IRSTI 39.19.31 https://doi.org/10.26577/JGEM.2023.v68.i1.06

Zh. Mustafayev , A. Tuletayev* , A. Kuderin

Institute of Geography and Water Security, Kazakhstan, Almaty
*e-mail: hat_0512@mail.ru

ASSESSMENT OF THERMAL AND NATURAL MOISTURE PROVISION IN TERRITORY OF TURKESTAN REGION OF THE REPUBLIC OF KAZAKHSTAN IN CHANGING CLIMATE CONDITIONS

The assessment of natural moisture availability of the natural areas of the Turkestan region of the Republic of Kazakhstan for 1941-2020 (by providing a comparative analysis of indicators for 1941-1960 and 2001-2020) was conducted based on the use of the natural moisture coefficient and hydrothermal index or "dryness index" predicated on energy resources (total of biologically active air temperatures above 10 °C, photosynthetically active radiation, evaporating capacity and water consumption of agricultural land). The results of a comparative analysis of climatic indices changes in the natural areas of the Turkestan region for 1941 to 2020 have shown that there is an increase in average annual air temperatures in all natural areas, and the annual precipitation tends downward which affects the formation of energy resources and natural water supply. The identified features of changes in the natural moisture coefficient and hydrothermal index or "dryness index" in natural area of Turkestan region, make it possible to adjust the spread of its boundaries and consider these changes in the territorial organization of agricultural nature management.

Key words: Climate change, air temperature, energy resources, natural moisture coefficient, hydrothermal index.

Ж.С. Мустафаев, А.Б. Тулетаев*, А.А. Кудерин

География және су қауіпсіздігі институты, Қазақстан, Алматы қ.
*e-mail: hat_0512@mail.ru

Өзгермелі климаттық жағдайларда Қазақстан Республикасы Түркістан облысы аумағының табиғи жылу және ылғалмен қамтамасыз етілуін бағалау

Қазақстан Республикасы Түркістан облысының табиғи аймақтарының 1941-2020 жылдардағы табиғи сумен қамтамасыз етілуіне (1941-1960 және 2001-2020 жж. кезеңдеріндегі көрсеткіштерге салыстырмалы талдау жүргізу арқылы) энергетикалық ресурстарға негізделген табиғи ылғалдану коэффициентін және гидротермиялық көрсеткішті немесе «құрғақтық индексін» пайдалану негізінде (ауаның биологиялық белсенді температурасының сомасы 10 °С-тан жоғары, фотосинтетикалық белсенді радиация, булану және ауыл шаруашылығы алқаптарын су тұтынуы) бағалау жүргізілді. 1941-2020 жылдар аралығында Түркістан облысының табиғи аймақтарындағы климаттық көрсеткіштердің өзгерістерін салыстырмалы талдау нәтижелері барлық табиғи аймақтарда ауаның орташа жылдық температурасының артуы байқалғанын, ал, жылдық атмосфералық жауын-шашынның төмендеу үрдісі байқалғанын көрсетті, бұл энергетикалық ресурстар мен табиғи сумен қамтамасыз етудің қалыптасуына әсер етеді. Түркістан облысының табиғи аймақтарында табиғи ылғалдану коэффициенті мен гидротермиялық көрсеткіш белгілерінің немесе «құрғақтық индексінің» өзгеру ерекшеліктерін анықтау олардың шекараларының таралуын түзетуге және ауыл шаруашылығы табиғатын пайдалануды аумақтық ұйымдастыру кезінде берілген өзгерістерді ескеруге мүмкіндік береді.

Түйін сөздер: Климаттың өзгеруі, ауа температурасы, энергия ресурстар, табиғи ылғалдылық коэффициенті, гидротермиялық индекс.

Ж.С. Мустафаев, А.Б. Тулетаев*, А.А. Кудерин

Институт географии и водной безопасности, Казахстан, г. Алматы.
*e-mail: hat_0512@mail.ru

Оценка природной тепло- и влагообеспеченности территории Туркестанской области Республики Казахстан в изменяющихся климатических условиях

Проведена оценка естественной водообеспеченности природных зон Туркестанской области Республики Казахстан за 1941-2020 годы (с проведением сравнительного анализа показателей за периоды 1941-1960 и 2001-2020 гг.) на основе использования коэффициента естественного увлажнения и гидротермического показателя или «индекса сухости», базирующихся на энергетических ресурсах (сумма биологически активных температур воздуха выше 10 °С, фотосинтетически активная радиация, испаряемость и водопотребление сельскохозяйственных угодий). Результаты сравнительного анализа изменений климатических показателей в природных зонах Туркестанской области за 1941-2020 гг. показали, что наблюдается возрастание среднегодовых температур воздуха во всех природных зонах, а годовые атмосферные осадки имеют тенденцию к снижению, что оказывает влияние на формирование энергетических ресурсов и естественной водообеспеченности. Выявленные особенности изменения коэффициента естественного увлажнения и гидротермического показателя или «индекса сухости» в природных зонах Туркестанской области позволяют скорректировать распространение их границ и учитывать данные изменения при территориальной организации сельскохозяйственного природопользования.

Ключевые слова: изменение климата, температура воздуха, энергоресурсы, коэффициент естественной увлажненности, гидротермический индекс.

Introduction

One of the main functions of climate is to support the life activities of the soil and vegetation cover of landscape systems in different natural-geographical zones, which differ in the quantitative values of the average annual air temperature and annual atmospheric precipitation, characterizing the energy resources and moisture content of the territory. At the same time, the moisture content of the territory, as a function of climatic indicators, directly depends on the annual atmospheric precipitation and, in turn, on the average annual air temperature, which determines their relative instability in space-time scales and, taking into account territorial differences, acquires important practical significance as a basis for nature management and at the same time is a difficult task due to the need to take into account interrelated factors of the natural system.

