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ASSESSMENT OF BIOCLIMATIC CONDITIONS OF WEST KAZAKHSTAN

This article provides an assessment of the bioclimatic conditions of the warm and cold periods for 2010-2020 for the territory of West Kazakhstan on the basis of a comprehensive accounting of meteorological parameters. For this assessment, four bioclimatic indices were calculated, such as effective temperature, equivalent-effective temperature, normal equivalent-effective temperature, the Bodman severity index, on the basis of which the level of comfortness of climatic conditions for the population living in the studied territory was evaluated. The calculations used the initial data of daily temperature, relative humidity and wind speed for the main five stations in West Kazakhstan. The importance of this work is to determine the dependence of human health on climatic factors and to study with the help of the found bioclimatic indicators how favorable the climatic conditions of the territory of West Kazakhstan are for human life and recreation. The analysis of the obtained results revealed that in the cold half of the year a moderately severe type of weather conditions prevails, and in the warm period of the year the climate of the studied territory is considered comfortably warm. In general, the climate of West Kazakhstan can be considered comfortable for living, health and work of the population in this region.

Key words: biometeorology, climate, bioclimatic indices, effective temperature, equivalent effective temperature, Bodman index.

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Батыс Қазақстанның биоклиматтық жағдайларын бағалау

Бұл мақалада метеорологиялық параметрлерді кешенді есепке алу негізінде Батыс Қазақстан аумағы үшін 2010-2020 жылдардағы жылы және суық кезеңдердің биоклиматтық жағдайларына баға беріледі. Осы бағалауды жүргізу үшін төрт биоклиматтық индекстер есептелді, мысалы тиімді температура, эквиваленттi тиімді температура, қалыпты эквиваленттi тиімді температура, Бодман индексі және солардың негізінде зерттелетін аумақта халықтың өмір сүруі үшін климаттық жағдайлардың жайлылық деңгейі анықталды. Есептеу кезінде Батыс Қазақстандағы негізгі бес станция үшін тәуліктік температураның, ауаның салыстырмалы ылғалдылығының және жел жылдамдығының бастапқы деректері пайдаланылды. Бұл жұмыстың маңыздылығы адам денсаулығының климаттық факторларға тәуелділігін анықтау және табылған биоклиматтық көрсеткіштердің көмегімен Батыс Қазақстан аумағының климаттық жағдайлары адамның тыныс-тіршілігі мен тынығуы үшін қаншалықты қолайлы екенін зерттеу болып табылады. Нәтижелердің талдауы көрсеткендей, суық жартыжылдықта ауа-райының орташа қатал түрі басым болады, ал жылы мезгілде зерттелетін аумақтың климаты жылы болып саналады. Жалпы, Батыс Қазақстанның климатын осы өңірде халықтың тұруы, денсаулығы және жұмысы үшін қолайлы деп санауға болады.

Түйін сөздер: биометеорология, климат, биоклиматтық индекстер, тиімді температура, баламалы тиімді температура, Бодман индексі.

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Оценка биоклиматических условий Западного Казахстана

В данной статье на основе комплексного учета метеорологических параметров приводится оценка биоклиматических условий теплого и холодного периодов за 2010-2020 годы для территории Западного Казахстана. Для проведения данной оценки были рассчитаны четыре биоклиматических индекса, такие как эффективная температура, эквивалетно-эффективная температура, нормальная эквивалетно-эффективная температура, индекс суровости Бодмана, на основе которых был выявлен уровень комфортности климатических условий для проживания населения на изучаемой территории. При расчетах были использованы исходные данные суточной температуры, относительной влажности воздуха и скорости ветра для пяти основных станций в Западном Казахстане. Важность данной работы заключается в определении зависимости здоровья человека от климатических факторов и в исследовании с помощью найденных биоклиматических показателей насколько благоприятны климатические условия территории Западного Казахстана для жизнедеятельности и отдыха человека. Анализ полученных результатов выявил, что в холодное полугодие преобладает умеренно суровый тип погодных условий, а в теплый период года климат исследуемой территории считается комфортно теплым. В целом, климат Западного Казахстана можно считать комфортным для проживания, здоровья и работы населения в этом регионе.

Ключевые слова: биометеорология, климат, биоклиматические индексы, эффективная температура, эквивалентно-эффективная температура, индекс Бодмана.

Introduction

For a successful assessment of the comfort of the climate of a certain territory, it is necessary to implement a complex biometeorological characteristic, which, firstly, characterizes the features of the natural environment, and secondly, it can be useful for taking preventive measures for some diseases. The assessment of the bioclimatic conditions of the territory should be carried out using various bioclimatic indices, which are based on various meteorological elements (Yakovenko, 2001). So, there are temperature-humidity and temperature-humidity-wind bioclimatic indices.

