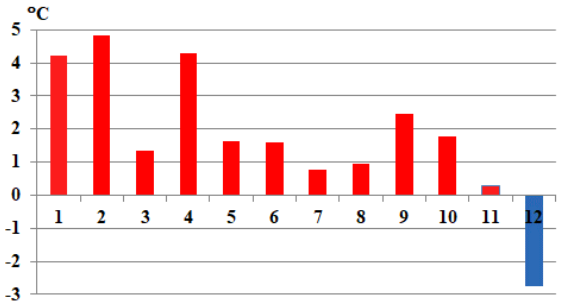


Figure 2.3 – Mean monthly air temperature anomalies averaged over the territory of Kazakhstan in 2022, calculated relative to the average for the period 1961-1990

Table 2.3 – Regionally averaged mean monthly air temperature anomalies in 2022: ***vT*** *- deviations from the mean for 1961-1990, ℃;* ***P(t≤T$_{2021}$)*** *- probability of non-exceedance (in brackets) calculated from data for the period 1941-2022 and expressed in %.*

Region	12 (2021)	1	2	3	4	5	6	7	8	9	10	11
Kazakhstan	3,45 (93)	4,21 (91)	4,84 (89)	1,35 (63)	4,29 (99)	1,64 (84)	1,59 (88)	0,76 (75)	0,94 (72)	2,46 (99)	1,76 (79)	0,29 (59)
Abay	3,61 (86)	3,98 (93)	2,95 (70)	3,00 (79)	3,66 (93)	4,28 (100)	2,38 (95)	0,86 (73)	-0,11 (37)	2,56 (96)	1,49 (67)	0,15 (53)
Almaty	3,62 (95)	5,29 (100)	2,78 (65)	2,89 (79)	4,73 (100)	2,57 (95)	2,56 (96)	1,83 (93)	-0,34 (25)	3,08 (98)	1,30 (73)	0,59 (62)
Akmola	2,63 (80)	3,21 (81)	5,10 (88)	-0,58 (40)	4,09 (90)	2,40 (85)	0,30 (64)	0,36 (72)	-0,01 (40)	2,33 (93)	2,04 (75)	-1,14 (43)
Aktobe	3,14 (86)	3,66 (83)	7,22 (93)	-0,88 (43)	4,39 (95)	-1,78 (20)	0,38 (56)	0,18 (58)	2,93 (90)	2,38 (95)	2,36 (79)	0,78 (69)
Atyrau	3,19 (94)	5,10 (95)	8,87 (100)	1,47 (64)	4,00 (96)	-2,17 (15)	1,80 (78)	0,20 (49)	4,10 (98)	2,67 (95)	2,83 (86)	0,87 (70)
East Kazakhstan	3,28 (83)	4,00 (90)	2,59 (70)	3,20 (80)	3,24 (91)	4,68 (100)	1,96 (90)	0,21 (54)	0,02 (37)	2,56 (95)	1,46 (70)	0,73 (54)
Zhambyl	5,03 (98)	6,64 (100)	4,91 (78)	2,43 (75)	5,07 (100)	2,14 (91)	2,80 (100)	1,37 (86)	-0,34 (30)	2,90 (98)	1,40 (72)	1,37 (65)
Zhetysu	3,87 (91)	6,00 (100)	2,64 (63)	3,79 (84)	4,20 (99)	2,76 (98)	2,43 (96)	1,21 (85)	-0,45 (22)	2,55 (96)	0,99 (67)	0,68 (59)
West Kazakhstan	2,50 (78)	4,45 (86)	8,06 (93)	0,49 (51)	3,85 (91)	-3,66 (7)	0,94 (64)	0,50 (57)	4,74 (95)	1,65 (85)	2,98 (86)	1,66 (80)
Karaganda	3,69 (94)	3,14 (89)	3,44 (78)	2,41 (77)	4,51 (96)	3,03 (96)	2,34 (96)	0,20 (60)	-0,59 (22)	1,93 (89)	1,50 (70)	-0,53 (49)
Kostanay	2,62 (79)	2,83 (78)	5,94 (93)	-0,90 (38)	4,20 (93)	0,18 (41)	-0,03 (49)	0,68 (73)	2,14 (83)	2,27 (94)	1,13 (58)	-1,09 (43)
Kyzylorda	3,58 (91)	4,92 (89)	6,82 (85)	2,04 (63)	5,28 (99)	1,76 (83)	3,04 (95)	1,06 (81)	1,46 (75)	2,84 (98)	1,70 (69)	1,52 (70)
Mangistau[1]	2,56 (90)	4,10 (94)	6,60 (100)	0,50 (54)	3,40 (95)	-1,40 (17)	2,60 (86)	0,50 (56)	5,00 (100)	3,00 (91)	2,80 (84)	0,90 (74)
Pavlodar	4,54 (90)	2,42 (74)	4,38 (84)	0,68 (54)	3,80 (91)	3,92 (96)	0,52 (65)	0,16 (63)	-0,26 (31)	1,68 (86)	2,36 (84)	-1,38 (33)
North Kazakhstan	2,91 (81)	3,01 (79)	4,96 (86)	-0,74 (38)	4,33 (93)	1,94 (79)	-0,01 (56)	0,53 (73)	1,43 (77)	1,89 (90)	1,83 (67)	-1,39 (33)
Turkestan	4,01 (96)	4,92 (96)	4,60 (78)	0,91 (62)	5,17 (100)	1,79 (84)	2,47 (98)	1,71 (89)	0,06 (46)	3,23 (99)	1,62 (73)	1,09 (67)
Ulytau	3,96 (91)	4,63 (93)	5,03 (83)	2,97 (74)	5,00 (99)	2,50 (93)	2,77 (98)	0,63 (72)	0,57 (53)	2,53 (98)	2,03 (79)	0,70 (62)

Notes: 1. For Mangistau region the assessment was carried out only by MS Fort Shevchenko;

2. values above 95th or below 5th percentile (respectively warm 95 % and cold 5 % extremes) are highlighted in bold and bright color.

Spatial distribution of seasonal anomalies of air temperature in 2022 over the territory of Kazakhstan is presented in Figure 2.4.

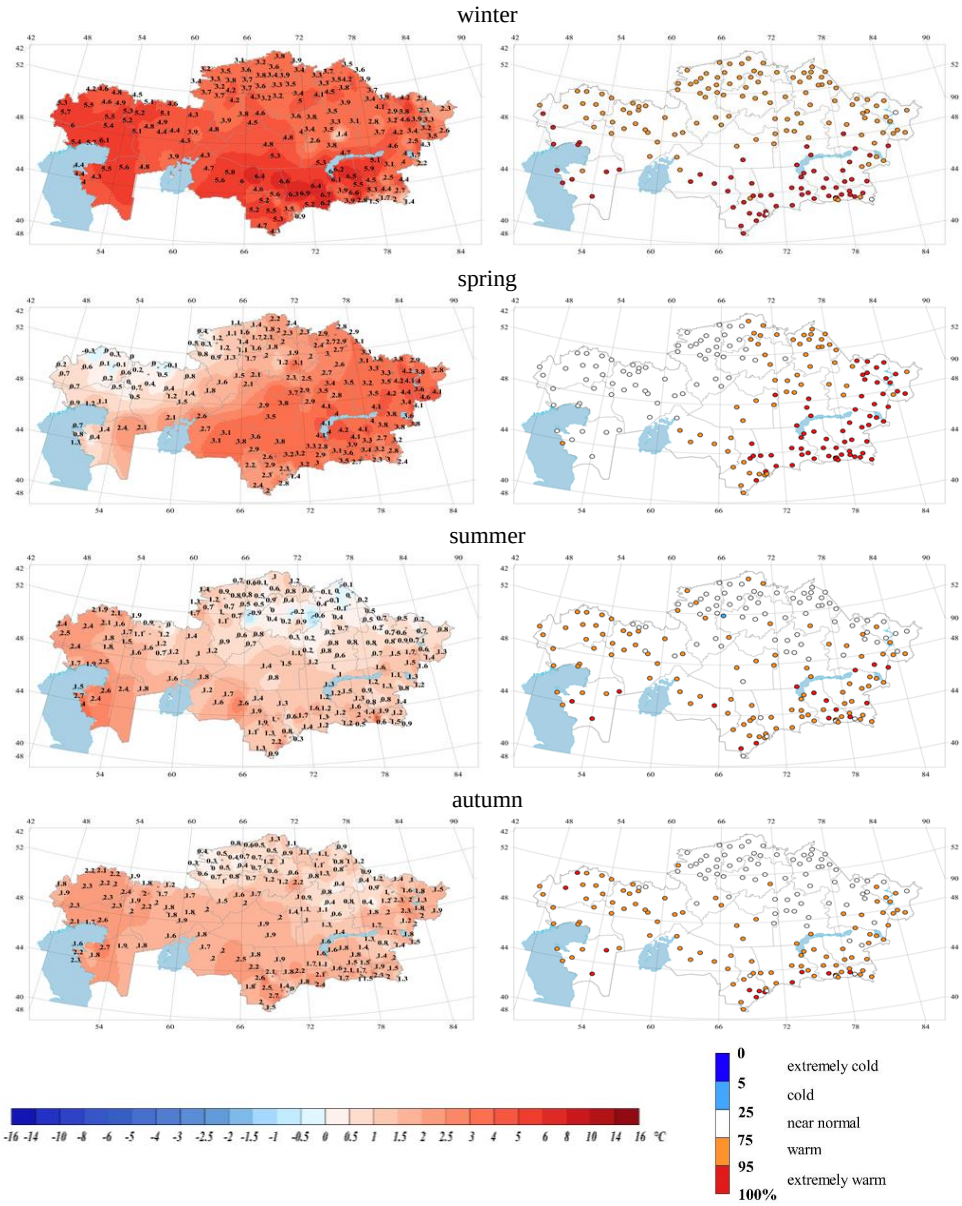


Figure 2.4 – Spatial distribution of air temperature anomaly (°C) in 2022, calculated relative to the base period 1961-1990, and probabilities of non-exceedance of air temperature values in 2022, calculated from the data of the period 1961-2022

In **winter 2021/22**, the average air temperature in Kazakhstan was 4.17 ℃ above the norm (rank 6, Table 2.2). The warmest winter season remained the winter of 2019/2020. In the winter season of 2021/2022, anomalies were positive throughout the Republic and exceeded 3.0 °C, except for the southeastern and eastern regions (Figure 2.4). Two hotspots of the most significant exceedance of the air temperature norm for the period 1961-1990 were observed: one occupied the entire territory of Atyrau region and its border areas (with anomalies from +5.0 ℃ to +6.1 °C); the second hotspot occupied most of the territory of Zhambyl region and some areas of neighboring regions (with anomalies from +6.1 to +6.9 ℃). In the east and north there were some areas with anomalies from +4.0 ℃ to +5.4 ℃. As a result, the winter was record warm (Table 2.2) for Zhambyl and Mangistau regions, where on average over the territory the anomalies were +5.54 and 4.42 °C, respectively. For the remaining regions, the winter of 2021/2022 was among the 5 % or 10 % of extremely warm winters with territory-averaged air temperature anomalies ranging from +3.30 °C for East Kazakhstan region and up to +5.74 °C for Atyrau region. At 62 meteorological stations of Kazakhstan, located in the western, southern, and south-eastern regions of Kazakhstan, extremely high temperatures corresponding to 95-100 percentiles were observed.

In **December 2021**, the average temperature anomaly over the territory of Kazakhstan was above the norm for the period 1961-1990 by 3.45 °C (rank 7, Table 2.3). The values of anomalies averaged over the regions lie within the range of 2.50 - 4.54 °C with a probability of non-exceedance of 78-96 %. Regions of temperatures significantly above the norm were formed in the southern and eastern regions and in Balkash lake region (from 4.2 to 6.8 °C). In the western half of the Republic, air temperature anomalies were positive, and their values decreased westwards, reaching 1.2 °C in the westernmost region. In the northern regions, the air temperatures were also above the multiyear average with anomalies ranging from 1.6 to 3.7 °C (Figure 2.5).

In **January 2022**, positive air temperature anomalies were observed over the entire territory of the country. The average air temperature over the territory of Kazakhstan was 4.21 °C above the mean annual value for the period 1961-1990 (rank 8 with a probability of non-exceedance of 91 %, Table 2.3). There were three hotspots of the most significant air temperature exceeding the norm for the period 1961-1990 on the territory of the republic. : the most significant of them occupied an extensive territory in the south, south-east of Kazakhstan and region Ulytau (with anomaly from +4,9 °C to +8,9 °C) with the center in south-western of Balkash lake region and sands Taukum and Saryesik Atyrau; the second hotspot occupied the whole territory of Atyrau, Mangistau and West Kazakhstan regions (with anomaly from +4,0 ℃ to +5,5 °C); the third hotspot occupied most of the territory of southern and eastern parts of Abay region and western part of East Kazakhstan region (with anomaly from +4,1 to +6,7 °C). In the rest of the country air temperature was above the multiyear average by 2.0-4.7 °C). As a result, January month was record warm for Zhetysu region, Almaty and Zhambyl regions, and for six regions of eastern, southern, central, western Kazakhstan among 5 % or 10 % of extremely warm month (Table 2.3, Figure 2.5).

According to data from 71 meteorological stations (MSs) located in these regions, it was extremely warm, with air temperature values entering the top 5 % of warmest Januarys, of which 21 meteorological stations updated the maximums of mean monthly air temperature.

In **February**, the average air temperature anomaly over Kazakhstan was above the climatic norm and totaled 4.84 °C (rank 10, Table 2.3). Record warm February was in Atyrau and Mangistau regions (average anomalies over the territory were +8.87 ℃ and +6.60 °C, respectively), on the territory of three more regions located in the northern and north-western regions, the average air temperature anomalies over the territory were among the 10 % of the warmest months. Positive

air temperature anomalies were observed throughout the country, increasing from east to west, reaching maximum values from +6.0 to +8.8 °C, in some places exceeding 9.0-9.8 °C. Temperatures slightly above the multiyear average (from 0.3 to 2.0 °C) were observed in mountainous and foothill areas of the south, south-east, and east of the country. Air temperature anomalies in the range from +2.2 to +4.8 °C were observed mainly in the eastern and south-eastern parts of the country, in central Kazakhstan, and in the northern and north-eastern parts of the country the temperature anomalies were in the range from +2.9 to +5.9 °C, in some places up to +6.8 °C (Figure 2.5). According to data from 60 MS located in the western and northern regions, it was extremely warm, with temperatures in these regions included in the 5 % or 10 % of extremely warm Februarys. New records of average monthly air temperature were recorded at 9 meteorological stations in Atyrau and Mangistau regions.

In **spring**, the average air temperature anomaly over the territory of Kazakhstan was +2.43 °C (rank 8) and, as in winter, exceeded the norm practically over the whole territory of the Republic (Table 2.2, Figure 2.4), except for small areas in the north-west with insignificant negative anomalies (minus 0.1-0.3 °C). The magnitude of positive air temperature anomalies increased from the western regions, where it was less than 1 °C, to the east, where it reached +4.0-4.6 °C in Balkash lake region and in the east.

Record warm spring was in Zhetysu region (average anomaly +3.59 °C), on the territory of 9 more regions spring season was included in 5 % or 10 % of extremely warm seasons. Extremely high seasonal air temperatures above the 95th percentile was recorded at 65 meteorological stations in Kazakhstan, including 8 MS of Almaty region, which recorded the highest seasonal temperatures since 1941.

In **March**, it was warm in most of the country (Figure 2.5), the average temperature anomaly for Kazakhstan was 1.35 ℃ (Table 2.3). Temperatures in the range of ±1 ℃, near the norm, were observed in the north-west, south-west, northern, northern part of the central and some southern regions of the country. The northern part of Aktobe and Kostanay regions was occupied by the region with negative air temperature anomalies up to minus 1.9 ℃. The zone of positive anomalies covered the eastern, south-eastern parts of the country, central, southern Kazakhstan, as well as several western regions. The most significant hotspots of heat were observed in the south-eastern part of Abay region, in the western half of East Kazakhstan region, in Balkash lake region, northern parts of Zhetysu region and Almaty region, in these regions the air temperature anomalies ranged from +4.3 to +5.2 °C (Figure 2.5).

In **April**, the average air temperature anomaly over the territory of Kazakhstan was 4.29 ℃ (rank 2 with a probability of non-exceedance of 99 %, Table 2.3). Over the whole territory of the country temperatures were above the climatic norm within the range from +2.0 to +5.9 °C (Figure 2.5). Hotspots with temperature anomalies within +5.0-5.9 ℃ occupied the territories of Mangistau, Kyzylorda, Turkestan regions, the south of Aktobe, Zhambyl and Almaty regions. In western and eastern regions air temperatures were above the norm with anomalies ranging from +3.2 to +3.9 ℃. In the rest of the country air temperatures were above the norm, mainly by 4.1 ℃.

Record warm April was in the south of Kazakhstan - in Almaty, Zhambyl and Turkestan regions, where the average anomalies over the territory were 4.73, 5.07 and 5.17 ℃, respectively. On the territory of the remaining 14 regions April was included in the 5 % or 10 % of extremely warm months. At 143 meteorological stations of Kazakhstan observed extremely high monthly air temperatures - above the 90-95th percentile, including 26 MS of southern and central Kazakhstan recorded the highest monthly air temperatures since 1941.

In **May**, the average air temperature anomaly over Kazakhstan was 1.64 °C (Table 2.3). Most of the country was in the zone of positive anomalies: the whole southern, central, and eastern part of the country, most of the northern regions, as well as some southern parts of Aktobe region. The temperature anomaly values increased from west to east reaching maximum values from +4.7 to +5.2 °C. A significant hotspot of heat was observed in the eastern and north-eastern parts of the country, where the anomalies were +4.1-5.4 °C (Figure 2.5). According to data from 79 meteorological stations located in the east of the country, as well as in Almaty, Karaganda region and Pavlodar regions, May was among the 5 % or 10 % of extremely warm months, of which 23 meteorological stations located in these areas set record monthly average air temperatures. Most of the western half of the country was in the zone of negative anomalies. In the western part of the country the temperatures decreased from south to north. Anomalies below minus 3 °C were observed in West Kazakhstan and Atyrau regions (minus 3.0-4.1 °C). At 23 meteorological stations in West Kazakhstan, Aktobe and Atyrau regions, air temperature values were included in the 5 % or 10 % of the lowest temperatures observed in May.

Summer was warm throughout Kazakhstan, only in Mangistau region was extremely warm, with a national average air temperature anomaly of 1.09 °C (rank 8, probability of non-exceedance 91 %, Table 2.2). In the northern part of the country, air temperatures were near normal (anomalies were ±1 °C), with hotspots with negative anomalies occupying only small areas in Akmola and Pavlodar regions (Figure 2.4). The zone with air temperature above the norm by more than 1.0 °C occupied almost the entire territory of western regions (where maximum anomalies in the range of +2.0 2.5 °C were observed in the extreme western regions, and in the south-west - up to +4.0 °C), as well as southern and south-eastern regions, where anomalies rarely exceeded 2.0 °C. In another 10 regions, the summer season was among the 10 % of extremely warm seasons (Table 2.2). At 15 meteorological stations in Kazakhstan, located in the southwest, south, and east, extremely high seasonal air temperatures were recorded - above the 95th percentile since 1941.

In **June**, the average air temperature anomaly over Kazakhstan was 1.59 °C (rank 11, Table 2.3). On the territory of Zhambyl region was record warm, the average monthly air temperature anomaly over the territory was +2.80 °C. In another 7 regions, the average air temperature anomalies over the territory were included in the 5 % of extremely high anomalies with values from +2.34 °C for Karaganda region to +3.04 °C for Kyzylorda region. Positive anomalies were observed almost throughout the country except for a small region in the north with negative anomalies up to minus 1.0 °C. Anomalies within ±1 °C near the norm were observed in the north of the country and in several areas of Aktobe, West Kazakhstan and Atyrau regions (Figure 2.5). Positive air temperature anomalies within 3.0-5.1 °C were observed in the southern regions and in Mangistau region. At 56 meteorological stations , air temperature anomalies were included in the 5 % of extremely high temperatures, of which 15 meteorological stations located in the south and south-east of the country set new record values of mean monthly air temperature.

In **July**, the air temperature anomaly averaged over the territory of Kazakhstan was 0.76 °C (Table 2.3). Air temperatures in the range of ±1 °C (near the norm) were observed practically on the whole territory of Kazakhstan, except for the southern and south-eastern region. On the territory of Almaty region was extremely warm, the temperature anomaly averaged 1.83 °C (rank 7 with a probability of non-exceedance of 93 %, Table 2.3). At 16 meteorological stations in these regions, the air temperature anomalies were included in the 5 % of extremely high temperatures.

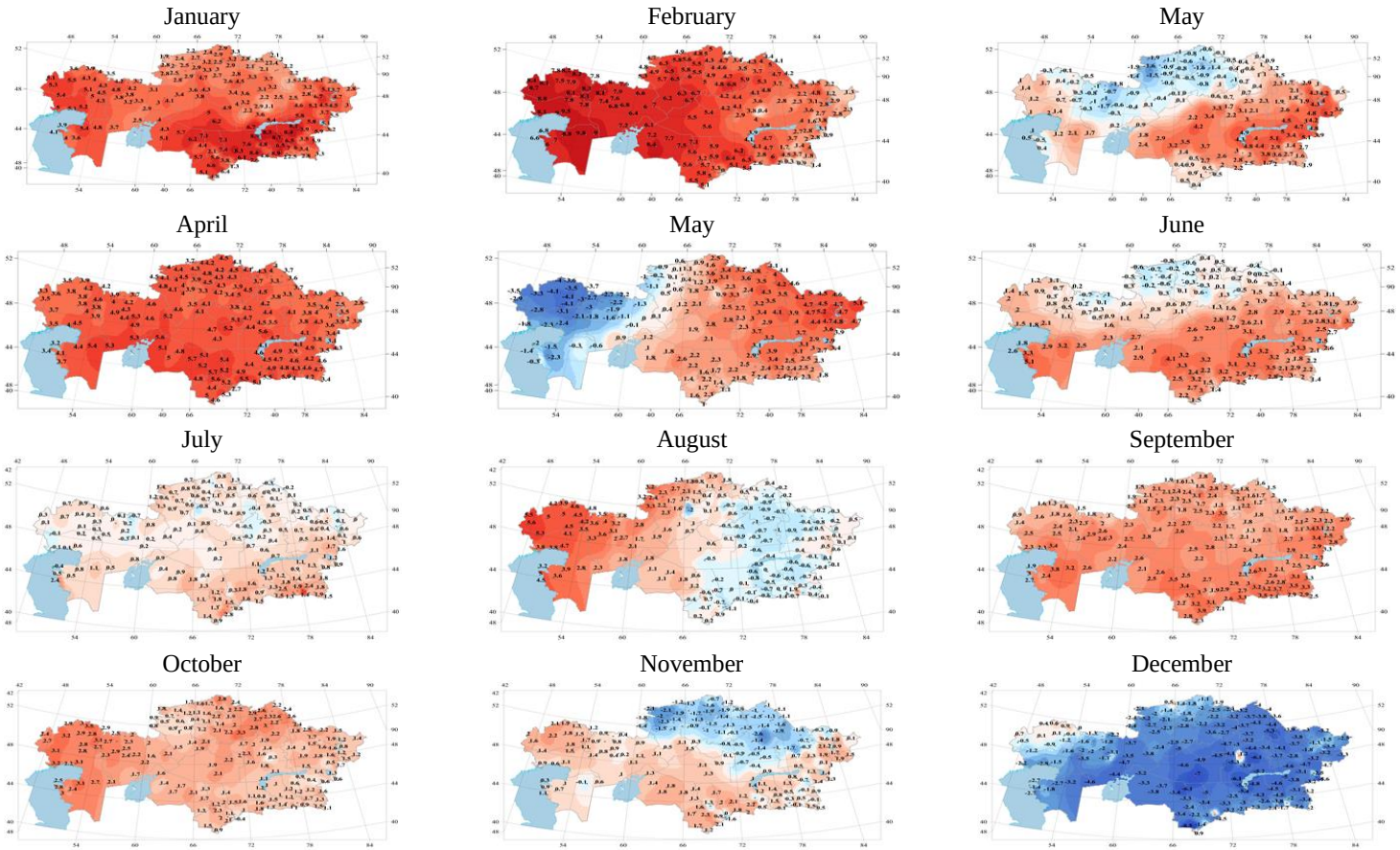


Figure 2.5 – Spatial distribution of the anomaly of mean monthly air temperature (°C) in 2022 calculated relative to the base period 1961-1990.

In **August**, the average monthly air temperature averaged over the territory of Kazakhstan was 0.94 °C above the climatic norm (Table 2.3). The western half of the territory of the republic and northern regions covered the zone of positive anomalies, the values of which increased to the west from +1.0 to +5.6 °C (Figure 2.5). Record warmth was on the territory of Mangistau region, the anomaly of average monthly air temperature on average over the territory was +5.0 °C. Extremely warm (5 % extremes) was in Atyrau and West Kazakhstan regions, the values of air temperature anomalies were +4.10 °C and +4.74 °C, respectively. On the territory of Aktobe region, August entered the 10 % of extremely warm months since 1941. At 21 meteorological stations air temperature anomalies entered the 5 % or 10 % of extremely high temperatures, at MS Fort-Shevchenko a new record of mean monthly air temperature was set. Negative anomalies covered the eastern parts of the territory of Akmola, Karaganda and Ulytau regions, the entire territory of Abay region, Pavlodar and Karaganda regions, southern and south-eastern regions, northern part of East Kazakhstan region. The most significant negative anomalies (up to minus 2.0 °C) were observed in Akmola region. At 3 meteorological stations , air temperature anomalies entered the 10 % of extremely low temperatures.

