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SPATIO-TEMPORARY CLIMATE VARIABILITY AND THEIR MANIFESTATIONS IN THE WATERSHED OF THE ASSA-TALAS RIVER BASIN

To predict current climate changes and their manifestations in the watershed of the Assa-Talas river basin, a research base has been created based on many years of information and analytical materials from RSE «Kazhydromet» and «Kyrgyzhydromet», the World Meteorological Organization (WMO), the reference and information portal «Weather and Climate», allowing to study trends on a spatio-temporal scale. Based on the established research base for the weather stations Susamyr, Talas, Kyzyl-Adyr, Nurlykent, Taraz, Saudakent and Oyyk, located in the catchment areas of the Assa-Talas river basin, graphs of time series of average annual air temperatures and annual precipitation amounts were constructed using classical and modern methods mathematical statistics based on standard application packages of digital technology and equations of their linear trend were obtained, which made it possible to develop a mathematical model of the growth rate of climatic and hydrological indicators, which has a fairly high physical and mathematical meaning, based on the law of nature.

An analysis of the growth rate of climatic indicators in the catchment area of the Assa-Talas River basin shows that their quantitative values for all meteorological stations do not coincide, that is, in modern conditions, the growth rate of average annual air temperatures in comparison with the growth rate of annual precipitation is twice as high, which contributes to increasing the shortage of water consumption of natural and cultivated agricultural land up to 25% and reducing the surface hydrological runoff up to 15% in comparison with the middle of the twentieth century, ensuring the water security of the region.

Key words: climate, forecast, change, air temperature, precipitation, linear trend, growth rate, model, law.

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Асса-Талас өзенінің су жинау алабындағы климаттың кеңістіктік-уақыттық өзгергіштігі және оның аймақтағы көріністері

Асса-Талас өзенінің су жинау алабындағы климаттың өзгеру бағыты және оның аймақтағы көріністерін уақыт-кеңістік масштабында болжау мақсатында «Қазгидромет» және «Қырғызгидромет» РМӨ-нің, Бүлікәлемдік Метеорологиялық Ұжымның (БМҰ) және «Ауа-райы және климат» анықтамалық-ақпараттық порталдың көпжылдық ақпараттық-талдау мәліметтерінің негізінде, зерттеу қоры құрылған. Асса-Талас өзенінің су жинау алабының аймағында орналасқан Сусамыр, Талас, Қызыл-Адыр, Нұрлыкент, Тараз, Саудакент және Ойық метеорологиялық бекеттер бойынша құрылған зерттеу қорының негізінде, стандартық цифрлық технологияларды қолдану бағдарламаларының пакеттеріне негізделген математиикалық статистиканың классикалық және заманауи әдістерін пайдалану арқылы, орташа жылдық ауа температурасы және жылдық атмосфералық жауын-шашынның уақытша қатарының сызбалық сұлбасы тұрғызылған және жоғары дәрежедегі физикалық және математикалық мағанаға ие, табиғи заңдылықтарға негізделіп құрылған сызықтық трендтердің теңдеулердің негізінде, климаттық және гидрологиялық көрсеткіштердің өсу қарқынының математикалық моделі құрылды. Асса-Талас өзенінің су жинау алабының аймағындағы климаттық көрсеткіштердің өсу қақынынына көрсеткендей, қарастырылып отырылған барлық метеорологиялық бекеттерде, олардың сандық мәні бірдей емес, яғни қазіргі кездегі орташа жылдық ауа температурасы өсу қарқыны, жылдық атмосфералық жауын-шашынның өсу қарқынымен салыстырғанда екі есе жоғары болғандықтан, ол XX ғасырдың ортасымен салыстырғанда, аймақтың су ресурстарымен қамтамасыз ету дәрежесіне әсер етіп, табиғи және мәдени ауылшаруашылық егістік жерлерді жетіспейтін суды тұтыну шамасын 25% өсуіне және жер беті гидрологиялық ағындардың шамасын 15 % төмендеуіне алып келуі мүмкін.

Түйін сөздер: климат, бағдарлама, өзгеру, ауа температурасы, атмосфералық жауын-шашын, сызықтық тренд, өсу қарқыны, моделі, заңдылық.

