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PRESENT TRENDS IN AIR TEMPERATURE IN THE EAST OF KAZAKHSTAN

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According to world research, over the past decades there has been a tendency for air temperature to rise and an increase in the frequency of extreme weather events. The study of the climatic predisposition of individual regions to extreme events, in particular fires, is an urgent problem of our time. The main purpose of this study was to define current trends in air temperature in Eastern Kazakhstan on an annual, seasonal and monthly scale. The non-parametric Mann-Kendall test and Sen's slope estimation were used for the analysis, and the co-kriging method was used to interpolate the data to obtain areal distribution. As a result of the study, it was revealed that in most of Eastern Kazakhstan, there has been an increasing trend in average and maximum temperatures significantly. It was also noted that the main statistically significant changes are observed in the spring and summer seasons. Changes at some stations were reached from 0,2 to 1,0 °C in ten years. The most consistent and significant trends in temperature increase were recorded in March and April.

Keywords: Air temperature, Non-parametric Mann-Kendall test, Co-kriging.

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INTRODUCTION

According to the world climate literature, there has been a trend of rising air temperatures and an increase in the frequency of extreme weather events in recent decades (Change, 2023, Perreault-Carranza, 2024, Valavanidis, 2023).

In the IPCC's sixth assessment Report on the physical basis of climate change, it was noted that human activities, mainly due to greenhouse gas emissions have caused global warming. The report showed that the temperature of the earth's surface between 2011 and 2020 was 1,1°C, higher than between 1850 and 1900. It was also noted that the global temperature of the earth's surface has risen faster than in any other 50-year period since 1970, according to the data of the last 2000 years (IPCC, 2021).

Climate risks are potential risks that may arise as a result of climate change (physical risks) or measures to minimize its effects (transitional risks) (Bank of Russia, 2022). The key factors that cause a high degree of vulnerability may be due to a number of geographical factors – for example, the presence of territories in different climatic zones.

In global research on climate change, especially changes in air temperature trends, it includes various methods, depending on the objectives of the study, the data used, and the time and spatial scale. In various works (Ceyhunlu, 2024, Costa, 2024, Mudelse, 2018) changes in air temperature were calculated using the linear regression method, the trend reversal analysis method, automatic and cross-correlation analysis, etc. In this study, the Mann-Kendall test and the Sen's slope estimation were selected for analysis.

In the works of many researchers (Faquseh, 2024, Hossen, 2023, Rahdari, 2024), it was noted that the Mann-Kendall test is especially effective in assessing monotonous trends such as air temperature, precipitation, snow cover height, etc.

This nonparametric test is used not only in meteorology but also in various fields of science and medicine. The Mann-Kendall test allows us to calculate the trend toward an increase or decrease in the values of meteorological parameters, as well as to assess the statistical significance of these changes (Neel, 2018).

The Mann-Kendall's statistics depend on the functions of the observation ranks rather than their actual values, which mean the method does not depend on the actual distribution of data and is less sensitive to outliers. Nonparametric statistics are usually much less affected by outliers and other forms of abnormality and are an indicator of monotonic linear dependence. A statistically significant trend identified using a nonparametric model, such as the Mann-Kendall test (MK), can be supplemented by an estimate of the slope of the Sen to determine the magnitude of the trend (Yadav, 2014).

One of the manifestations of climate change is an increase in air temperature, which is continuously associated with an increase in the incidence of extreme weather events such as droughts and fires and other dangerous phenomena. It should be noted that in the east of Kazakhstan, which is the object of research, there are forests important for the ecosystem, the area of which decreases every year and suffers from forest fires. The fire that occurred in 2023 in the territory of the Abad region destroyed more than 60,000 hectares of forest, which is a major disaster on a global scale (Wikipedia contributors, 2023).

In this regard, the purpose of this study was to analyse trends in changes in the average and maximum air temperature in the Eastern Kazakhstan associated with an increase in extreme weather events, in particular wildfires.

MATERIALS AND METHODS

The study area. The climate of the east of Kazakhstan is very diverse and in this regard, the climatic risks of different regions of Kazakhstan are also not the same. The key factors that cause a high degree of vulnerability may be due to a number of geographical factors – for example, the presence of territories in different climatic zones.

The study area is the East of Kazakhstan, which includes the Abai and East-Kazakhstan regions. It is located between latitudes 45,32 and 51,43 north latitude and 76,47 and 87,19 east longitude, has a maximum length of 760 km from east to west and 610 km from north to south, covers an area of 283,300 km^2, altitude ranges from 121 meters to 4350 meters above sea level. On the territory of the east of Kazakhstan there are both vast flat areas and high-altitude areas where the Altai and Saur-Tarbagatai mountains are located (Egorina, 2014).