In **autumn** on the whole territory of the republic air temperatures were above the climatic norm, on average over the territory of Kazakhstan air temperature was +1.5 °C above the climatic norm (rank 12, Table 2.2). In the northern regions, temperature anomalies rarely exceeded 1.0 °C. Air temperature anomalies of more than +2.0 °C were recorded in the western, south-western and eastern regions (up to +2.3 °C), in some places in the southern regions up to +2.7 °C (Figure 2.4). In 7 regions, the autumn season was among the 10 % of extremely warm seasons. At 11 meteorological stations of Kazakhstan extremely high seasonal air temperatures were observed - above the 95th percentile since 1941.

The month of **September** was very hot: the average monthly air temperature averaged over the territory of Kazakhstan was 2.46 °C above the climatic norm (rank 2 with a probability of non-exceedance of 99 %, Table 2.3). Extreme warmth (5 % extremes) was on the territory of 10 regions located in the eastern, southern, and western regions. On the territory of northern and south-western region (Kostanay, North-Kazakhstan, Akmola and Mangistau regions) September was included in 10 % of extremely warm months. Hotspots of maximum positive anomalies (+3.1-3.8 °C) occupied the Caspian lowland, Turkestan region, extreme south of Zhetysu region, Almaty region, eastern part of Abai region (Figure 2.5). At 150 meteorological stations in Kazakhstan, air temperature anomalies were included in the 5 % or 10 % of extreme high temperatures, of which 13 meteorological stations located in the south, south-west and east of the country set new record values of mean monthly air temperature.

In **October**, on average over the territory of Kazakhstan, the anomaly of mean monthly air temperature was 1.76 °C (Table 2.3). On the whole territory of the country air temperatures were above the climatic norm. Air temperatures near the norm were in the northern half of Kostanay region, in the eastern part of Zhetysu region and in mountainous areas of the south and south-east. Hotspots with air temperature anomalies ranging from +2.4 to +3.5 °C occupied the territories of the western and north-eastern regions of the country. On the rest of the country air temperatures were above the multiyear average within 1.1-2.3 °C. At 3 meteorological stations of West Kazakhstan region (MS Kamenka, Uralsk, Aksai) extremely high monthly air temperatures were observed - above the 10th percentile.

In **November**, the anomaly of mean monthly air temperature on average over the territory of Kazakhstan was about normal (anomaly +0.29 °C, Table 2.3). Negative air temperature anomalies

covered the northern and north-eastern territories of the country (northern half of Kostanay, North Kazakhstan, Akmola, Karaganda regions, Pavlodar, and northern part of Abay region), as well as mountainous areas of the south and south-east (Figure 2.5). The most significant negative anomalies (to minus 2.6 °C) were observed at the junction of the south of Pavlodar region and Abai region, the zone of another significant hotspot of cold (to minus 2.3 °C) was in the northern half of Kostanay region. The western half of the country, southern and south-eastern regions (except for mountainous areas) covered the zone of positive anomalies, the values of which were in the range of 1.0-2.3 °C. Hotspots of more significant positive anomalies (with anomalies up to +2.1-2.3 °C) occupied the extreme north-western parts of the country and the southern parts of Turkestan and Zhambyl regions.

For the purposes of monitoring the extreme values of climatic parameters most significant for specific sectors of the economy and social sphere, the WMO Commission for Climatology developed the ClimPACT software product (www.climpact sci.org), which makes it possible to calculate a set of specialized climatic indices based on daily values of maximum and minimum air temperature and precipitation. The indices most indicative for characterizing the degree of extremity of the temperature regime in 2022 are given below.

In 2022, the warm period of the year is characterized by the fact that the daily maximum temperature exceeded 30 and even 35 °C over the entire territory of Kazakhstan (except for the highland areas of the south-east). The number of days when the maximum daily air temperature exceeded 30 °C increases from north to south. In northern, north-eastern, eastern, central, north-eastern part of Ulytau region and northern part of western regions ***the number of days when the maximum daily air temperature exceeded 30 °C (Txge30 index)*** was mainly from 10 to 70 days (Figure 2.6), in the rest of the territory - from 80 to 120 days, the maximum number of such days was in the south of Turkestan region - 142 days.

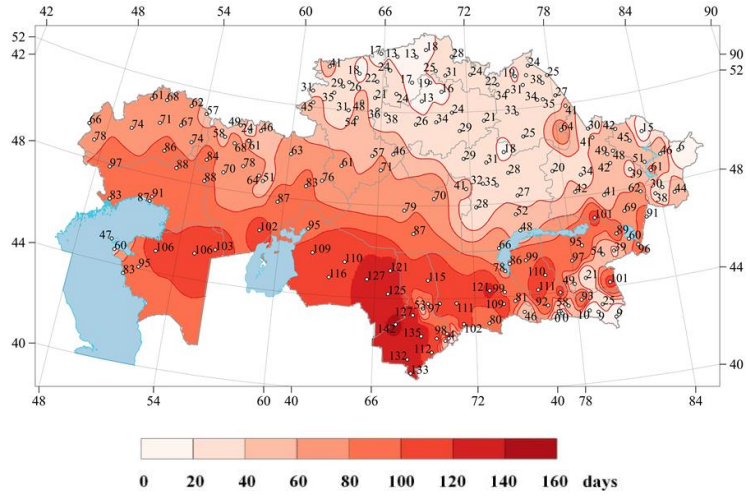


Figure 2.6 – Number of days in 2022 when the maximum air temperature exceeded 30 °C (*Txge30 index*)

Another characteristic of temperature extremes in the warm period of the year is the total duration of all heat waves (a heat wave is a case when the heat surplus factor has a positive value for 6 or more consecutive days, the HWF/EHF index, Figure 2.7). On the territory of Kazakhstan, the HWF/EHF index varies in the northern and central region within 10-20 days. In the directions to the south, west, and east the index values increase. As a result, the total duration of all heat waves was 41-68 days in the western regions, 41 59 days in the southern regions and 41-43 days in the eastern regions.

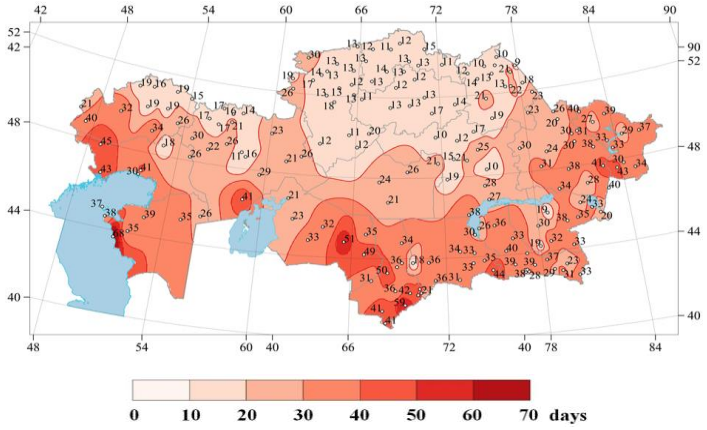


Figure 2.7 – Total duration of warm period heat waves in 2022 (*HWF/EHF index*, days)

In 2022, in most of the western and southern regions (except for mountainous areas) of the country, as well as in some regions of Ulytau region and Kostanay region, ***the daily maximum air temperature (TXx index)*** exceeded 40 °C, in Mangistau, Kyzylorda and Turkestan regions in some places the daily maximum air temperature exceeded 45 °C (Figure 2.8). In other regions ***TXx index*** values varied within 35-39 °C.

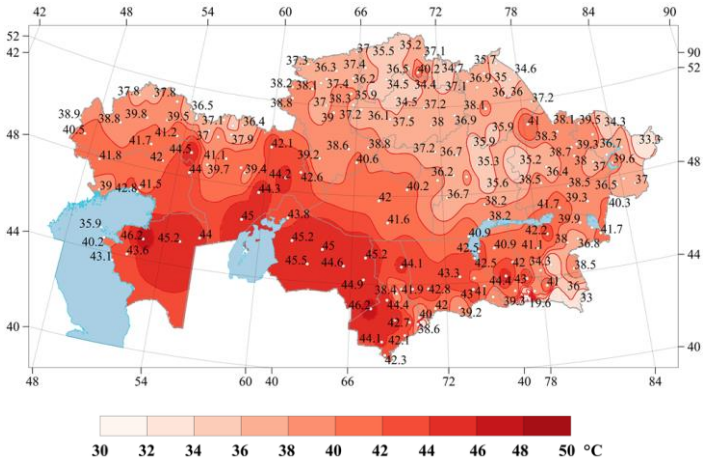


Figure 2.8 – Values of maximum daily air temperature maxima (°C, *index TXx*) recorded in 2022.

As a result of this increased background temperature in the summer months, the values of previous absolute daily maximums of air temperature were updated at some meteorological stations in 2022 (highlighted in red, Figure 2.9). In blue color shows the values of absolute maximums recorded from station opening to 2022. In 2022, the values of absolute maximums were exceeded at four meteorological stations participating in climate monitoring in Kazakhstan: MS Kazaly by 1.5 °C (45.2 °C); MS Chkalovo by 0.2 °C (40.2 °C); MS Shalkar by +0.2 °C (44.3 °C); MS Peshnoi by 0.4 °C (42.8 °C). Most of the highest air temperatures (absolute maximums) in Kazakhstan were recorded in July 1983, when at some meteorological stations of Turkestan region air temperatures reached +49...+50 °C (MS Turkestan, Shayan, Arys, Tasty), and in July 1995, when at MS Kyzylkum air temperatures rose to +51 °C.

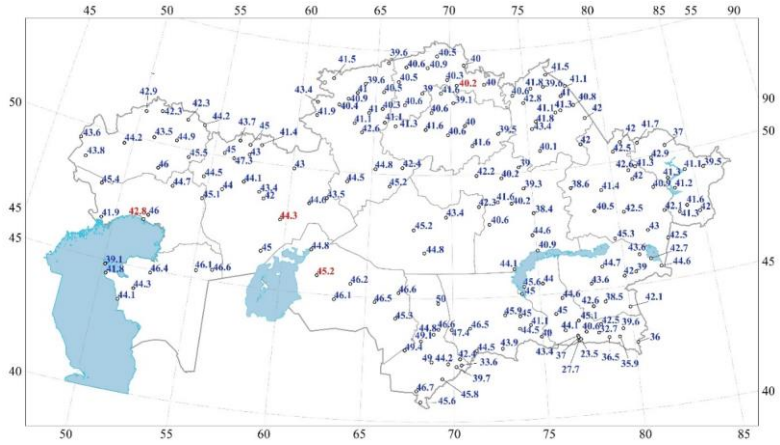


Figure 2.9 – Absolute maximum air temperature values (°C) recorded from the beginning of the weather station opening to 2022. If the record value of the maximum daily air temperature is recorded in 2022, this value is plotted in red.

According to WHO recommendations, an index characterizing ***the number of days when the daily minimum temperature does not fall below 20 ºC (TR index, "tropical night")*** was introduced, as at such night temperatures the human body does not have time to rest from the heat of the day. In most of the southern and western regions, the number of days with high night temperatures was highest. In Turkestan, Kyzylorda and Zhambyl regions, ***TR index*** values were more than 58-78 days, in Mangistau region - more than 60-70 days, and in some places more than 90 days (Figure 2.10). The minimum number of tropical nights, or their absence, was observed in the northern, central, south-eastern, eastern, and mountainous regions of Kazakhstan.

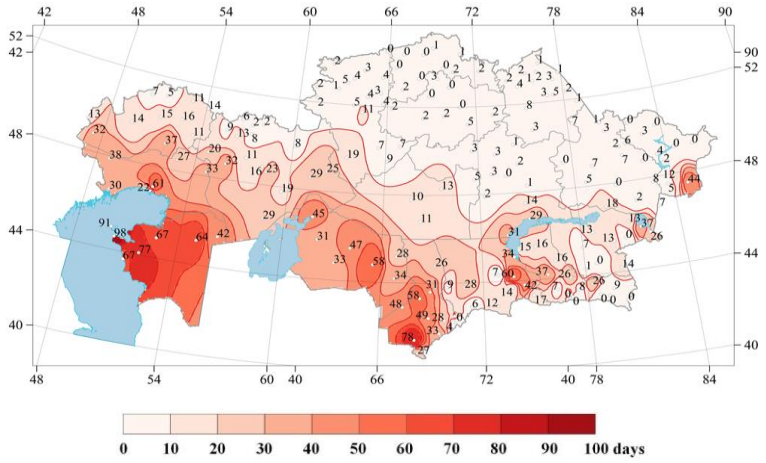


Figure 2.10 – Number of days when the daily minimum temperature is above 20 ºC in July 2022 (*TR index*)

As a consequence of high air temperatures for a significant part of the warm period of the year, especially in the western and southern regions of Kazakhstan, there was an acute need to maintain a favorable indoor temperature. In this case, a threshold of 23 ºC is taken as a favourable temperature, exceeding which means *a cold deficit* (CDDcold23 index, Figure 2.11). The maximum cold deficit was observed in Mangistau, Kyzylorda and Turkestan regions, where the index values were 500-600 and even 682 ºC-days in places.

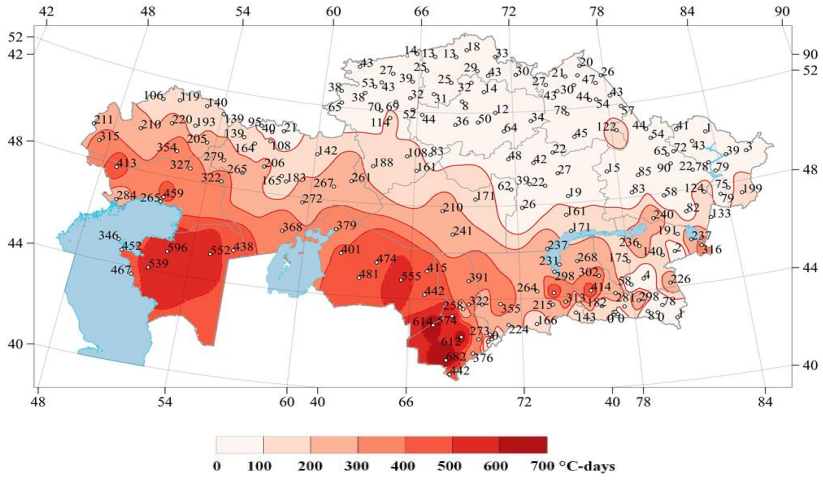


Figure 2.11 – Cold deficit (ºC-days) observed in 2022 (*CDDcold23 index*)

In January 2022, usually the coldest month of the year, significant negative anomalies were observed in the northern and north-eastern and central regions of Kazakhstan and ***the daily minimum air temperature*** (*TNn index*, Figure 2.12) fell below minus 35-40 ºC, in some places below 43 ºC.

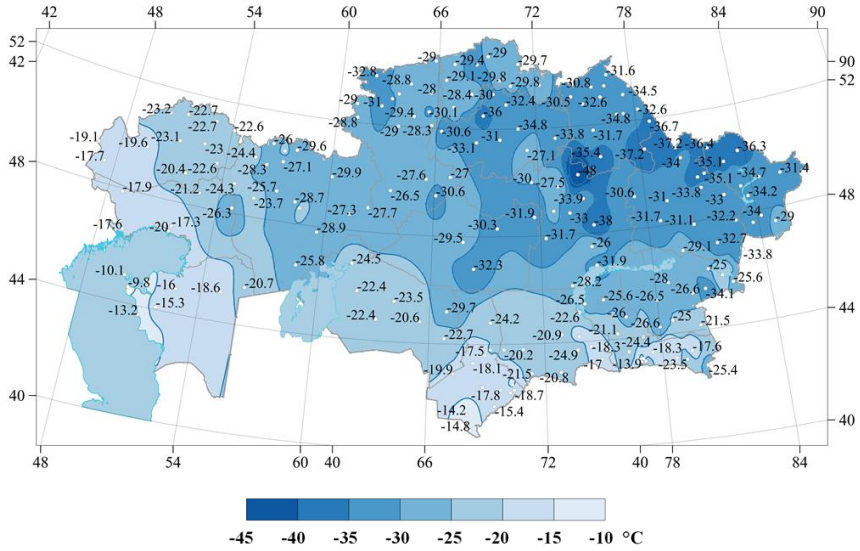


Figure 2.12 – Daily minimum air temperature values (ºC) recorded in 2022 (*TNn index*)

Figure 2.13 presents the absolute minimum air temperatures recorded since the meteorological station was opened. In Kazakhstan, absolute minimum air temperatures below minus 50 °C were recorded at 2 stations - in January 1931 at MS Shaganatty/Orlovsky settlement (minus 54 °C) and in January 1893 at MS Astana (minus 52 °C). Air temperatures below minus 45 °C were observed mainly in the northern and eastern regions of Kazakhstan. In 2022, no new records of daily minimum temperature were recorded.

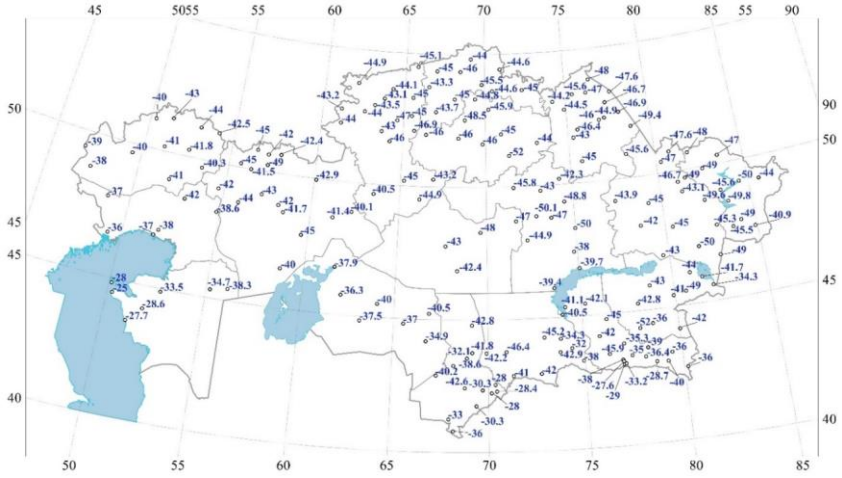


Figure 2.13 – Absolute minimum air temperature values (°C) recorded from the beginning of the weather station opening to 2022. If the record value of the minimum daily air temperature is recorded in 2022, this value is plotted in red.

2.2 Air temperature changes observed on the territory of Kazakhstan

Figures 2.14-2.15 present time series of mean annual and seasonal surface air temperature anomalies averaged over the territory of Kazakhstan and administrative regions and their 11-year moving averages for the period 1941-2022, as well as linear trends in air temperature for the period 1976-2022. The anomalies are calculated relative to the base period 1961-1990. The linear trends provide clear information on the gradual increase in annual and seasonal mean surface air temperatures over the past decades. Table 2.4 presents estimates of air temperature change for the period 1976-2022: the linear trend coefficient, which characterizes the average rate of change of the air temperature anomaly over the time interval under consideration; and the coefficient of determination, which shows the contribution of the trend to the total variance of the time series.

On average over the territory of Kazakhstan for the period 1976-2022, the increase in mean annual air temperature is 0.33 ºC every 10 years, the contribution to the total temperature variability is 30 % (Figure 2.14, Table 2.4). There is also a steady increase in average annual mean air temperature across all regions of Kazakhstan during 1976-2022 - coefficients of determination are within 10-55 %, trends are significant at the 5 % level (Figure 2.15, Table 2.4). Warming is faster in the western, south-western and southern regions of Kazakhstan (from 0.44 ºC/10 years to 0.54 ºC/10 years) and slower in the central, northern and eastern regions (from 0.21 ºC/10 years to 0.29 ºC/10 years).

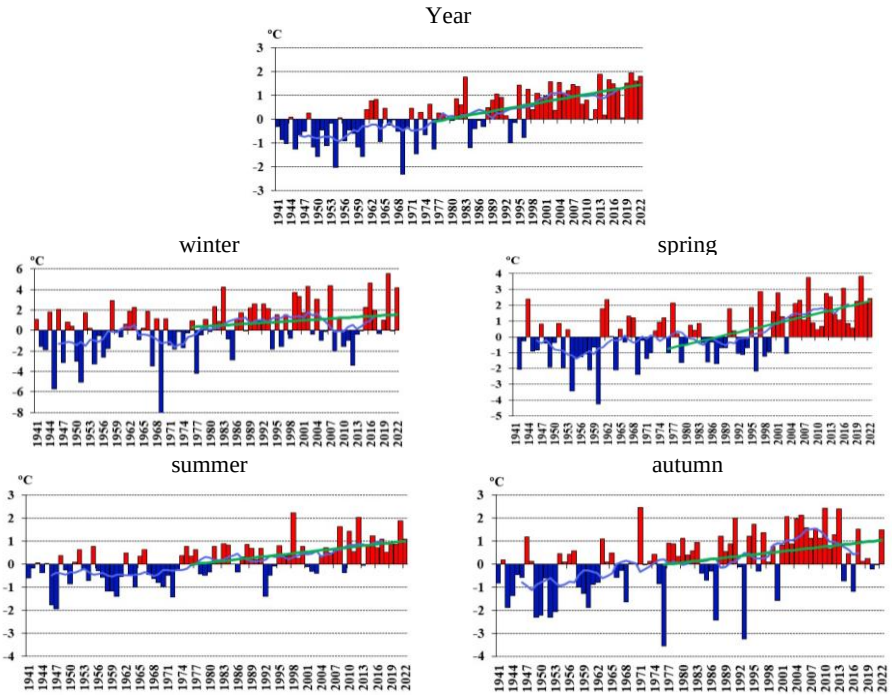


Figure 2.14 - Time series of annual and seasonal air temperature anomalies (ºC) averaged over the territory of Kazakhstan for the period 1941-2022. Anomalies are calculated relative to the base period 1961-1990. The linear trend for the period 1976-2022 is highlighted in green color.
The smoothed curve is obtained by 11-year moving average

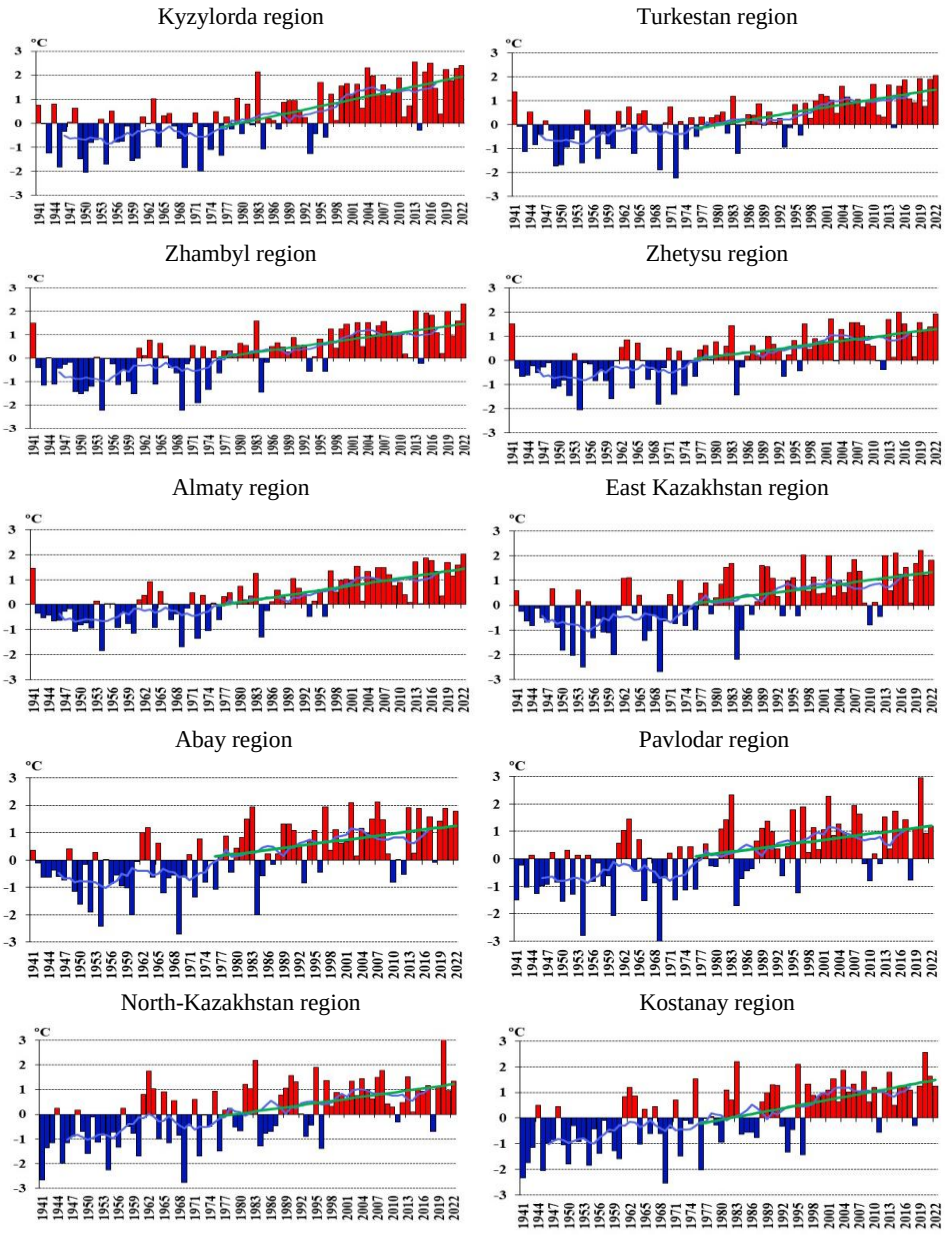


Figure 2.15 - Time series of annual air temperature anomalies (ºC) averaged over regions of Kazakhstan for the period 1941-2022. Anomalies are calculated relative to the base period 1961-1990. The linear trend for the period 1976-2022 is highlighted in green color.
The smoothed curve is obtained by 11-year moving average. Sheet 1