Temperature increases, reduced precipitation and increased evaporation in Central Asia, documented in several studies (Xu, 2016: 395-400; Yin, 2016: 378-382; Sheffield and Wood, 2008: 86-93), increase the sensitivity of natural areas to droughts because of limited water resources, low-adaptive capacity and growing population (Qi, 2012: 115-118; Patrick, 2017: 95). The climate changes in the territory of Kazakhstan, located in the northern part of Central Asia, have occurred somewhat faster in recent decades compared to other regions of the world situated in the same latitudinal zone (Zheleznova, 2022: 144; Karatayev, 2022: 28): the rate of change in average annual air temperatures over the past 20 years at all meteorological stations has increased from 0.8 to 2.2 °C. Such changes can also impact erosion and salinization, the principal processes of desertification (Lal, 2012: 212). Soil salinization is a global environmental concern that can negatively affect sustainable land use, crop land productivity, and food security.

In the conditions of global climate change, in order to neutralize the negative impact of climatic indicators and ensure favorable conditions for territorial organization of agricultural nature management (Aldazhanova, 2022: 1187, Viana, 2022: 806), forecasts of natural thermal and moisture supply and trends in the development of this process in spatial and temporal scales in terms of natural and geographical zones and administrative regions serve as a means of ensuring food and feed security in the region (Wang, 2020: 137-139; Yu, 2019: 5-10).

The purpose of the research is to obtain scenario-based forecasts of changes in natural heat and moisture availability and its annual indicators' variability under possible climate change and the development trend of this process in territories characterized by different natural conditions.

The Turkestan region of the Republic of Kazakhstan located in the northwestern part of Central Asia in the basin of the Syrdarya River, with an area of 11 609.4 thousand ha, is taken as the object of study. The total area of all agricultural lands is 10 043.4 thousand ha, including 926.4 thousand ha of arable land, 38.3 thousand ha of perennial plantings, 94.9 thousand ha of hayfields, 120.2 thousand ha of fallow land and 8 863.6 thousand ha of pastureland (Consolidated report, 2021: 56).

Materials and Methods

Study area. The research is concerned with the natural area of Turkestan region of the Republic of Kazakhstan. The region is located in the southern part of the Republic of Kazakhstan. The following natural zones are distinguished on the territory of the region with an area of 116 094 km^2 (4.3 % of the territory of the Republic of Kazakhstan): forest-meadow-steppe zone of mid-mountains; steppe zone of low-hill terrain and midlands; semi-arid zone of foothills; arid zone of foothills, lowland and high land plains. All natural areas are characterized by a variety of natural and climatic conditions. The region's climate is sharply continental.

Data sources. The time series of the average annual temperature and annual precipitation indicators for 1941-2020 by sixteen weather stations represented in the following analytic databases: Kazgidromet RSE (Kazgidromet, 2021), World Meteorological Organization (WMO, 2021) and in the "Weather and Climate" reference and information portal have been used as information support to assess the natural moisture availability of natural zones of the Turkestan region of the RK (http://www.pogodaiklimat.ru/).

The initial information for the allocation of natural areas of the Turkestan region was: materials of the field landscape research of contributors, landscape map of the Republic of Kazakhstan.

Methods. The following indicators were used to assess the moisture availability of natural areas in the Turkestan region (Mustafayev and Ryabtsev, 2012: 212-214):

– natural moisture coefficient ($К_у$), enabling to assess the heat – and water availability of the territory which was determined according to the formula 1 (Ivanov, 1941: 15):

$$К_у = О_с/Е_о, \qquad (1)$$

where $О_с$ – precipitation amount, $Е_о$ – monthly average evaporation;

– hydrothermal index or "dryness index" ($\overline{R}_i$), representing the ratio of the radiation budget (Ri) to the heat input for evaporation of precipitation ($L \cdot О_{ci}$), which was determined by formula 2 (Budyko, 1956: 256):

$$\overline{R}_i = R_i / L \cdot O_{ci}, \qquad (2)$$

where L – specific heat of evaporation assumed constant and equal to 2.5 kJ/cm^2, which, firstly, takes into account the idea of hydration (Dokuchaev, 1948: 25-29) and the provision on the value of the ratio of the radiation balance to precipitation for the characterization of moisture conditions (Grigoriev, 1966: 381); secondly – qualifies the conditions of heat and moisture availability of soil and vegetation cover; thirdly – specifies considerably the conditions of formation of soil, hydrogeological and geochemical environment and, fourthly, it allows considering the nature and intensity of human anthropogenic activity.

The following estimation integral criteria have been used to assess changes in the energy resources indicators of climate in the natural areas of the Turkestan region for 1941-1960 and 2001-2020:

– sum of biologically active air temperatures ($\sum t_c, ^\circ C$) above 10 °C, which was calculated by summing the product of average monthly air temperatures and the number of months with average monthly air temperatures above 10 °C that was determined by formula 3 (Mustafayev and Ryabtsev, 2012: 214-216):

$$\sum t_c, ^\circ C = \sum_{i=1}^{n} t_м \cdot N, \qquad (3)$$

where $t_м$ – average monthly air temperature above 10 °C; N – number of days in a month; n – number of months where the average monthly air temperature is above 10 °C;

– photosynthetically active radiation (R_i, kJ/cm^2) during the biological active period of the year, which was determined by the formula 4 (developed by the authors):

$$R_i = 4.1868 \cdot [13.39 + 0.0079 \cdot \sum t_i > 1(, \qquad (4)$$

– monthly evaporation (E_o, мм), which was determined by formula 5 (Ivanov, 1941: 15):

$$E_o = 0.0018(t_м + 25)^2(100 - \alpha), \qquad (5)$$

where $t_м$ – average monthly air temperature, °C; t_α – average monthly relative humidity, %;

– water consumption by agricultural land (vegetation and soil cover) (ET_{ci}), which was determined by formula 6 (Budyko, 1956: 256):

$$ET_{ci} = 10 \cdot R_i \cdot L^{-1}, \qquad (6)$$

where L – heat of evaporation numerically equal to 2.5 kJ/cm^3.