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Пространственно-временная изменчивость климата и их проявления на водосборе бассейна реки Асса-Талас

Для прогноза современных изменений климата и их проявления на водосборе бассейна реки Асса-Талас создана база исследований, на основе многолетних информационно-аналитических материалов РГП «Казгидромет» и «Кыргызгидромет», Всемирной Метеорологической Организации (ВМО) и справочно-информационного портала «Погода и климат», позволяющих изучить тенденции в пространственно-временном масштабе. На основе созданной базы исследования по метеорологическим станциям Сусамыр, Талас, Кызыл-Адыр, Нурлыкент, Тараз, Саудакент и Ойык, расположенных на водосборных территориях бассейна реки Асса-Талас, с использованием классических и современных методов математической статистики, основанных на стандартных пакетах прикладных программ цифровой технологии, построены графики временного ряда среднегодовых температур воздуха и годовых атмосферных осадков и, получены уравнения их линейного тренда, которые позволили разработать математическую модель темпа прироста климатических и гидрологических показателей, имеющих достаточно высокий физический и математический смысл, базирующихся на законе природы. Анализ темпа роста климатических показателей на территории водосбора бассейна реки Асса-Талас показывает, что их количественные значения по всем метеорологическим станциям не совпадает, то есть в современных условиях темп прироста среднегодовых температур воздуха в сравнении темпа роста годовых атмосферных осадков в два раза больше, который способствует повышению дефицита водопотребления естественных и культурных сельскохозяйственных угодий до 25% и уменьшению поверхностного гидрологического стока до 15 % в сравнение середине XX века, обеспечивающих водную безопасность региона.

Ключевые слова: климат, прогноз, изменение, температура воздуха, атмосферные осадки, линейный тренд, темп прироста, модель, закон.

Introduction

Features of the formation of surface runoff, soil and vegetation cover of watersheds of river basins are mainly determined by the climatic factor, that is, the average annual air temperatures and annual precipitation, characterizing their heat and moisture supply, performing the functions of environment formation. In this regard, a comprehensive assessment of climate change in the catchment areas of river basins on a spatio-temporal scale, characterizing the activities of the natural system, is the main issue of water supply and the development trend of this process. At the same time, the need to study modern climate change is due to insufficient knowledge of their watershed areas of the Assa-Talas river basin and practical needs for reliable information on the state of the temperature and humidity regime on a spatio-temporal scale that affects the evolution of natural conditions for the formation of the productivity of landscape ecosystems.

The purpose of the study is explore the trend of climate change in the catchment areas of river basins on a spatio-temporal scale to form a research base, for the natural and climatic orientation of their environment-forming activities.

The object of research is the catchment area of the Assa-Talas river basin located in the northwest of the Kyrgyz Republic and southwest of the Republic of Kazakhstan. The Talas River is formed at the confluence of the Karakol and Uchkoshoy rivers, which form at the junction of the Kirghiz and

Talas ridges, in the lower reaches it is lost in the Muyunkum sands. The length of the Talas River is 661 km, the catchment area is 52,700 km^2. The river Assa originates from the confluence of the Kurkureu – Suu rivers, originating on the northern slope of the Talas Ala- Too and Ters, formed on the southeastern slope of Asa Karatau, the length of which is 253 km and the catchment area is 6670 km ^{2,} is the left tributary of the Talas River and flows into the desert reservoir in the Muyunkum sands (Mustafayev Zh.S. et al., 2022).

Materials and research methodology

To form the research base, long-term information and analytical materials of the Republican State Enterprise «Kazhydromet» (Scientific and applied reference book on the climate of the USSR, 1989) and «Kyrgyzhydromet» (Scientific and applied reference book on the climate of the USSR: Kirghiz SSR, 1989), the World Meteorological Organization (WMO; https://public.wmo.int/en) and the reference and information portal "Weather and Climate" (www.pogodaiklimat.ru) located on the watersheds of the Assa-Talas River basin of the meteorological stations Susamyr, Talas, Kyzyl-Adyr, Nurlykent, Taraz, Saudakent and Oyik, which are more than 81 years and include years with different natural and climatic conditions.

The assessment and determination of all statistical parameters of linear trends in the time series of climate indicators were carried out using classical and modern methods of mathematical statistics, based on standard digital technology application software packages.

Analysis of recent research and publications on the issue of climate change. There is a large number of works carried out in various continents of the globe, the administrative territories of individual countries and the catchment areas of river basins, among which the following works should be highlighted:

- Salma Khalid, Salahuddin Azad, Alia Naz, Zia ur Rahman and Arshad Iqbal (Khalid, S. et al., 2017), Barry R.G. (Barry R.G., 2001), Bhutiyani M., Kale V. and Pawar N. (Bhutiyani M. et al., 2010), Dash S., Jenamani R., Kalsi S. and Panda S. (Dash S. et al., 2007), Shrestha A.B. and Aryal R. (Shrestha A., Aryal R., 2011), where both surface and ocean temperature changes, extreme weather events, glacier melt and sea level rise, water quality and crop management practices are widely attributed to both short-term and long-term climate change, with particular emphasis on South Asia and Pakistan, India, Mongolia and the Himalaya mountain ranges;
- Mokhov I.I (2019), Kadioğlu M. (1997), where the trends of modern and regional climate changes are described using long-term data from the Arctic and various regions of Russia, Turkey using linear trends and their consequences in the 21st century;
- Hanski I. (2005), Holten J.I. (1993), where the impact of climate change on landscape fragmentation, the distribution of plant species and the natural ecosystems of Europe was studied;
- Karl T.R. and Trenberth K.E. (2003), Kawahara M. and Yamazaki N. (1999), Kaser G., Hardy D.R., Mölg T., Bradley R.S. and Hyera T.M. (Kaser G. et al., 2004), Markham A. (1996), Muhammed A., Stewart B.A., Mitra A., Shrestha K.L., Ahmed A.U. and Chowdhury A. (Muhammed A. et al., 2004) where the problems of modern climate change and their influence on the natural system of America, Japan, glaciers are considered Kilimanjarai water resources formation South Asia.

According to the results of the analysis of studies conducted in various continents of the globe, the administrative territories of individual countries and the drainage areas of river basins, it can be stated that the direction and intensity of changes in climate indicators are not the same and the conclusions are very contradictory due to the conditions for the formation of natural systems that determine the scientific and practical feasibility of their study, to create a regional base for climate research.

Research results

The climate, as a long-term regime of weather factors inherent in the geographical zones of the Planet, performing special functions – runoff formation, biomass production, soil formation and human habitat, has direct and inverse relationships in natural processes that require analysis and evaluation on a spatio-temporal scale. This functional activity of the climate determines the scientific and practical feasibility of studying the trend of climate change in order to identify their favorable and negative impacts, taking into account the interests of environmental management and nature management.

Currently natural the system has entered the active stage of "succession", i.e. the successive regular replacement of one biological community by another in connection with global climate change, within which it is possible to assess climate change in the watersheds of river basins, which are the spatial bases of nature management, requires the need to determine their favorable or negative impacts at the level of water and food security and the safety of society.

For the analysis and assessment of the climate change trend, the mean annual air temperatures (t,°C), characterizing energy resources ($\sum t > 10^oC = f(t)$) and being a function of the evaporating ($E_o = f(t)$) capacity of the natural system and annual precipitation (O_c), which are the incoming part of the water balance of the Earth's day surface, as well as the linear trend method, which is written as a linear regression equation with two free numerical indicators:

$$y(n) = a_o + a_i \cdot n, \qquad (1)$$

where $y(n)$ is the calculated value of the observation index; n is the ordinal number of the observed value; a_o and a_i – regression coefficients or a free numerical indicator.

Depending on the long-term regime of climatic indicators, that is, the average annual air temperatures (t,°C) and annual precipitation (O_c), occur in nature in the form of an increase or decrease in a linear trend characterizing the trend in changes in climatic indicators:

- positive – $t_i = a_i \cdot n_i + a_o$ and $O_{ci} = a_i \cdot n_i + a_o$;
- negative – $t_i = – a_i \cdot n_i + a_o$ and $O_{ci} = – a_i \cdot n_i + a_o$ or – $t_i = a_i \cdot n_i – a_o$ and $O_{ci} = a_o \cdot n_i – a_o$.

The study of the climate change trend in the catchment area of the Assa-Talas river basin as a model of river basins with diverse natural and climatic areas was carried out on the basis of geomorphological schematization characterizing catenary patterns (Table 1).

Table 1 – Natural and climatic zones of zoning of the catchment area of the Assa-Talas river basin based on geomorphological schematization

Natural and climatic zones		Weather station	Terrain altitude (m)
landscape class	catenary facies		
Mountain	Eluvial	Susamyr	2092.0
Foothill	Transeluvial	Talas	1218.0
foothill plain	Transaccumulative	Nurlykent	954.0
		Kyzyl-Adyr	824.0
		Taraz	655.0
southern desert	Superaqueous	Saudakent	338.0
		Oyik	336.0

Based on the created research base for the meteorological stations Susamyr, Talas, Kyzyl-Adyr, Nurlykent, Taraz, Saudakent and Oyik (Table 1), located in the catchment area of the Assa-Talas river basin using the Microsoft program Excel plots of the time series of average annual air temperatures and annual precipitation were constructed and the equations of their linear trend were obtained (Table 2, Figures 1-4).

An analysis of the long-term course of changes in climatic indicators at the Susamyr meteorological station located in the mountainous zone (eluvial facies) of the Assa-Talas river basin and its climate model indicates that for the period under consideration 1940-2020, the change in average annual air temperatures (Table 2 and Figure 1) for 81 years is 2.6180 ˚C with an intensity of 0.032 ˚C/year and annual precipitation (Table 2 and Figure 2) decreases by 36.2640 mm from 0.45 mm/year.