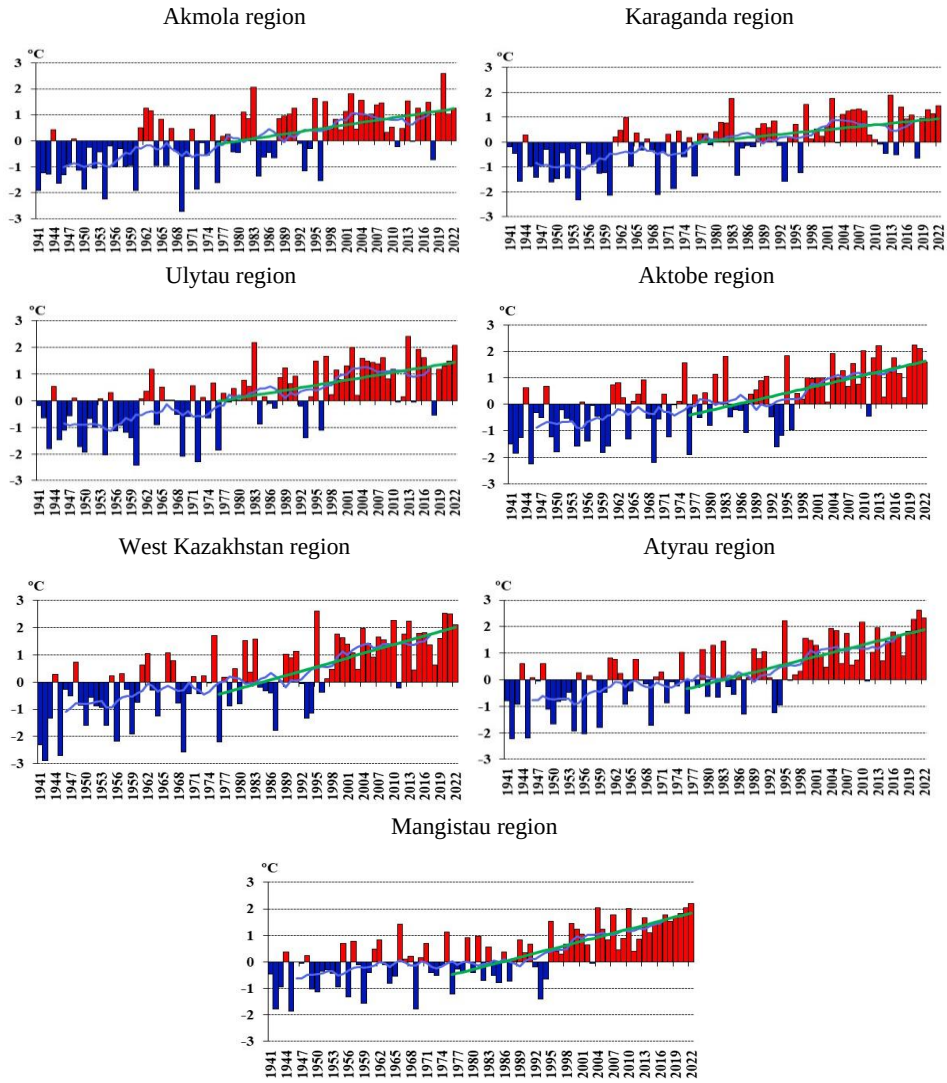


Figure 2.15 - Time series of annual air temperature anomalies (ºC) averaged over regions of Kazakhstan for the period 1941-2022. Anomalies are calculated relative to the base period 1961-1990. The linear trend for the period 1976-2022 is highlighted in green color.
The smoothed curve is obtained by 11-year moving average. Sheet 2

On average for the territory of Kazakhstan, the trend of winter season warming is 0.26 °C/10 years (Table 2.4), but it should be noted that the trend describes only about 3 % of the total variance and is insignificant at the level of 5 %. Trends of region average winter temperatures were positive and mostly explain up to 5 % of the variance of the series and are statistically insignificant. The most noticeable warming, by 0.41 0.55 °C/10 years, was observed in

the western, south-western, and southern regions of Kazakhstan - in Aktobe, West Kazakhstan, Atyrau, Mangistau, Kyzylorda and Turkestan regions, where the coefficient of determination is 7-15 %. In Atyrau and Mangistau regions, the trend describes 10 and 15 % of the total variance, respectively, and is statistically significant at the 5 % level. According to data from several stations in the extreme west and extreme south, this trend is stable (Figure 2.16). On the territory of Kazakhstan there is a rather extensive region, where the tendency for temperature decrease is outlined - this is the center, north-east and east of Kazakhstan.

Table 2.4 - Characteristics of linear trend of surface air temperature anomalies averaged over the territory of Kazakhstan and its regions for the period 1976-2022.

Region/ region	Year		Winter		Spring		Summer		Autumn	
	a	**D**	**a**	**D**	**a**	**D**	**a**	**D**	**a**	**D**
Kazakhstan	0,33	**30**	0,26	3	0,65	**32**	0,22	**18**	0,23	6
Abay	0,25	**12**	0,06	0	0,73	**31**	0,14	**8**	0,11	1
Almaty	0,32	**36**	0,27	4	0,66	**37**	0,24	**24**	0,14	3
Akmola	0,29	**17**	0,21	1	0,68	**24**	0,03	0	0,28	5
Aktobe	0,44	**33**	0,41	5	0,61	**19**	0,36	**15**	0,38	**11**
Atyrau	0,49	**40**	0,55	**10**	0,51	**22**	0,52	**39**	0,37	**13**
East Kazakhstan	0,27	**15**	0,14	1	0,68	**27**	0,18	**11**	0,15	2
Zhambyl	0,31	**29**	0,32	4	0,65	**34**	0,22	**20**	0,11	1
Zhetysu	0,27	**24**	0,19	2	0,64	**32**	0,21	**20**	0,09	1
West Kazakhstan	0,54	**39**	0,54	**7**	0,56	**18**	0,59	**29**	0,44	**17**
Karaganda	0,21	**11**	0,12	1	0,70	**29**	0,01	0	0,05	0
Kostanay	0,37	**24**	0,27	2	0,62	**19**	0,19	4	0,40	**10**
Kyzylorda	0,46	**36**	0,43	4	0,87	**37**	0,33	**26**	0,23	5
Mangistau	0,51	**55**	0,49	**15**	0,41	**21**	0,66	**53**	0,47	**22**
Pavlodar	0,24	**10**	0,05	0	0,72	**29**	0,04	0	0,21	3
North Kazakhstan	0,28	**15**	0,16	1	0,57	**19**	0,04	0	0,37	**8**
Turkestan	0,35	**41**	0,41	**7**	0,58	**34**	0,27	**22**	0,18	4
Ulytau	0,32	**20**	0,22	1	0,81	**32**	0,13	5	0,14	2

* a - linear trend coefficient, ºC/10 years
** D is the coefficient of determination, %
*** statistically significant trends at the 5 % level are highlighted in bold

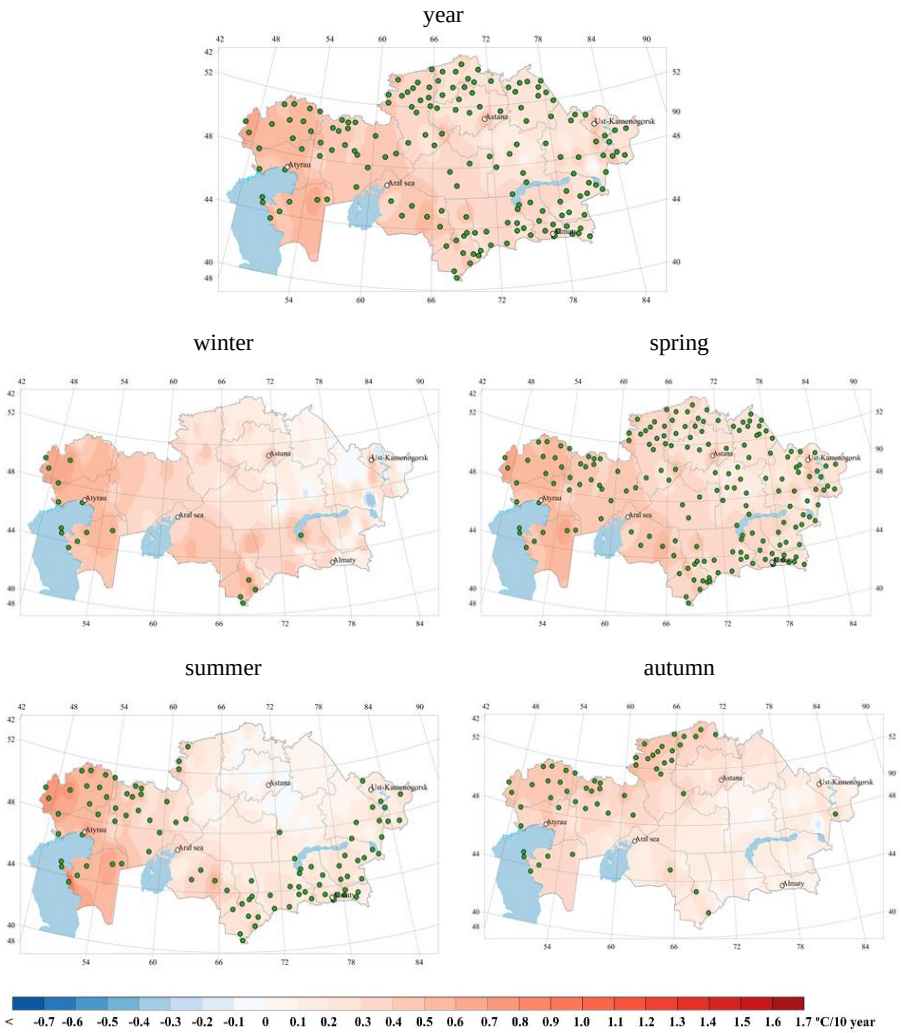


Figure 2.16 – Spatial distribution of values of the linear trend coefficient of mean annual and seasonal surface air temperature (°C/10 years) calculated from observations for the period 1976-2022.

In December 2021, there are no stable trends in the change of mean monthly temperatures. In most of the territory of Kazakhstan, the trends are positive, with maximum values in the west (up to 0.31 ºC/10 years). In the southern half of Kazakhstan there are several hotspots with downward trends in air temperature, with maximum values up to 0.50 ºC/10 years in the southern and south-eastern regions of the country (Figure 2.17).

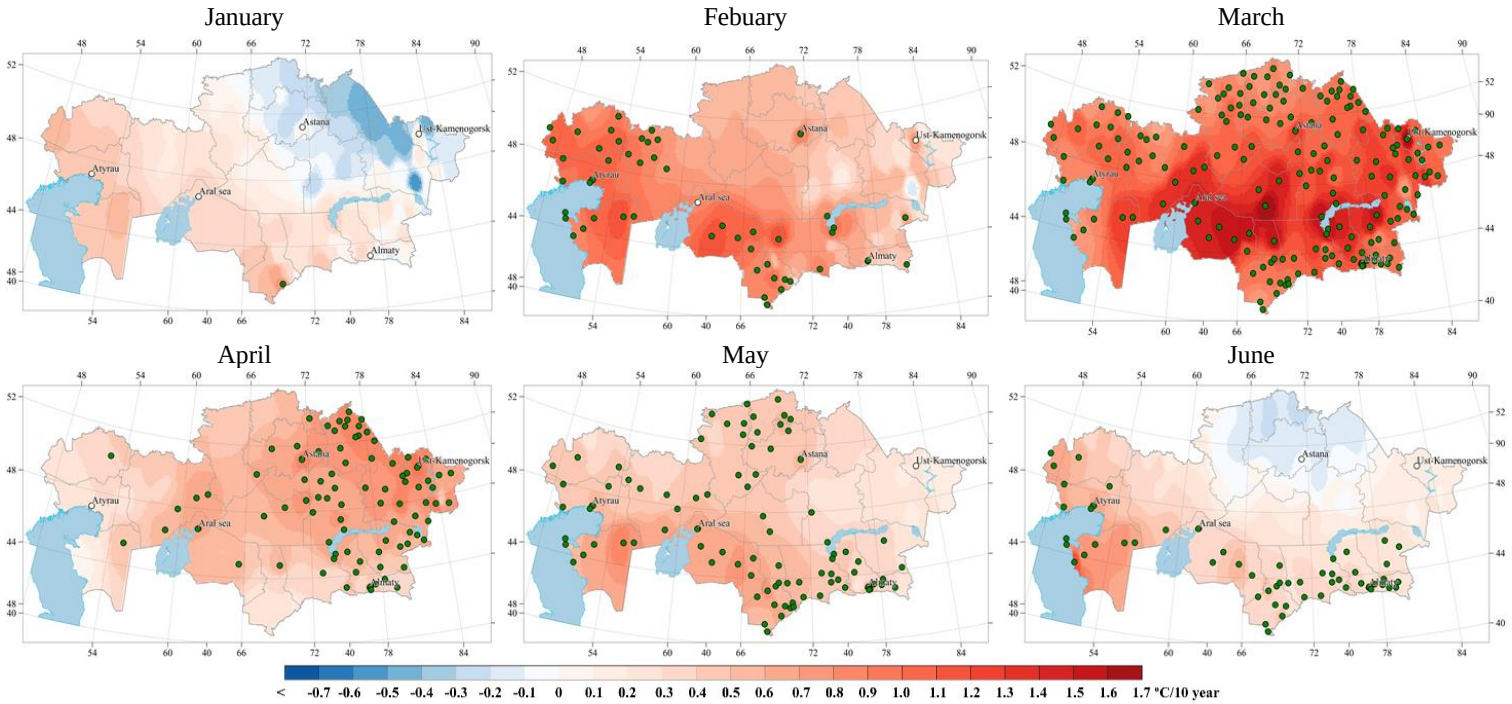


Figure 2.17 – Spatial distribution of values of the linear trend coefficient of the mean monthly surface air temperature (°C/10 years) calculated from the observation data for the period 1976-2022. *Sheet 1*

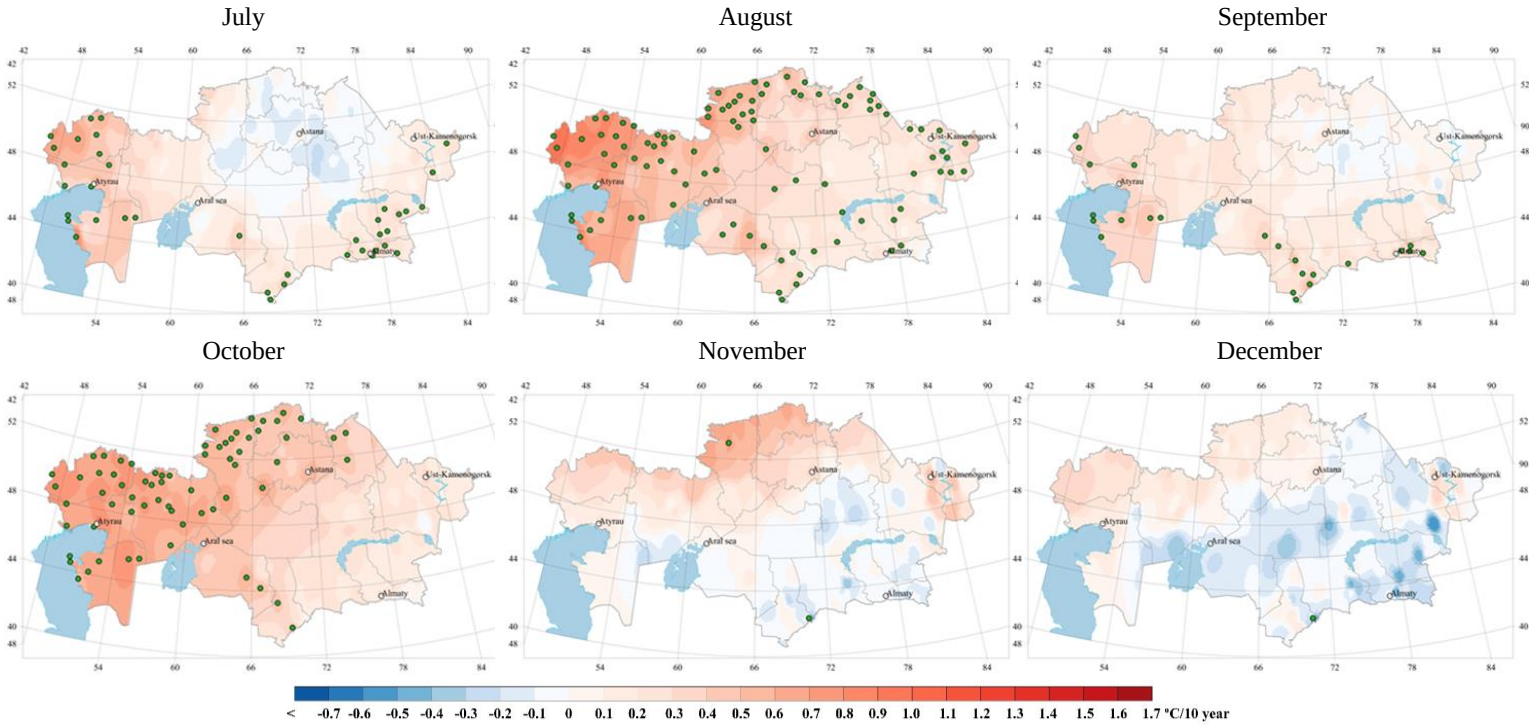


Figure 2.17 – Spatial distribution of values of the linear trend coefficient of the mean monthly surface air temperature (°C/10 years) calculated from the observation data for the period 1976-2022. *Sheet 2*

In January, the region with a tendency to lower air temperature occupied the vast territory of the central, north, and north-eastern and eastern parts of the country, with maximum with a rate of up to 0.34-0.60 ºC/10 years, the temperature decreases in the north-eastern regions and in the south of the region of Abay (Figure 2.17). Maximum positive trends up to 0.36-0.68 ºC/10 years are observed in the west and south. Although the values of the angular coefficient for December and January temperatures are quite high, but due to the large inter-annual variability of temperature in these months, the contribution of the trend component to the total variance is insignificant. A statistically significant positive temperature trend was observed only at the Kazygurt MS (0.79 ºC/10 years, Turkestan region).

In February, there is a trend of air temperature increase throughout Kazakhstan with maximum values in western regions, Kyzylorda, and Turkestan regions of 0.80-1.19 ºC/10 years. Statistically significant rates of air temperature increase in February were observed at 49 meteorological stations located in the western, southern, and south-eastern regions of the country, as well as in the city of Astana (Figure 2.17).

In the **spring** season, the most intensive warming trend is observed in all regions of Kazakhstan (Table 2.4). On average over the territory of Kazakhstan, air temperature increased by 0.65 ºC/10 years (contribution of the trend component 32 %). The range of air temperature increase rate by region is from 0.41 ºC/10 years (Mangistau region) to 0.87 ºC/10 years (Kyzylorda region) with 18-37 % of variance explained by trend. Hotspots of the most intense warming are observed in West Kazakhstan, eastern part of Mangistau, Kyzylorda, Ulytau, Karaganda, Pavlodar, Abai regions (0.70-0.98 ºC/10 years), Figure 2.16. At all meteorological stations of the country the trends are statistically significant.

The highest and statistically significant according to data from all stations the rate of air temperature increase in the spring period was observed in March (by 0.63-1.69 ºC/10 years), Figure 2.17. In April and May, the trend of significant increase in air temperature was also observed over the entire territory of the Republic. In April, statistically reliable rates of increase were observed mainly in the eastern part of the Karaganda region, in the eastern region of the country and in the south-east from about 70º E (in the range from 0.35 to 0.99 ºC/10 years), in May – in the opposite part (north-west, west, south-west, and south) of the Republic (in the range from 0.36 to 0.88 ºC/10 years).

In **summer**, the average seasonal air temperature in Kazakhstan increases by 0.22 ºC/10 years (coefficient of determination 18 %, Table 2.4). The most significant rates of air temperature increase are observed in the western regions - by 0.36-0.66 ºC/10 years. Less intensive warming is observed in the southern and south-eastern regions of Kazakhstan, where summer air temperatures tend to increase by 0.18-0.27 ºC/10 years (Figure 2.16). Trends here describe from 15 to 53 % of the time series variance. In the northern and central regions, trends are practically absent - the share of the trend component in the total dispersion of the series in these regions is practically zero, although the positive sign of the trend is preserved.

In June and July, a slight cooling trend was observed in the northern, north-eastern, and central regions (maximum up to 0.30 ºC/10 years, Figure 2.17). In some western, southern, and south-eastern regions of the country, statistically significant rates of increase in surface air temperature by 0.25-0.78 ºC/10 years were observed. In August, statistically significant positive trends of air temperature in the range from 0.20 to 0.94 ºC/10 years were observed in most regions

of Kazakhstan. The highest rate of air temperature increase in the summer months is observed in the western region.

In **autumn**, the average seasonal temperature in Kazakhstan increases by 0.23 ºC/10 years (coefficient of determination 6 %, Table 2.4). Trends of average air temperature by regions are also positive. The most significant rates of temperature increase are observed in the western and northern regions by 0.37-0.47 ºC/10 years, with the share of variance explained by the trend being 8-22 %. In the central, some southern and eastern regions, trends are practically absent - although the sign of the trend is positive, but the share of the trend component in the total variance of the series is not more than 5 %. While in summer the maximum and significant trends were observed in the western, southern, and south-eastern regions, in autumn - in the western and northern regions (Figure 2.16). That is, significant climate warming was observed in the western regions of the country in all seasons of the year.

In September, warming occurs over most of the territory of the Republic, with some southern and western regions experiencing statistically significant rates of increase in surface air temperature by 0.26-0.49 ºC/10 years (Figure 2.17). In the eastern and central regions there are hotspots with insignificant cooling. In October, warming occurred throughout Kazakhstan, with statistically significant positive trends in air temperature in the range from 0.41 to 0.86 ºC/10 years in the western region, in the north and in some places in the south - in Kyzylorda and Turkestan regions. In November, positive trends (in the range 0.22-0.73 ºC/10 years) covered the northern half of Kazakhstan, including the eastern region, and only at the Rudnyi meteorological station in the Kostanay region was the trend statistically significant (0.73 ºC/10 years). Negative trends in November covered the southern, south-eastern, and central regions, with only the Shuyldak meteorological station in the Turkestan region showing a statistically significant trend (0.50 ºC/10 years).

2.3 Trends in surface air temperature extremes

Not only the average level of air temperature and precipitation change, but also other characteristics of the regimes of these basic climate elements, including the frequency and intensity of extremes. Thus, climate change can affect practically all spheres of human activity, physical and chemical processes in the biosphere.

Correct assessment of such climate change impacts should have a pronounced regional, and even local character, since both climate change and the vulnerability of systems, as well as the potential for adaptation, depend significantly on the physical geographical, economic, and demographic characteristics of regions, which are specific in this respect.

The increase in air temperature leads to shifts in the timing of phenological events in plants and animals, the boundaries of vegetation zones, mainly to the north and upwards in mountainous areas, as well as to changes in the structure of ecosystems.

Increase in duration of vegetation period (GSL index, Figure 2.18) by 1-5 days/10 years is observed on the whole territory of the republic. Statistically significant increase by 3-5 days/10 years is traced on data of most stations of West Kazakhstan, Aktobe, Kyzylorda, Turkestan, Zhambyl, Almaty, Zhetysu, Ulytau, Abai and East Kazakhstan regions. Here and further in the figures red or green circles highlight the points for which the trend coefficients are statistically

significant at the 5 % level. In the northern and north-eastern regions, the increase in the length of the growing season is mostly statistically insignificant.

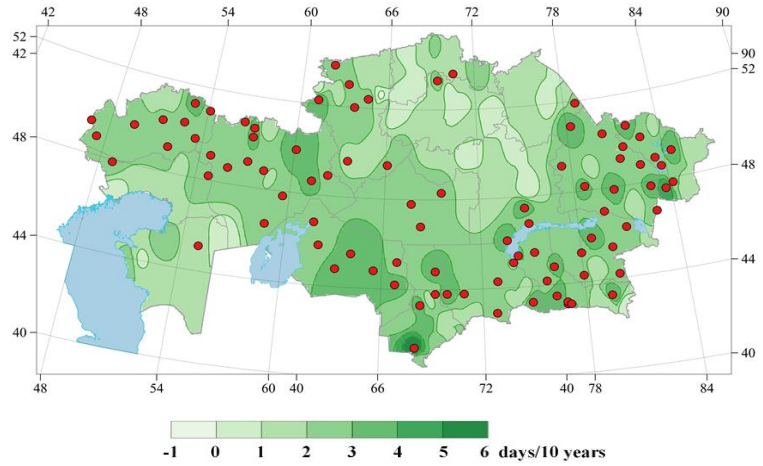


Figure 2.18 – Rates of change in growing season length (days/10 years) for the period 1961-2022 (*GSL index*)

In addition to the increase in the duration of the growing season, a statistically significant increase in the sum of temperatures during the growing season is observed throughout the territory of Kazakhstan (GDDgrow10 index, Figure 2.19). In the southern and western parts of the country, the increase in the sum of temperatures is significantly higher than in the northern part of the country. The largest and statistically significant increase, by more than 60 degree-days/10 years, can be traced in data from most stations in the south-western part of the West Kazakhstan, Atyrau, Mangistau, Kyzylorda, Turkestan, Zhambyl and Almaty regions.