In the nature, annual photosynthetically active radiation (R_i) and precipitation ($О_{ci}$) qualify the material and energy environment enabling to determine the cost of solar energy for the soil formation process ($Q_{пi}$), which is determined by formula 7 (Budyko, 1956: 256):

$$Q_{пi} = R_i \cdot exp\left(-\alpha \cdot \overline{R}_i\right), \qquad (7)$$

where R_i – annual radiation balance of the soil surface (kJ/cm^2); α – index of the complete use of radiant energy in soil-forming processes, numerically equal to 0.47; $\overline{R}_i$ – "radiation dryness index" or Nesterov's fire-danger index.

The favorable conditions for developing the soil formation process in the natural environment are observed in the natural and climatic conditions, where the Nesterov's fire-danger index ($\overline{R}$) is equal to 0.9-1.0, that commonly corresponds to the area of highly productive chernozem soil formation. By reference to specific features of these natural processes, potential cost of solar energy on the soil-forming process (Q^n_{ni}) with $\overline{R}_i = 1.0$ is determined by formula 8 (Mustafayev and Ryabtsev, 2012: 216):

$$Q^n_{ni} = R_i \cdot exp(-\alpha), \quad (8)$$

In the natural environmental conditions, "excess solar energy on the soil-forming process" (ΔQ^u_{ni}), that is, the unused annual radiation balance of the soil surface (R_i) is determined by formula 9 (developed by the authors):

$$\Delta Q^u_{ni} = Q^n_{ni} - Q_{ni} = R_i \cdot exp(-\alpha) - R_i \cdot exp(-\alpha \cdot \overline{R}_i).$$

$$\Delta Q^u_{ni} = R_i[exp(-\alpha) - exp(-\alpha \cdot \overline{R}_i)] = R_i \cdot exp[-(\alpha - \alpha \cdot \overline{R}_i)];$$

$$\Delta Q^u_{ni} = R_i \cdot exp\{-[\alpha \cdot (1 - \overline{R}_i)]\} \quad (9)$$

The natural heat and moisture availability in the natural areas of the Turkestan region which has made it possible to establish the impact of climatic change on the natural moisture and heat supply of agricultural land (soil and vegetation cover) on the space-time scale is determined on the basis of the proposed integral climatic and energy indicators.

Results and Discussion

Average annual air temperature and annual precipitation of natural zones

A comparative analysis of data for the 1941-1960 and 2001-2020 periods for sixteen weather stations was conducted for identification of changes in annual average air temperature (t_i, °C) and annual precipitation (O_{ci}, mm) affecting the natural moisture and heat supply of the natural areas of the Turkestan region (Table 1).

Table 1 – Indicators of annual average air temperature (t_i, °C) and annual precipitation (O_{ci}, mm) in the natural areas of Turkestan region

Natural area	Weather bureau stations	Climatic indices					
		Average annual air temperature (t_i, °C)			Annual precipitation (O_{ci}, mm)		
		average of period		difference	average of period		difference
		1941-1960	2001-2020		1941-1960	2001-2020	
Forest-meadow steppe zone of mid-mountains	Shuyldak	7.5	6.2	-1.3	602.0	601.0	-0.1
	Tassaryk	9.3	10.2	0.8	816.0	754.0	-62.0
Steppe zone of low-hill terrain and midlands	Achisai	10.3	11.4	1.1	500.0	552.0	52.0
	T. Ryskulov	11.5	12.4	0.9	855.0	786.0	-69.0
Semi-arid zone of foothills	Shymkent	11.9	13.6	1.7	640.0	615.0	-25.0
	Kazygurt	11.3	13.6	1.3	517.0	524.0	7.0
Arid zone of foothills, lowland and high plains	Shayan	11.6	13.3	1.7	349.0	362.0	13.0
	Sholakkorgan	9.1	11.0	1.9	180.0	203.0	23.0
	Shardara	12.6	14.8	2.2	230.0	230.0	0.0
	Bugen	11.8	13.7	1.9	305.0	294.0	-11.0
	Arys	12.5	14.1	1.6	290.0	282.0	-8.0
	Bayirkum	11.7	13.6	1.9	275.0	275.0	0.0
	Turkestan	11.8	13.8	2.0	207.0	225.0	18.0
	Tasty	8.7	10.9	2.2	185.0	163.0	-22.0
	Akkum	11.3	13.1	1.8	154.0	174.0	20.0
	Kyzylkum	12.1	13.8	1.7	190.0	195.0	5.0

A comparative analysis of changes in the average annual air temperature in the natural areas of the Turkestan region for the periods considered has showed that there is an increase in this indicator in all natural areas, except for the indicator at the Shuyldak weather station (forest-meadow steppe zone of mid-mountains), where there was a decrease in the average annual air temperature by 1.3 °C, which is due to the high-altitude location of this weather station with 1984 m elevation above sea level (Ugam mountain system).

It has been established that the rate of change in the average annual air temperature in the natural areas of the region over the past 20 years (2001-2020) has significantly increased from 0.8 (Tassaryk weather station, forest-meadow steppe zone of mid-mountains) to 2.2 °C (Tasty weather station, arid zone of low-land and high plains).