Research in the field of studying the impact of climate on human health is currently extensive. Many Russsian and foreign scientists assessed bioclimatic indices for different territories. For example, a bioclimatic assessment was carried out for the territory of the Udmurt Republic (Perevedentsev, 2016), Krasnodar Territory (Kuzyakina and Gura, 2020) and other regions of Russia (Sinitsyn, 2013) using standard indices such as effective temperature, Bodman's index, pathogenicity index, etc. For the territory of the Middle Ob region (Bikmukhametova, 2019), the overall impact of meteorological indicators was assessed using the Total Pathogenicity Index using the Boksha and Bogutsky method, which showed that severe weather conditions occur for most time of the year in the studied territory. In addition to that, this study used the Osokin, Bodman methods and calculated the Wind-Cold Index to assess the severity of the climatic conditions during winter. Isaeva (2008) used the same indexes and added Khairullin and Adamenko methods for the bioclimatic assessment of the severity of the winter in Kazan. A similar methodology was used for an assessment of biometeorological characteristic of the southeastern part of Kazakhstan (Beku, 2013; Nyssanbayeva, 2019). In addition to these bioclimatic indices, additional ones, such as Mean Radiant Temperature, were used to assess the thermal comfort of a person outdoors in sunny weather (Kantor and Unger, 2011). Also, several works are devoted to investigation of diseases associated with extreme weather events (Orimoloye, 2018; Ketterer, 2014; Matzarakis, 2011). For example, Orimoloye et al. (2018) considered diseases (skin cancer, heart disease, heat stroke, diarrhea, etc.) associated with elevated temperatures and radiation in African countries and highlights the importance of taking preventive measures in public health programs. Belkin et al (2015) considered possible health risks in the Antarctic (polar) region to prevent frostbite using the Wind Chill Index (WCI) and the Bioclimatic Climate Severity Index (BISCR). Recently, studies of the impact of climate change on human health are also gaining popularity (Orimoloye, 2019; Szwed, 2010).

Many studies have been devoted to the issues of assessing the impact of the modern climate on various spheres of human life, including tourism, recreation and sports. For example, Pestereva et al. (2018) analyzed the bioclimatic resources of the Russian Far East in the context of modern climate change to enhance health tourism due to the rapid pace of its development in Russia. Stefanovich (2019) analyzed the comfort of recreational conditions in the Crimean region. In their study, they use the calculation of the partial oxygen density according to the method of Ovcharova, which is actively used in the preparation of medical forecasts.

Pavel Ichim and Lucian Sfîcă (Ichim 2020) conducted a study to determine the conditions of human bioclimatic stress in the area of the city of

Yash in Romania using the Thermohygrometric Index (THI) as well as the Relative Deformation Index (RSI), the analysis of which showed that in general, rural areas are more comfortable for living in summer, while comfortable conditions are observed inside the city in winter.

Also, in connection with the outbreak of the global COVID-19 pandemic, some scientists have tried to find a connection between climatic conditions and the spread of this virus. For example, Werner P. et al. (2021) in their article investigated the influence of climate and bioclimate on cases of COVID-19 in Poland. They hypothesized that as the air temperature drops, the number of cases of COVID-19 increases (Werner, 2021).

This study provides an assessment of bioclimatic conditions for the area of West Kazakhstan using the most frequently used indices in practice, which are the most effective and informative: Effective Temperature, Equivalent-Effective Temperature, Normal Equivalent-Effective Temperature and Bodman's Severity Index. Meteorological data from five stations Aktau, Aktobe, Emba, Uralsk, Atyrau (Figure 1) were used in this study. When calculating the indices, we used the data of the average values of air temperature, relative humidity and wind speed for the period from 2010 to 2020 for the considered stations in West Kazakhstan. This work can be used in the field of public health and recreation.

Materials and methods

Currently, several dozen complex biometeorological indicators have been developed that are used to solve various problems. Bioclimatic indicators are calculated for warm and cold periods (Rusanov, 1981:70).

Radiation Equivalent Effective Temperature (REET) proposed by G. Sheleikhovsky is used to assess recreational and climatic resources for the warm period (Khairullina, 2005:231). REET is an indicator of a person's thermal sensation under the influence of the complex effects of several factors such as air temperature and relative humidity, wind speed and solar radiation.

For the purpose of an analytical assessment of the heat sensations of a dressed person (summer clothes of the same type), I. Butyeva proposed a Normal Equivalent-Effective Temperature (NEET), taking into account the influence of temperature, air humidity and wind speed. The NEET is recognized as comfortable in the temperature range from +17 to +22 ºC (Khairullina, 2005:231).