An analysis of the dynamics of climatic indicators for the Talas meteorological station (Table 2 and Figure 3), located in the foothill zone (transeluvial facies) of the Assa-Talas river basin, and its climate model showed that in the study area for the period under consideration of 1940-2020, changes in average annual air temperatures (Table 2 and Figure 3) for 81 years, it increased by 2.3840 ˚C with an intensity of 0.029 ˚C/year and annual precipitation increases by 24.400 mm from 0.30 mm/year.

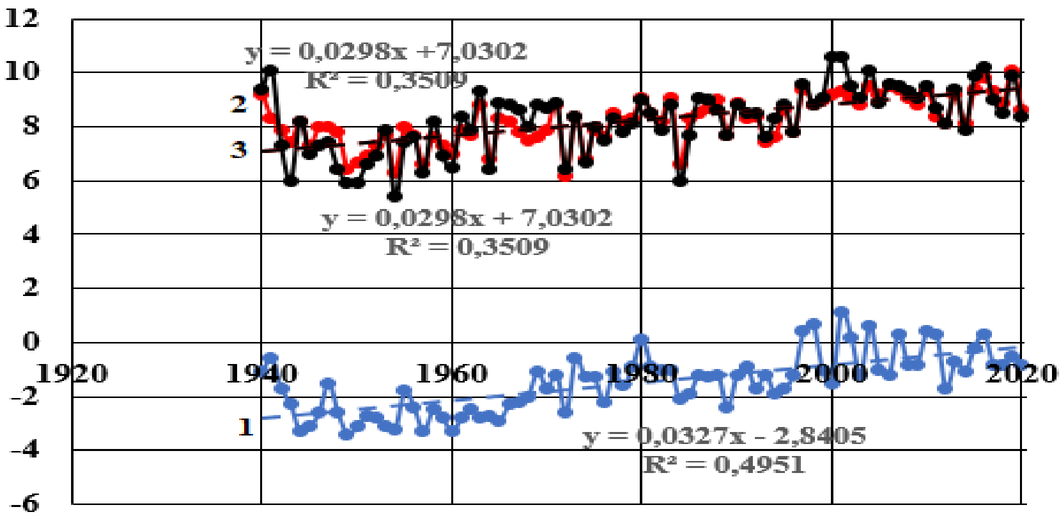

Figure 1 – Graph of changes in the average annual air temperatures of the mountain (1 – meteorological station Susamyr), foothill (2 – meteorological station Talas) and foothill plains (3 – meteorological station Kyzyl- Adyr) zones (ordinate – average annual air temperature; abscissa – years) for 1940-2020 and their linear trend

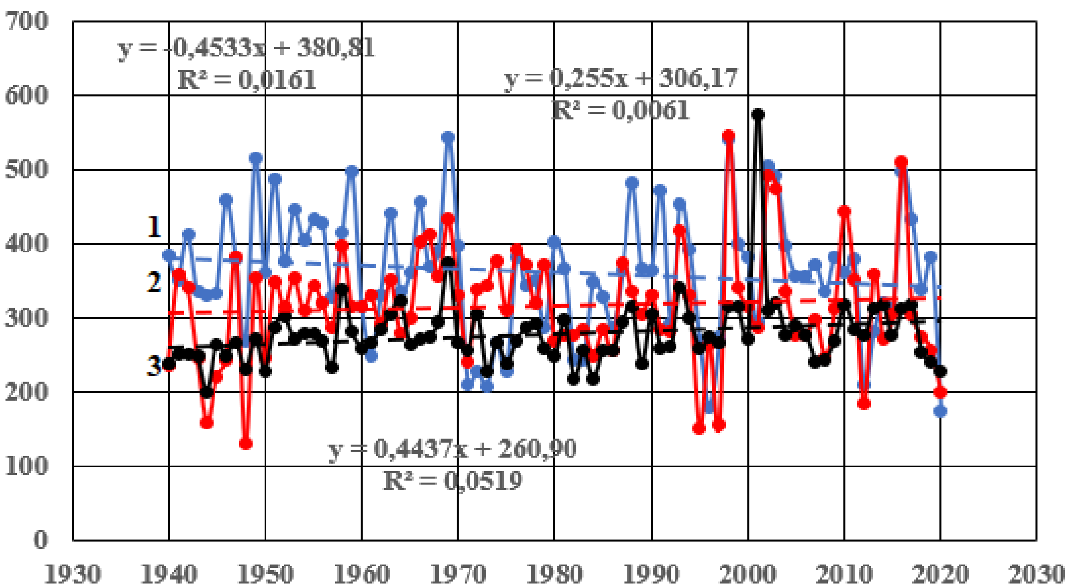

Figure 2 – Annual change chart precipitation mountainous (1- meteorological station Susamyr), foothill (2- meteorological station Talas) and foothill plain (3- meteorological station Kyzyl- Ardyr) zones (ordinate – average annual air temperature; abscissa – years) for 1940-2020 and their linear trend