From the above calculation data (Table 1), a decrease in the amount of annual precipitation in all natural areas has been established, specifically in the forest-meadow steppe zone of mid-mountains (Tassyryk weather station) by 62.0 mm, in the steppe zone of low-hill terrain and midlands (T. Ryskulov weather station) by 69.0 mm, in the semi-arid zone of the foothills (Shymkent weather station) by 25.0 mm, in the arid zone of foothills, lowland and high plains (weather stations – Bugen, Arys and Tasty) from 11 to 22 mm. It was noted that the general trend of changes in the amount of precipitation in all natural zones of the Turkestan region in recent years (2001-2020) is directed downwards.

The conducted analysis of changes in climatic indices in the natural areas of the Turkestan region in the space-time terms has allowed establishing increase in the average annual air temperature, especially during 2001-2020, which had an effect on the natural moisture availability of natural areas decreasingly since the increase of air temperature has caused expectable decreases in the annual average values of relative humidity enhancing the evaporative capacity of the natural environment.

Energy resources of natural areas climate

The conducted assessment of changes in energy resources indicators based on climatic indices (Table 1) depending on the average annual air temperature and solar radiation in the natural areas of the Turkestan region for 1941-1960 and 2001-2020 has demonstrated that (Table 2):

Table 2 – Indicators of energy resources of natural areas climate of the Turkestan region

Natural area	Weather stations	Periods	Indicators of energy resources climate			
			($\sum t_c$, $^o C$)	R_i, kJ/cm ²	E_{oi}, mm	ET_{ci}, mm
1	2	3	4	5	6	7
Forest-meadow-steppe zone of mid- mountains	Shuyldak	1941-1960	3172.2	161.0	911.0	644.0
		2001-2020	2281.3	131.5	707.0	526.0
		difference	-890.9	-29.5	-204	-118
	Tassaryk	1941-1960	3461.3	170.5	993.0	682.0
		2001-2020	3594.9	175.0	1114.0	700.0
		difference	133.6	4.5	121	18
Steppe zone of low-hill terrain and midlands	Achisai	1941-1960	3877.3	184.3	1385.0	737.0
		2001-2020	4069.3	190.7	1590.0	763.0
		difference	192	6.4	205	26
	T. Ryskulov	1941-1960	4054.0	190.2	1405.0	761.0
		2001-2020	4163.8	193.8	1438.0	775.0
		difference	109.8	3.6	33	14
Semi-arid zone of foothills	Shymkent	1941-1960	4179.5	194.3	1359.0	777.0
		2001-2020	4454.2	203.4	1526.0	814.0
		difference	274.7	9.1	167	37
	Kazygurt	1941-1960	3977.6	187.6	1280.0	750.0
		2001-2020	4435.8	202.8	1553.0	811.0
		difference	458.2	15.2	273	61

1	2	3	4	5	6	7
Arid zone of foothills, lowland and high plains	Sholakkorgan	1941-1960	3849.4	183.4	1239.0	734.0
		2001-2020	4206.3	195.2	1472.0	781.0
		difference	356.9	11.8	233	47
	Shayan	1941-1960	4301.9	198.3	1547.0	793.0
		2001-2020	4594.9	208.0	1788.0	832.0
		difference	293	9.7	241	39
	Shardara	1941-1960	4695.6	211.4	1677.0	845.0
		2001-2020	4842.6	216.2	1863.0	865.0
		difference	147	4.8	186	20
	Bugen	1941-1960	4458.0	203.5	1586.0	814.0
		2001-2020	4695.7	211.4	1799.0	845.0
		difference	237.7	7.9	213	31
	Arys	1941-1960	4537.4	206.1	1603.0	825.0
		2001-2020	4790.6	214.5	1828.0	858.0
		difference	253.2	8.4	225	33
	Bayirkum	1941-1960	4307.7	198.5	1544.0	794.0
		2001-2020	4646.5	209.7	1794.0	839.0
		difference	338.8	11.2	250	45
	Turkestan	1941-1960	4445.4	203.1	1588.0	812.0
		2001-2020	4765.8	213.7	1805.0	855.0
		difference	320.4	10.6	217	43
	Tasty	1941-1960	4035.5	189.5	1426.0	758.0
		2001-2020	4365.3	200.4	1705.0	802.0
		difference	329.8	10.9	279	44
	Akkum	1941-1960	4399.5	201.6	1560.0	806.0
		2001-2020	4671.3	210.6	1846.0	842.0
		difference	271.8	9	286	36
	Kyzylkum	1941-1960	4567.6	207.1	1603.0	829.0
		2001-2020	4851.6	216.5	1903.0	866.0
		difference	284.0	9.4	300.0	37

– in the forest-meadow steppe zone of mid-mountains (Shuyldak weather station) during the period under consideration there were decreases in: sum of biologically active air temperature values ($\sum t, ^oC$) by 890.9 °C; photosynthetically active radiation (R_i) by 29.5 kJ/cm^2; evaporation from the water surface (E_{oi}) by 204.0 mm and water consumption by agricultural land (vegetation and soil cover) (ET_{ci}) by 118.0 mm which is due to the high-altitude location of the natural area (1984 m above sea level). According to data of the Tassaryk weather station located in this natural area, but well below in the mountains (1523 m above sea level) there is already an increase in: sum of biologically active air temperatures by 133.6 °C, photosynthetically active radiation by 4.5 kJ/cm^2, evaporation from the water surface by 121.0 mm and water consumption by agricultural land (vegetation and soil cover) by 18.0 mm;

– in the steppe zone of low-hill terrain and midlands (T. Ryskulov and Achisai weather stations), there has been an increase in: sum of biologically active air temperatures from 109.8 to 192.0 °C, photosynthetically active radiation from 3.6 to 6.4 kJ/cm^2, evaporation from the water surface from 33 to 205 mm and water consumption by agricultural land from 14 to 26 mm;

– in the semi-arid zone of foothills, (Shymkent and Kazygurt weather stations), there was an increase in: sum of biologically active air temperatures from 274.7 to 458.2 °C, photosynthetically active radiation from 9.1 to 15.2 kJ/cm^2, evaporation from the water surface from 167.0 to 273.0 mm and water consumption by agricultural land from 37.0 to 61.0 mm.