Figure 1 – West part of Kazakhstan including West Kazakhstan, Aktobe, Atyrau and Mangystau regions

The Biologically Active Temperature (BAT) that was proposed by G. Tsitsenko makes it possible to determine the complex effect of temperature, air humidity, wind speed, total solar radiation, long-wave radiation of the underlying surface on a human. The BAT comfort zone is within the temperature range from +10 to +20 ºC (Khairullina, 2005: 231; Shtal, 1981:18).

Methods for assessing the severity of the weather also exist for bioclimatic assessment of the cold period. The severity of weather can be estimated by the values of low air temperature and wind speed, which affect the cooling of unprotected parts of body and respiratory organs. In other words, it can be considered not as an objective property of the weather, but as its influence on the cooling of a person, as a result of which the stay in the open air is limited and there is a need for clothing. To assess the severity of the weather the Bodman method is most often used (Kolokotroni, 2003: 26; Vitchenko, 2007:102).

Effective Temperature (ET) is one of the main biometeorological indices characterizing the effect of a complex of meteorological elements (air temperature and humidity) on a person through a single indicator, the so-called effective air temperature. The body's resistance to the environment depends on the physical characteristics of a person. Index ET combines the physiological and physical factors of the body, clothing and meteorological environmental factors. ET is designed for an “average” person, that is, an adult of average height and weight, dressed according to weather conditions and walking in shade (Khairullina, 2005: 231).

ET is directly proportional to air temperature and relative humidity. ET was calculated using Equation 1 that was also used in other similar studies (Perevedentsev, 2016: 533):

$$ET = t - 0,4 \cdot (t - 10) \cdot (1 - \frac{f}{100}) \quad (1)$$

where, t – dry air temperature (°C); f – relative humidity (%).

The calculation of ET can be used to assess thermal loads in different seasons and environmental comfortness and can also be used for climate treatment. Using the calculated values, it is possible to determine the thermal state at meteorological stations. Table 1 shows the comfort level scale based on ET values for warm (from April to September) and cold (from October to March) seasons.

Table 1 – Scale of effective air temperature during warm and cold periods

Warm period		**Cold period**	
Comfort level	**ET values °C**	**Comfort level**	**ET values ºC**
"very hot"	>30	"very cool"	-6-12
"hot"	24-30	"moderately cold"	-12-18
"comfortably warm"	18-24	"cold"	-18-24
"comfortable"	12-18	"very cold"	-24-30
"cool"	6-12	"frostbite threat"	>-30
"moderately cool"	-6-+6		

Equivalent Effective Temperature (EET) takes into account the complex effect of temperature, air humidity and wind speed on a person. EET is a combination of meteorological values that produces the same thermal effect as stationary air at 100% relative humidity and a certain temperature, and evaluates the heat sensation of a person naked to the waist. EET calculations are made according to the formula of A. Missenard (Beku, 2013: 68):

$$EET = 37 - \frac{37 - t}{0.68 - 0.0014 f + 1/\left(1.76 + 1.4 v^{0.75}\right)} - 0.29 t \ \left(1 - f/100\right), \quad (2)$$

where t – air temperature (°C); v – wind speed (m/s); f – relative humidity (%).

The bioclimatic index EET can be used to characterize the comfortness of both warm and cold periods of the year (Table 2). EET is determined by a combination of meteorological factors in which a person naked to the waist experiences subjectively good heat sensation and maintains a normal body temperature. Unlike ET, this index takes into account wind speed, in addition to relative humidity and air temperature.

Table 2 – Equivalent – effective air temperature scale

Heat sensation category	EET for humans, °C	
	unclothed	**clothed**
Comfortable	20-30	16,7-20,6
Cooling zone	6-12	less 16,7
Overheating zone	higher 21,7	higher 20,6

In addition to the EET index, the Normal Equivalent-Effective Temperature (NEET) was calculated using formula of Butyeva (3) to assess the heat perception of a dressed person (Sinitsyn, 2013: 281):

$$NEET = 0.8 \cdot EET + 7\ °C \tag{3}$$

In NEET index the fact that at an air temperature below -7 °C any wind has a cooling factor was taken into account. The NEET indicator is used to assess the heat perception of a dressed person, and, accordingly, is a more informative indicator of the comfort of the climate than EET (Sinitsyn, 2013: 281).

For the bioclimatic assessment of the cold period, the Bodman Index can be used to evaluate the severity of the weather in points (Khairullin, 1997: 132). The index can be calculated using equation 4:

$$S = (1 - 0.04 \cdot t)(1 + 0.27 \cdot v), \tag{4}$$

where S – severity index (points); t – air temperature (°C); v – wind speed (m/s).