The state of Kazakhstan's forest lands is of particular concern. Occupying only 4 % of the country's territory, they are the habitat of the most valuable and rare species of animals, 90 % of the species of higher plants known in the republic. The forest cover of the entire republic is mainly in the east and north of Kazakhstan, for each region the total forest cover is 14 % (Makeeva, 2022). The most important forests for the republic are located in the studied area, and climate change can affect changes in the ecosystem and forest cover in this area.

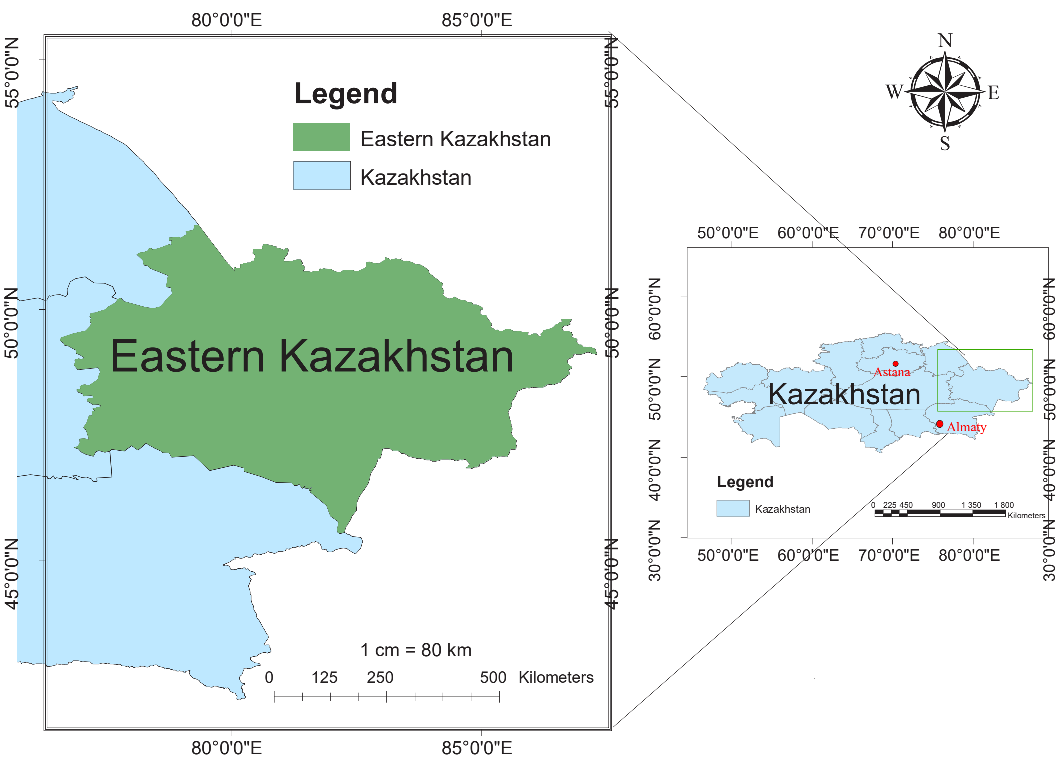

Fig. 1. The map of object of the study – the east of Kazakhstan

To conduct this study, data were taken from the archive of urgent observations of RSE Kazhydromet for the period 1978...2023 from 24 meteorological stations (Kazhydromet, n.d.).
The non-parametric Mann-Kendall test was used to analyze the data, which allows us to identify trends and determine the statistical significance of changes in time series. It is important to note that these methods are resistant to emissions and are used to identify significant climatic trends, which makes them optimal for this type of data and they are justified in the context of analyzing temperature trends.

According to this test, the statistics of S and Z, Kendall's tau (τ), the p value, etc. were evaluated. Also, the values of Sen's slope were determined to assess the trend. All calculations were created using the Python programming language (Python Software Foundation, n.d.) in the Jupyter Notebook software (Project Jupyter, n.d.).

The Mann-Kendall test. The MK test is a nonparametric test for detecting trends in time series data. The S statistics for the MK test are calculated using the following formulas (1...2):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k), \quad (1)$$

$$\mathrm{sgn}(X_j - X_k) = \langle \mathrm{if}\,(X_j - X_k) = 0{,}0\ \rangle, \quad (2)$$

where, n is the length of the dataset, X_j and X_k are the data values at times j and k, and sgn is a signed function that takes values -1, 0 and +1. The value of t from S shows uptrends or downtrends in climate datasets:

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{p} t_k(t_k-1)(2t_k+5)}{18}, \quad (3)$$

where, p is the associated group, and tk is the number of observations in the k group.
The standard Z statistic for the Mann-Kendall test is calculated using the following formula:

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & S < 0 \end{cases}, \quad (4)$$

where, Z_S shows the significance of the trend. Then, standardized test statistics are applied to test the null hypothesis, H_0, if $Z_S > Z_\alpha/2$ and α shows the confidence level.

