Climate aridization within Chelyabinsk Region in the mid-20th and early 21th Centuries

N N Nazarenko¹, M V Panina² and M K Skudar³

¹ Department of Chemistry, Ecology and Chemistry Teaching Methods, South Ural State Humanitarian Pedagogical University, 48, Bazhov St., Chelyabinsk, Russia, 454071
² Department of Geography and Geography Teaching Methods, South Ural State Humanitarian Pedagogical University, 48, Bazhov St., Chelyabinsk, Russia, 454071
³ Lyceum No. 11, 6, Timiryazev St., Chelyabinsk, Russia, 454091

E-mail: panina80@mail.ru

Abstract. The features of spatial distribution of heat and water availability on the territory of the Chelyabinsk Region for the period of the mid-20th century and the beginning of the 21st century have been studied. The boundaries of changes in temperature zones for the indicated periods are shown, as well as changes in the boundaries of moisture in the territory and its displacement. The indices of the hydrothermal coefficients for the study area are calculated, the leading factors determining the hydrothermal coefficient for the period of active vegetation, as well as the dynamics directions are indicated. It has been established that the distribution of temperatures and precipitation in the territory of the Chelyabinsk Region is subject to seasonal fluctuations. At the same time, thermal conditions indicate tendencies for an increase in aridization of the southern territories, while humidification conditions, on the contrary, are dispersed in nature and are determined by both active atmospheric circulation and regional reasons.

1. Introduction

The resource assessment of heat and water availability of the territories is important for predicting the development of agricultural production, industrial and civil construction, as well as assessing the comfort of living conditions for the population.

At the moment these estimates are informative and technologically outdated for the Southern Urals in many respects, due to the fact that the overwhelming majority of climate reference books, cartographic materials and calculated climatic indicators are based on data up to the 60s or up to the 90s of the last century.

Meanwhile, over the past decades, for the territory of Russia in general, and in the Southern Urals, in particular, quite significant changes in climatic indicators have been noted.

Since 1976 there has been an intense warming with an average annual rate of about 0.43 °C/10 years in the territory of Russia [1]. In the period 1990–2005 the average annual air temperature increased by 0.4 °C [2].

The analysis of changes in the average annual temperature of 16 meteorological stations in the Urals also shows its growth from 2–3 °C/100 years for the south and the Trans-Urals and up to 0.7–0.8 °C/100 years for the Northern Urals [3, 4]. For the Chelyabinsk Region, the increase in temperatures is...
confirmed by the studies of 19 meteorological stations for the period of 1960–2005 [2]. An assessment of the trends in temperature changes over a longer period according to data from 5 meteorological stations shows an increase in temperature on average 1.83 °C [5].

In the course of the study, an assessment of trends in temperature changes in the Southern Urals [6] showed that there is no direct relationship between the absolute increase in temperatures and an increase in a number of dynamics, with the exception of the steppes of the Southern Urals, where there is a linear increase in temperatures. At the same time, the temperature peaks at the beginning of the 20th century for the Trans-Urals turned out to be comparable to the temperatures of the peak of the beginning of the 21st century, and for its last decade, a drop in average annual temperatures or, at least, the absence of increase is possible. Also for the Southern Urals, the nature of the distribution of temperatures and precipitation has changed [7].

In this regard, it is necessary to reevaluate the agroclimatic resources of the territory of the South Urals, and it is important to answer the question of whether the climate aridization has occurred in the territory of the Chelyabinsk region in connection with the observed tendency of an increase in average annual air temperatures.

2. Materials and methods

The study is based on the values of average monthly temperatures and average monthly precipitation for three periods. For the first period – until the beginning of the 60s – the data are taken from the Handbook on the Climate of the USSR [8]. For the second period – 1966–1978 – the data are taken from the observations of the Chelyabinsk Hydrometeorological Observatory. The third period is the data of daily monitoring of the Chelyabinsk Central Hydrometeorological Service, a branch of the Ural Department for Hydrometeorology and Environmental Monitoring. The data were processed using generally accepted statistical and climatological methods.

In modern climatology, there is no single indicator characterizing the degree of aridity (aridity) of a territory (just as there is no unified definition of the concept of “aridity” and its types). The World Meteorological Organization provides several definitions and several dozen currently used climate aridity indices [10]. In Russia and the CIS countries, such indicators as the hydrothermal coefficient of G.T. Selyaninov (HTC), the moisture coefficients of D.I. Shasko (Md), P.I. Koloskova, A.V. Protserova, N.N. Ivanova, L.S. Kelchevkaya, D.A. Brinenk, S.A. Sapozhnikova and Yu.I. Chirkov, aridity indicator of D.A. Pedya, agrometeorological humidification coefficient (AHC) [11–13]. Beside, a system is being used successfully in Russia incorporating eight indicators, including HTC, Md and reserves of productive moisture [13, 14].