Table 3 provides a scale for the level of comfortness according to the Bodman's Index

Table 3 – Bodman Severity Index scale

Comfort level	**Value S**
"warm winter"	S < 1
"mild winter"	1–2
"moderately severe"	2–3
"severe"	3–4
"very severe"	5–6
"extremely harsh"	>6

In addition to the Bodman Index, the Adamenko-Khairulin "Reduced Temperature" Index was calculated (Tkachuk, 2012: 12; Abdirazak, 2016: 85). This index takes into account human heat losses depending on the combination of actual air temperatures and wind speeds, compared to heat losses with the same air temperature, but in calm wind conditions. The index is also used in assessing the severity and continentality of the climate. The index is considered to be more objective in assessment of the discomfort of the cold period compared to the Bodman Weather Severity Index since takes into account the warming effect of radiation. The Index of "Reduced Temperature" is calculated by the formula:

$$t_{red} = t - 1.8\sqrt{V}, \tag{5}$$

where $t_{red.}$ – reduced temperature; t – actual temperature; V – wind speed.

Results and discussion

The Effective Temperature Index characterizes the heat perception of an undressed human body. The same heat perception can be experienced with a wide variety of combinations of meteorological elements. Figure 2 shows a graph of annual distribution of the average effective air temperature for studied stations in West Kazakhstan for the period of 2010 – 2020.

The values of the ET depend more on air temperature than on humidity, and repeat the spatial distribution of temperature, slightly increasing from north to south. The difference between the northern (Uralsk, Aktobe, Emba) and southern (Atyrau, Aktau) stations can be from 2.5 до 10 °C. As a result of calculations, it was found that in the territory of West Kazakhstan during the year, the ET value ranges from 1.0 to -11.3 ⁰C in winter and 21.4 to 23.9 ⁰C during summer, which corresponds to the level of comfortness from "very cool" to "hot".

During the transitional seasons of the year, the Effective Temperature Index varies from -1.8 to 18.9 ⁰C. Thus, conditions in early spring and late autumn are characterized as "moderately cool", while conditions in late spring and early autumn are characterized as "comfortable". Thus, the climate from the first half of April to October, when the average monthly values of the ET are above 12.0 ° C, can be called comfortable for the population of West Kazakhstan.

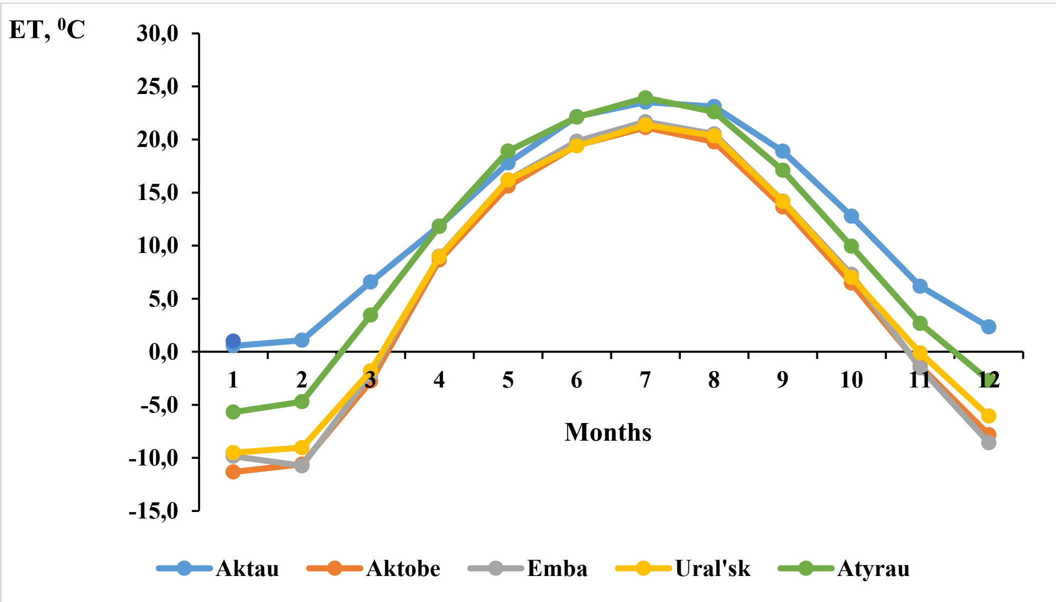

Figure 2 – Annual variation of the average effective temperature for considered stations in West Kazakhstan

Figure 3 shows the histogram of the average annual ET value for the stations in the region under study.