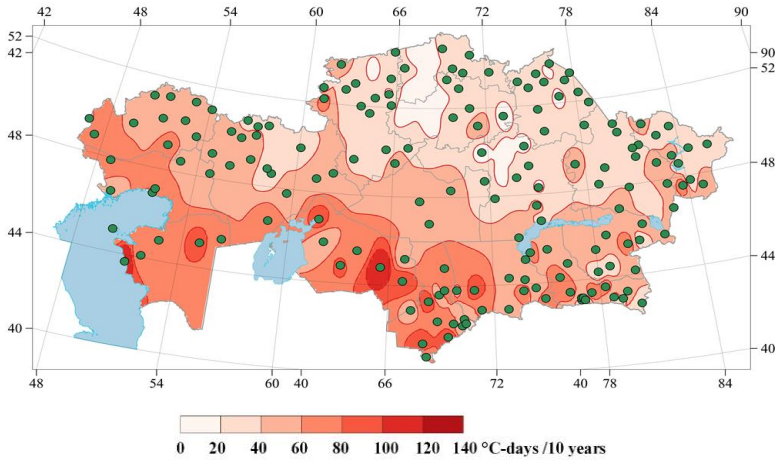


Figure 2.19 – Rate of change in the sum of temperatures during the growing season (degree-days/10 years) for the period 1961-2022 (*GDDgrow10 index*).

Not only the average level of air temperature increases, but also the recurrence of high summer temperatures increases. In conditions of hot and dry summer in the western and southern regions of Kazakhstan, this has a negative impact not only on vegetation, but also on human and animal organisms. For example, the number of days with temperatures above 30 °C increases almost everywhere, especially noticeably in the western and southern regions of the country - by 4-7 days in 10 years (Figure 2.20). The highest rate of increase in the recurrence of high summer temperatures was observed at the meteorological stations of Aktau (7.6 days/10 years, Mangistau region) and Aral tenyzy (7.0 days/10 years, Kyzylorda region). At the stations of North-Kazakhstan and Akmola regions, a statistically insignificant negative trend of recurrence of hot days was observed.

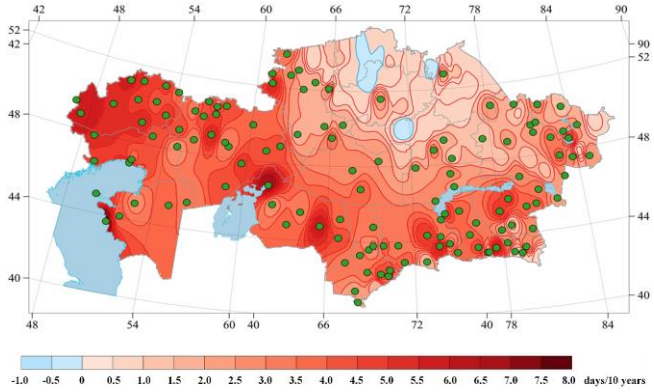


Figure 2.20 – Rate of change in the number of days when the maximum daily temperature is equal to or above 30 °C (days/10 years) in the period 1961-2022 (*TXge30 index*)

A statistically significant positive trend of the total duration of all heat waves in the warm period (a heat wave is 3 or more consecutive days when the heat excess coefficient has a positive value, *HWF/EHF index*, Figure 2.21) is observed over most of the territory of the Republic. The largest significant positive trend (more than 6-9 days/10 years) was observed at meteorological stations located in the western and southern regions.

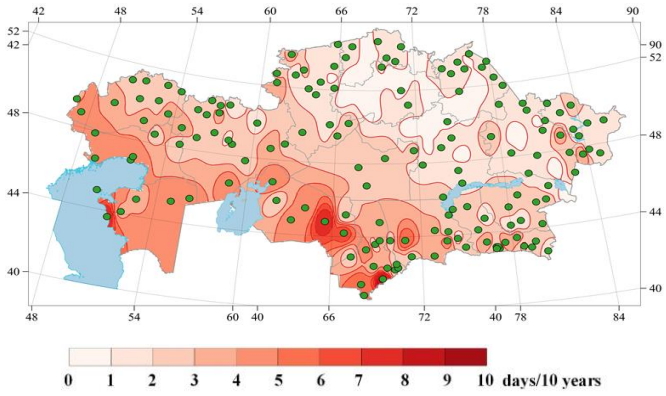


Figure 2.21 – Rates of change in total warm period heat wave duration (days/10 years) for 1961-2022 (*HWF/EHF index*)

A statistically significant positive trend of the number of individual heat waves in the warm period (*HWN index*, Figure 2.22) is observed almost over the entire territory of the republic. At the stations of the southern regions, such waves become one more on average every 10 years.

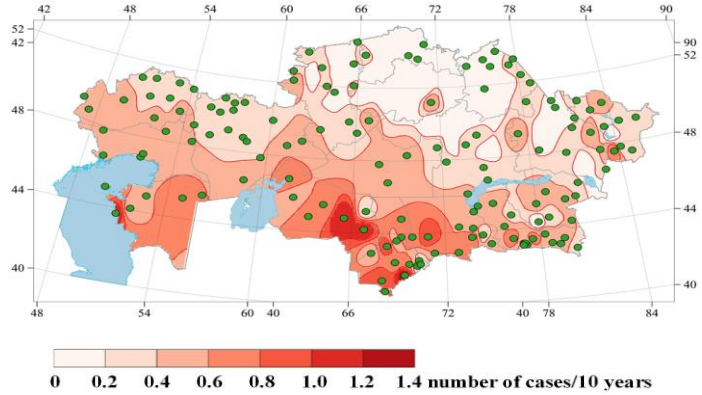


Figure 2.22 – Rate of change in the number of heat waves during the warm period (number of occurrences/10 years) during 1961-2022 (*HWN index*)

The duration of the maximum warm period heat wave is increasing everywhere (HWD index, Figure 2.23), with the wave lengthening by more than one day on average for every 10 years in the western and southern regions.

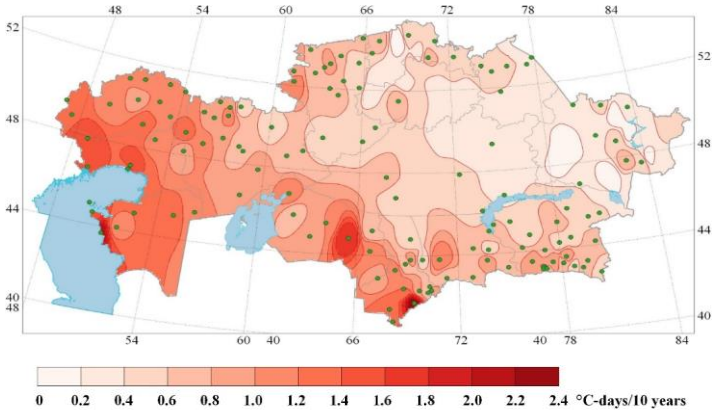


Figure 2.23 – Rate of change of maximum warm period heat wave duration (day/10 years) in 1961-2022 (*HWD index*)

The increase in air temperature in all seasons of the year leads to an increase in the *total annual duration of heat waves* (when, for at least 6 consecutive days, the daily maximum air temperature was above the 90th percentile, *WSDI index*) over the entire territory of the Republic (Figure 2.24). In the northern regions and in some central, southern, and eastern regions, the increase is by 1-3 days/10 years. The most significant increase (by 3-6 days/10 years) is observed in the western half of the country.

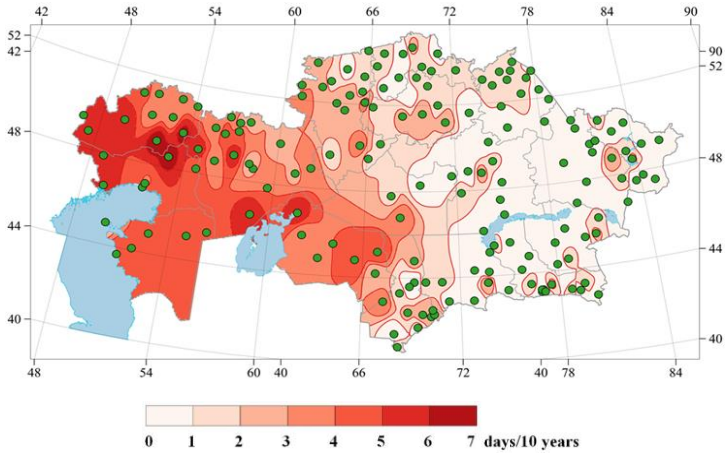


Figure 2.24 – Rate of change in total annual heat wave duration (days/10 years) for the period 1961-2022 (*WSDI index*)

The consequence of higher air temperatures in most months of the warm season is an increase in the *cold deficit*, or the need to maintain a favorable indoor temperature, in this case a threshold of 23 °C (*CDDcold23 index*, Figure 2.25). Only in the north and north-east of the country there are small regions with some decrease in the cold deficit. In the rest of the country there is an increase in the cold deficit, in the western regions, south-west and south the rate of increase in the cold deficit is more than 10 °C every 10 years. The maximum increase in cold deficit is observed in Atyrau, Mangistau, Kyzylorda, Turkestan regions (30-50 °C/10 years).

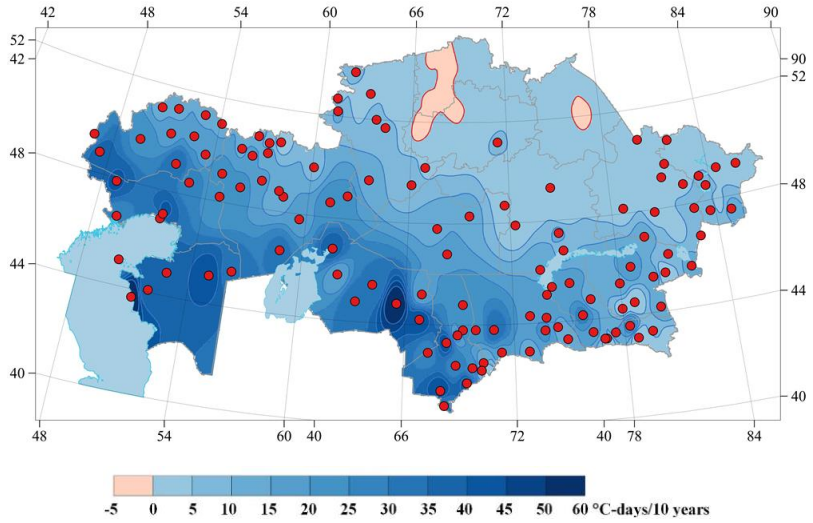


Figure 2.25 – Rate of change in cold deficit (degree days/10 years) for the period 1961-2022 (*CDDcold23 index*)

In many regions of Kazakhstan, the value of the daily minimum temperature is increasing, in about half of the cases outpacing the increase in the daily maximum. Figure 2.26 shows the *change in the number of days when the minimum temperature ≥ 20 °C (TR index, number of tropical nights)*. Over the last more than 60 years in Kazakhstan, there is mainly an increase in the number of such days, maximally in the Atyrau and Mangistau regions by 4-8 days/10 years, and by 6-7 days/10 years at some stations in the Kyzylorda and Turkestan regions. Thus, here the conditions for night rest of the human organism from the daytime heat, which, as shown above, also increases, are significantly worsened.

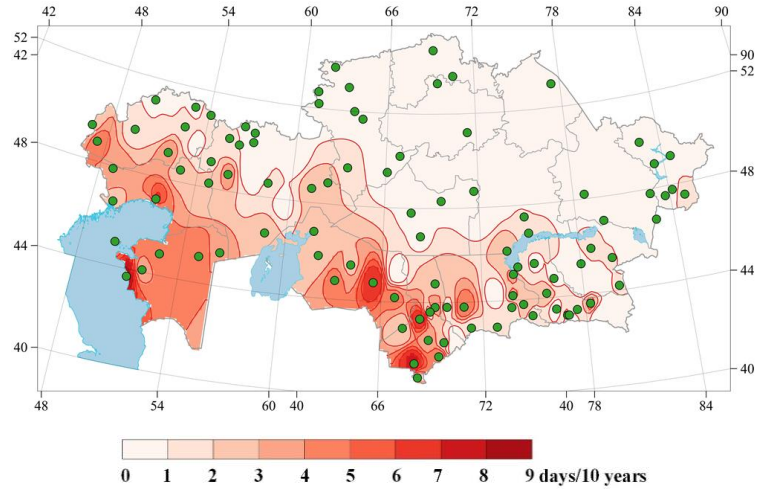


Figure 2.26 – Rate of change in the number of tropical nights (days/10 years) for the period 1961 2022 (*TR index*)

As a consequence of the increase in air temperature, *the number of days per year when the daily minimum temperature is equal to or falls below 0 ºC* (day with frost, *index FD0*, Figure 2.27) *and below minus 2 ºC* (hard frost, *index TNltm2*, Figure 2.28) decreases throughout the territory of Kazakhstan. The rate of reduction varies over the territory, mainly from 2 to 4 days/10 years, in some places the rate of reduction is higher than 5-6 days per 10 years.

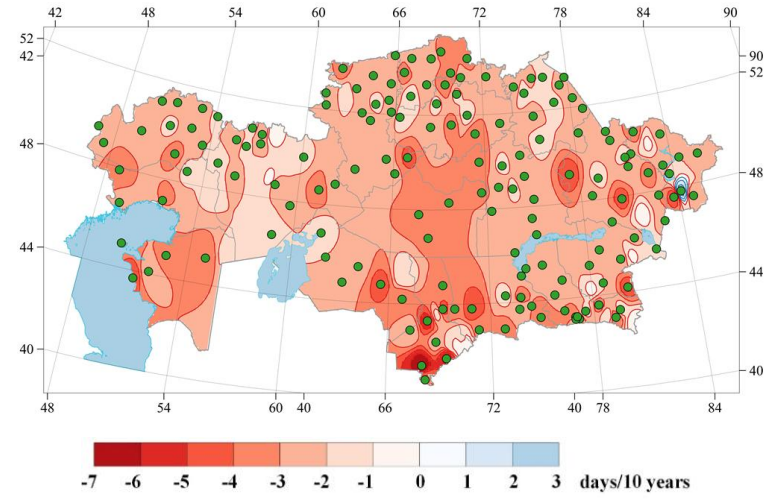


Figure 2.27 – Rate of change in the number of days with frost (days/10 years) in the period 1961-2022 (*FD0 index*)

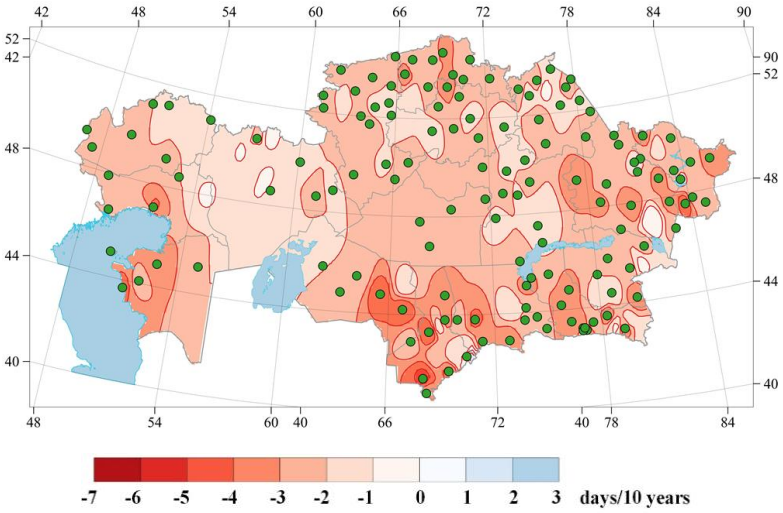


Figure 2.28 – Rate of change in the number of days with hard frosts (days/10 years) in the period 1961-2022 (*TNltm2 index*)

The number of days with very hard frosts (when the daily minimum air temperature is below minus 20 °C, *TNltm20 index*, Figure 2.29) is almost everywhere in the territory of the Republic. The number of such days significantly decreases (by 2-3 days/10 years) in the north-western, central, and south-eastern regions. In some regions of the East Kazakhstan region, the frequency of days with very hard frosts decreases at a more significant rate by 4-5 days/10 years.

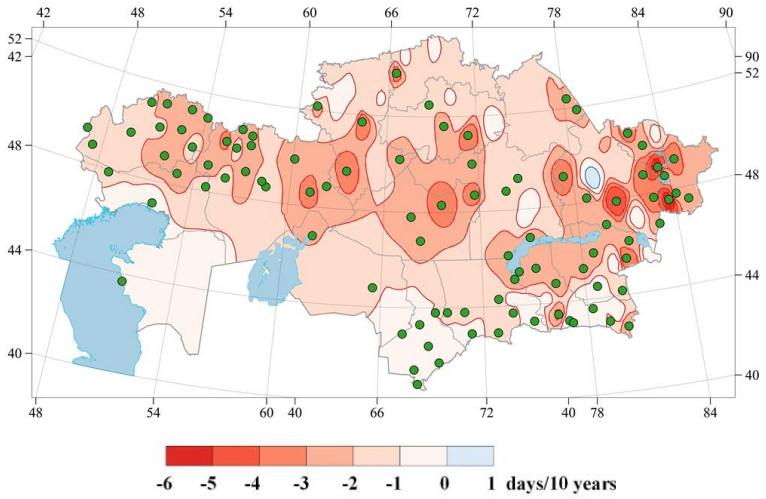


Figure 2.29 – Rates of change in the number of days with very hard frost (days/10 years) in the period 1961-2022 (*TNltm20 index*)

Reducing the number of days with negative temperatures leads to a widespread reduction in the heat deficit in the cold season (HDDheat18 index, Figure 2.30). Here, a temperature of 18 °C is taken as the threshold value of the air temperature that is desirable to maintain indoors. The range of heat deficit reduction is 60-100 degree-days for every 10 years. In places in different regions of Kazakhstan, this reduction was more than 120 degree-days/10 years.

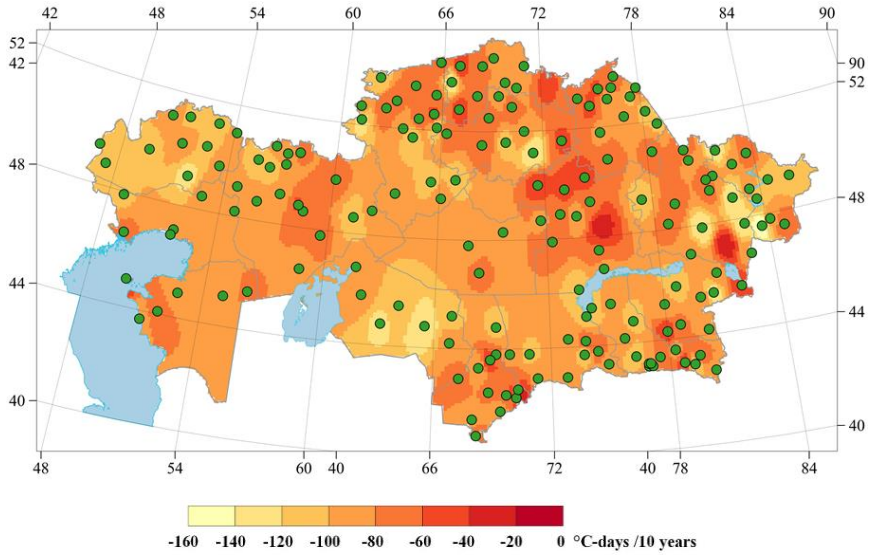


Figure 2.30 – Rate of change of heat deficit (degree days/10 years) in the period 1961-2022 (*HDDheat18 index*)

3 ATMOSPHERIC PRECIPITATION

3.1 Anomalies of precipitation on the territory of Kazakhstan in 2022

In 2022, the average annual precipitation on the territory of Kazakhstan was close to normal and amounted to 98.0 % of the norm, or 311 mm (rank 47, the probability of non-exceedance 43 %). Table 3.1 shows the values of anomalies of annual and seasonal precipitation amounts, Table 3.2 shows the values of anomalies of monthly precipitation amounts observed in 2022 and averaged over the whole territory of Kazakhstan and its regions. For each anomaly value, the probabilities of non-exceedance calculated for the period 1941 - 2022 are given. The probability of non-exceedance characterizes the frequency of occurrence of the corresponding anomaly value in several observations. Precipitation above the 95th or below the 5th percentile is highlighted in bold.

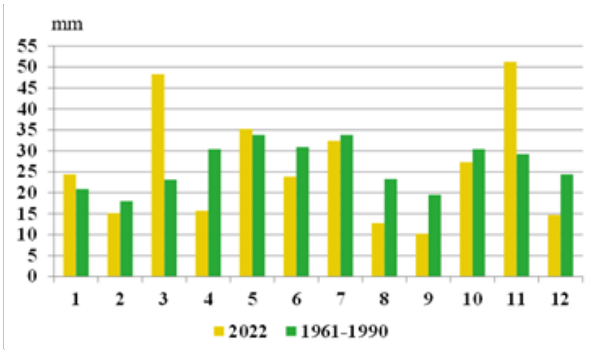
Table 3.1 – Regionally averaged average annual (January-December) and seasonal precipitation anomalies in 2022: **vR** – *deviations from long–term averages for 1961-1990, mm/season;* ***P(r≤R2021)*** *- probability of non-exceedance (in parentheses), calculated from data for the period 1941-2022 in %;* ***RR*** *-the ratio of R2022 to the norm in %*

Region	Year		Winter		Spring		Summer		Autumn	
	vR (P)	RR	vR (P)	RR	vR (P)	RR	vR (P)	RR	vR (P)	RR
Kazakhstan	-6,5 (43)	98,0	-4,5 (40)	92,8	11,9 (70)	113,6	-19,0 (13)	78,4	9,7 (80)	112,2
Abai	-47,2 (11)	83,6	-8,3 (34)	85,6	-2,5 (51)	96,3	-22,1 (14)	74,5	-9,2 (46)	87,8
Almaty	13,4 (55)	102,8	-20,3 (12)	68,5	42,7 (82)	124,1	-35,3 (16)	74,4	27,3 (82)	127,1
Akmola	19,7 (59)	106,0	10,2 (72)	121,4	**-28,8 (3)**	**58,4**	14,5 (64)	111,1	25,5 (88)	132,6
Aktobe	29,5 (65)	111,2	8,8 (69)	114,8	27,0 (85)	142,2	-7,2 (45)	89,4	3,6 (65)	105,0
Atyrau	22,3 (60)	114,9	17,0 (83)	154,1	48,2 (93)	227,8	-23,4 (16)	42,5	-4,2 (49)	89,5
East Kazakhstan	-76,3 (9)	80,6	-11,7 (37)	81,1	-20,9 (28)	77,5	-27,2 (17)	78,7	-17,6 (32)	84,2
Zhambyl	34,8 (69)	111,4	-19,8 (17)	73,0	40,9 (90)	134,3	-2,9 (40)	92,5	17,9 (72)	124,2
Zhetysu	11,9 (55)	103,1	-26,2 (6)	64,1	45,8 (85)	138,6	-25,2 (18)	72,5	16,5 (80)	116,4
West Kazakhstan	62,8 (83)	122,3	9,1 (79)	113,9	**67,5 (98)**	**216,6**	-27,6 (25)	65,3	34,8 (88)	144,4
Karaganda	-56,0 (13)	78,0	-9,0 (38)	82,2	-12,2 (33)	81,2	-20,2 (27)	73,9	-18,2 (24)	70,5
Kostanay	-36,8 (20)	87,3	10,1 (77)	120,7	-11,6 (24)	80,6	-39,4 (13)	63,3	16,2 (80)	122,0
Kyzylorda	-31,5 (19)	77,7	3,6 (49)	109,1	-7,4 (40)	85,0	-10,5 (23)	44,8	-7,3 (40)	78,0
Mangystau 1	11,9 (72)	108,3	-1,7 (51)	92,9	-5,7 (58)	87,8	-17,7 (34)	48,8	**36,6 (95)**	**198,1**
Pavlodar	-62,4 (6)	78,7	-4,3 (39)	90,4	-22,1 (8)	59,8	-23,2 (22)	80,7	-14,7 (25)	79,7
North Kazakhstan	-44,9 (25)	87,3	-2,8 (44)	94,0	-21,1 (9)	67,9	-22,6 (30)	85,2	5,7 (66)	106,6
Turkestan	50,8 (70)	111,6	-17,1 (27)	88,7	35,1 (72)	120,9	-12,5 (19)	48,6	50,5 (86)	153,7
Ulytau	-29,1 (32)	86,5	3,6 (65)	106,9	4,1 (64)	106,9	-19,5 (20)	63,8	-6,7 (43)	86,5

Notes: 1. For the Mangystau region, the assessment was carried out only according to MS Fort Shevchenko;
2. values above the 95th or below the 5th percentile (wet 95 % and dry 5 % extremes, respectively) are highlighted in bold and bright color;
3. values above the 90th or below the 10th percentile are highlighted in pale color;
4. Average precipitation anomalies were obtained by averaging the data of 121 stations of the Republic of Kazakhstan.