At the same time, very good results in assessing climate aridity are traditionally given by the HTC calculated for the period of active growing season [15] (or for the period from May through August [16]). For the Chelyabinsk Region, the HTC was calculated for the period of active growing season, and the nature of its spatial distribution was estimated based on the results of spatial interpolation using the Inverse Distance Weighted (IDW) method [17, 18] in the Arc GIS 10.1 application package.

3. Results and Discussion

The sum of the active temperatures is one of the most important agrometeorological indicators characterizing the potential for agricultural production and the choice of leading crops for growing in the region. In addition, the sum of active temperatures is used in the calculation of HTC of Selyaninov to assess the climate aridity. The nature of the spatial distribution of the sum of active temperatures (Fig. 1) makes it possible to carry out agroecological zoning and to assess the nature of the spatial dynamics of zones of heat supply and evaporation during the active growing season.

Thus, for the period before the beginning of the 60s of the 20th century (Fig. 1a) two zones of heat supply are determined for the Chelyabinsk region having a meridional character of location.

The first zone, which occupies the flat part of the region and the southern spurs of the Ural Mountains, is determined by the average sum of active temperatures of 2000–2500 °C for the growing season, sufficient for growing mid-early varieties of grain corn and mid-season varieties of sunflower.
The second zone is typical for the mountainous and foothill territory of the region and is characterized by sums of active temperatures of 1500–2000 °C sufficient for growing grain and corn for silage. At the same time separate areas of low heat supply during the growing season are determined within the first zone (meteorological stations Zlatoust, Nyazepetrovsk and Verkhniy Ufaley).

Later on, in the 60s and 70s of the last century (Fig. 1b), the warm zone expanded significantly, covering the foothills of the Southern Urals and partly the mountainous part in the north of the Chelyabinsk Region. And the colder zone, moving to the Verkhneuralsk meteorological station in the south, acquires a meridional character, determined by the meridional ridges of the South Urals. At the same time, enclaves of the lowest heat supply are not determined in the mountainous zone.

In the modern period since the beginning of the 2000s (Fig. 1c), three zones of heat supply have already been identified. First, the cold zone continues to shrink, assuming a disjunctive (broken) character already within the mountain ranges, but at the same time the coldest enclave in the area of the Nyazepetrovsk meteorological station is being restored. The warm zone (2000–2500 °C) expands even more, entering the mountainous part of the Chelyabinsk Region along the valleys. Finally, in the south of the Region (meteorological stations Kizilskoe – Bredy – Kartaly – Troitsk), the meridional third zone of the highest heat supply is determined with the sum of active temperatures > 2500 °C, which is sufficient for growing sunflowers.

Thus, the upward trend in average annual temperatures resulted in an increase in the sum of active temperatures during the growing season. This determines more favorable temperature conditions for growing crops, both in the north of the region, including in mountainous areas, and in the south (the possibility of cultivating more heat-loving crops). In addition, the process of differentiation of temperature conditions was determined in the beginning of the 21st century and the nature of the agroecological zoning of the region has become more complicated, especially in the southern part. The distribution of precipitation during the active growing season differs sharply from the distribution of the sum of active temperatures.
Figure 1c. Spatial distribution of heat supply zones in the Chelyabinsk region (2000–2019, 20th century)

For the period before the beginning of the 60s of the 20th century (Fig. 2a), there was no zonal distribution of precipitation during the active growing season on the territory of the Region, i.e. for the entire territory of the Region an average amount of precipitation for this period was 200–300 mm.

In the 60s and 70s (Fig. 2b), such distribution of precipitation during the active growing season for the territory of the Region is preserved, but several zones of atmospheric humidification are distinguished.

First, the zone of increased precipitation in the area of the Zlatoust meteorological station (the amount of precipitation during the active growing season is 300-400 mm) is associated with the industrial development of this area. In this case, the industrial development of enterprises determines the intense emissions into the atmosphere, forming condensation nuclei, which leads to more active precipitation. Secondly, zones of low atmospheric moisture (<200 mm) during the active growing season, primarily in the area of one of the southernmost meteorological stations – Bredy.

Finally, in the modern period from the beginning of the 2000s (Fig. 2c) within the Chelyabinsk Region, there are already four zones of increased precipitation. The industrial regions of Katav-Ivanovsk, the Chelyabinsk urban agglomeration (including weather stations Argayash and Brodokalmak) and Kartalinsky are submitted to the Zlatoustovsky (includes the Miass Region).

The latter, in our opinion, is primarily associated with the activities of OJSC Novokaolin Ore Mining and Processing Plant. In addition, zones of a low precipitation level appear. The regions of the Oktyabrskoye and Mirny meteorological stations (Uysky grain state farm) are submitted to the Bredinsky. There is a tendency to decrease the level of precipitation in the southern and eastern parts of the Region.