The Sen's slope is calculated using the following formula:

$$Q = \frac{X_j - X_k}{j-k} \quad k<j, \quad (5)$$

where, Xj and Xk are the values of meteorological parameters at time j and k (Gulakhmadov, 2021).

Data visualization. The co-kriging method was chosen to visualize and calculate the spatial distribution of data. Co-kriging is an advanced kriging technique that is used to interpolate spatial data using multiple interconnected data. The co-kriging method has been extensively studied by various researchers and adapted to different practical scenarios. The advantage of co-kriging is that it shows more accurate results (Giraldo, 2020). In this paper, Mann-Kendall statistics and the height of the earth's surface were used for co-kriging.

RESULTS AND DISCUSSION

In many studies (Bisai, 2014, Latrech, 2023, Liyew, 2024) that the non-parametric Mann-Kendall test was used, calculations have shown that the trends to increase of the air temperature is statistically significant. For example, in studies conducted in Morocco from 1970 to 2019, the test results showed that air temperature has seasonal trends and revealed a trend towards an increase in temperature in spring and summer (Qadem, 2024).

In studies in India, the results were also obtained, according to which there is an increase in the number of warm days and nights and the number of cold days and nights decreases. The authors also noted that the observed growing warming trends may lead to floods in India in the future (Frimpong, 2022).

The Mann-Kendall test was also used to study trends of changes in average temperature values across the territory of Kazakhstan. According to the results of this study, the authors note that there is a tendency for a significant increase in air temperature in Kazakhstan. The average annual temperature over the past 50 years has increased by an average of 0,034 °C per year. In all four seasons of the year, there were trends towards an increase in the corresponding average temperatures, especially significant changes were in spring, summer and autumn (Farooq, 2021).

The same results, i.e. significant trends in temperature increases in spring, summer, autumn and minor changes in winter, were obtained according to the study over the Kyzylorda region of Kazakhstan (Abdolla, 2024).

Mann-Kendall statistics in the east of Kazakhstan. As mentioned above, their average and maximum values were taken to study trends in air temperature changes. The analysis of changes in the temperature range in the east of Kazakhstan over the past 45 years was carried out. Tables 1...3 provide Z-values calculated for the average and maximum air temperature. Table 1 shows annual and seasonal Mann-Kendall statistics on average and maximum temperatures for 24 meteorological stations.

Table 1

Seasonal Mann–Kendall statistics (Z-values) for average (a) and maximum (b) temperatures (in °C) for the period 1978…2023 in Eastern Kazakhstan

MS	Average air temperature					Maximum air temperature				
	Ann.	Spr.	Sum.	Fall	Wint.	Ann.	Spr.	Sum.	Fall	Wint.
Aksuat	**3,97***	**3,94**	**2,97**	1,82	1,18	**3,95**	**4,14**	**2,78**	1,44	1,26
Aktogai	**2,49**	**3,15**	**2,33**	0,70	-0,06	**2,61**	**2,98**	**3,14**	1,09	-0,26
Ayagoz	**3,27**	**3,95**	**2,91**	0,91	0,24	**2,45**	**3,63**	1,41	0,32	-0,42
Bakty	**3,29**	**3,59**	**3,67**	1,34	-0,33	**3,61**	**3,77**	**4,01**	1,21	-0,14
Barshatas	**2,89**	**3,60**	**2,02**	0,70	0,04	1,30	**3,11**	0,53	-0,27	-0,44
Dmitriyevka	1,77	**3,26**	**2,21**	0,20	-0,50	1,83	**3,39**	1,77	0,15	-0,54
Kainar	**2,11**	**3,31**	0,66	-0,40	0,00	**2,15**	**3,79**	1,24	-0,04	-0,71
Karaaul	1,58	**3,60**	1,37	-0,30	-0,49	1,68	**3,92**	1,54	-0,08	-0,67
Katon-karagai	**2,41**	**3,49**	**3,69**	0,22	-0,56	**1,96**	**3,11**	**2,17**	-0,13	-0,49
Kokpekty	**3,18**	**3,98**	**3,36**	0,90	0,92	**3,41**	**3,28**	**3,44**	0,86	0,93
Kurshim	**2,05**	**3,05**	**3,01**	0,05	0,09	**3,21**	**3,38**	**4,19**	0,91	0,65
Leninogorsk	1,43	**4,08**	**3,02**	-0,41	-0,86	0,30	**3,04**	**2,30**	-1,41	**-2,00**
Zapovednik Markakol	**3,70**	**4,36**	**4,24**	1,08	0,97	**4,47**	**4,94**	**4,91**	1,35	1,48
Samarka	**2,83**	**3,32**	**2,85**	0,66	0,64	**2,48**	**3,21**	**2,55**	0,26	-0,10
Semey	1,73	**3,54**	1,66	0,39	-0,34	**2,42**	**4,17**	**2,22**	0,59	-0,38
Semiyarka	1,60	**3,57**	1,65	0,39	-0,26	**2,67**	**3,96**	**3,25**	0,84	-0,38
Shalabai	1,36	**3,30**	1,59	-0,14	-0,64	1,37	**3,38**	**2,64**	0,31	-1,72
Shar	1,72	**3,50**	1,87	0,09	-0,44	**2,21**	**3,90**	**2,67**	0,63	-0,57
Shemonaiha	**2,39**	**3,88**	**2,47**	0,67	0,13	**2,66**	**4,42**	**3,18**	0,92	-0,46
Terekty	1,57	**3,28**	**2,47**	-0,16	-0,73	1,87	**3,05**	1,91	-0,09	-0,06
Ulken Naryn	1,61	**2,61**	**2,45**	0,59	-0,49	**2,19**	**2,33**	**2,25**	0,33	0,62
Urzhar	0,30	**2,49**	1,44	-0,64	**-2,55**	0,37	**2,13**	0,39	-0,01	**-2,09**
Zaisan	**2,63**	**3,56**	**3,13**	0,40	0,17	1,20	**2,92**	**2,50**	-0,42	-0,91
Zhalgyztobe	1,76	**3,57**	**2,07**	0,22	-0,59	1,64	**3,51**	**2,53**	0,24	-1,17