On average, in the territory of Kazakhstan in the summer of 2022, precipitation was below normal (78.4 %), in winter, spring and autumn – about and above normal and amounted to 92.8 %, 113.6 %, 112.2 %, respectively (Table 3.1).

Figure 3.1 shows the intra-annual distribution of precipitation in 2022, averaged on the territory of Kazakhstan, as well as the average long-term monthly precipitation for the period 1961-1990.



Добавлено примечание ([TT1]): Шкалу изменить на «mm»

Figure 3.1 – Monthly precipitation amounts averaged over the territory of Kazakhstan in 2022 and their norms calculated for the period 1961-1990

In 2022, on average, there was a shortage of precipitation on the territory of Kazakhstan for most of the year (in February, April, from June to October and in December). April (15.7 mm, 52 % of the norm) and September (10.2 mm, 53 % of the norm) with a probability of non-exceedence 8 % are characterized as "dry" months. March was the wettest on record, in which the average layer of precipitation was 48.3 mm or 209 % of the norm, and November was extremely wet, when 51.2 mm (175 % of the norm) fell on average across the country, the probability of non-exceedence the amount of precipitation was 98 %.

Figure 3.2 shows the territorial distribution of annual and seasonal precipitation in 2022, expressed as a percentage of the norm for the period 1961-1990, and shows the probabilities of non-exceedance of annual and seasonal precipitation amounts in a given year.

In most of the territory of Kazakhstan, precipitation in 2022 fell either near the norm or more than the norm (Figure 3.2). In 2022, Pavlodar, East Kazakhstan, Karaganda and Kyzylorda regions experienced a shortage of precipitation, where the average annual precipitation in the region was slightly less than 80 % of the norm (Table 3.1), while In Pavlodar and East Kazakhstan regions, the annual precipitation has entered 10 % of extremely dry. The average annual norm in the territory of the West Kazakhstan region was exceeded by 22 %, but the average precipitation layer was only 344 mm. On average, the territories of the western, northern, south-eastern and some southern regions: Aktobe, Atyrau, Mangystau, Kostanay, North Kazakhstan, Akmola, Almaty, Zhetysu, Zhambyl and Turkestan precipitation fell about normal.

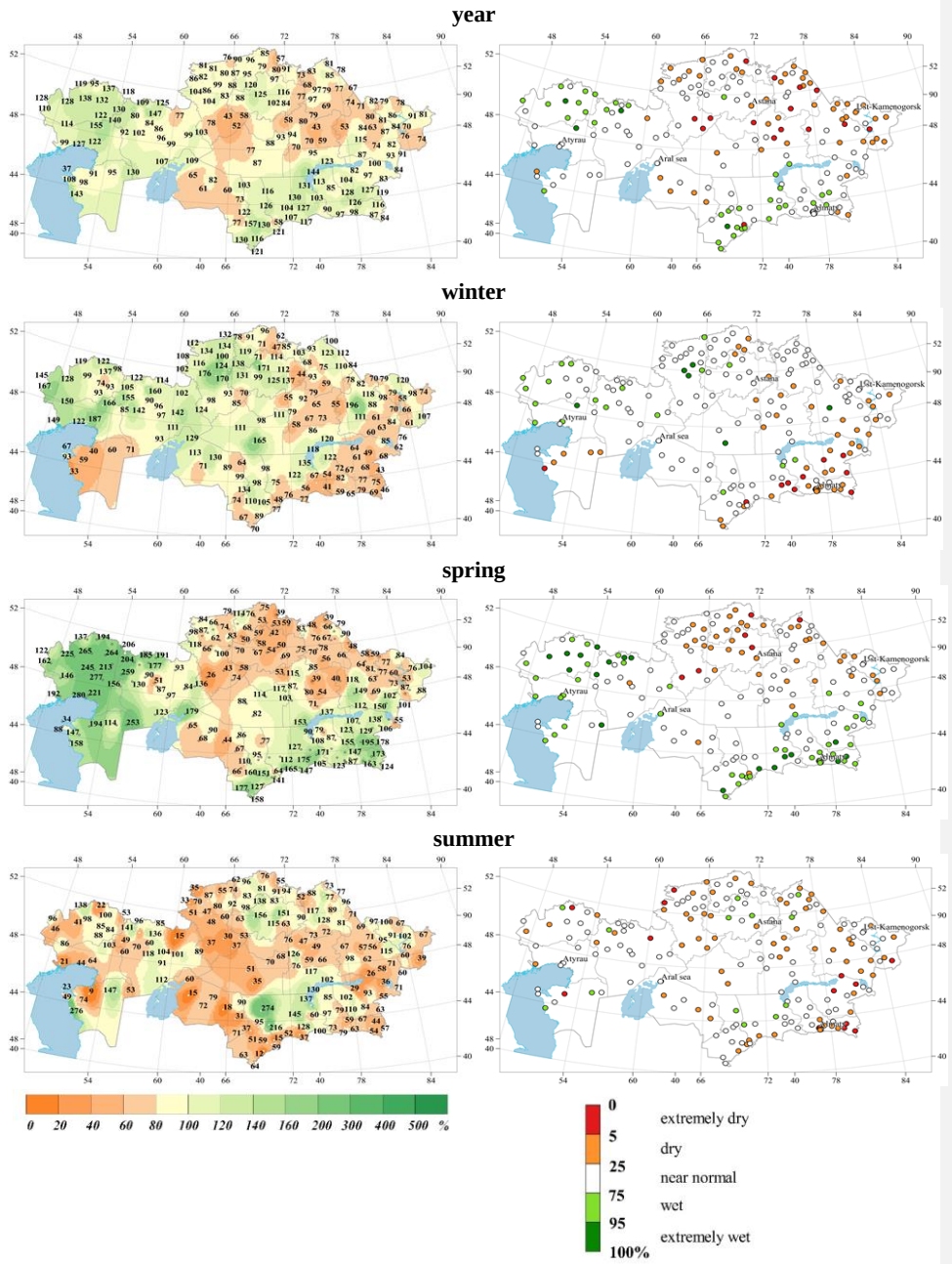


Figure 3.2 – Geographical distribution of annual and seasonal precipitation in 2022, expressed as % of the norm (left), as well as the probability of non-exceedence it (right), calculated for the period 1961 – 2022. Sheet 1

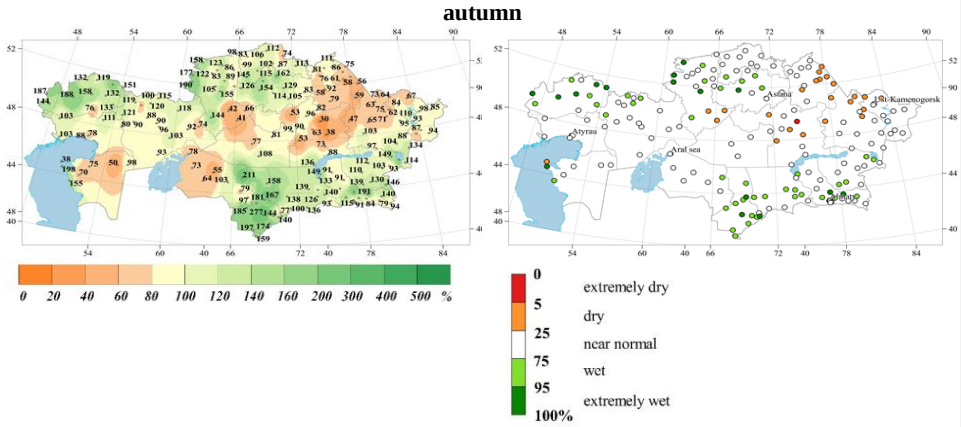


Figure 3.2 – Geographical distribution of annual and seasonal precipitation in 2022, expressed as % of the norm (left), as well as the probability of non-exceedence it (right), calculated for the period 1961 – 2022. Sheet 2

The centers of maximum precipitation relative to the norm were located in the northwestern regions (122, 155 % of the norm), in the central regions of the Akmola region (125 % of the norm), in the southeastern region and in the Zhambyl region (123, 144 % of the norm), in the Turkestan region the amount of precipitation in some places exceeded 122, 157% of the norm. Precipitation deficit was experienced by some areas in the south of Kostanay region, in Ulytau and Kyzylorda regions, as well as in Central Kazakhstan (precipitation was 20-60 % below normal), and in the northeast and east (20-50 % below normal, Figure 3.2).

New minimums of annual precipitation were set at 4 weather stations: MS Besoba in Karaganda region had 107.6 mm of precipitation at the previous minimum of 126.8 mm in 2011; MS Ekidin in Kostanay region – 116.8 mm at the previous minimum of 118.4 mm in 1993; MS Upland in North Kazakhstan region – 188.8 mm, the previous record for the minimum amount of precipitation was in 2010 and was 205.3 mm; on the MS of T.Ryskulov Village in Turkestan region – 402.0 mm with the previous minimum of 470.3 mm in 1936.

In the winter of 2021/2022 (December 2021 – February 2022), the average amount of precipitation in winter in Kazakhstan (Table 3.1) was 92.8 % of the norm (rank – 49). More than 80 % of the norm fell in most of the country (Figure 3.2). Excess precipitation (more than 120 %) was observed in the western part of the country (122,187% of the norm), in the northern regions (124, 176 % of the norm) and in some areas of the southern part of the country (122, 134 % of the norm). A significant excess of the norm of precipitation was observed according to MS Zhetykonur in Ulytau region (165 %), MS Karaul in Abai region (196 %), three meteorological stations of Kostanay region (Kushmurun, Dievskaya, Karamendy) and MS Karabau (Atyrau region), the winter period at these meteorological stations was 5 % extremely humid. Pockets of significant precipitation deficit in winter (less than 80 % of the norm) were observed in Mangystau region (33, 71 %), in mountainous and foothill areas of southern regions (41, 79 %), in Karaganda region, in the eastern part of the country (55, 79 % of the norm) and in some areas of the northern part of the country

(44, 78 %) (Figure 3.2). According to 10 meteorological stations located in the south of the country and in the Mangystau region, there was a shortage of precipitation and it was extremely dry. New records of the minimum amount of precipitation for the winter period (38.5 mm, 110.5 m) were set at MS Kordai, T.Ryskulov aul, the previous values (41.0 mm, 115.8 mm) were recorded in 1983, 1937, respectively.

In December 2021, the average amount of precipitation on the territory of Kazakhstan was 79 % of the norm for the period 1961-1990, or 5.2 mm below the norm (the probability of non-exceedence 28 %), but the distribution of precipitation across the territory was uneven. In the southern half of Kazakhstan, with the exception of the Kyzylorda region and small isolated, mainly foothill and mountainous areas, there was a shortage of precipitation. Thus, less than 20 % of the norm of precipitation fell on almost the entire territory of the Mangystau region, in the Northern Baltic region, in the south of Zhetysu and Almaty regions. New monthly precipitation minima (1.60 mm, 2.70 mm) were established on the MS Balkash and Bektauata, their previous values (1.61 mm, 2.99 mm) were noted in 1965, respectively (Annex 1). In most parts of the country, precipitation fell near or significantly above normal (Figure 3.3). In some western, northern, northeastern and central regions, precipitation exceeded the norm by 1.5-2.5 times. The largest in the territory and the record maximum monthly precipitation (32.90 mm) fell on MS Zhetykonur, the previous record was observed in 2015 (31.70 mm).

In January, the average amount of precipitation on the territory of Kazakhstan was 116.6 % of the norm (rank 21, probability of non-exceedance 75 %, Table 3.2). The distribution of precipitation was uneven. Precipitation of more than 120 % of the norm was observed in different parts of the country. Precipitation near the norm and above the norm, in some places above 200 % of the norm, fell in the western and northern regions, in the north of the East Kazakhstan region, in the Northern Baltic region, as well as in Turkestan, Zhambyl regions, in the southwestern part of the Southern Baltic region, in the north of the Abai region, where precipitation was even more than 300 % of the norm (Figure 3.3). At 16 meteorological stations located in different parts of the country, humidification conditions were characterized as extremely humid (5 % extremes), including a record amount of monthly precipitation fell at three weather stations: MS Karauyl (29 mm), the previous record was set in 1947 and was 25.6 mm, MS Chiganak (31.2 mm), the previous record was 27.4 mm (2014), MS Sholakkorgan (42.8 mm), the previous value was 32.7 mm in 1940 (Annex 1). In January, the eastern and southeastern regions of the country were in the zone of significant precipitation deficit, where humidification conditions are characterized as dry and in places extremely dry (5 % and 10 % extremes). A significant field of moisture deficiency was observed in the north-eastern and central regions of the country. The amount of precipitation in these regions was within 30 to 60 % of the norm. Small areas with precipitation deficiency (55-69 % of the norm) were located in the northeastern part, in some areas of the Kyzylorda region and in the west of the Mangystau region (Figure 3.3). According to the data of 6 meteorological stations located in the south-east of the country, the humidification conditions were characterized as extremely dry (5 % extremes), including precipitation on the Zhalanashkol MS was absent throughout the month (Annex 1).

Table 3.2 – Regionally averaged monthly precipitation anomalies in 2022, calculated as deviations from the long-term average values for 1961-1990, (in mm), and the *probability of non-exceedance (in parentheses), calculated from data for the period 1941-2022 and expressed in %*

Region	**12 (2021)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Kazakhstan	-5,2 (28)	3,5 (75)	-2,8 (25)	**25,2 (100)**	-14,7 (8)	1,4 (54)	-7,1 (23)	-1,4 (49)	-10,5 (11)	-9,3 (8)	-3,1 (56)	**22,0 (98)**
Abai	-2,9 (43)	0,3 (59)	-5.7 (23)	**23,6 (96)**	-11,0 (13)	-15,1 (24)	-3,5 (38)	-8,7 (30)	-9,9 (18)	-11,5 (11)	-14,5 (23)	16,8 (91)
Almaty	-14,5 (7)	-5,7 (32)	-0,1 (45)	**61,8 (100)**	-25,9 (18)	6,8 (65)	-12,3 (28)	-17,1 (23)	-6,0 (30)	-19,4 (6)	-9,7 (48)	**56,4 (100)**
Akmola	-0,7 (41)	4,8 (76)	6,1 (80)	7,4 (77)	-16,5 (6)	-19,7 (8)	5,4 (56)	20,0 (74)	-10,8 (37)	-10,4 (23)	5,8 (79)	**30,1 (97)**
Aktobe	-6,6 (33)	13,2 (90)	2,2 (60)	2,2 (55)	-8,6 (32)	33,4 (91)	-9,1 (29)	17,0 (83)	-15,2 (12)	-5,4 (46)	-7,3 (33)	16,3 (92)
Atyrau	4,6 (69)	8,0 (79)	4,4 (71)	19,6 (90)	-2,6 (50)	31,2 (93)	-10,0 (18)	-2,4 (58)	-11,1 (11)	-2,1 (59)	4,1 (66)	-6,2 (30)
East Kazakhstan	0,4 (56)	-2,2 (45)	-10,0 (7)	**24,0 (97)**	-9,5 (22)	**-35,5 (4)**	3,6 (60)	-9,3 (27)	-21,5 (11)	-15,0 (18)	-12,4 (34)	9,7 (74)
Zhambyl	-16,6 (12)	7,3 (76)	-10,6 (12)	**58,8 (100)**	-21,5 (18)	3,6 (70)	-2,2 (43)	-5,3 (32)	4,7 (77)	**-9,7 (2)**	5,0 (70)	22,6 (88)
Zhetysu	-10,7 (16)	-14,7 (6)	-0,9 (37)	**55,9 (98)**	-21,0 (18)	11,0 (79)	-7,0 (37)	-8,9 (33)	-9,4 (17)	-12,7 (12)	-13,7 (43)	**42,9 (97)**
West Kazakhstan	7,6 (81)	6,7 (79)	-5,2 (29)	**24,8 (96)**	-0,5 (46)	**43,3 (98)**	-21,2 (7)	13,8 (79)	-20,3 (7)	6,6 (70)	13,7 (71)	14,5 (88)
Karaganda	-4,7 (30)	-1,3 (56)	-3,1 (44)	16,1 (93)	-10,6 (14)	-17,6 (13)	-16,4 (8)	0,6 (54)	-4,4 (41)	**-13,1 (3)**	-9,2 (35)	4,1 (66)
Kostanay	2,9 (66)	4,5 (74)	2,8 (69)	-1,4 (43)	-13,4 (11)	3,3 (53)	-5,5 (44)	-12,1 (35)	**-21,8 (2)**	-10,5 (23)	6,5 (70)	**20,2 (97)**
Kyzylorda	1,4 (60)	1,1 (49)	1,1 (55)	2,5 (66)	-5,6 (53)	-4,2 (39)	**-7,7 (4)**	0,6 (71)	-3,5 (29)	-5,1 (19)	-10,8 (9)	8,6 (85)
Mangystau[1]	-8,6 (28)	3,4 (65)	3,5 (76)	6,1 (81)	-13,3 (20)	1,5 (79)	**-14,9 (0)**	5,0 (75)	-7,8 (30)	-7,5 (40)	**46,7 (100)**	-2,6 (50)
Pavlodar	1,3 (54)	-4,8 (38)	-0,9 (56)	4,6 (72)	-6,8 (20)	**-19,9 (2)**	-15,5 (14)	-11,7 (27)	4,0 (59)	-6,4 (33)	-11,3 (27)	3,0 (65)
North Kazakhstan	-1,3 (48)	3,3 (71)	-4,8 (22)	-0,6 (43)	-10,8 (18)	-9,7 (32)	-5,2 (35)	7,0 (59)	-24,4 (12)	-9,2 (24)	-6,7 (37)	**21,6 (95)**
Turkestan	-30,1 (17)	28,2 (91)	-15,2 (17)	**71,1 (97)**	**-46,4 (4)**	10,4 (67)	-2,0 (34)	-7,8 (20)	-2,7 (53)	**-7,1 (0)**	13,5 (79)	44,0 (91)
Ulytau	7,4 (81)	-4,3 (43)	0,5 (58)	12,5 (87)	-3,8 (41)	-4,5 (55)	**-15,8 (2)**	-7,8 (38)	4,1 (61)	-9,4 (16)	-10,4 (25)	13,1 (90)

Notes: 1. For the Mangystau region, the assessment was carried out only according to MS Fort Shevchenko;

2. Values above the 95th or below the 5th percentile are highlighted in bold and bright color;

3. values above the 90th or below the 10th percentile are highlighted in pale color;

4. Average precipitation anomalies were obtained by averaging data from 121 stations in Kazakhstan.

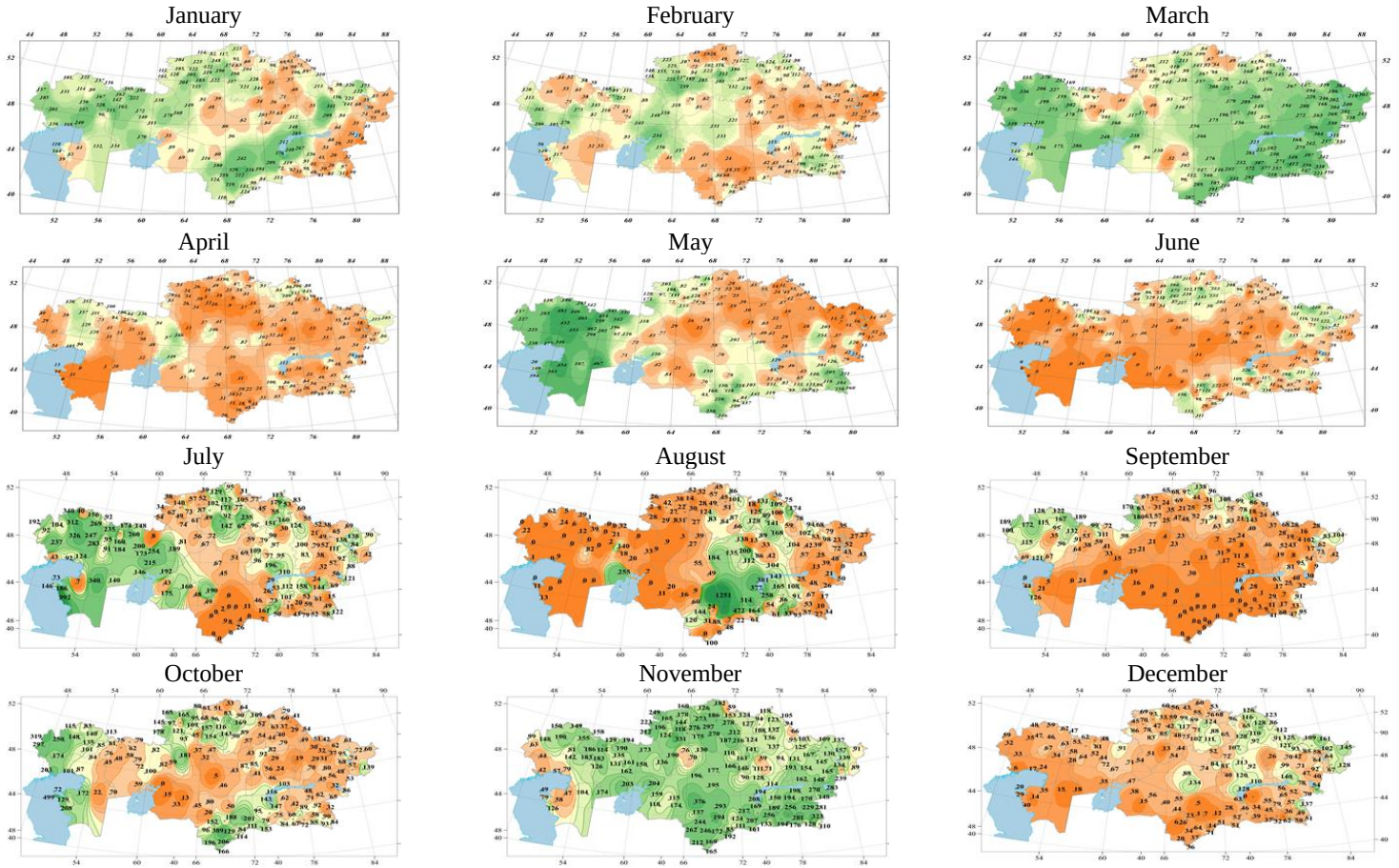


Figure 3.3 – Spatial distribution of monthly precipitation in 2022 (in % of the norm calculated relative to the base period of 1961-1990)

February was dry in most of the territory of Kazakhstan, the average amount of precipitation on the territory of the republic was 84.2 % of the norm (rank 61, the probability of non-exceedence 25 %, Table 3.2). In most parts of the country there was a significant shortage of precipitation – less than 60 % of the norm. Precipitation of less than 45 % of the norm fell in the southern, eastern regions and in the far north (Figure 3.3). At 8 meteorological stations located in the south and far north of the country, humidification conditions were characterized as extremely dry (5 % extremes). Precipitation of more than 120 % of the norm was observed in some western regions, north-western, north-eastern regions, in the south of the Zhetysu region, in Ulytau region and in the western half of the Kyzylorda region. In these areas, several small foci were observed, where the amount of precipitation exceeded the norm by two or more times.

In spring, on average, precipitation in Kazakhstan amounted to 114 % of the norm with a probability of non-exceedence 70 % (rank 25, Table 3.1). Excess precipitation prevailed in the west of the country and in the southern regions, except for the Kyzylorda region (Figure 3.2). At most meteorological stations in the western regions, precipitation exceeded the norm by more than two times (204, 280 % of the norm). Pockets of significant precipitation (more than 120 %) were also observed in the southern regions of Turkestan, Zhambyl, Almaty and Zhetysu regions (122,195 % of the norm), in the Aral Tenizi MS, located in the west of the Kyzylorda region (179 % of the norm), in some places of the Northern Baltic region and the southeastern part of the country (137,153 % of the norm). As a result, on average, 216.6 % of the norm fell in the spring on the territory of the West Kazakhstan region, humidification conditions here were characterized as extremely humid (5 % extremes), and in Atyrau and Zhambyl regions, on average, precipitation over the spring period amounted to 227.8 and 134.3 % of the norm, respectively, and humidification conditions were characterized as wet (10 % extremes). In the spring of 2022, new records were set for the maximum seasonal rainfall: 270.7 mm on MS Zhalanash (Almaty region); and 151.1 mm at MS Chapaevo (West Kazakhstan region). Precipitation deficit (less than 80 % of the norm) prevailed in the north and east of Kazakhstan (26-79 % of the norm), and areas with insufficient precipitation were observed in Kyzylorda (44-68 %), Karaganda (39-80 %) regions. As a result, in the North Kazakhstan and Pavlodar regions, the humidification conditions were characterized as dry (10 % extremes), the average amount of precipitation over the spring period was 67.9 and 59.8 % of the norm, respectively. According to six weather stations, it was extremely dry in the northern part of the country.

March was the wettest on record, the average monthly precipitation in Kazakhstan was 209.0 % of the norm or 25.2 mm above the long-term average (rank 1, Table 3.2). In most of the country, precipitation exceeded the norm by 1.5-2.0 times, and in the far west and in mountainous, foothill areas of the south and southeast even by 3 times. (Figure 3.3). It was record humid in Almaty and Zhambyl regions, the average humidification in the territory was 257-267 % of the norm, extremely humid (5% extremes) was observed in the territory of 5 regions: East Kazakhstan, Abai, Zhetysu, Turkestan and West Kazakhstan, where the average humidification in the territory was from 213 to 284 % of the norm (with a probability of non-exceedence 96-98 %). The greatest amount of precipitation (289.7 mm) fell on MS Tasaryk (Turkestan region), which amounted to 291 % of the norm. At 54 meteorological stations located in the south, southeast, and west, humidification conditions were characterized as extremely humid (5 % extremes were recorded), including record values of the maximum monthly precipitation were set at 13 MS (Annex 1). Zones of significant precipitation deficit (less than 40 % of the norm) were observed in the north of Aktobe, south-west of Kostanay, eastern part of Kyzylorda and North Kazakhstan regions.