It should be noted that the information given above highlights the regional features of the development of humidification zones, but the increase in precipitation is associated not only with objective reasons for the industrial development of the territory, dustiness of the atmosphere of large urban ‘units’, but also with factors associated with natural processes and the dynamics of atmospheric circulation. The researchers note that over the past five decades, the amount of precipitation of the convective (storm) type has increased significantly for the territory of the south of the European and Asian parts of Eurasia [19]. The greatest trends in the absolute characteristics of precipitation are noted for most regions of Eurasia in the summer period, which makes its contribution later to the calculations of HTC of the growing season. A number of reasons for the increasing role of
precipitation include the following: an increase in air temperature, which results in an increase in air humidity at the rate of saturated vapor pressure; convective instability of the atmosphere, which is an important factor in the intensity of convective precipitation; changes in the frequencies of atmospheric fronts in different seasons, an increase in the intensity of the Siberian anticyclone leads to a decrease in stratiform (uniform) precipitation.

Figure 2a. Spatial distribution of precipitation in the Chelyabinsk Region (1936–1960, 20th century)

Figure 2b. Spatial distribution of precipitation in the Chelyabinsk Region (60s and 70s, 20th century)

Figure 2c. Spatial distribution of precipitation in the Chelyabinsk Region (2000–2019, 20th century)

All these factors exhibit a combined effect with the complex orographic conditions of moistening the study area. That is why these issues require a more detailed study in order to identify local differentiations and the impact of global ones on them. Thus, the nature of the distribution of
precipitation on the territory of the Chelyabinsk Region during the active growing season is closely related to both the regional factors (with orographic conditions and industrial development of the territory, which determines the zones of excessive moisture) and the influence of general atmospheric circulation in different periods of the year.

In connection with the above-described features of the spatial distribution of the sum of active temperatures and the sum of precipitation over the growing season, the nature of the moisture conditions, in particular, the dynamics of aridization of the Region’s territory turned out to be of complex and ambiguous nature (Fig. 3a).

By the 1960s of the last century, the HTC indicators were determined exclusively by the temperature conditions of the active growing season (due to the evenness of the amount of precipitation during this period). In fact, for the Chelyabinsk Region, two humid zones were determined. The zone of excessive humidity (HTC > 1.3) occupied the northwestern part of the Region, including the mountainous, foothill and northern and part of the central lowland regions. The second zone provided with humidity (GTC 1.0–1.3) covered almost the entire remaining flat part. Thus, the entire territory of the Chelyabinsk Region in terms of heat and water availability or supply during the active growing season belonged to the forest-steppe climatic zone. The exception was two distinct areas of steppe climatic conditions in the regions of the Oktyabrskoye and Bredy meteorological stations. In the 60s and 70s of the last century, the process of aridization of the Region’s territory was manifested most clearly (Fig. 3b).

The zone of excessive humidity is shrinking and occupies the northwestern mountainous and, partially, the foothill part. The zone of moderate humidity significantly expands to the north, completely covering the northern and central regions of the Region. However, in the south, a steppe dry zone (HTC is 0.7–1.0) is clearly identified, which has a partially meridional strike and covers areas with a central line along the meteorological stations Kizilskoe – Kartaly – Varna – Troitsk – Oktyabrsksy including the southern Bredinsky Region. Thus, there is an aridization of the territory of the Region going to the northwest.

Currently the character of aridization of the territory of the Chelyabinsk Region in the northwest as well as clear zoning in terms of the level of moisture supply is violated (Fig. 3c).
4. Conclusion

Thus, the trend towards an increase in the average annual temperatures in the mid-20th and early 21st centuries resulted in an increase in the sum of active temperatures during the growing season in the Chelyabinsk Region and to an active manifestation of the process of temperature conditions differentiation and the complication of the nature of agroecological zoning of the Region. At the same time, changes in the temperature conditions of the growing season make it possible to cultivate more thermophilic crops, both in the north and in the south of the Region.

Since the 1960s of the 20th century, the tendency of aridization of the climate of the Chelyabinsk Region has been determined in the direction from the south and southeast to the north and northwest. At the same time, the determining aridity is an increase in temperatures, since until the end of the 1970s the nature of the distribution of precipitation during the period of active growing season in the region was averaged evenly with the exception of the very south where a tendency to decrease in precipitation was outlined for this period.

However, complex combinations of regional climatic factors and industrial aerosol pollution of the atmosphere lead to a sharp spatial redistribution of precipitation during the active growing season. The precipitation has increased quite sharply in industrially developed regions. This led to the fact that the nature and direction of aridization of the Region’s climate changed dramatically, i.e. the area of arid territories has decreased and the steppe climatic zone has become disjunctive and is specific for the eastern and southeastern parts of the Region.