**In the table, values in bold represent Mann–Kendall results that are significant at p < 0,05*

Calculations show (Table 1) an increase in the annual tends of the average temperature at 13 stations out of 24 and the maximum temperature at 15 stations, which was statistically significant (p value < 0.05). At the same time, none of the stations showed negative dynamics.

During the spring season, significant positive temperature changes were observed at all meteorological stations. There was also a significant positive trend during the summer period, with the exception of a few stations such as Shar, Shalabai, Semiyarka, Karaaul and Kainar, for which temperature trends were insignificant. In autumn and winter, no significant trends were detected at the stations.

The average annual and seasonal trend of maximum temperature repeats the average temperature.

Table 2 shows the results of the statistical Z values of the Mann–Kendall test for the average temperature by month.

Table 2

Mann–Kendall statistics (Z-values) by month (in °C) for the period 1978…2023 in the eastern Kazakhstan for average temperature

Station	Average air temperature											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aksuat	0,08	**2,12***	**3,22**	**2,60**	0,78	1,89	1,14	**2,55**	0,65	**2,32**	1,67	0,44
Aktogai	0,15	1,18	**2,72**	**2,42**	0,93	1,64	1,39	1,34	0,27	1,44	0,32	-0,50
Ayagoz	0,00	1,55	**3,46**	**3,18**	1,10	1,85	1,43	1,82	0,93	1,40	0,55	-0,67
Bakty	-0,04	1,12	**2,94**	**2,94**	0,88	**3,05**	**2,09**	**2,09**	1,41	1,84	0,12	-0,68
Barshatas	0,28	1,53	**3,32**	**2,70**	1,08	1,50	0,23	1,68	0,09	1,50	0,05	-0,42
Dmitriyevka	-0,58	0,55	**2,99**	**2,89**	1,00	1,45	0,31	1,72	-0,09	1,09	0,15	-1,33
Kainar	-0,36	1,17	**3,13**	**2,25**	0,99	0,82	0,13	1,16	-0,75	0,41	-0,24	-0,64
Karaaul	-0,83	0,98	**3,20**	**2,56**	0,76	0,98	-0,10	0,99	-0,72	0,57	-0,17	-1,64
Katon-karagai	-0,64	0,62	**2,92**	**2,67**	0,41	**2,05**	1,83	**3,24**	-0,02	1,08	0,05	-1,62
Kokpekty	-0,01	1,46	**3,51**	**2,70**	0,93	**2,26**	1,55	1,88	-0,03	1,14	0,90	-0,08
Kurshim	-0,40	1,09	**2,41**	**2,83**	-0,17	1,74	1,67	1,84	-0,40	0,25	0,42	-0,65
Leninogorsk	-1,25	0,70	**3,13**	**2,79**	0,76	1,55	1,13	**2,25**	-0,84	0,64	-0,40	-1,88
Zapovednik Markakol	0,30	1,81	**2,61**	**3,35**	**2,17**	**3,21**	**2,09**	**3,06**	0,71	1,46	0,26	0,07
Samarka	0,15	1,65	**2,79**	**2,53**	0,60	1,83	1,04	1,77	-0,63	1,28	0,85	-0,22
Semey	-0,55	0,80	**2,85**	**2,69**	1,15	1,07	-0,28	1,71	0,14	1,12	0,04	-1,37
Semiyarka	-0,56	0,73	**2,99**	**2,44**	1,17	0,83	0,11	1,79	-0,27	1,18	0,28	-0,92
Shalabai	-1,34	0,66	**2,99**	**2,99**	0,47	1,17	0,13	1,03	-0,04	0,49	0,08	-1,49
Shar	-0,70	0,87	**2,96**	**3,12**	0,72	1,39	0,20	1,15	-0,09	0,76	0,06	-1,42
Shemonaiha	-0,47	1,23	**3,28**	**2,99**	1,13	1,35	0,99	1,89	0,20	1,15	0,55	-0,63
Terekty	-0,80	0,71	**3,17**	**2,61**	0,04	1,90	0,66	1,47	-0,37	0,80	0,09	-1,44
Ulken Naryn	-1,28	0,14	**2,77**	1,89	-0,32	1,62	0,83	1,13	-0,99	0,64	1,07	-0,09
Urzhar	-1,49	-0,20	**2,07**	**2,11**	0,30	1,22	0,57	0,62	-1,16	-0,23	-0,09	-1,52
Zaisan	-0,37	1,12	**2,76**	**2,96**	0,58	**2,04**	1,72	**2,13**	-0,06	0,64	0,72	-0,46
Zhalgyztobe	-0,87	0,71	**2,96**	**2,95**	0,60	1,62	0,65	1,37	0,00	0,83	0,17	-1,56