In April, a significant shortage of precipitation prevailed in most of Kazakhstan. On average, the amount of precipitation on the territory of Kazakhstan was 51.6 % of the norm (this is the eighth driest month in a series of observations since 1941, Table 3.2). There was a severe shortage of precipitation in Turkestan and Akmola regions on average in the territory by 26.7 % and 23.2 % of the norm, where precipitation was below 5 % and 10 %-th percentile, respectively. The greatest shortage of monthly precipitation amounts was experienced in Mangystau, the western half of Atyrau and West Kazakhstan, Aktobe regions, in the northern and southern half of Kazakhstan (with the exception of the northeast and the far east), where less than 40-50 % of the precipitation norm fell, in places less than 10-20 % of the norm (Figure 3.3). No precipitation was observed at two meteorological stations of the Mangystau region (MS Aktau, Kyzan) throughout the month (Annex 1). According to 16 meteorological stations located in Mangistau, Kostanay, North Kazakhstan, Akmola and Turkestan regions, humidification conditions were characterized as extremely dry. Precipitation near the norm and in some areas more than 120% of the norm were observed in West Kazakhstan (157 % of the norm), Aktobe (166 % of the norm), Pavlodar regions (143 % of the norm) and the northern Aral Sea region (149 % of the norm). The most significant amount of precipitation fell on Ulken Almaty MS with a value of 102.7 mm.

In May, precipitation was unevenly distributed over the territory. On average, precipitation on the territory of Kazakhstan amounted to 104.1 % of the norm Table 3.2. In most of the territory of the western region, precipitation fell significantly more than normal (Figure 3.3), here their amount exceeded the norm by 2.0-4.8 times, with a maximum value of 482 % of the norm or 59.6 mm above the long–term average (MS Chapaevo, West Kazakhstan region). Zones with a significant excess of the norm of precipitation were observed in the southern (maximum value of 250 % of the norm) and south-eastern parts (maximum value of 231 % of the norm) of the country, also in places precipitation of more than 120 % of the norm was observed in the Northern Baltic region and the regions of Abai and Kostanay. According to 31 meteorological stations in the western, southern and southeastern regions, humidification conditions are classified as extremely humid (5 % or 10 % extremes), including record rainfall at four meteorological stations located in the western regions (Annex 1). Precipitation deficit was observed in the northern and eastern regions of the country and their minimum values were: in the North Kazakhstan region – 28 % of the norm, in the Pavlodar region – 14 % of the norm, in the Akmola region – 19 % of the norm, in the southern part of the Kostanay region – 12 % of the norm. In the east of Kazakhstan precipitation was observed in the amount of less than 30 % of the norm with minimum values in the Abai region (MS Shalabai – 2 % of the norm) and in the East Kazakhstan region (MS Shemonaiha – 6 % of the norm). Zones with a lack of moisture occupied areas from the northern border of the Karaganda region (at least 15 % of the norm), covering the Balkash lake region region (at least 29 % of the norm), the Alakol district of the Zhetysu region (at least 23 % of the norm) and some areas of the Almaty and Zhambyl regions in the range from 42 to 58 % of the norm. In most of the Kyzylorda and Ulytau regions, as well as in the east of the Aktobe region, the precipitation observed was insignificant and varied from 21 to 77 % of the norm. The minimum layer of precipitation fell on MS Shalabay in the Abai region – 0.9 mm. According to 19 weather stations, the humidification conditions were characterized as extremely dry (Figure 3.3).

In summer, the average amount of precipitation in the territory was 78 % of the norm with a probability of non-exceedence 13 % (rank – 71, i.e. the tenth "dry" summer since 1947, Table 3.1). In most of the country there was a shortage of precipitation, less than 80 % of the norm (Figure 3.2). Precipitation was less than normal in all regions, the driest zones (less than 20 %

of the norm) were in Mangistau (only 9 % of the norm), in the north of Aktobe (15 % of the norm), Kyzylorda (15-18 % of the norm) and Turkestan (12-15 % of the norm) regions. On MS Narynkol (Almaty region) a new record of the minimum seasonal precipitation was set – 82.7 mm, the previous value was in 1976 – 102.1 mm. At 13 meteorological stations located in different parts of the country, humidification conditions were characterized as extremely "dry" (5 % extremes were noted). Excess precipitation was observed only in some places in the western (136,276 % of the norm), southern (130, 274 % of the norm) and northern (128,156 % of the norm) parts of the country.

A significant deficit of monthly precipitation amounts persisted in most regions throughout the summer months, and taking into account April and May – for 5 consecutive months (Table 3.2, Figure 3.3). This is primarily Mangystau and all the southern regions, most of the territory of the northern and central regions.

In June, a significant shortage of precipitation was observed in most of the territory of Kazakhstan, the average amount of precipitation in the country was 77.2 % of the norm. It was record dry in the Mangystau region. A significant shortage of precipitation was noted in Ulytau and Kyzylorda regions, on average, the amount of precipitation in the territory was 14.4 % normal and 7.7 % normal (5 % extremes) accordingly. In the West Kazakhstan and Karaganda regions, the month entered the 10 % of the driest June (Table 3.2). Precipitation of less than 80 % of the norm was observed in the far north, in some areas of the eastern regions and in mountainous and foothill areas of the republic. In Zhetysu, Almaty, Zhambyl and Turkestan regions, the predominance of deficit over excess precipitation is noticeable. In the central part of the country, in the western regions, as well as in the Kyzylorda region, there was a widespread shortage of precipitation, less than 40 % of the norm. At 11 meteorological stations located mainly in Mangistau, Kyzylorda and Ulytau regions, precipitation was absent throughout the month. At 23 MS, located in different regions of the country, precipitation values entered the gradation of 5 % extremes, and characterize the humidification conditions as extremely "dry" (Figure 3.3). In some areas of the northern, eastern and southern regions, as well as in places along the northern borders of western Kazakhstan, the amount of precipitation was about normal, in some places above the norm from 130 to 240 % of the norm.

In July, the average amount of precipitation in Kazakhstan amounted to 95.9 % of the norm or 1.4 mm below the long-term average, but the distribution of precipitation across the territory was uneven (Table 3.2). In the western half of the country (with the exception of some areas where precipitation was 7-43 % of the norm), as well as in some areas of the central and northern regions, excessive precipitation prevailed, precipitation exceeded the norm by 1.5-3.4 times (Figure 3.3). The maximum excess of precipitation was observed in the south-west of the Mangystau region (Aktau MS), where the monthly precipitation amounted to 992 % of the norm (or 61.5 mm) – this is a record amount of precipitation, the previous record was set in 2021 (52.2 mm). According to the data of 9 meteorological stations in July, the humidification conditions were characterized as extremely humid – 5 % extremes were noted. In July, in most regions of the southern half of the territory of the republic, including the east, northeast, Kostanay, Ulytau regions and some areas of the Karaganda region, precipitation was less than 60 % of the norm. In Turkestan and Zhambyl, in the north of Aktobe and north-west of Mangistau regions, precipitation fell less than 10 % of the norm, at 9 meteorological stations in these areas precipitation was absent throughout the month. At 12 meteorological stations located mainly in the south of the country, it was extremely dry (5 % or 10 % extremes).

In August, a shortage of precipitation prevailed in most of the country, the average amount of precipitation on the territory of Kazakhstan was 54.8 % of the norm (August was among the 10 driest months since 1941, Table 3.2). A catastrophic situation with a shortage of precipitation is observed in many regions in the western half of Kazakhstan, where there was either no precipitation in August (by about 20 weather stations), or less than 10-20 % of the norm fell (Figure 3.3). Many regions of the eastern, southeastern parts, mountainous and foothill areas, in some parts of the central region and in the northern region, precipitation was less than 40 % normal, in some places less than 10 % normal. According to data from more than 40 weather stations, August 2022 was extremely dry (5 % or 10 % extremes), precipitation was not observed at 22 meteorological stations located in the western, eastern and southern regions for a whole month. A record minimum value of precipitation (13.40 mm) was set at MS Katon Karagai (East Kazakhstan region), the previous record was recorded in 1945 – 13.93 mm. Excess precipitation (more than 120 % of the norm) was observed in several southern regions, in the western Baltic region, in the south of the Aktobe region, in some areas of central and northeastern Kazakhstan. A record amount of 48.8 mm of precipitation fell on MS Tasty (Turkestan region), which amounted to 1251 % of the norm (Annex 1).

In autumn, the average precipitation layer on the territory of Kazakhstan amounted to 112 % of the norm (rank – 17 with a probability of non-exceedence 80 %, Table 3.1). Excessive precipitation (Figure 3.2) was observed in the northern regions of 121,190 % of the norm, in the western part of the country – 132,198 % of the norm, in the southern and southeastern regions – 130-277 % of the norm. According to sixteen meteorological stations located in the western, southern and northern regions, humidification conditions were characterized as extremely humid. Larger zones of significant precipitation deficit, with precipitation less than 80 % of the norm, were located in the east and northeast of the country, in its central part, in the south of Kostanay region, in Kyzylorda and Mangistau regions, small pockets of precipitation deficit were also observed in different parts of the country. A new minimum of seasonal precipitation was set at MS Besoba in the Karaganda region – 17.6 mm, the previous minimum was 19.20 mm in 1966.

In September, a significant shortage of precipitation prevailed in most of the country. The average amount of precipitation on the territory of Kazakhstan was 52.5 % of the norm (rank 75 with a probability of non-exceedence 8 %, Table 3.2). It was record dry in the Turkestan region, there was no precipitation throughout the entire month. A significant shortage of precipitation was noted in Zhambyl and Karaganda regions, on average, the amount of precipitation in the territory was 1.9 % normal and 14.1 % normal (5 % extremes) accordingly. In Almaty region, humidification conditions in September were in 10 % of the driest months (Table 3.2). The entire southern part of the country, most of the western regions, the central and eastern regions of Kazakhstan and almost all the northern regions of the country were in the zone of acute shortage. In the southern regions of Kazakhstan, precipitation was much less than normal, no precipitation was observed at more than 30 meteorological stations throughout the month. At 28 weather stations, humidification conditions were characterized as extremely dry, here precipitation was 20 % less than normal (10 % extremes). Excess precipitation, more than 120 % of the norm, was observed in the West Kazakhstan region and in several districts in the north and far east of the country (Figure 3.3).

In October, the average amount of precipitation on the territory of the republic was 89.8 % of the norm (rank 36, Table 3.2). According to Figure 3.3, it can be seen that most of the country was in a precipitation deficit zone. It was very dry in the Kyzylorda region, where the amount of precipitation was only 17.1 % of the norm (the probability of non-exceedence 9 %). Zones with precipitation of less than 70 % of the norm (in some places less than 40 and even 20 %

of the norm) covered the entire eastern and central Kazakhstan, the north-eastern and far north of the country, Almaty, Zhetysu and Kyzylorda regions, most of Aktobe and some areas of Atyrau and Mangystau regions. Excess precipitation was observed in the south in Turkestan (up to 389 % of the norm) and Zhambyl (up to 201 % of the norm) regions, in West Kazakhstan region (up to 319 % of the norm), in the western part of Atyrau (203 % of the norm) and Mangystau (up to 499 % of the norm) regions. It was record wet in the Mangystau region, on average, humidification in the territory amounted to 499 % of the norm, where a new maximum of monthly precipitation was set at the Fort Shevchenko weather station: 58.4 mm (the previous maximum was 31.5 mm in 1979, Annex 1). Also, small areas of precipitation exceeding the norm can be noticed in some northern regions – 120-180 % of the norm. According to 10 meteorological stations located in the north, south, and west of the country, it was extremely humid, 5 % or 10 % extremes were recorded.

November was extremely humid – the average amount of precipitation in the country was 175.4 % of the norm (rank 2, the probability of non-exceedance 98 %). Almost the entire territory of Kazakhstan was in the zone of excessive precipitation (120,200 % of the norm), with the exception of several districts of western Kazakhstan. A record amount of precipitation fell in Almaty region (260.2 % of the norm (or 91.59 mm), rank 1), the previous maximum was 85.03 mm in 2003. It was extremely humid in the North Kazakhstan, Akmola, Kostanay and Zhetysu regions (5 % extremes). According to 43 weather stations, the above–listed areas, humidification conditions were characterized as extremely humid - 5 % extremes were noted. Records of the maximum monthly precipitation were set at 11 meteorological stations (Annex 1). It was dry in most of Atyrau and the western part of West Kazakhstan regions, at many meteorological stations in these areas precipitation fell less than 60 % of the norm.

To assess the extremes of precipitation in 2022, climate change indices proposed by the World Meteorological Organization were evaluated. Below is an analysis of some of the most significant precipitation indices and the distribution of their values across the territory of Kazakhstan in 2022.

Figure 3.4 shows the values of absolute maxima of daily precipitation recorded from the beginning of the opening of the weather station to 2022 (shown in blue). The values of daily precipitation maxima that exceeded the previous absolute maximum in 2022 are highlighted in red. In 2022, the value of the absolute maximum was exceeded at one meteorological station in Kazakhstan: 58.8 mm fell on MS Kogaly per day, the previous maximum was in 2010 and was 51.3 mm.

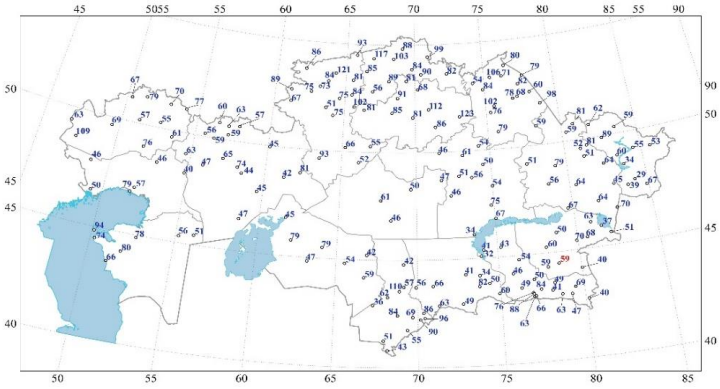


Figure 3.4 – The absolute maximum of daily precipitation (mm), selected for the period from the beginning of the opening of the weather station to 2022. If the record daily precipitation is recorded in 2022, the value is marked in red

The daily maximum of precipitation, selected according to data for 2022 (index Rx 1 day), was 10-20 mm in most of the territory of Kazakhstan (Figure 3.5). The maximum daily precipitation was observed in the north-west, north-east and in the foothill and mountainous areas of the south was more than 40 mm in places, in the northern regions and in the foothill and mountainous areas of the south-east – more than 50-60 mm.

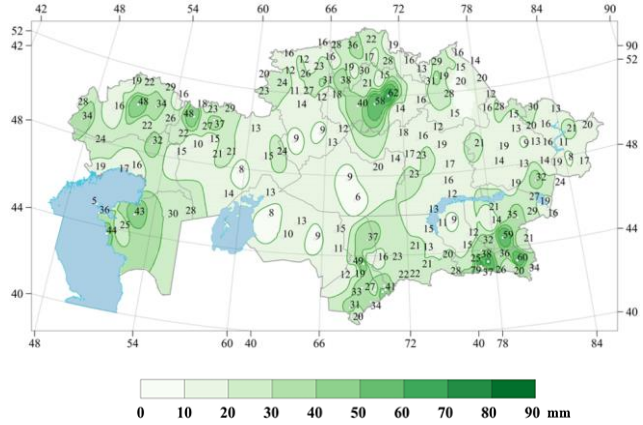


Figure 3.5 – Daily maximum precipitation in 2022 (Rx1day index)

In 2022, ***the share of very heavy precipitation*** (when the daily precipitation is equal to or greater than the 95th percentile, the r95ptot index) in the annual precipitation in most of the territory of Kazakhstan was less than 20 % (Figure 3.6). The largest contribution of very heavy precipitation (more than 40-50 %) was noted in the Mangystau region, as well as in places in the north West Kazakhstan, Aktobe, Kostanay and Akmola regions. In various regions of Kazakhstan, the daily precipitation did not reach the 95th percentile.

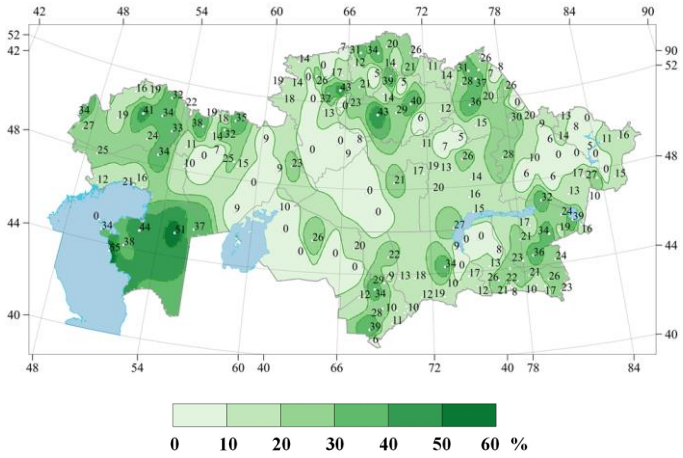


Figure 3.6 – The share (in %) of extreme daily precipitation in the annual precipitation amount for 2022 (*r95ptot index*)

In the conditions of the arid climate of Kazakhstan, the CDD index is very important, which shows the ***maximum duration of the rainless period*** when the daily precipitation was less than 1 mm. In 2022, in most of the territory of the republic, the maximum continuous duration of the rainless period was 20-60 days. The longest duration of the rainless period was observed in the Kyzylorda and Turkestan regions – more than 100 days (Figure 3.7). In the Kyzylorda region, the maximum duration of the rainless period is recorded on MS Kazaly (116 days without precipitation), in the Turkestan region – on MS Sholakkorgan (130 days without precipitation). The shortest duration of the rainless period (21 days) was noted at MS Shaldai in the Pavlodar region.

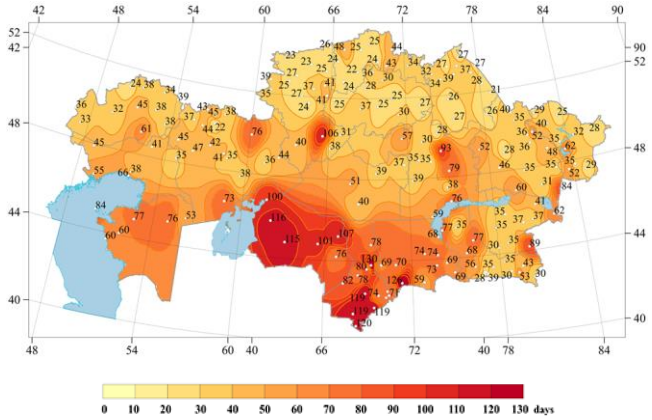


Figure 3.7 – Maximum duration of the idle period in 2022, day (CDD index)

3.2 Observed changes in precipitation

Linear trends in the series of monthly, seasonal and annual amounts of atmospheric precipitation were estimated according to the data of the 121st station.

The time series of anomalies of annual and seasonal precipitation totals for the period 1941-2022, calculated relative to the base period of 1961 – 1990 and spatially averaged over the territory of Kazakhstan and regions give a general idea of the nature of modern changes in the precipitation regime (Table 3.3, Figures 3.8 and 3.9). The annual precipitation on average in Kazakhstan decreased in the 1960s and 1970s, in the last 40-year period there were no long-period trends, there was an alternation of short periods with positive and negative anomalies in the amount of precipitation.

In the period 1976-2022, trends in the average annual and seasonal precipitation amounts in Kazakhstan are practically absent – the share of the trend component in the total variance of the series does not exceed 3 %, a positive trend sign for winter, spring and annual precipitation amounts, for summer and autumn – negative (Table 3.3, Figure 3.8).

In most areas, the trends towards both an increase and a decrease in annual precipitation are insignificant, the coefficient of determination is 3 % or less. In the Akmola region, the rate of increase in precipitation was about 3 % of the norm / 10 years with a determination coefficient of 5 %. In the Kyzylorda and Mangystau regions, precipitation decreased at a rate of 4.7 and 6 % of normal/10 years, respectively, with a determination coefficient of 6 % (Table 3.3, Figure 3.9). On average in Kazakhstan in the period 1976 – 2022. there is a slight tendency to increase the annual amount of precipitation by 0.2 % of the norm /10 years (Table 3.3).

Table 3.3 – Characteristics of the linear trend of the anomaly of seasonal and annual precipitation amounts (% norm/10 years) averaged over the territory of Kazakhstan and its regions for the period 1976-2022.

Region/region	Year		Winter		Spring		Summer		Autumn	
	a	**D**	**a**	**D**	**a**	**D**	**a**	**D**	**a**	**D**
Kazakhstan	0,2	0	0,8	0	2,9	3	-0,2	0	-2,2	2
Abai	0,9	1	0,1	0	0,6	0	3,8	3	-1,1	0
Almaty	0,5	0	2,6	1	0,9	0	-0,5	0	0,5	0
Akmola	3,1	5	**8,6**	**10**	2,2	1	2,8	1	1,3	0
Aktobe	-2,1	2	-1,7	1	5,6	3	-5,4	3	**-6,0**	**8**
Atyrau	2,3	2	7,2	5	**18,4**	**14**	-7,9	3	-5,3	3
East Kazakhstan	0,3	0	1,2	0	1,5	0	0,2	0	-0,8	0
Zhambyl	-1,4	1	-0,8	0	-0,6	0	1,8	2	-3,7	2
Zhetysu	1,2	1	4,8	3	3,1	2	-0,3	1	-1,9	1
West Kazakhstan	-0,9	0	-3,3	3	**11,4**	**14**	-6,2	1	-2,2	1
Karaganda	0,1	0	0,1	0	-0,7	0	4,2	4	-4,5	4
Kostanay	-1,0	1	-0,6	0	**7,3**	**8**	-3,0	6	-4,8	6
Kyzylorda	-4,7	6	-0,4	0	-2,0	0	**-6,5**	**16**	**-12,2**	**16**
Mangystau 1	-6,0	6	6,7	3	**-12,9**	**10**	-4,8	2	-5,6	2
Pavlodar	1,2	1	0,9	0	3,8	2	1,3	0	0,1	0
North Kazakhstan	1,8	2	3,1	1	**9,4**	**12**	0,1	0	-1,4	0
Turkestan	0,4	0	0,1	0	2,3	1	0,8	0	-1,8	0
Ulytau	0,3	0	-3,5	3	3,1	1	3,8	1	-2,2	1

* a – linear trend coefficient, %norm/10 years;
** D – coefficient of determination, %;
*** statistically significant trends are highlighted in bold.

In winter, on average, precipitation in Kazakhstan increased slightly – by 0.8 % of the norm/10 years. The most significant trends towards an increase in precipitation are in the Akmola region – 8.6 % of the norm/10 years (the coefficient of determination is 10 %), Atyrau – by 7.2 % of the norm/10 years (the coefficient of determination is 5 %) and Mangystau regions – by 6.7 % of the norm/10 years (the coefficient of determination is 3 %) (Table 3.3, figure 3.9). The tendency to increase precipitation in the Akmola region is statistically significant. A noticeable decrease in the amount of precipitation on average in the territory is observed in the West Kazakhstan and Ulytau regions - by 3.3 and 3.5 % of the norm / 10 years, respectively (the coefficients of determination are 3 %).

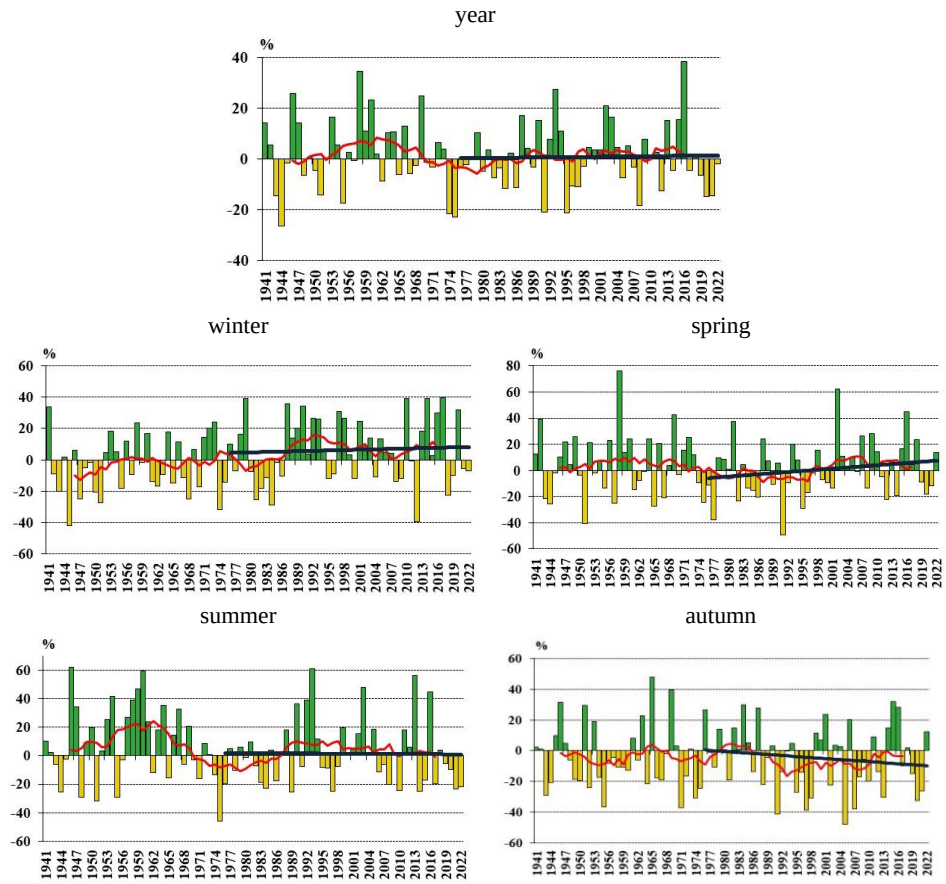


Figure 3.8 – Time series of anomalies of annual and seasonal precipitation amounts (%) spatially averaged over the territory of Kazakhstan for the period 1941 – 2022. Anomalies are calculated relative to the base period of 1961 – 1990. The linear trend for the period 1976 – 2022 is highlighted in black. The smoothed curve is obtained by an 11-year moving average.