An analysis of the dynamics of climatic indicators for the Talas meteorological station (Table 2 and Figure 3), located in the foothill zone (transeluvial facies) of the Assa-Talas river basin, and its climate model showed that in the study area for the period under consideration of 1940-2020, changes in average annual air temperatures (Table 2 and Figure 3) for 81 years, it increased by 2.3840 ˚C with an intensity of 0.029 ˚C/year and annual precipitation increases by 24.400 mm from 0.30 mm/year.

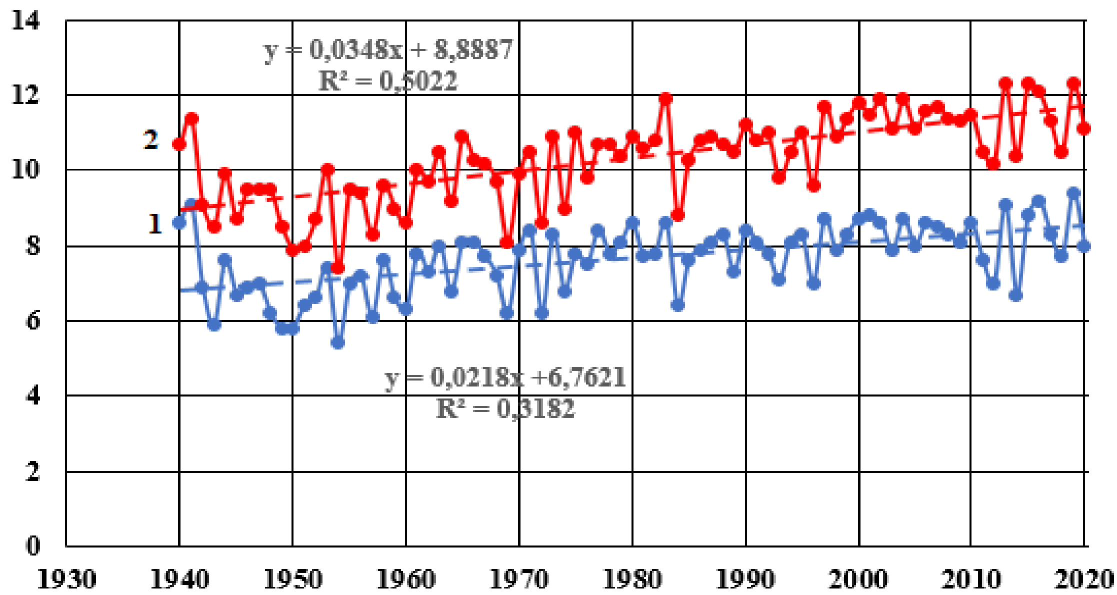

Figure 3 – Graph of changes in average annual air temperatures foothill plain zone of the catchment area of the Assa-Talas river basin (ordinate – average annual air temperature; abscissa – years; 1 -Nurlykent meteorological station; 2- Taraz meteorological station) for 1940-2020 and their linear trend