It was found that in the territory of West Kazakhstan during the year the value of ET ranges from 5.9 to 12.2 °C. Based on the graph shown in Figure 3, it can be seen that the highest average annual effective air temperature was noted at Aktau station (12.2 °C), and the lowest – at Aktobe station (5.9 °C) during the period from 2010 to 2020.

Figure 4 shows the dynamics of the average monthly January and July Effective Temperature over the last decade (2010-2020).

Based on Figure 4, there is a pronounced positive trend of the ET in January at all the stations studied. However, in July, there is a downward trend in the values of the ET for the same period under consideration. Over the past decade, the minimum values of the average monthly ET for January were observed in 2010 and the maximum average July ET values were observed in 2010, 2011 and 2018.

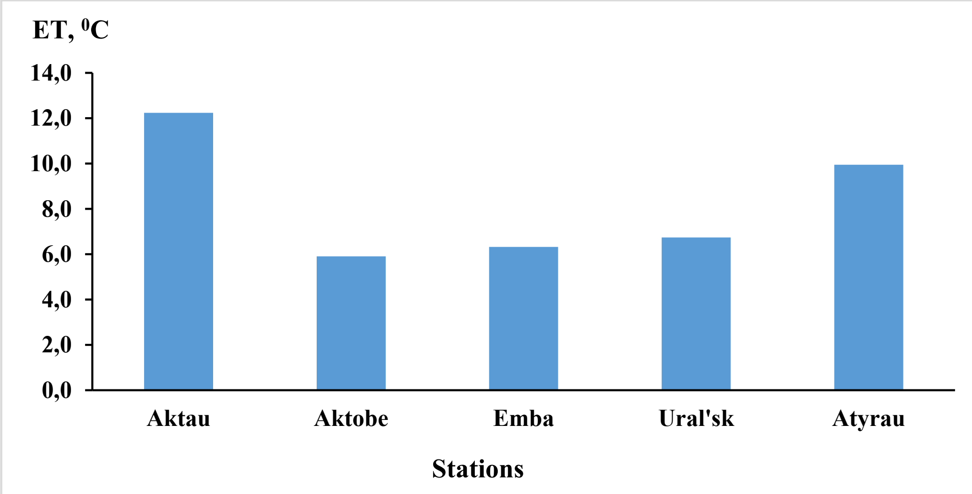

Figure 3 – Average annual values of ET for considered stations in West Kazakhstan for the period 2010-2020.

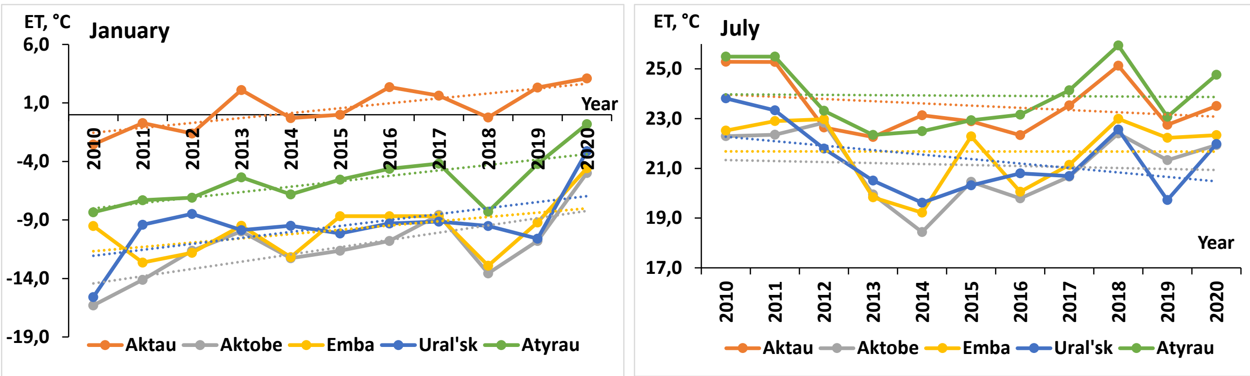

Figure 4 – Changes in the average January and Average July effective temperature (ET) for considered stations in West Kazakhstan (2010-2020)

The next index, which was calculated in the course of this work, is the EET indicator, which characterizes the heat perception of the human body in the dressed form. Figure 5 shows the graph of the annual variation of the average equivalent-effective air temperature for the studied stations for the period of 2010 – 2020.

According to the Missenard method, the average monthly values of human thermal sensitivity range from "comfortably warm" in summer to dangerous "frostbite threat" in winter months. In winter, the average EET values vary from -29.3 °C (Emba) to -10.2 °C (Aktau). In summer, the spatial variability of the EET is two times lower: the minimum values are typical for the northern stations (Uralsk, Emba, Aktobe) from +15.6 to +18.4 °C ("comfortable" conditions), the maximum values were observed in Aktau and Atyrau (+18.5 to 21.1 °C) ("comfortably warm" conditions). The spatial distribution of the index within the region repeats the distribution of the temperature and the ET index.