– in the arid zone of foothills, lowland and high plains (Sholakkorgan, Shayan, Shardara, Bugen, Arys, Bayirkum, Turkestan, Tasty, Kyzylkum and Akkum weather stations), there was an increase in: sum of biologically active air temperatures from 147.0 to 356.9 °C, photosynthetically active radiation from 4.8 to 11.8 kJ/cm^2, evaporation from the water surface from 186.0 to 300.0 mm and water consumption by agricultural land from 20.0 to 47.0 mm.

Therefore, in the natural areas of the Turkestan region there is a positive trend of changes in the average annual air temperature and negative trend in the amount of annual precipitation which will have an impact on the productivity of agricultural land. In particular, there will be increase in the sum of biologically active air temperature values and photosynthetically active radiation since as energy resources of the climate which will drive up the evaporation from the water surface and water consumption by agricultural land (vegetation and soil cover).

Natural moisture and heat supply of natural areas

Based on the proposed integral climatic and energy indicators, the natural heat and moisture availability of the territories of the Turkestan region are determined, which allow us to establish the impact of global climate change on the natural moisture and heat supply of agricultural land on a spatio-temporal scale (Table 3).

Table 3 – Changes in the natural heat and moisture supply of agricultural lands in the Turkestan regions compared to the base period (1941-1960) and the last 20 years (1961-2020)

Natural area	Weather stations	Periods	Indicators				
			$К_{yi}$	R_i	$Q_{пi}$	Q_{ni}^{n}	ΔQ_{ni}^{n}
Forest-meadow-steppe zone of mid- mountains	Shuyldak	1941-1960	0.66	1.07	97.4	100.6	3.2
		2001-2020	0.85	0.88	87.2	82.2	-5
		difference	0.19	-0.19	-10.2	-18.4	
	Tassaryk	1941-1960	0.82	0.84	115.1	106.6	-8.5
		2001-2020	0.68	0.93	113.1	109.4	-3.7
		difference	-0.14	0.09	-2	2.8	
Steppe zone of lowhill terrain and midlands	Achisai	1941-1960	0.36	1.47	92.2	115.2	23
		2001-2020	0.35	1.38	99.6	119.2	19.6
		difference	-0.01	-0.09	7.4	4	
	T. Ryskulov	1941-1960	0.61	0.89	125.2	118.9	-6.3
		2001-2020	0.55	0.99	121.9	121.1	-0.8
		difference	-0.06	0.10	-3.3	2.2	
Semiarid zone of foothills	Shymkent	1941-1960	0.47	1.21	109.8	121.4	11.6
		2001-2020	0.40	1.32	109.2	127.1	17.9
		difference	-0.07	0.11	-0.6	5.7	
	Kazygurt	1941-1960	0.40	1.45	94.8	117.3	22.5
		2001-2020	0.34	1.55	98.0	126.8	28.8
		difference	-0.06	0.1	3.2	9.5	
Arid zone of foothills, lowland and high plains	Sholakkorgan	1941-1960	0.15	4.08	27.0	114.6	87.6
		2001-2020	0.14	3.85	32.0	122.0	90
		difference	-0.01	-0.23	5	7.4	
	Shayan	1941-1960	0.23	2.27	68.1	123.9	55.8
		2001-2020	0.20	2.30	70.6	130.0	59.4
		difference	-0.03	0.03	2.5	6.1	
	Shardara	1941-1960	0.14	3.68	37.6	132.1	94.5
		2001-2020	0.12	3.76	36.9	135.1	98.2
		difference	-0.02	0.08	-0.7	3	
	Bugen	1941-1960	0.19	2.67	58.1	127.2	69.1
		2001-2020	0.16	2.88	54.7	132.1	77.4
		difference	-0.03	0.21	-3.4	4.9	

	Arys	1941-1960	0.18	2.84	54.2	128.8	74.6
		2001-2020	0.15	3.04	51.3	134.1	82.8
		difference	-0.03	0.20	-2.9	5.3	
	Bayirkum	1941-1960	0.18	2.89	51.1	124.1	73
		2001-2020	0.15	3.05	50.0	131.1	81.1
		difference	-0.03	0.16	-1.1	7	
	Turkestan	1941-1960	0.13	3.92	32.1	126.9	94.8
		2001-2020	0.12	3.80	35.8	133.6	97.8
		difference	-0.01	-0.12	3.7	6.7	
	Tasty	1941-1960	0.13	4.10	27.6	118.4	90.8
		2001-2020	0.10	4.92	19.9	125.3	105.4
		difference	-0.03	0.82	-7.7	6.9	
	Akkum	1941-1960	0.10	5.24	17.2	126.0	108.8
		2001-2020	0.09	4.84	21.6	131.6	110
		difference	-0.01	-0.4	4.4	5.6	
	Kyzylkum	1941-1960	0.12	4.36	26.7	129.4	102.7
		2001-2020	0.10	4.44	26.9	135.3	108.4
		difference	-0.02	0.08	0.2	5.9	

The identified spatial variations in the boundaries of natural moisture and hydrothermal index in the natural areas of the Turkestan region for 1941-1960 and 2001-2020 are shown in Table 3 and Figure 1-2, that have an impact on energy cost for the soil formation:

– in the forest-meadow steppe zone of mid-mountains (Shuyldak weather station), a natural moisture coefficient has increased by 0.19 and the Nesterov's fire-danger index has dropped by 0.19. In the area of Tassaryk weather station location, natural moisture coefficient has decreased by 0.14, Nesterov's fire-danger index has increased by 0.09;

– in the steppe zone of low-hill terrain and midlands, natural moisture coefficient has decreased by 0.01 (Achisai weather station) and 0.06 (T. Ryskulov weather station), Nesterov's fire-danger index has decreased by 0.09 and 0.10 accordingly;

– in the semi-arid zone of foothills, natural moisture coefficient has decreased by 0.07 (Shymkent weather station) and 0.06 (Kazygurt weather station), Nesterov's fire-danger index (dryness index) has increased by 0.10 and 0.11 accordingly;

– in the arid zone of foothills, lowland and high plains (Sholakkorgan, Shayan, Shardara, Bugen, Arys, Bayirkum, Turkestan, Tasty, Kyzylkum and Akkum weather stations) natural moisture coefficient is prone to decrease from 0.01 (Sholakkorgan weather station) to 0.03 (Arys weather station, etc.) and the Nesterov's fire-danger index (dryness index) to the increase from 0.03 to 0.82.

Generally, in the space-time terms, in the natural areas of the Turkestan region from 1941 to 2020 there is a decrease in the coefficient of natural moisture by 15-20 %, with simultaneous increase in the Nesterov's fire-danger index (dryness index), which affects the spatial spread of the boundaries of natural areas, and requires the development of measures to ensure water security in agricultural activities, with respect to the natural and climatic differences of the Turkestan region.

The identified spatial variations in the boundaries of natural moisture and hydrothermal index in the natural areas of the Turkestan region for 1941-1960 and 2001-2020 are shown in Figure 1-2, that have an impact on energy cost for the soil formation.

The natural ($Q_{пi}$) and potential (Q_{ni}^{n}) cost of solar energy on the soil-forming process under the same conditions of the radiation balance of the soil surface (R_i) is highly correlated to the Nesterov's fire-danger index (dryness index) ($\overline{R}_i$), which is reported in our estimated calculations for the periods from 1941-1960 to 2001-2020 within the boundaries of the natural areas of the Turkestan region:

– in the forest-meadow steppe zone of mid-mountains (Shuyldak and Tassaryk weather stations), natural energy input for the soil-forming process was from 100.6 to 106.6 kJ/cm^2 (1941-1960) and from 82.2 to 109.4 kJ/cm^2 (2001-2020), there has been a decrease by 18.4 kJ/cm^2 (Shuyldyk weather station) and increase by 2.8 kJ/cm^2 (Tassaryk weather station);

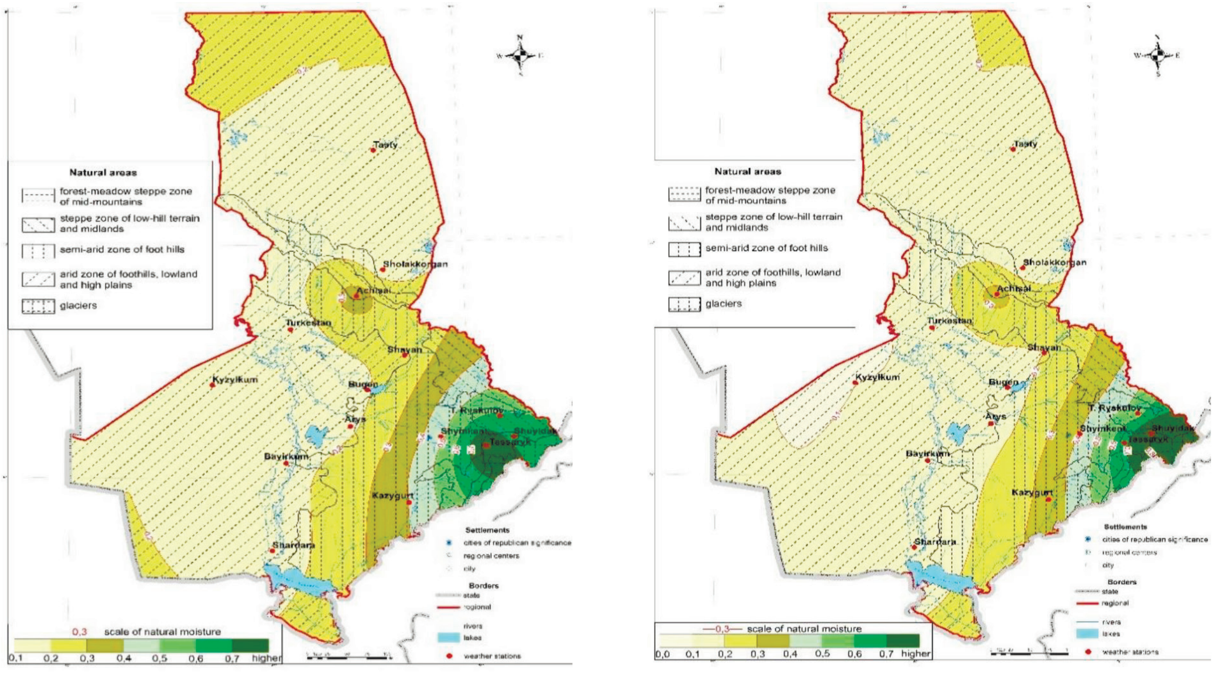

Figure 1 – Spatial variations of natural moisture boundaries in the natural areas of the Turkestan region