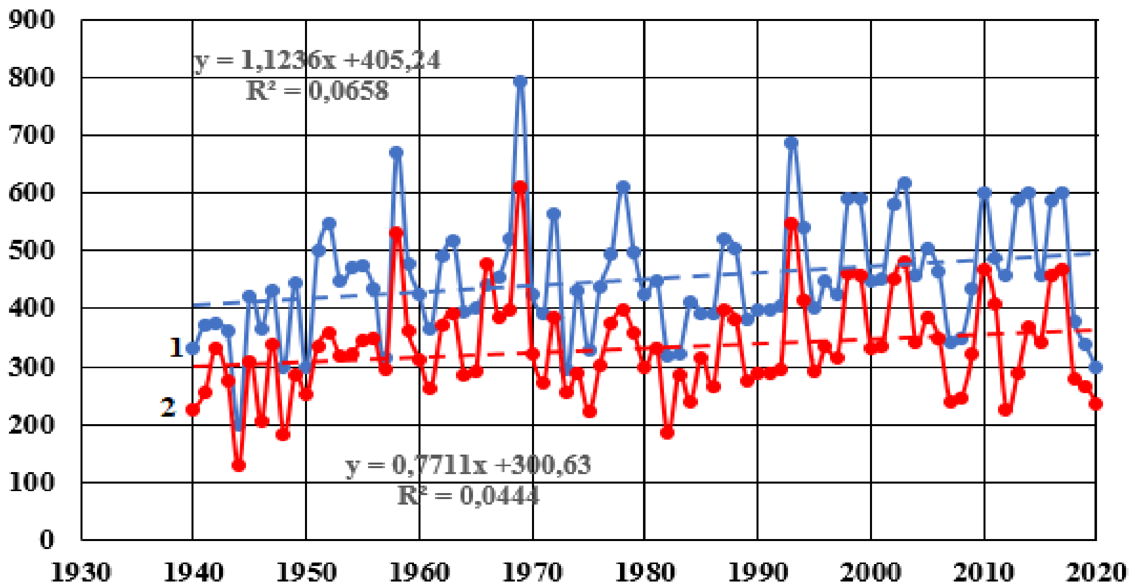

Figure 4 – Annual change chart precipitation foothill plain zone of the catchment area of the Assa-Talas river basin (ordinate – average annual air temperature; abscissa – years; 1 – Nurlykent meteorological station; 2 – Taraz meteorological station) for 1940-2020 and their linear trend

Studies conducted by the meteorological stations Saudakent and Oyik, located in the southern desert of the drainage area of the Asa-Talas river basin, which are a zone of hydrological runoff storage, showed that, despite significant variability over the years, general patterns of change in climate indicators are characteristic, that is, for the period under consideration 1940-2020 (Table 2 and Figure 5-6), respectively, the change in average annual air temperatures for 81 years is 1.880 ˚C with an intensity of 0.023 °C/year and 2.9120 °C with an intensity of 0.036 °C/year, as well as annual precipitation (Table 2) decreases by 30.740 mm from 0.379 mm/year and 72.7360 mm from 0.898 mm / year, respectively.

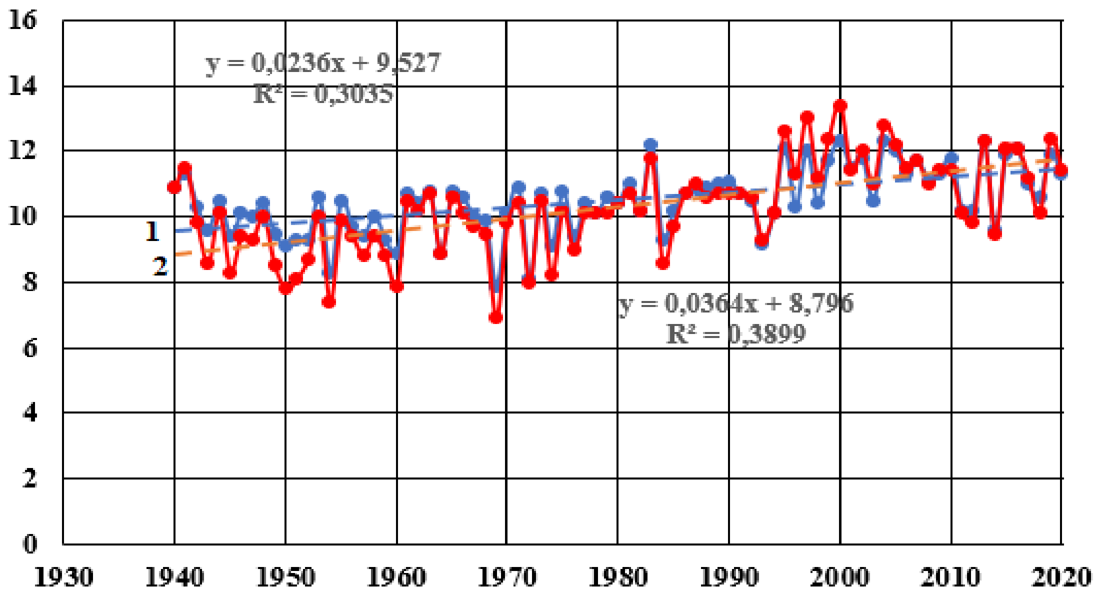

Figure 5 – Graph of changes in the average annual air temperature foothill plain zone of the catchment area of the Assa-Talas river basin (ordinate – average annual air temperature ; abscissa – years; 1 – meteorological station Saudakent; 2 – meteorological station Oyik) for 1940-2020 and their linear trend