**In the table, values in bold represent Mann–Kendall results that are significant at p < 0,05*

It was found that in the period from 1978 to 2023, there was a tendency for temperatures to rise in most months. However, not all months have equally significant trends in temperature increase. During the cold period of the year (September-February), negative trends are also noted, but they are not significant. The most consistent and significant trends in temperature increase were recorded in March and April. In summer, in June and August, a significant positive trend was recorded only at 5...6 stations.

Table 3 shows the results of the statistical values of the Mann–Kendall test for the maximum temperature by month.

Table 3

Mann–Kendall statistics (Z-values) by month (in °C) for the period 1978…2023 in the eastern Kazakhstan for maximum temperature

Station	Maximum air temperature											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aksuat	0,68	**1,99***	**3,20**	**3,32**	1,48	**2,31**	1,59	**2,16**	0,28	1,30	1,52	0,24
Aktogai	-0,24	0,44	**2,43**	**2,11**	1,33	**2,28**	1,58	1,38	0,34	1,21	0,93	-0,56
Ayagoz	-0,54	1,29	**3,11**	**2,68**	0,88	1,59	0,68	0,62	-0,43	0,68	0,58	-1,27
Bakty	0,17	1,36	**3,15**	**2,54**	1,53	**2,94**	**2,16**	**2,53**	0,72	1,27	0,80	-0,70
Barshatas	-0,46	0,88	**2,73**	**2,49**	1,07	1,03	-0,80	0,47	-1,16	0,39	0,02	-1,20
Dmitriyevka	-0,84	0,97	**3,13**	**3,03**	1,13	1,19	0,37	1,28	-0,03	1,15	-0,09	-1,77
Kainar	-0,44	0,98	**2,92**	**2,57**	1,80	1,14	0,06	0,77	-0,72	0,52	-0,13	-1,55
Karaaul	-1,04	0,90	**3,20**	**2,94**	1,49	1,66	0,30	1,15	-0,53	0,72	-0,19	-1,94
Katon-karagai	-0,48	0,93	**2,72**	**2,03**	0,31	1,57	0,70	1,68	-0,35	1,06	-0,20	-1,65
Kokpekty	0,44	1,68	**3,08**	**2,34**	1,19	**2,62**	1,55	**2,21**	0,02	1,00	0,89	-0,08
Kurshim	0,09	1,46	**2,38**	**2,66**	1,13	**2,50**	**2,86**	**3,21**	0,88	1,07	0,67	-0,26
Leninogorsk	-1,56	0,25	**2,69**	**2,04**	0,65	1,93	1,11	1,95	-0,89	-0,05	-1,31	**-3,01**
Zapovednik Markakol	0,62	**2,40**	**2,88**	**4,26**	**2,87**	**3,70**	**3,04**	**4,11**	1,62	1,52	0,47	0,38
Samarka	-0,09	0,91	**2,30**	**2,57**	1,05	**2,28**	0,99	1,47	-0,09	0,74	0,59	-0,69
Semey	-0,62	1,17	**3,08**	**3,49**	1,54	1,37	0,31	**1,97**	0,20	1,47	0,09	-1,44
Semiyarka	-0,71	0,63	**3,16**	**3,18**	**2,13**	1,75	1,29	**2,68**	0,27	1,73	0,27	-0,92
Shalabai	-1,56	-0,19	**2,06**	**3,17**	1,18	1,84	1,24	1,75	0,42	1,06	-0,06	**-2,21**
Shar	-0,87	0,78	**2,79**	**3,40**	1,15	1,95	0,99	1,81	0,31	1,48	0,33	-1,47
Shemonaiha	-0,69	1,00	**3,22**	**3,55**	1,60	**2,13**	1,86	**2,34**	0,59	1,60	0,46	-1,18
Terekty	-0,33	1,29	**2,85**	**2,52**	0,69	1,81	-0,01	1,86	-0,05	0,82	-0,17	-0,95
Ulken Naryn	-0,30	1,06	**2,27**	1,80	0,47	1,82	0,35	1,21	-0,66	-0,15	1,02	0,27
Urzhar	-1,50	0,10	1,84	1,71	0,25	0,58	0,03	-0,15	-0,97	0,35	0,06	-1,43
Zaisan	-1,23	0,45	**2,42**	**2,44**	0,31	1,93	1,37	1,38	-0,45	0,03	0,08	-1,21
Zhalgyztobe	-1,11	0,57	**2,78**	**3,22**	0,74	1,94	0,98	1,42	-0,08	0,96	-0,01	**-2,06**