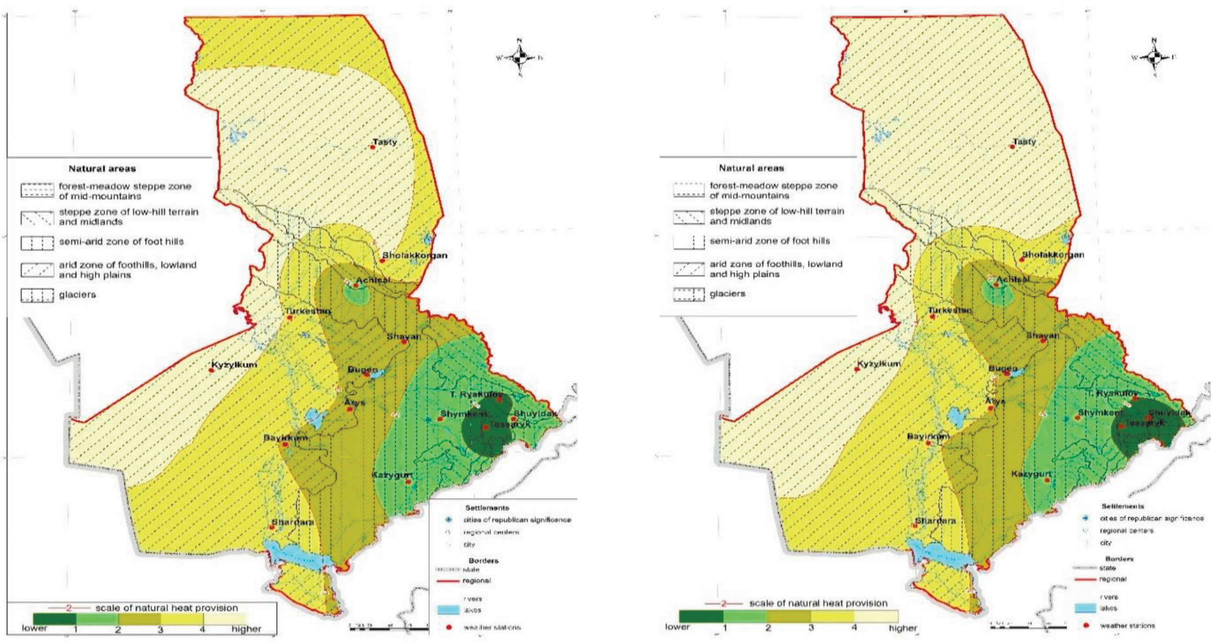

Figure 2 – Spatial variations in the boundaries of natural heat provision in the natural areas of the Turkestan region

– in the steppe zone of low-hill terrain and midlands (Achisai and T. Ryskulov weather stations), natural energy cost for the soil-forming process was from 115.2 to 118.9 kJ/cm^2 (1941-1960) and in 2001-2020 from 119.2 to 121.1 kJ/cm^2, there is an increase from 2.2 to 4.0 kJ/cm^2;

– in the semi-arid zone of the foothills (Shymkent and Kazygurt weather stations), natural energy cost for the soil-forming process was from 121.4 to 117.3 kJ/cm^2 (1941-1960) and for 2001-2020 from 126.8 to 127.1 kJ/cm^2, there is an increase from 5.7 to 9.5 kJ/cm^2;

– in the arid zone of foothills, lowland and high plains (Sholakkorgan, Shayan, Shardara, Bugen, Arys, Bayirkum, Turkestan, Tasty, Kyzylkum and Akkum weather stations) for 1941-1960, natural energy input for the soil-forming process was observed in the range from 118.4 to 129.4,0 kJ/cm^2 and in 2001-2020 – from 122.0 to 135.3 kJ/cm^2, a widespread upward trend is observed.

In general, for the natural areas of the Turkestan region, potential cost of solar energy on the soil-forming process for 1941-1960 period is observed in the range of 100.6-132.1 kJ/cm^2 and for 2001-2020 – 82.2-135.3 kJ/cm^2, and the unused annual radiation budget of the soil surface varies from 3.2 to 108.8 kJ/cm^2.

From the presented calculation data it follows that the natural moisture coefficient ($К_{yi}$) and Nesterov's fire-danger index (dryness index) ($\overline{R}_i$) indicative of heat provisions and natural energy consumption for the soil-forming process ($Q_{пi}$) in the natural areas of Turkestan region have profoundly changed, especially over the last 20 years (2001-2020). There have been quite sharp changes downwards.

Therefore, hence it appears that there is a trend of climate change in all natural areas located within the territory of the Turkestan region. In the natural areas, there is a displacement of the boundaries of distribution of natural moisture coefficient and hydrothermal index (dryness index) towards aridization, which will affect fundamentally on the formation of vegetation and soil cover, and – on the territorial organization of agricultural nature management.

Conclusion

The conducted assessment of climatic changes in the natural areas located within the territory of Turkestan region for the eighty-year period (1941-2020) has allowed to establish:

– increase in annual average air temperature (t_i, °C) in all natural areas, whereby the rate of its change over the past 20 years (2001-2020) has significantly increased from 0.8 (forest-meadow steppe zone of mid-mountains) to 2.2 °C (arid zone of foothills, lowland and highland plains). Over the past 20 years there has also been a sharp decrease in annual precipitation (O_{ci}, mm) in all natural areas, specifically in the forest-meadow steppe zone (Tassaryk weather station) by 62 mm and in the steppe zone of the low-hill terrain and midlands (weather station T. Ryskulov) by 69.0 mm;