References

[1] Frolov A V (Ed.) 2014 The second assessment report of Roshydromet on climate changes and their consequences on the territory of the Russian Federation General summary (Moscow: Roshydromet) p 61

[2] Lenskaya O Yu 2008 Features of the temperature and precipitation regime in the Chelyabinsk Region against the background of global warming Problems of the geography of the Urals and adjacent territories: Materials of the III Interregional scientific-practical. conf. (Chelyabinsk) pp 3–5
[3] Shklyaev V A and Shklyaeva L S 2006 Secular changes in air temperature in the Urals, In: Modern Geographical Research: Collection of Works of scientists geogr. Fac., dedicated to 90th anniversary of Perm State University (pp 254–265) (Perm)

[4] Shklyaev V A and Shklyaeva L S 2011 Assessment of changes in air temperature and precipitation of the Middle and Southern Urals in the 20th century Bulletin of Chelyabinsk State University Ecology. Environmental management 5(220) 61–69

[5] Pavlenko E F 2010 Trends in climate change in the Chelyabinsk Region in the era of global warming XIX Ural Biryukov Readings. Culture and education in the regions: history and modernity: Materials of the All-Russian scientific and practical conference dedicated to the Year of the teacher in Russia (Chelyabinsk: Publishing house of the CSPU) pp 560–570

[6] Nazarenko N N 2020 Models of temperature dynamics in the South Ural and adjacent territories Problems of geography of the Urals and adjacent territories: Mat. of the II Intern. Scient. and Pract. Conf. (Chelyabinsk) pp 19–25

[7] Panina M V and Nazarenko N N 2020 Spatial distribution of temperature and precipitation in the South Ural Region IOP Conf. Ser.: Earth Environ. 579

[8] 1965 Reference book on the climate of the USSR Vol 9 Part 2 Temperature of air and soil Ch. ex. Hydrometeorog service at the Council of Ministers of the USSR (Moscow: Gidrometeoizdat, Moscow branch; Ural. manag. hydrometeorol. Service; Sverdl. hydrometeorol. Observatory) 362 p

[9] 1968 Reference book on the climate of the USSR Vol 9 Part 4 Air humidity, atmospheric precipitation and snow cover Ch. ex. Hydrometeorol. service at the Council of Ministers of the USSR (Moscow: Gidrometeoizdat., Moscow branch; Perm; Sverdlovsk; Chelyabinsk; Kurgan regions and Bashkir ASSR; Ural. manag. hydrometeorol. Service; Sverdl. hydrometeorol. Observatory) 372 p

[10] 2016 Handbook on indicators and indices of drought Vol 173 (Geneva: World Meteorological Organization) p 60

[11] Gordeev A V, Kleschenko A D, Chernyakov B A and Sirotenko O D 2006 Bioclimatic potential of Russia: theory and practice (Moscow: T-in scientific publications KMK) 512 p

[12] Strashnaya A I, Maksimenkova T A and Chub O V 2011 Agrometeorological features of the 2010 drought in Russia in comparison with the previous droughts Proceedings of the Hydrometeorological Center of Russia 345 194–214

[13] Strashnaya A I, Purina I E, Chub O V, Zadornova O I and Chekulaeva T S 2013 Automated technology for monitoring and calculating the number of decades with soil and atmospheric-soil drought under grain crops Proceedings of the Hydrometeorological Center of Russia 349 150–160

[14] Zoidze E K and Khomyakova T V 2002 Fundamentals of the operational system for assessing the development of droughts and its experimental exploitation experience Works VNIISKhM 34 48–66

[15] Grigoruk V V, Ayulov A M, Dolgikh S V and Baisholanov S S 2012 Akmola region: climate and harvest (Almaty: Zhania Polygraph LLP) 88 p

[16] Baisholanov S S Pavlova V N, Zhakieva A R, Chernov D A and Gabbasova M S 2018 Agroclimatic Resources of Northern Kazakhstan Hydrometeorological Research and Forecasts 1 168–184

[17] Arilson J, Souza S, Dal P, Rodrigues E B and Souza V 2019 Mobile application for analysis of spatial variability of thermal comfort indexes of animals and people, using IDW interpolation Computers & Geosciences 34 1044–1055

[18] Lu G Y and Wong D W 2008 An adaptive inverse-distance weighting spatial interpolation technique Computers & Geosciences 34 1044–1055

[19] Chernokulsky A, Kozlov F, Zolina O, Bulygina O, Mokhov I and Semenov V 2019 Observed changes in convective and stratiform precipitation in Northern Eurasia over the last five decades Environmental Research Letters 14(4) 045001