**In the table, values in bold represent Mann–Kendall results that are significant at p < 0,05*

The monthly statistical values of Mann–Kendall for maximum temperature have a similar pattern to the average temperature. Significant changes were also detected in March and April, and an increase in temperature is observed at all stations.

Visualization of the current trend in air temperature in the East of Kazakhstan. According to the statistical data of the Sen's slope estimator, interpolated data were calculated using the co-kriging method and maps of the spatial distribution of air temperature changes in Eastern Kazakhstan were visualized using the ArcGIS desktop environment. On a seasonal scale, statistical values varied within different limits for each season, which made it difficult to use a single scale for data visualization. Because of this difference, each season has its own specific scale (Fig. 2).

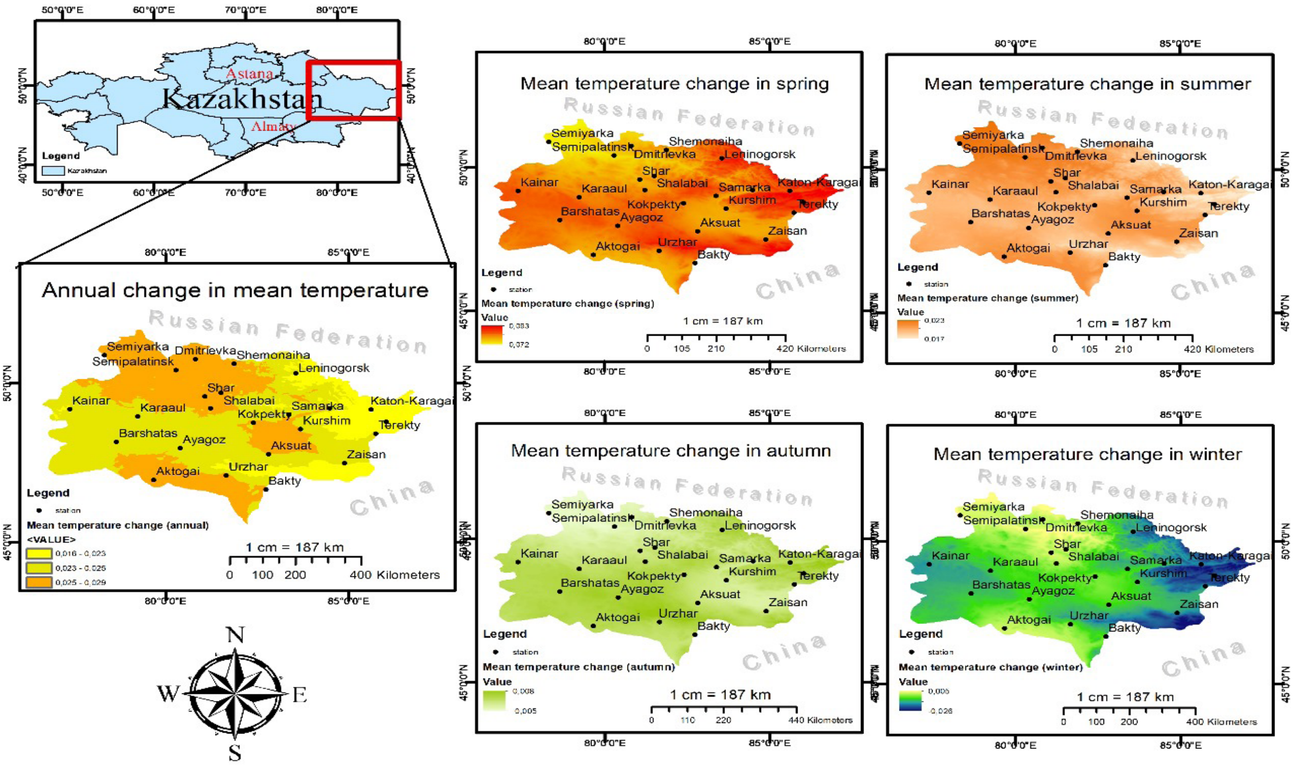

Fig. 2. Annual and seasonal changes in average temperature (in °C/year) in the eastern Kazakhstan