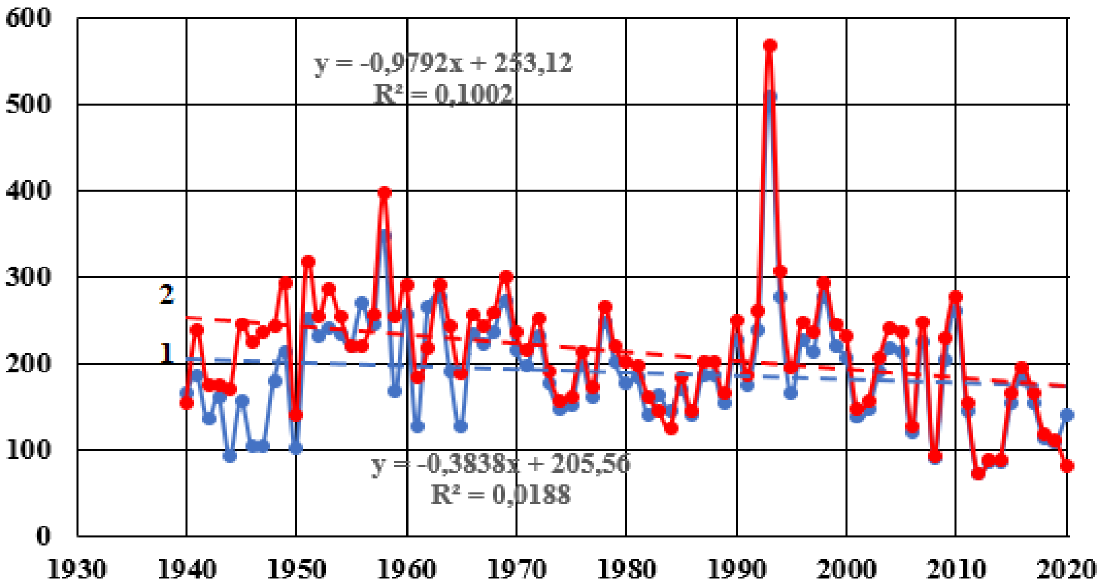

Figure 6 – Annual change chart precipitation foothill plain zone of the catchment area of the Assa-Talas river basin (ordinate – average annual air temperature; abscissa – years; 1 – Saudakent meteorological station; 2 – Oyyk meteorological station) for 1940-2020 and their linear trend

Consequently, the sharply continental, arid nature of the climate in general for the catchment area of the Assa-Talas river basin, which is smoothed out by an increase in precipitation due to the high mountain relief, is determined by its location in the Kyrgyz and Talas the ridge akh, as well as the close location of natural and artificial reservoirs and an increase in air temperatures, are associated with the close proximity of deserts and Moyinkum.

Climate change is a large-scale manifestation of natural processes that go beyond the historical balanced state of nature, inherent in individual natural and geographical zones, which depend on the growth rate of climatic indicators.

Table 2 – Regression models of climate change in the context of natural and climatic zones in the catchment area of the Assa-Talas river basin

weather station	Indicators	Linear trend equation	Change indicators	Growth rate
Susamyr	t_i, °C	$t_i = 0{,}0327 \cdot n_i - 2{,}8405$	2.6180	136.80
	O_{ci}, mm	$O_{ci} = -0{,}453 \cdot n_i + 380{,}81$	-36.2640	-27.98
Talas	t_i, °C	$t_i = 0{,}0298 \cdot n_i + 7{,}0302$	2.3840	24.35
	O_{ci}, mm	$O_{ci} = 0{,}2550 \cdot n_i + 306{,}07$	24.4000	6.24
Nurlykent	t_i, °C	$t_i = 0{,}0218 \cdot n_i + 6{,}7621$	1.7440	20.45
	O_{ci}, mm	$O_{ci} = 1{,}1236 \cdot n_i + 405{,}24$	89.8880	18.11
Kyzyl-Adyr	t_i, °C	$t_i = 0{,}0298 \cdot n_i + 7{,}0302$	2.3840	24.35
	O_{ci}, mm	$O_{ci} = 0{,}4437 \cdot n_i + 260{,}90$	35.4960	11.96
Taraz	t_i, °C	$t_i = 0{,}0348 \cdot n_i + 8{,}8887$	2.7840	23.78
	O_{ci}, mm	$O_{ci} = 0{,}7711 \cdot n_i + 300{,}63$	61.6880	16.99
Saudakent	t_i, °C	$t_i = 0{,}0236 \cdot n_i + 9{,}5270$	1.8880	16.50
	O_{ci}, mm	$O_{ci} = -0{,}384 \cdot n_i + 205{,}56$	-30.704	-17.60
Oyik	t_i, °C	$t_i = 0{,}0364 \cdot T_i + 8{,}7960$	2.9120	24.70
	O_{ci}, mm	$O_{ci} = -0{,}909 \cdot n_i + 253{,}12$	-72.7360	-40.59

The assessment of the growth rate of climatic indicators is carried out on the basis of the equation of linear trends of the time series, characterizing the average annual air temperatures and annual precipitation, allowing to determine their current and base values within the considered time series (Table 2). At the same time, the growth rate of climate indicators is determined as the ratio of the difference between the current and base values of climate indicators to the current value of the time series expressed as a percentage according to the following formulas:

$$\Delta T_t = [(t_m - t_v) / t_v] \cdot 100; \quad (2)$$

$$\Delta T_{Oc} = [(O_{cm} - O_{cv}) / O_{cv}] \cdot 100, \quad (3)$$

where ΔT_t – growth rate of mean annual air temperatures; ΔT_{Oc} – growth rate of mean annual air temperatures; t_m – current values of average annual air temperatures; O_{cm} – current value of annual precipitation; t_v – base value of average annual air temperatures; O_{cv} – base value of annual precipitation.