In spring, Kazakhstan's average precipitation of the spring period increased slightly – by 2.9 % of the norm every 10 years. On the territory of most regions, precipitation trends are positive, but also insignificant. In the West Kazakhstan and Atyrau regions of the western region,

in the Kostanay and North Kazakhstan regions of the northern region of the republic, precipitation increased at the highest rate – by 7.3 18.4 % of the norm /10 years with a determination coefficient of 8-14 % (Table 3.3, Figure 3.9). These trends are statistically significant. The greatest contribution to the increase in precipitation of the spring season falls on the month of March, when stable statistically significant trends are observed almost throughout the territory of Kazakhstan. A noticeable statistically significant trend towards a decrease in precipitation is observed in the Mangystau region – by 12.9 % of the norm / 10 years with a determination coefficient of 10 %.

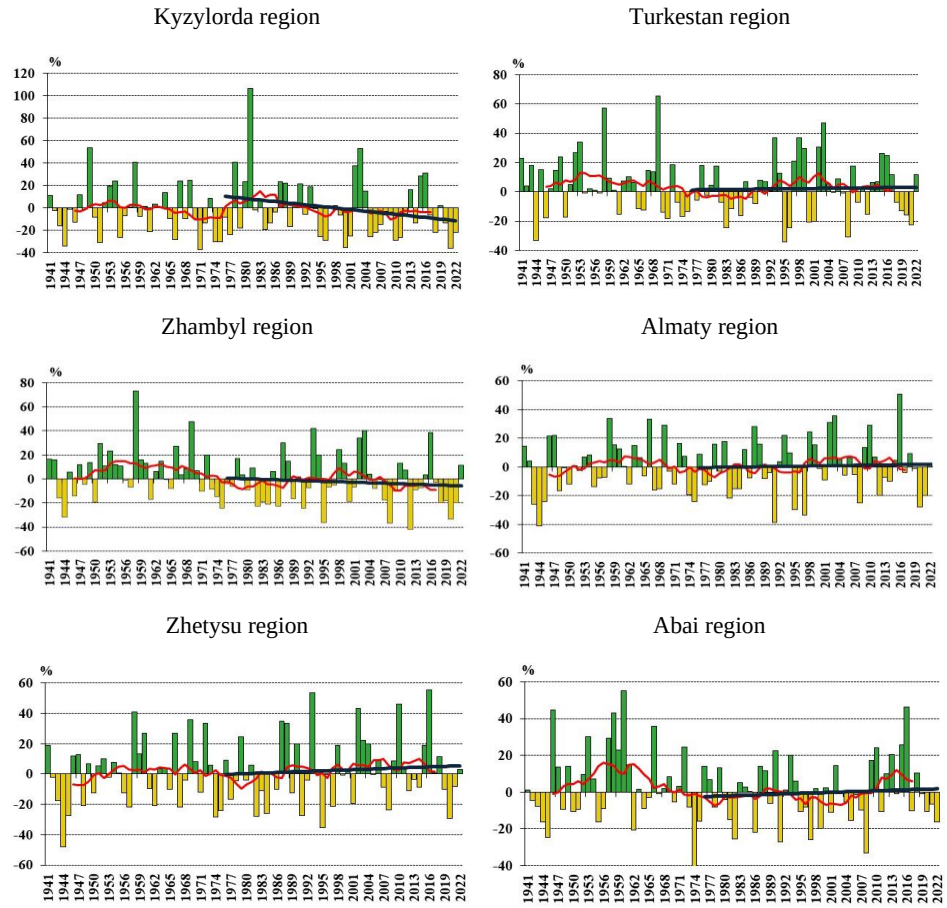


Figure 3.9 – Time series of anomalies of annual precipitation amounts (%) for the period 1941-2022, spatially averaged across the regions of Kazakhstan. Anomalies are calculated relative to the base period of 1961 – 1990. The linear trend for the period 1976 – 2022 is highlighted in black. *The smoothed curve is obtained by an 11-year moving average. Sheet 1*

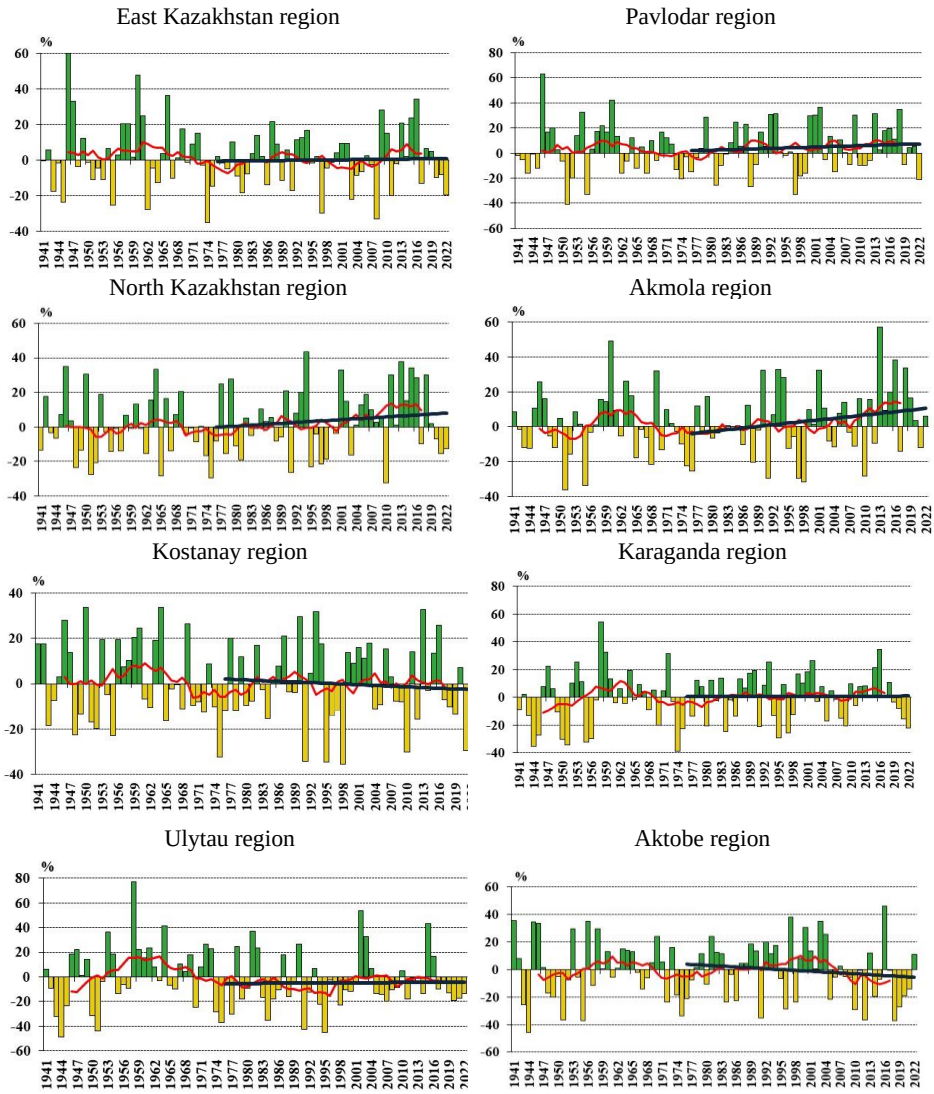


Figure 3.9 – Time series of anomalies of annual precipitation amounts (%) for the period 1941-2022, spatially averaged across the regions of Kazakhstan. Anomalies are calculated relative to the base period of 1961 – 1990. The linear trend for the period 1976 – 2022 is highlighted in black. *The smoothed curve is obtained by an 11-year moving average. Sheet 2*

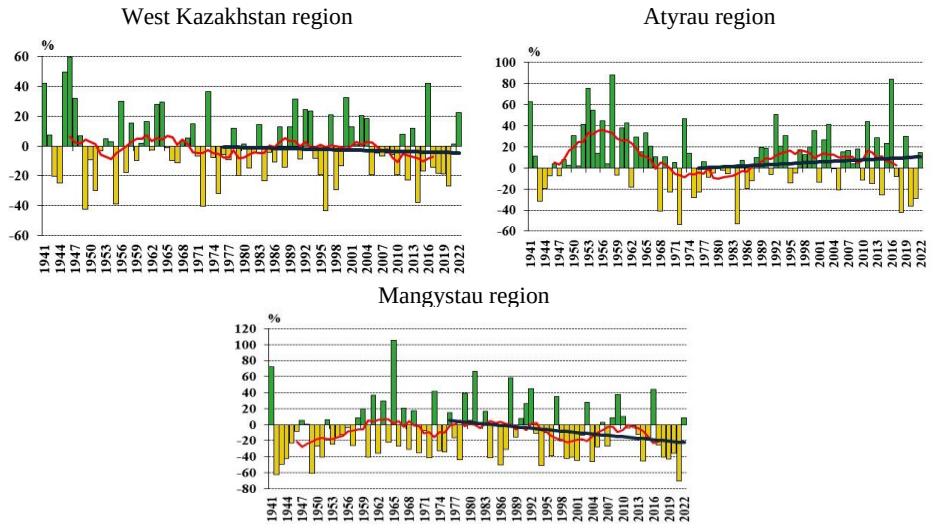


Figure 3.9 – Time series of anomalies of annual precipitation amounts (%) for the period 1941-2022, spatially averaged across the regions of Kazakhstan. Anomalies are calculated relative to the base period of 1961 – 1990. The linear trend for the period 1976 – 2022 is highlighted in black. *The smoothed curve is obtained by an 11-year moving average. Sheet 3*

In summer, there were practically no trends in the amount of seasonal precipitation in all regions of Kazakhstan, since the contribution of the trend to the overall variance was insignificant and did not exceed 4 %. The most significant trends in decreasing precipitation are in Atyrau – by 7.9 % of the norm / 10 years (the coefficient of determination is 3 %), Kyzylorda – 6.5 % of the norm/10 years (the coefficients of determination is 16 %), West Kazakhstan - by 6.2 % of the norm/10 years (the coefficient of determination is 1 %), Aktobe – by 5.4 % of the norm/10 years (the coefficient of determination is 3 %) and Mangystau regions – by 4.8 % of the norm/10 years (the coefficient of determination is 2 %). Only in the Kyzylorda region the tendency to decrease in precipitation is statistically significant (Table 3.3, Figure 3.9).

In autumn, the trends in precipitation over the autumn season are negative in most regions. The most significant rates of precipitation decrease are observed in Aktobe and Kyzylorda regions – by 6.0 and 12.2 % of the norm/10 years, respectively, with a determination coefficient of 8 and 16 %, respectively. The trends of decreasing precipitation in these areas are statistically significant (Table 3.3, Figure 3.9).

More detailed information about the nature of changes in the precipitation regime in Kazakhstan is provided by the spatial distribution of the values of the linear trend coefficient of annual, seasonal and separately for each month precipitation amounts (%/10 years) presented in Figures 3.10 and 3.11. Estimates are obtained from station time series of annual, seasonal, and monthly precipitation anomalies for the period 1976-2022.

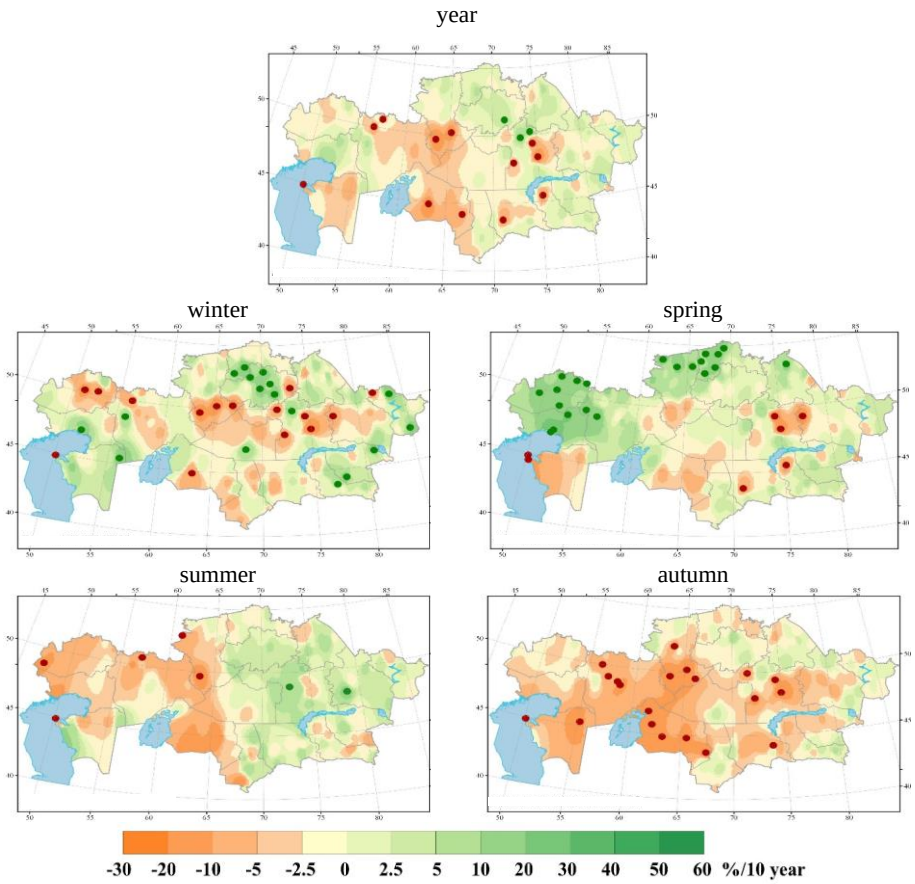
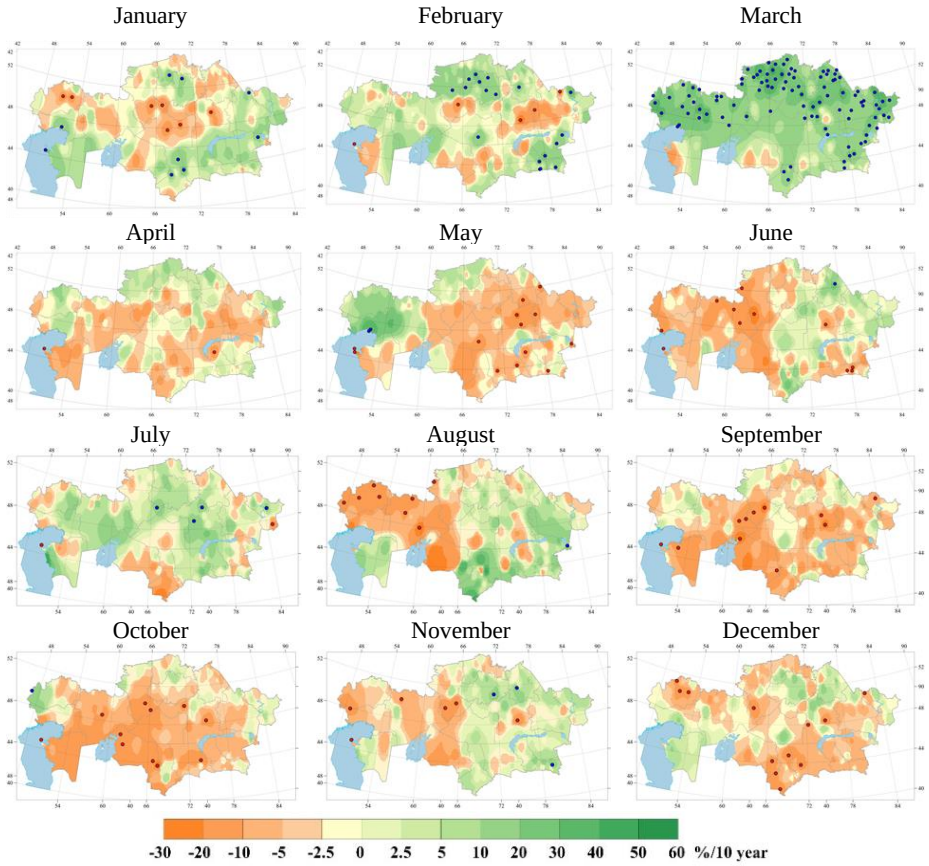


Figure 3.10 – Spatial distribution of values of the linear trend coefficient of annual and seasonal precipitation amounts (%/10 years) calculated for the period 1976–2022.

On the territory of the republic, there is a spotting in the direction of changes in seasonal and monthly precipitation (Figures 3.10 and 3.11). **In winter**, a significant increase in precipitation was recorded in several regions – in the north (mainly in the Akmola region), south-west, south-east and east (by 7-17 % of the norm / 10 years). The main contribution to this increase was made by February (Figure 3.11). A statistically significant trend towards a decrease in seasonal precipitation is observed in the northwestern and central regions, in the south of the Kyzylorda region and is within 7-12 %/10 years.

In December, precipitation decreasing trends were observed in the northern and northwestern parts, in the eastern part of central Kazakhstan and in the southern and southeastern half of Kazakhstan (Figure 3.11). Significant precipitation decreasing trends were observed at some meteorological stations in the north of West Kazakhstan region and south of Kostanay region

(by 10-15 % norms/10 years), in the central and eastern region (by 9-17 % norms/10 years), in the southern region (by 12-17 % norms/10 years).



significant positive and negative values of the linear trend coefficient are highlighted in blue and red

Figure 3.11 – Spatial distribution of values of the linear trend coefficient of monthly precipitation (%/10 years) calculated for the period 1976–2022.

In January, precipitation decreasing trends are observed in the north of the western region, in the central region, in the northeast, in some small pockets in the north and in the mountainous regions of the south, southeast and east (Figure 3.11). Statistically significant precipitation decreasing trends are observed at some stations in the central and western part of the country in within 10-15 %/10 years. The tendency to increase precipitation is observed in some areas of the north (by 15-17 %/10 years), in the eastern part of the country (9 %/10 years), in the south and southeast (13-21 % /10 years), as well as in the Caspian region (by 20-33 %/10 years).

In February, an increase in precipitation is observed almost throughout Kazakhstan, but several large foci are recorded, where there is a tendency to decrease precipitation:

in the southern region – the western part of the Mangystau region, the southern part of the Kyzylorda, the northern part of the Turkestan and Zhambyl regions, as well as the southern Baltic region; in the central region – the southern part of the Kostanay region and the area of the Kazakh Uplands. A statistically significant trend towards an increase in monthly precipitation is observed in the northern and southeastern regions, also in places in the northeastern, eastern, and central parts of the country within 14-25 %/10 years. Zones with statistically significant trends in precipitation decrease are observed at some stations located in the Kazakh Uplands, in the north in East Kazakhstan, south Kostanay and west Mangystau regions – 12-23 % of the norm for every 10 years (Figure 3.11).

In spring, a steady statistically significant increase in the amount of seasonal precipitation is observed in the western (by 10-26 % of the norm /10 years) and northern (by 8-14 % of the norm/10 years) regions of the country. There are no statistically significant trends in the southern half of Kazakhstan, with the exception of small areas where precipitation decreases significantly (Figure 3.10). Among the spring months, March stands out, when a statistically significant increase in monthly precipitation amounts is recorded in most of the territory of Kazakhstan: in the northern (by 16.45 % of the norm /10 years), western (by 13.37 % ofthe norm/10 years), in the southern, mainly the south of Turkestan, Almaty and Zhetysu regions, by 9-24 % of the norm /10 years, central and eastern (by 14-35 % of the norm /10 years) regions of the country (Figure 3.11).

In April, a tendency to decrease monthly precipitation amounts prevails in Kazakhstan, two large foci are observed – one focus is located in the direction from southwest to northeast, trends in this zone are statistically insignificant, except for the value on MS Kulaly Island, where precipitation decreases by 35.6 % of the norm/10 years; the second focus, covers part of the southern, central regions, the regions of the Baltic and Alakol, as well as the Abai region, there are also no stable trends in this focus, with the exception of MS Aul-4, where the rate of precipitation decrease is 15 % normal/10 years. Zones of increased precipitation were observed to the north of the Caspian Sea, capturing the West Kazakhstan region, in the northern and northeastern regions, in some areas of the central part of the country, as well as foothill areas of the southeast and east of the country. There are no statistically significant trends towards an increase in precipitation.

In May, in most of the eastern half and the south-west of the country, there is a tendency to decrease the amount of precipitation. According to the data of 6 meteorological stations located in the northeastern, eastern, and central parts of the country, as well as 5 meteorological stations in the southern regions and 2 meteorological stations in the Mangystau region, the trends towards a decrease in monthly precipitation are statistically significant. The tendency to increase the amount of precipitation is observed in several regions – in the north-west, west and some areas in the south of Kazakhstan. Statistically significant trends in increasing precipitation are observed at some stations of the coastal part of the Caspian lowland within 35-42 % of the norm/10 years.

In summer, the western half of the republic's territory is in the zone of precipitation decrease, the eastern half is in the zone of increase, but the trends of both signs are rarely statistically significant (Figure 3.10).

In June, most of the western half of Kazakhstan, the central part of the Kazakh Uplands and the southeastern region are in the zone of decreasing precipitation (Figure 3.11). Statistically significant trends in decreasing monthly precipitation are observed at 11 meteorological stations located in the Caspian region, in the eastern part of Aktobe and western parts of Kostanay regions, in the center of Karaganda regions and in mountainous and foothill areas of the south-east.

Trends towards an increase in precipitation are observed in most of the eastern half of Kazakhstan, but statistically significant trends of a significant increase in precipitation are observed only in MS Krasnoarmeyka (Pavlodar region) by 21 % of the norm/10 years.

In July, there are trends towards an increase in precipitation in most of the country (Figure 3.11), but there are small pockets in different parts of the country where a decrease in precipitation is recorded. The most significant trends towards an increase in precipitation are observed in the central region of Kazakhstan – 13-19 % of the norm/10 years (the coefficient of determination is 3-4 %), and in the east – 11-15 % of the norm/10 years (the coefficient of determination is 2-4 %). At the same time, statistically significant trends in increasing precipitation are observed only at 4 meteorological stations in these regions. A noticeable decrease in precipitation on the territory of Kazakhstan is observed in the south of the country – by 8,27 % of the norm/10 years (the coefficient of determination is 1-3 %), in the Ulytau region – by 1,6 % of the norm/10 years, in places in the western, northern and eastern regions. There are no statistically significant trends in decreasing precipitation on the territory of Kazakhstan, except for two stations: MS Zaisan (12 % norm/10 years, determination coefficient 5 %) and MS Kulaly Island (25 % norm/10 years, determination coefficient 6 %).

In August, precipitation trends were observed everywhere in the western half of the country (except for the Mangystau region). Statistically significant precipitation decreasing trends were recorded only at seven meteorological stations located in the northern part of West Kazakhstan, Aktobe and Kostanay regions and amounted to 11-22 % of the norm/10 years (determination coefficient 4-7 %) (Figure 3.11). Trends towards an increase in precipitation are observed in the Mangystau region (by 4-16 % of the norm/10 years), in most of the eastern half of Kazakhstan (by 321 % of the norm/10 years), trends in these zones are statistically insignificant, except for the value on the MS Zhalanashkol, where precipitation increases by 18 % of the norm/10 years.

In autumn, most of the territory was in the zone of negative trends in precipitation (Figure 3.10). Precipitation amounts for the autumn season decreased significantly according to many stations in Aktobe, the south of Kostanay, Kyzylorda regions, in places in the central and southern regions (by a maximum of 13-22 % of the norm / 10 years, the contribution to the dispersion at these stations is 21-34 %). As a result, according to most stations, these changes are statistically insignificant (Figure 3.10).

In September, a downward trend in precipitation was observed in most of the country. The most significant rates of precipitation decrease are observed in Mangistau, Aktobe, Kostanay, Kyzylorda, Zhambyl and Karaganda regions (above 10 % of the norm/10 years), but at most stations the trends are statistically insignificant. Statistically significant trends were noted only at 11 meteorological stations located in these regions, where the rate of precipitation decrease was in the range of 10-22 % of the norm /10 years, while the proportion of variance explained by the trend was 4-10 %. In some western, northern, eastern, central and southeastern regions, there was a slight tendency to increase precipitation (Figure 3.11).