Figure 2 shows maps with interpolated values of Sen's slope (in °C/year) on an annual and seasonal scale for the average temperature. Trend calculations of annual mean temperatures show an increase of 0,2...0,4 °C over the decade. The map shows a significant increase in the plains of eastern Kazakhstan. Minimal changes were recorded in the highlands.

Among the four seasons of the year, the greatest temperature increase is observed in spring and summer, and the minimum change is during the cold season.

The smallest change was recorded in autumn, during this period the trend varies between 0,1...0,2 °C per decade. In spring, the temperature increase varies between 0,6...1,0 °C over ten years, changes with maximum values are localized in the high-altitude area. In summer, you can also see a significant positive increase in temperature, in the range of 0,2...0,4 °C per decade.

The calculated data based on the maximum temperature were shown in the following maps (Fig. 3).

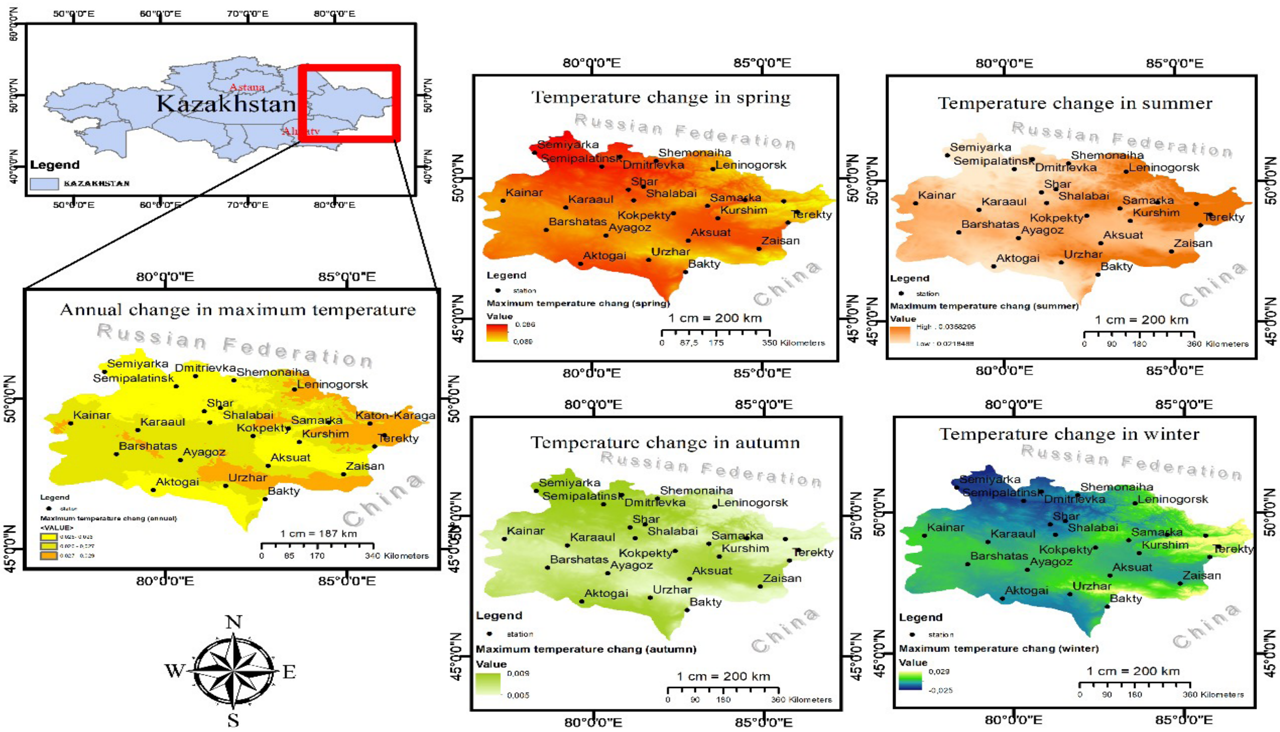

Fig. 3. *Annual and seasonal changes in maximum temperature (in °C/year) in the eastern Kazakhstan*

Trend calculations of annual maximum temperatures show an increase of 0,2...0,5 °C over the decade. The map shows that a significant increase was recorded in the mountain area of eastern Kazakhstan.

Among the four seasons of the year, the maximum temperature has a similar pattern to the average temperature. The greatest increase is observed in spring and summer, and the minimum in winter and autumn.