The evaporative capacity of the day surface (soil and vegetation cover) of the natural system depends on energy resources (temperature and air humidity deficit, radiation balance), that is, it can be represented as a mathematical function having the following form: E_o=f(t,d,R). Based on the physical nature of the evaporative capacity of the day surface (soil and vegetation cover) of the natural system, their growth rate can be represented as follows:

$$\Delta T_t = \Delta T_{Eo};$$
$$[(t_m - t_v) / t_v] \cdot 100 = [(E_{om} - E_{ov}) / E_{ov}] \cdot 100, \quad (4)$$

where ΔT_{Eo} is the growth rate of day surface evaporation; E_{om} – current values of day surface evaporation; E_{ov} – the base value of the evaporation of the day surface.

Based on the theory of water balance in the catchment area of river basins, proposed by A.I.Voeikov (Voeikov A.I., 2021), which includes a three-term equation (layers of atmospheric precipitation, river runoff, total evaporation) characterizing formation of the average annual runoff layer in the watersheds of river basins, depending on the layer of atmospheric precipitation for the year, together with the genetic theory of runoff, according to A.N. Befani (Befani A.N., 1957), can be presented in the following form: $V_c = O_c - E_o$, where V_c is the evaporation layer, mm; O_c – atmospheric precipitation layer, mm.

In this case, the water balance of the catchment area of river basins can be represented by an equation of straight lines with a correlation regression coefficient less than one in the form $Y = k \cdot X + b$ (where k is the regression coefficient; b is the free term of the equation) or $V_c = k \cdot O_c - E_o$, which allows, on the basis of the growth rate of annual precipitation (ΔT_{Oc}), to determine the growth rate of the surface runoff of the river catchment (ΔT_{Qc}), which has a functional straight-line relationship between them in the form $\Delta T_{Qc} = f(\Delta T_{Oc})$

$$\Delta T_{Qc} = \Delta T_{Oc};$$
$$[(O_{cm} - O_{cv})/O_{cv}]\cdot 100=[(O_{cm} - O_{cv})/O_{cv}]\cdot 100, \quad (5)$$

Where ΔT_{Qc} – growth rate of surface runoff in the catchment area of river basins; O_{cm} – the current value of the surface runoff of the catchment area of the river basins; Q_{cv} – the base value of the surface runoff of the catchment area of the river basins.

At the same time, the system equation of linear trends not only characterizes the mathematical meaning of long-term natural processes, but also is an indicator of the physical processes of the catchment of river basins, characterizing the growth rate of climatic and hydrological indicators.

The resulting systems of equation of linear trends in the study of climate change in the spatio-temporal scale of the catchment area of the Assa-Talas river basin, using long-term information and analytical materials of meteorological stations Susamyr, Talas, Kyzyl-Adyr, Nurlykent, Taraz, Saudakent and Oyik, differing in climatic conditions, allow us to state that the mathematical model of the growth rate of climatic and hydrological indicators proposed on the basis of them has a fairly high physical and mathematical meaning based on the law of nature.

An analysis of the growth rate of climatic indicators in the catchment area of the Assa-Talas River basin shows that their quantitative values for all meteorological stations do not coincide, that is, in modern conditions, the growth rate of average annual air temperatures is twice as high as compared to the growth rate of annual precipitation (Table 2), which contributes to an increase in the water consumption deficit of natural and cultivated agricultural land up to 25% and a decrease in surface hydrological runoff to 15% compared to the middle of the twentieth century, ensuring water security region.

Conclusions

The study of changes in climatic indicators in the catchment area of the Assa-Talas river basin showed that at the meteorological stations Susamyr, Talas, Kyzyl-Adyr, Nurlykent, Taraz, Saudakent and Oyik, the identified trends in average annual air temperatures and annual precipitation differ both in sign and magnitude. Based on them, it can be stated that the growth rate of average annual air temperatures compared to the growth rate of annual precipitation is twice as high, which contributes to an increase in the evaporative capacity of the soil and vegetation covers of the natural system, that is, the water consumption of agricultural land can become the main factor determining the conditions for the formation of river runoff, ensuring water and food security of the region.

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