In October, as well as in September, there were mainly weak trends in the territory of Kazakhstan, both in the direction of increasing and decreasing precipitation. Precipitation is decreasing in most of the territory of the republic (Figure 3.11), in some western, southern and central regions of the country there were statistically significant rates of precipitation reduction by 12-28 % of the norm/10 years, while the proportion of variance explained by the trend was 6-17 %. The most significant rates of precipitation decrease were noted on the Kulaly Island MS (Mangystau region). In some areas in the far west, north and east, there are practically no trends

towards an increase in precipitation, the share of the trend component in the total dispersion of the series is no more than 3 %. The most significant and statistically significant rate of increase in precipitation is observed in MS Zhanybek (West Kazakhstan region) by 20 % of the norm/10 years, while the proportion of the explained variance is 4 %.

In November, precipitation decreasing trends were observed in the western half of Kazakhstan and in some areas of the northwest, center and south, at most stations the trends are statistically insignificant. Statistically significant trends were observed only at 6 meteorological stations located in these regions, where the rate of precipitation decrease was in the range of 11-23 % of the norm/10 years, while the proportion of variance explained by the trend was 5-16 %. The most significant rate of precipitation reduction was observed at the Aktogay MS (Karaganda region) by 20 % of the norm/10 years, while the proportion of variance explained by the trend is 16 %. The tendency to increase precipitation was observed in most of the northern, central, eastern, and southern regions of Kazakhstan, trends in these regions at most stations are statistically insignificant, except for the values of 3 weather stations, where precipitation increases by 14-18 % of normal/10 years (Figure 3.11).

Annual precipitation amounts are significantly decreasing in some northwestern, central and southern regions (by 6-12 % of the norm/10 years) and are significantly increasing only according to several stations in the northern region (by 5-7 % of the norm/10 years).

3.3 Trends in precipitation extremes

Figure 3.12 shows the change in *the maximum duration of the waterless period when the daily precipitation was less than 1 mm* (CDD index). On the territory of Kazakhstan, there are mainly weak trends, both in the direction of decreasing and increasing the rainless period. The exception is some northern, northeastern, and central regions, where a decrease in such a period by 1-3 days/10 years is recorded.

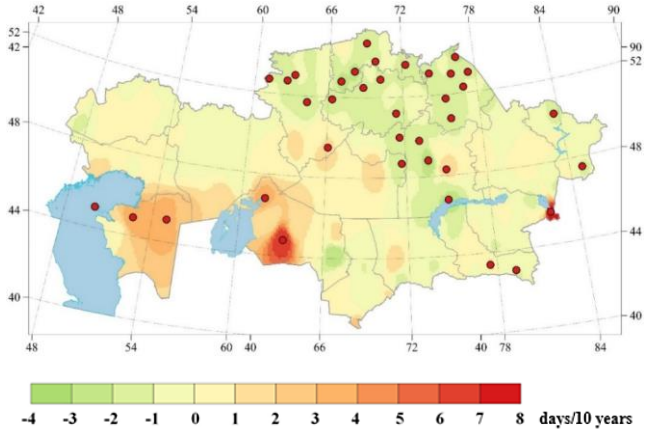


Figure 3.12 – The rate of change in the maximum duration of the idle period (days /10 years) in the period 1961 – 2022 (CDD index)

ANNEX 1

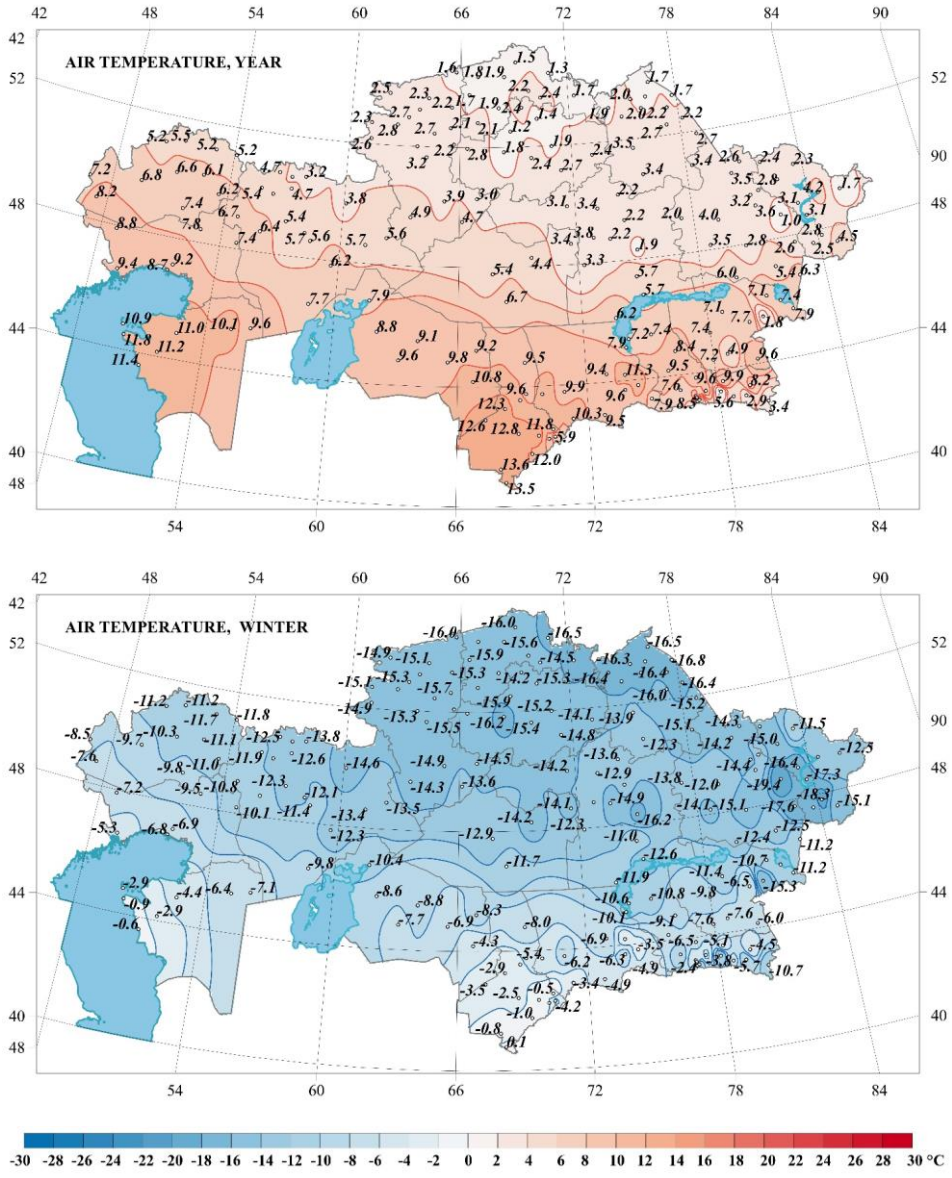
RECORD VALUES OF MONTHLY PRECIPITATION, SET IN 2022

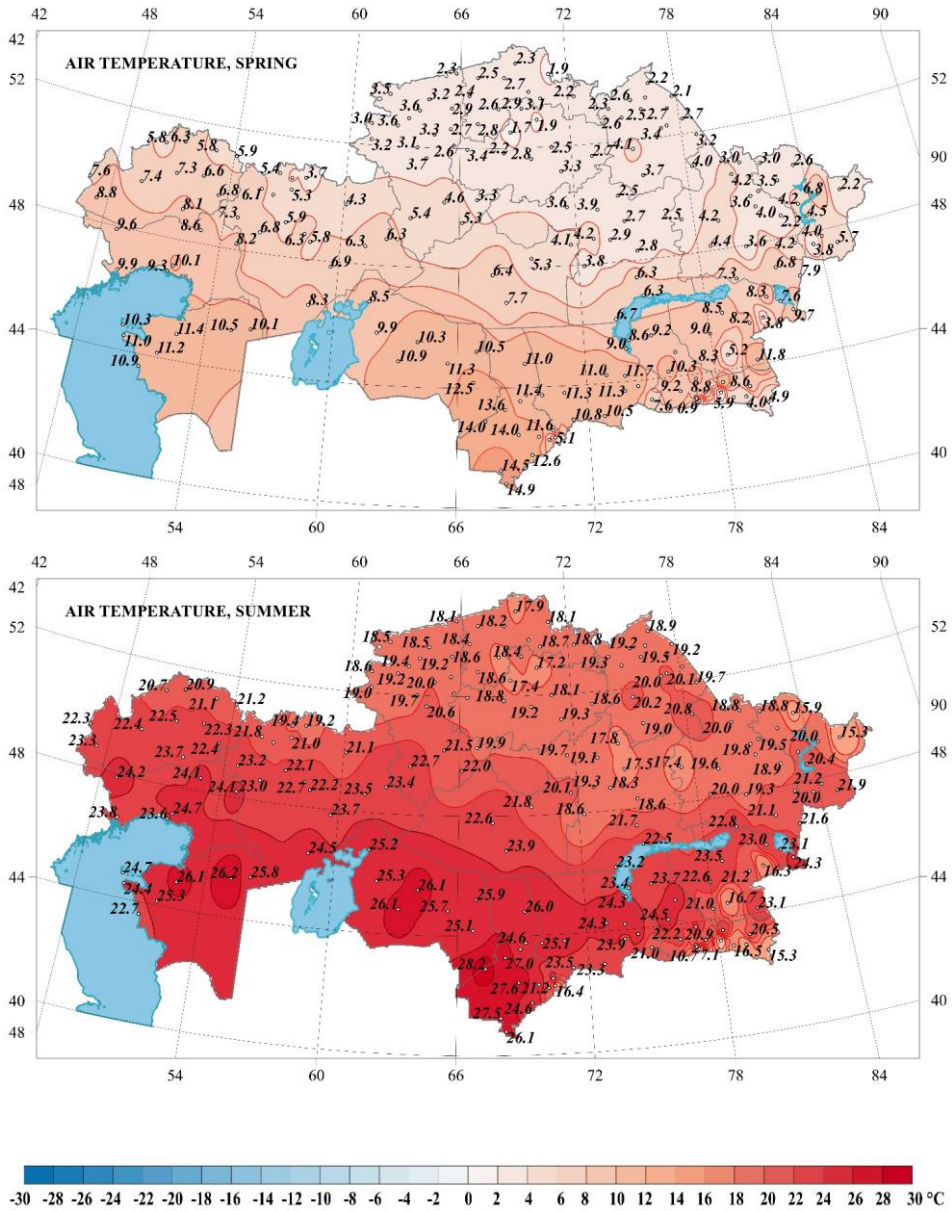
№	Name of the meteorological station	Area	Maximum amount of precipitation, mm	Previous maximum precipitation, mm	Minimum amount of precipitation, mm	Previous minimum rainfall, mm
	December, 2021					
1	Jetykonur	Ulytau	32,90	31,70 (2015)		
2	Balkash	Karaganda			1,6	1,61 (1965)
3	Bektau ata	Karaganda			2,7	2,99 (1965)
	January, 2022					
1	Karauyl	Abay	29,00	25,63 (1947)		
2	Chiganak	Zhambyl	31,20	27,40 (2014)		
3	Sholakkorgan	Turkestan	42,80	32,67 (1940)		
	March, 2022					
1	Aksengir	Almaty	85,10	77,40 (2010)		
2	Kyrgyzsay	Almaty	112,00	91,00 (2010)		
3	Almaty	Almaty	165,70	153,80 (2002)		
4	Kapshagai	Almaty	91,00	71,40 (2010)		
5	Shelek	Almaty	72,90	70,60 (2010)		
6	Aktogay	Abay	35,20	34,00 (1960)		
7	Shokpar	Zhambyl	137,50	105,62 (1959)		
8	Khantau	Zhambyl	82,30	69,66 (1964)		
9	Kulan	Zhambyl	118,60	114,48 (1955)		
10	Shardara	Turkestan	113,70	105,80 (1973)		
11	Shymkent	Turkestan	231,20	207,80 (1969)		
12	Tasaryk	Turkestan	289,70	246,30 (1969)		
13	Arys	Turkestan	107,20	105,50 (2013)		
	May, 2022					
1	Aktobe	Aktobe	93,90	80,40 (1989)		
2	Uil	Aktobe	86,90	86,24 (1958)		
3	Jambeita	West Kazakhstan	94,20	79,70 (2016)		
4	Sam	Mangystau	66,30	50,60 (1956)		
5	Leninogorsk	East Kazakhstan			10,70	15,40 (1974)
	June 2022					
1	Narynkol	Almaty			8,20	27,60 (1975)
2	Besoba	Karaganda			3,00	3,20 (1991)

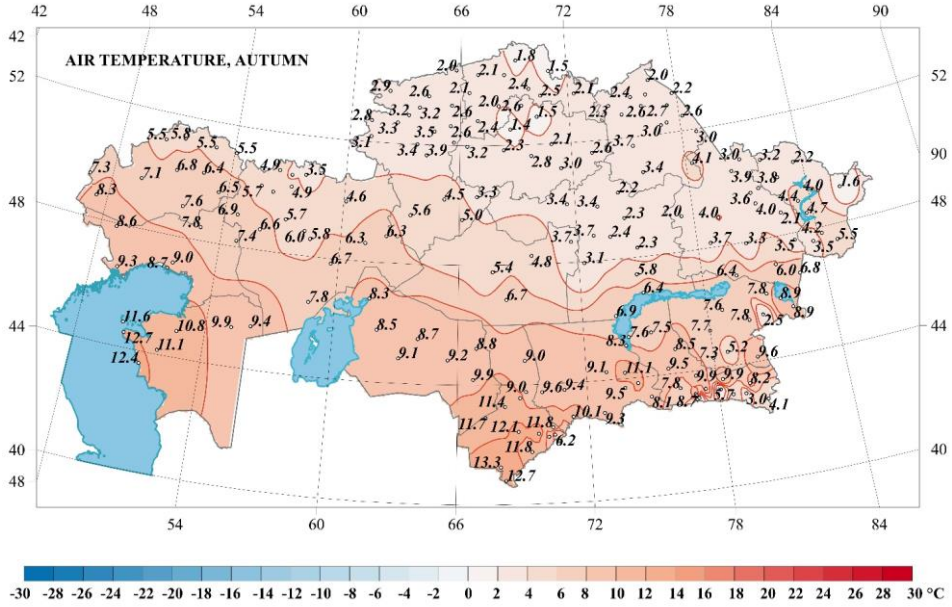
№	Name of the meteorological station	Area	Maximum amount of precipitation, mm	Previous maximum precipitation, mm	Minimum amount of precipitation, mm	Previous minimum rainfall, mm
3	Zholboldy	Pavlodar			4,60	4,80 (1988)
	July 2022					
1	Aktau	Mangystau	61,50	52,20 (2021)		
	August 2022					
1	Tasty	Turkestan	48,80	32,40 (1958)		
2	Katon-Karagai	East Kazakhstan			13,40	13,93 (1945)
	October 2022					
1	Fort Shevchenko	Mangystau	58,40	31,50 (1979)		
	November 2022					
1	Atbasar	Akmola	66,10	57,36 (1963)		
2	Esik	Almaty	180,70	162,00 (2003)		
3	Ucharal	Zhetysu	95,00	83,45 (1965)		
4	Kapshagai	Almaty	88,80	78,50 (1994)		
5	Shelek	Almaty	106,70	78,34 (1941)		
6	Tobol	Kostanay	56,50	55,60 (1965)		
7	Karamendy	Kostanay	62,20	58,30 (1941)		
8	Karabalyk	Kostanay	59,60	55,55 (1965)		
9	Zlikha	Kyzylorda	52,30	36,40 (2003)		
10	Ruzaevka	North Kazakhstan	66,90	63,43 (1963)		
11	Sholakkorgan	Turkestan	63,40	49,50 (1993)		
	December 2022					
1	Kuigan	Almaty	0,00	1,04 (1965)		

ANNEX 2

SPATIAL DISTRIBUTION OF AVERAGE ANNUAL AND SEASONAL AIR TEMPERATURES OVER THE TERRITORY OF KAZAKHSTAN, CALCULATED FOR THE PERIOD 1961-1990.

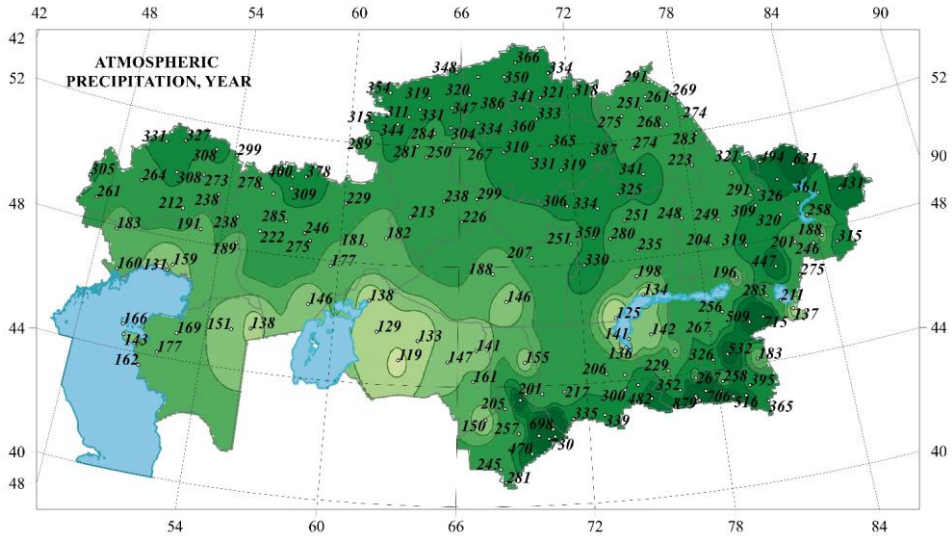


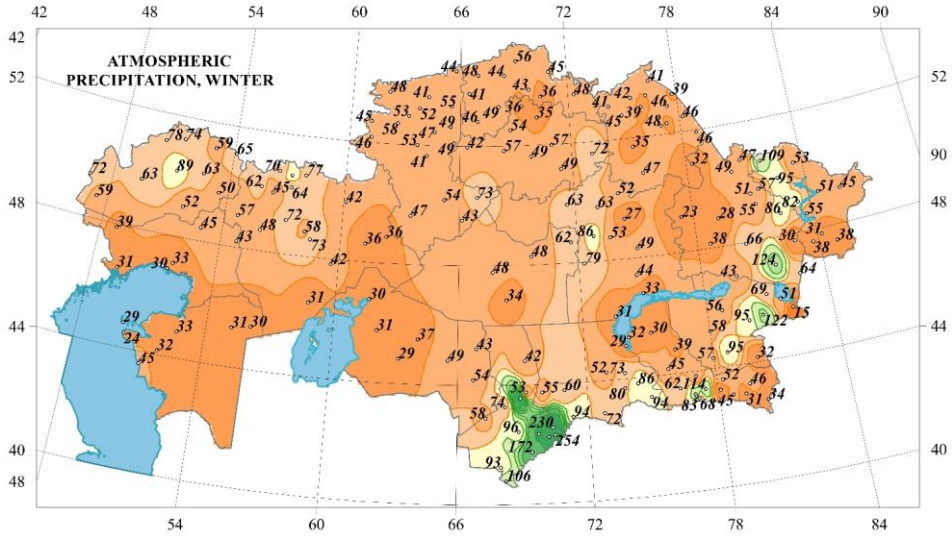

AIR TEMPERATURE, SPRING
AIR TEMPERATURE, SUMMER
-30 -28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 °C

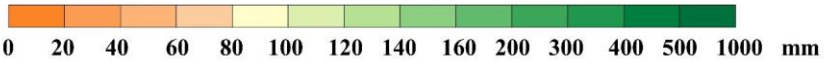

AIR TEMPERATURE, AUTUMN
42
48
54
60
66
72
78
84
90
52
44
40
-30 -28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 °C

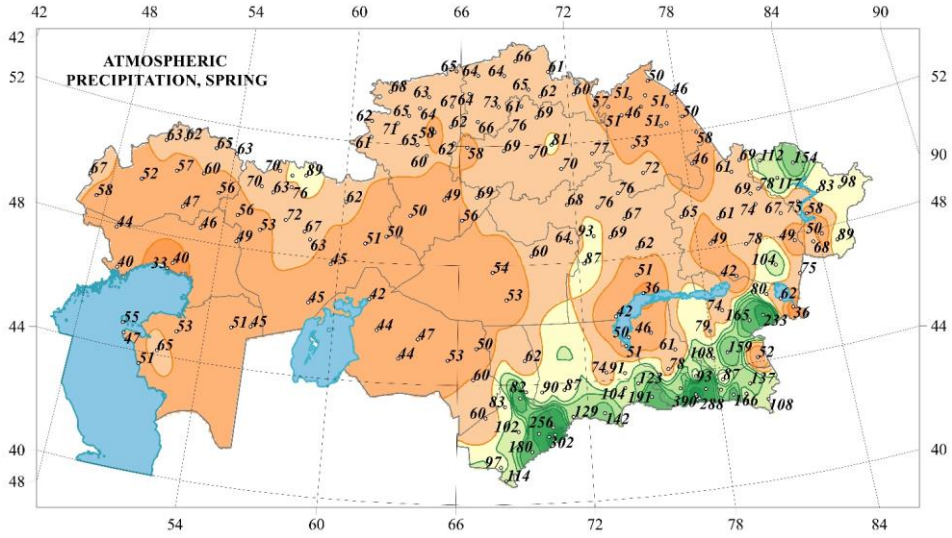
ANNEX 3

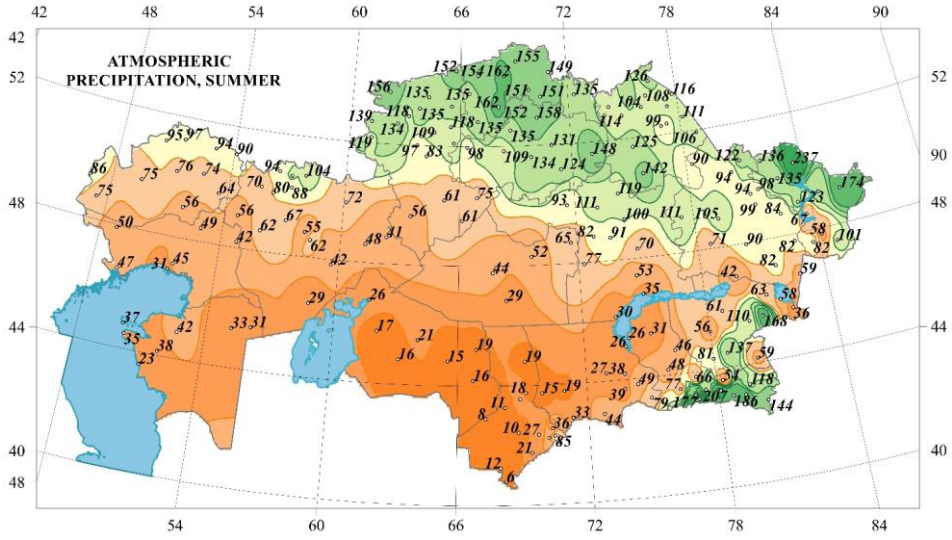
SPATIAL DISTRIBUTION OF ANNUAL AND SEASONAL PRECIPITATION AMOUNTS OVER THE TERRITORY OF KAZAKHSTAN, CALCULATED FOR THE PERIOD 1961-1990.

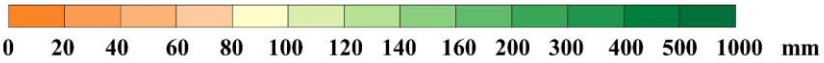


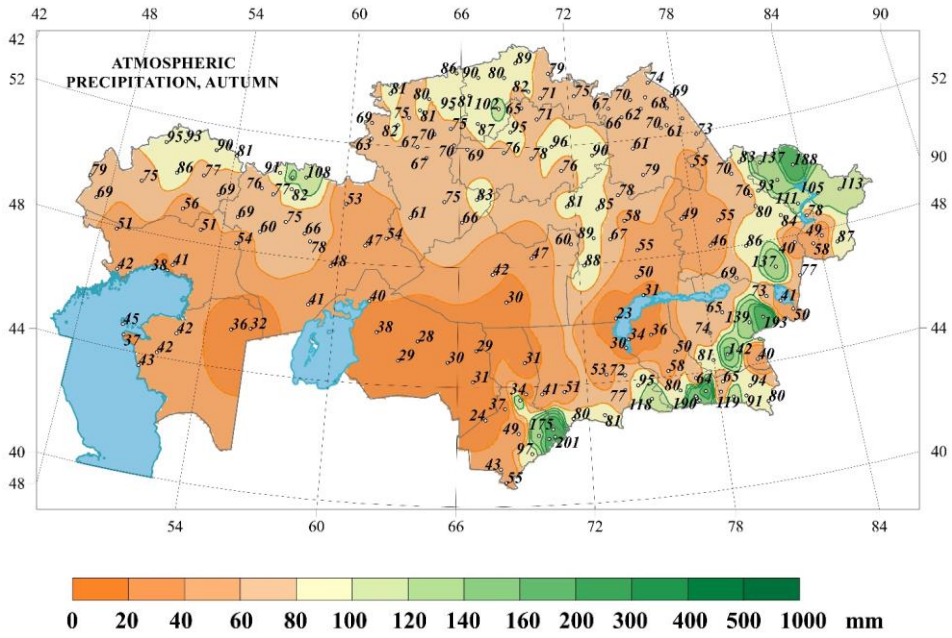





ATMOSPHERIC
PRECIPITATION, SPRING


ATMOSPHERIC
PRECIPITATION, SUMMER


0 20 40 60 80 100 120 140 160 200 300 400 500 1000 mm


ATMOSPHERIC
PRECIPITATION, AUTUMN
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0 20 40 60 80 100 120 140 160 200 300 400 500 1000 mm