The smallest change was recorded in autumn and winter, during this period the trend varies between 0,1...0,2 °C per decade. In spring, the temperature increase varies between 0,6...1,0 °C over ten years, changes with maximum values are localized in flat terrain. In summer, you can also see a significant positive increase in temperature, in the range of 0,2...0,8 °C per decade.

CONCLUSION

Climate change in the studied region has a significant impact on the ecosystem, agriculture and economic stability. In this work were calculated an annual, seasonal and monthly air temperature changes in the territory of eastern Kazakhstan and the following conclusions were made:

1. There is an increase in the average and maximum temperature in most of the territory of eastern Kazakhstan. Calculations show an increase in the annual tends of the average temperature at 13 stations out of 24 and the maximum temperature at 15 stations, which was statistically significant (p value < 0,05).

2. A significant increase in the average air temperature was in the flat terrain of eastern Kazakhstan and minimal changes were recorded in the highlands.

3. The spatial distribution of changes in the maximum temperature has a diametrically opposite distribution of the average temperature, a significant increase in it was recorded in mountainous areas.

4. According to the Sen's slope estimator, annual increases in average air temperature were in the range of 0,2...0,4 °C over ten years. For the maximum temperature, the changes were in the range of 0,2...0,5 °C over ten years.

5. In spring and summer, there was a significant increase in the average and maximum temperature at all stations, the changes ranged from 0,6...1,0 °C over ten years in terms of average terms of maximum air temperature.

In conclusion, it can be noted that statistically significant temperature changes with an upward trend have been observed in recent decades. The observed changes may lead to an increase in the frequency of natural hazards associated with high temperatures, in particular fires, droughts and floods in the studied region.

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ҚАЗАҚСТАННЫҢ ШЫҒЫСЫНДАҒЫ АУА ТЕМПЕРАТУРАСЫНЫҢ АҒЫМДАҒЫ ҮРДІСТЕРІ

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Әлемдік зерттеулерге сәйкес, соңғы жылдары ауа температурасының жоғарылау тенденциясы және экстремалды ауа райы құбылыстарының жиілігінің артуы байқалуда. Өңірлердің экстремалды құбылыстарға, атап айтқанда өрттерге климаттық бейімділігін зерттеу қазіргі заманның өзекті мәселелерінің бірі болып табылады. Бұл зерттеудің мақсаты Қазақстанның шығысындағы ауа температурасының жылдық, маусымдық және айлық ауқымдағы қазіргі заманғы трендтерін зерттеу болып табылады. Талдау үшін Манн-Кендаллдың параметрлік емес сынағы және Сенның өзгеру трендің бағалау әдісі қолданылды, ал деректерді визуализациялау үшін ArcGIS-те ко-кригинг әдісі қолданылды. Осы зерттеу нәтижесінде Қазақстанның шығысындағы үлкен аумақта орташа және ең жоғары температураның көтерілу үрдісі байқалғаны анықталды. Сондай-ақ, негізгі статистикалық маңызды өзгерістер көктем мен жаз мезгілдерінде байқалатыны атап өтілді. Қарастырылып отырған кезеңде кейбір станциялардағы өзгерістер он жыл ішінде 0,2-ден 1,0 °С-қа дейін жетеді. Температураның көтерілуінің ең дәйекті және маңызды тенденциялары наурыз және сәуір айларында тіркелді.

Түйін сөздер: ауа температурасы, параметрлік емес Манн-Кендалл тесті, ко-кригинг әдісі.

ТЕКУЩИЕ ТЕНДЕНЦИИ ТЕМПЕРАТУРЫ ВОЗДУХА НА ВОСТОКЕ КАЗАХСТАНА

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По данным мировых исследований, за последние десятилетия наблюдается тенденция повышения температуры воздуха и увеличение частоты экстремальных погодных явлений. Изучение климатической предрасположенности отдельных регионов к экстремальным явлениям, в частности пожаров, является актуальной проблемой современности. Целью данного исследования является изучение современных трендов температуры воздуха на востоке Казахстана в годовом, сезонном и месячном масштабе. Для анализа были использованы непараметрический тест Манн-Кендалла и оценка наклона Сена, а для визуализации данных был использован метод ко-кригинг в ArcGIS. В результате данного исследования, были выявлено, что на большей территории востока Казахстана наблюдается значительная тенденция к повышению средней и максимальной температуры. Так же было отмечено, что основные статистически значимые изменения наблюдаются в весенние и летние сезоны. В этот период изменения на некоторых станциях достигают от 0,2 до 1,0 °С за десять лет. Наиболее последовательные и значимые тенденции к повышению температуры были зафиксированы в марте и апреле.

Ключевые слова: температура воздуха, непараметрический тест Манн-Кендалла, метод ко-кригинга.

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