Figure 6 shows the graph of changes in the average monthly EET for January and July for the period 2010-2020.

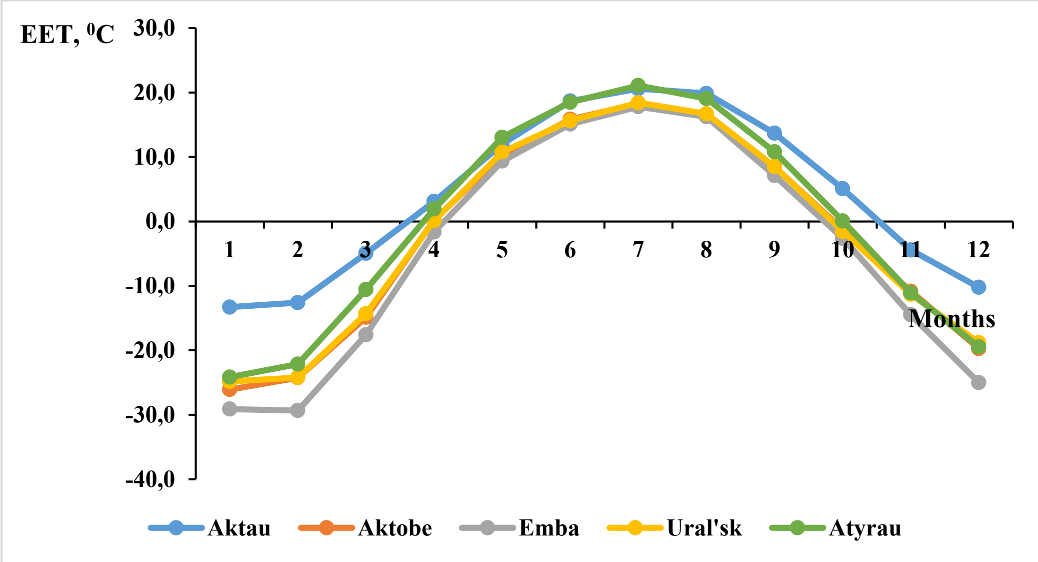

Figure 5 – Annual variation of the average equivalent-effective air temperature for considered stations in West Kazakhstan

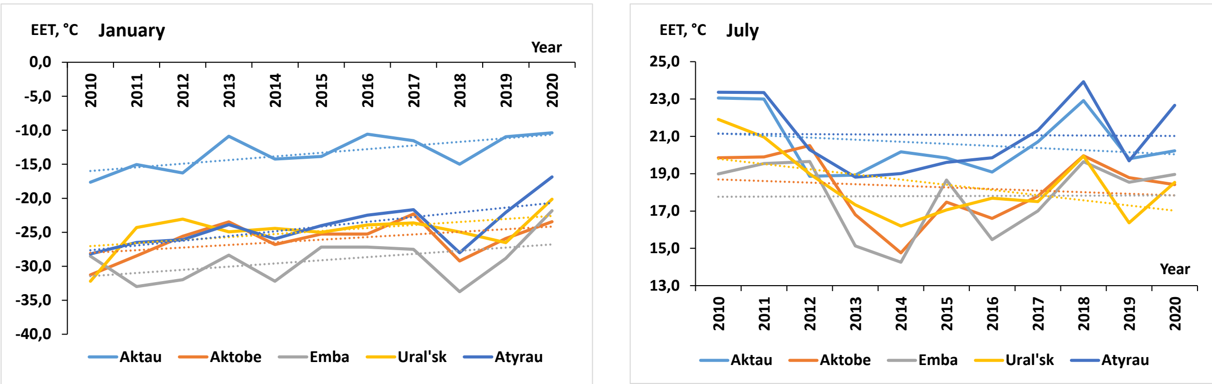

Figure 6 – Changes in the average January and average July equivalent-effective temperature (EET) for considered stations in West Kazakhstan (2010-2020)

From the Figure 6, it follows that in January, at all the stations under study, as it was with the case of ET, there is a positive trend in EET values. In July, almost all stations have a negative trend of EET values, with the exception of Emba station. The time course of the average January and average July EET values is analogous to the time course of the ET.

Figure 7 shows the annual distribution of the average normal equivalent-effective air temperature for the stations under consideration for the period 2010-2020.