– increase of indicators: total of biologically active air temperature ($\sum t_c, ^\circ C$) from 109.8 (steppe zone of low-hill terrain and midlands) from 458.2°C (semi-arid zone of the foothills), photosynthetically active radiation (R_i) from 3.6 to 15.2 kJ/cm^2 (same natural areas), evaporation from the water surface (E_{oi}) to 33.0 (steppe zone of low-mountain terrain and mid-mountains) to 300.0 mm (arid zone of foothills, lowland and high plains) and water consumption by agricultural land (vegetation and soil covering) (ET_{ci}) from 14.0 to 61.0 mm (same natural areas);

– decrease of the natural moisture (water availability) coefficient ($К_{yi}$) by 15-20 % with simultaneous increase in the Nesterov's fire-danger index (dryness index) $\overline{R}_i$ in all natural zones, which to some extent impacts the formation of the boundaries of natural areas;

– potential solar energy consumption for the s soil-forming process Q^n_{ni} for 1941-1960 ranges from 100.6 (forest-meadow and steppe zone of the mid-mountains) to 132.1 kJ/cm^2 (arid zone of foothills, lowland and high plains) and for 2001-2020 – 82.2 to 135.3 kJ/cm^2 (same natural areas) where the unused annual radiation balance of the soil surface ranges from 3.2 to 108.8 kJ/cm^2.

The identified climatic changes of natural moisture coefficient and indicator of heat and water availability in the natural areas of Turkestan region allow agricultural formations, especially farming enterprises, to arrange the sustainable agricultural natural resource use, determine the optimal cropping pattern of agricultural crops.

Acknowledgements

This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14869663 – To develop scientific and applied foundations of landscape-agroecological regionalization of Turkestan region for the balanced land use) (2022-2024 years).

References

Aldazhanova G., Beissenova A., Skorintseva I., Mustafayev Zh. and Aliaskarov D. Assessment of land resources of the Zhambyl region as the basis of recreation development and food security of the Republic of Kazakhstan // GeoJournal of Tourism and Geosites. – 2022. – №4. – P. 1183–1189.

Budyko M. Teplovoj balans zemnoj poverhnosti [Thermal balance of the earth's surface] // Gidrometeoizdat. – 1956. – P. 256. (in Russian)

Consolidated analytical report on the state and use of land in the Republic of Kazakhstan // Nur-Sultan. – 2021. – P. 56.

Dokuchaev V. Uchenie o zonah prirody [The doctrine of the zones of nature] // Moscow: Geografgiz. – 1948. – P. 20–30. (in Russian)

Grigoriev A. Zakonomernosti stroenija i razvitija geograficheskoj sredy [Patterns of the structure and development of the geographical environment] // Selected theoretical works. Mysl'. – 1966. – P. 381.

Information and reference portal "Weather and climate". URL: http://www.pogodaiklimat.ru/

Ivanov N. Zony uvlazhnenija zemnogo shara [Humidification zones of the globe] // Proceedings of the Academy of Sciences of the USSR. Series of geography and geophysics. – 1941. – №3. – P. 15. (in Russian)

Karatayev M., Clarke M., Salnikov V., Bekseitova R. and Nizamova M. Monitoring climate change, drought conditions and wheat production in Eurasia: the case study of Kazakhstan // Heliyon. – 2022. – №1. – P. 28.

Kazgidromet. Annual Bulletin of monitoring the state and climate change in Kazakhstan. The national hydrometeorological service of the Republic of Kazakhstan. – 2021. – P. 13–60. URL: https://www.kazhydromet.kz/en/

Lal R. Climate change and soil degradation mitigation by sustainable management of soils and other natural resources // Agricultural Research. – 2012. – №3. – P. 199–212.

Mustafaev Zh. and Ryabtsev A. Methodologicheskie osnovy adaptivno-landshaftnoj melioracii [Methodological foundations of adaptive landscape reclamation] // Bulletin of the Kyrgyz State University of Construction, Transport and Architecture named after N. Isanov. – 2012. – №3. – P. 210–216. (in Russian)

Patrick E. Drought characterization and management in Central Asia region and Turkey // FAO Water Reports. – 2017. – №44. – P. 95.

Qi J., Bobushev T., Kulmatov R., Groisman P. and Gutman G. Addressing global change challenges for Central Asian socio-ecosystems // Frontiers of Earth Science. – 2012. – №2. – P. 115–121.

Sheffield J. and Wood E. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations // Climate dynamics. – 2008. – №1. – P. 79–105.

Viana C., Freire D., Abrantes P., Rocha J. and Pereira P. Agricultural land systems importance for supporting food security and sustainable development goals: A systematic review // Science of The Total Environment. – 2022. – P. 806.

Wang J., Gao X., Zhou Y., Wu P. and Zhao X. Impact of conservation practices on soil hydrothermal properties and crop water use efficiency in a dry agricultural region of the Tibetan plateau // Soil and Tillage Research. – 2020. – №10. – P. 136–145.

World Meteorological Organization. – 2021. URL: https://public.wmo.int/en

Xu H., Wang X., Zhang X. Decreased vegetation growth in response to summer drought in Central Asia from 2000 to 2012 // International journal of applied earth observation and geoinformation. – 2016. – №52. – P. 390–402.

Yin G., Hu Z., Chen X. and Tiyip T. Vegetation dynamics and its response to climate change in Central Asia // Journal of Arid Land. – 2016. – №3. – P. 375–388.

Yu Y., Pi Y., Yu X., Ta Z., Sun L., Disse M. and Yu R. Climate change, water resources and sustainable development in the arid and semi-arid lands of Central Asia in the past 30 years // Journal of Arid Land. – 2019. №1. – P. 1–14.

Zheleznova I., Gushchina D., Meiramov Z. and Olchev A. Temporal and Spatial Variability of Dryness Conditions in Kazakhstan during 1979-2021 based on Reanalysis Data // Climate. – 2022. – №10. – P. 144.