It should be noted that the values of the NEET significantly exceed the corresponding values of the EET for the same annual course. The cold period of the year (October-April) is characterized by negative NEET values. Thus, in winter, according to the NEET value, Aktobe, Emba, Uralsk, Atyrau are in the zone of “very cold” discomfort, while Aktau is in the zone of “moderate cold”. In December, January and February, the NEET values could reach -28.3, -33.1, -33.1 °C, respectively, which has negative consequences for the well-being and health of people. In the first half of spring and in the second half of autumn, West Kazakhstan is in the zone of “very cool” and “moderately cold”, only Aktau is characterized by relatively “warm” NEET values (1.4 °C and 3.6° C, respectively) and is in "moderately cool" zone. May and September are characterized as "cool" in terms of the NEET value (from 5.7 to 12.8 ° C). In all summer months, according to the NEET indicator, the climate of the region under consideration can be characterized as "comfortably warm". Consequently, the climatic conditions in the summer are favorable for a person's stay in the open air and should not cause unfavorable heat sensations.

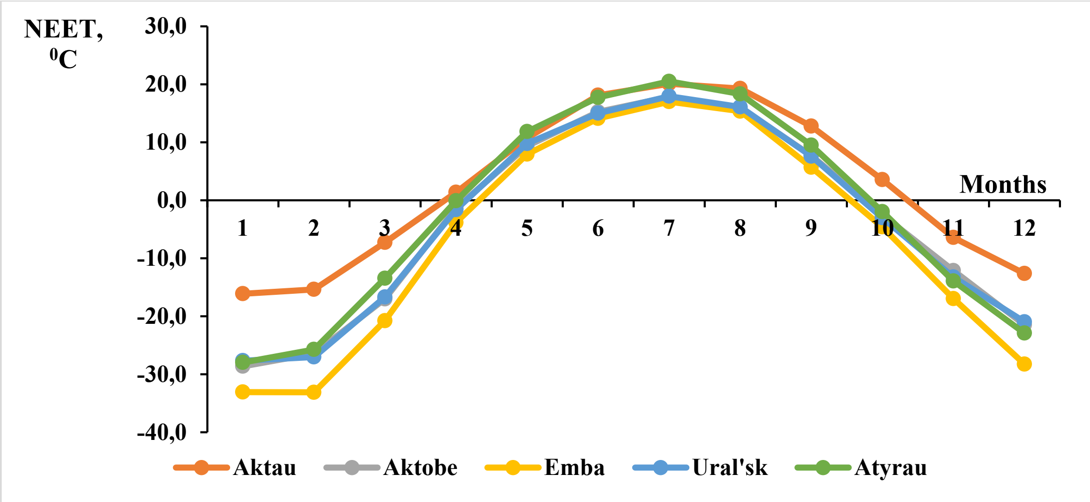

Figure 7 – Annual variation of the average normal equivalent-effective temperature for considered stations in West Kazakhstan

Figure 8 shows the time series of the average monthly Normal Equivalent-Effective Temperature (NEET) for January and July for 2010-2020.

Recently, there has been an increase in the trend of the NEET values for January, while in July there is no pronounced change in the trend. This result is similar to the results of studies conducted in other regions (Perevedentsev, 2016; Nysanbayeva, 2019).

Table 4 shows the average values of the Bodman Severity Index, calculated for the cold season months from 2010 to 2020 for stations in West Kazakhstan.

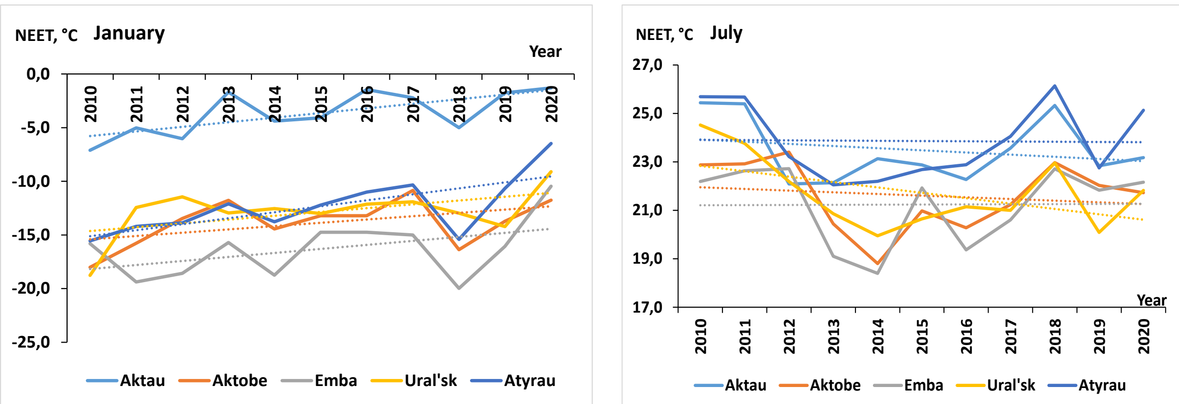

Figure 8 – Changes in the average January and average July normal equivalent-effective temperature (NEET) for considered stations in West Kazakhstan (2010-2020)

Table 4 – Average values of the Bodman Index for considered stations in West Kazakhstan from 2010 to 2020

Stations	January	February	March	October	November	December
Aktau	2,1	2,0	1,6	0,9	1,5	1,9
Aktobe	2,6	2,4	2,0	1,2	1,7	2,9
Emba	3,3	3,2	2,5	1,5	2,1	2,8
Uralsk	2,6	2,6	2,0	1,2	1,8	2,2
Atyrau	3,0	2,9	2,3	1,4	2,2	2,7
Average	2,7	2,6	2,1	1,2	1,8	2,5

Most of West Kazakhstan during the winter period is characterized as moderately severe by the Bodman Index (S = 1.9-3.0). During the study period, among all stations, Emba stands out with its highest values of the S index, for example, the average monthly value of S was 3.2 and 3.3 in January and February could be associated with significant wind speeds at low temperature values.

From the table 4, it follows that the Bodman Index in the territory of West Kazakhstan varies from 0.9 to 3.3 points with the lowest values in Aktau and Emba for the entire cold period of the year. The winter months are characterized by the highest values of the severity index. For example, the average value of the Bodman Index for West Kazakhstan is 2.4, 2.7, 2.5 for December, January and February, respectively, while in October and November these values were 1.3 and 2.0. Thus, the bioclimatic conditions of the cold half of the year in this territory are characterized as low and moderately severe.

Table 5 shows the average values of the Reduced Temperature, calculated for the cold season months from 2010 to 2020 for considered stations in West Kazakhstan.

Table 5 – Average values of the Reduced Temperature considered stations in West Kazakhstan from 2010 to 2020

Station	Months					
	January	February	March	October	November	December
Aktau	-3,6	-3,1	2,6	9,9	2,5	-1,7
Aktobe	-16,0	-15,1	-7,0	3,2	-5,0	-11,8
Emba	-15,4	-16,1	-7,3	3,3	-5,9	-13,6
Uralsk	-14,2	-13,6	-6,3	3,7	-3,9	-10,0
Atyrau	-10,5	-9,8	-1,7	6,0	-2,2	-7,6
Average	-11,9	-11,5	-3,9	5,2	-2,9	-8,9

According to the values of the Reduced Temperature, there were no severely uncomfortable conditions in the West Kazakhstan region. The lowest values of the Reduced Temperature of Khairullin-Adamenko were observed in January (from -3.6 to -16 °C) at all stations, except for Emba, where the minimum is in February (-16.1 °C). Among all considered stations, the minimum values were observed at Aktobe and Emba stations during the cold season. In January and February in Uralsk, Emba and Aktobe the given temperatures were considered to be relatively favorable. At other stations in the remaining months, the index indicates the favorable climate of the region.

Conclusion

Active synoptic activity during the cold half of the year in West Kazakhstan can form uncomfortable conditions, which were confirmed by the results of this work based on values of ET, EET, NEET, Bodman's Index, Reduced Temperature.

ET, EET and NEET indices show that during the cold half of the year (October-April), the northern part of the West Kazakhstan is in the "very cold" zone, while the southern part (Aktau) is in the "moderate cold" zone. Very low values of these indices in the northern part of West Kazakhstan can lead to negative consequences for the well-being and health of people. In the first half of spring and in the second half of autumn, West Kazakhstan is in the zone of "very cool" and "moderately cold", only Aktau is characterized by "warmer" values of ET, EET and NEET. May and September are characterized as "cool" months. In all summer months, according to the indicators of ET, EET and NEET, the climate of the studied region can be described as "comfortably warm". Therefore, the climatic conditions in the summer are favorable for a person's stay in the open air and should not cause unfavorable heat sensations.

According to the calculated values of the Bodman Severity Index for the cold period of time (October-March), it was found that the Bodman Index in the territory of West Kazakhstan varies from 0.9 points to 3.3 points. In general, the bioclimatic conditions of the cold half of the year in the study area are characterized as low and moderately severe.

Based on the obtained results, the climate of West Kazakhstan from the first half of April to October, when the average monthly values of ET are above 12 °C, can be called comfortable for the population of this region. Bioclimatic conditions of West Kazakhstan vary significantly from season to season and knowledge of climatic features makes it possible to choose the optimal conditions for people to live in a particular zone. The values of the Reduced Temperature indicate favorable climatic conditions in the West Kazakhstan region.

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