Assessment of conditions of aridity and humidity in the growing season on the territory of Samara region

N A Mirsaeva

Institute of Environmental Sciences, Kazan Federal University, 18 Kremlyovskaya Street, Kazan, Russia

Abstract. An analysis of the spatiotemporal variability of some agroclimatic characteristics shows that aridity is growing in the region, especially in the warm period. This is more evident in the south and southwest, where droughts are more intense than in the other areas of the region. A real-time analysis of the Ivanov-Vysotsky wetting coefficient and the BEI index has not revealed any significant changes. Currently, Samara region has satisfactory agroclimatic resources with moderate and low productivity. In Samara region, there are unfavorable moisture conditions due to droughts in 2010, 2011, 2015, and 2016 and extensive heat supply.

1. Introduction
The study of climate impacts on plant life processes is becoming increasingly important due to the increasing influence on the problem of obtaining highly productive communities. The means of communication between climate and agriculture is agroclimatic information, which is based on the knowledge of climate as a resource.

Agroclimatic information is used for agroclimatic support of agriculture; in agroclimatic calculations, analyses and generalizations; in agroclimatic zoning of the territory and individual crops; in operational assessments of the current agrometeorological conditions of agricultural production, including when assessing the growth, development, and productivity of agricultural crops.

2. Description and comparison of models
This paper analyzes the conditions of aridity and moisture content of the growing season on the territory of Samara region based on the following agro-climatic indicators: the Ped aridity index (PAI), the index of biological efficiency and the moisture coefficient of G. N. Vysotsky and N. N. Ivanov. Analysis of the long-term dynamics of these indicators is carried out, and the main spatial and temporal patterns in their distribution are revealed. As initial data we used average daily data on the air temperature and precipitation at ten stations in Samara region for 1954 – 2019.

To determine the conditions of aridity and humidity of the growing season observed from May to September, the PAI (Table 1) was calculated for the territory of Samara region, which takes into account the deviation from the average value of precipitation and air temperature [1]:

\[ S_a = \frac{\Delta T}{\sigma_m} \cdot \frac{\Delta P}{\sigma_R} \]  

where \( S_a \) is the summer PAI, \( \Delta T \) and \( \Delta P \) are anomalies of the average monthly air temperatures and precipitation; \( \sigma_m \) and \( \sigma_R \) are their standard deviations.
As an indicator of aridity, the biological efficiency index (BEI) is the product of the sum of active temperatures $T>10 \, ^\circ\text{C}$ in hundreds of degrees $(0.01 \sum T>10)$ by the moisture coefficient (MC):

$$\text{BEI} = (0.01 \sum T>10) \leq \text{MC}. \quad (2)$$

The BEI synthesizes the most important climatic parameters: precipitation, temperature and relative humidity considered in their annual course, as well as annual heat supply, and expresses well the overall environmental background. The zone of ecological optimum corresponds to the BEI of order 22.

The moisture coefficient was calculated using the Vysotsky-Ivanov formula [2], it is used to identify conditions of varying degrees of aridity (Table 2).

### Table 1. Gradients of PAI ($S_0$) [1].

| Criteria $S_i$ | Weather and climate conditions |
|----------------|-------------------------------|
| $S_i \geq 3$   | Severe drought                |
| $3 > S_i > 2$  | Average drought               |
| $1 < S_i \leq 2$ | Dry conditions (mild drought) |
| $-1 \leq S_i \leq 1$ | Normal humidification conditions |
| $-2 \leq S_i < -1$ | Wet conditions (weak excessive moisture) |
| $-3 < S_i < -2$ | Average excessive moisture    |
| $S_i \leq -3$  | Strong excessive moisture     |

### Table 2. Classification of conditions by gradation of the moisture coefficient MC.

| MC                  | Conditions       |
|---------------------|------------------|
| Very humid (extraluminal) | $>1.33$         |
| Wet (humid)         | 1.33-1.00        |
| Wet (Semiramide)    | 1.00-0.55        |
| Semi-dry (semiarid) | 0.55 – 0.33      |
| Dry (arid)          | 0.33 – 0.12      |
| Very dry (extraorally) | $<0.12$        |

**3. Results**

The repeatability of moisture conditions according to the average data of Samara region is shown in Table 3.

### Table 3. Frequency of atmospheric droughts (%) according to the PAI:

| Station               | May  | June | July | August |
|-----------------------|------|------|------|--------|
|                       | 1    | 2    | 3    | 1      | 2    | 3    | 1    | 2    | 3    |
| Tolyatti              | 4.5  | 34.8 | 7.6  | 7.6   | 40.9 | 7.6 | 4.5 | 27.3 | 9.1 | 7.6 | 4.5 | 10.6 |
| Novodevichye          | 4.5  | 37.9 | 7.6  | 9.1   | 37.9 | 10.6 | 10.6 | 28.8 | 6.1 | 6.1 | 47.0 | 9.1 |
| Syzran                | 1.5  | 47.0 | 10.6 | 10.6  | 40.9 | 9.1 | 15.2 | 37.9 | 1.5 | 7.6 | 39.4 | 10.6 |
| Bezenchuk             | 0.0  | 24.2 | 24.2 | 12.1  | 30.3 | 7.6 | 10.6 | 33.3 | 10.6 | 7.6 | 50.0 | 9.1 |
| Chelno-Vershiny       | 9.1  | 34.8 | 9.1  | 9.1   | 45.5 | 12.1 | 9.1 | 47.0 | 9.1 | 6.1 | 56.1 | 6.1 |
| Klyavlino             | 10.6 | 45.5 | 4.5  | 12.1  | 37.9 | 6.1 | 10.6 | 43.9 | 9.1 | 3.0 | 51.5 | 6.1 |
| Sernovodsk            | 10.6 | 42.4 | 7.6  | 13.6  | 34.8 | 12.1 | 9.1 | 42.4 | 4.5 | 3.0 | 53.0 | 7.6 |
| Samara, OGMS          | 6.1  | 47.0 | 3.0  | 10.6  | 34.8 | 6.1 | 7.6 | 31.8  | 0.0 | 7.6 | 43.9 | 9.1 |
| Apos                  | 3.0  | 45.5 | 6.1  | 10.6  | 27.3 | 6.1 | 15.2 | 36.4 | 4.5 | 6.1 | 42.4 | 9.1 |
| Avangard, Grain Farm  | 7.6  | 57.6 | 1.5  | 12.1  | 48.5 | 87.9 | 12.1 | 54.5 | 0.0  | 4.5 | 37.9 | 15.2 |
According to Table 3, almost 50% of the cases have normal humidification conditions (Figure 1). Average droughts occur more often in July (Figure 2).

Droughts are usually observed with an anticyclonic form of circulation. A spur of the Azores anticyclone extends to the territory of Samara region, with rapidly warming Arctic air masses encroaching on its eastern periphery. The most extreme values of the PAI index in the case of droughts in summer were reached in July 2010 at most stations of the region, the maximum was observed at Syzran (4.44) and in August 1972 at Novodevichye (4.40). The average PAI value for the growing season (May-September) peaked at all stations of Samara region in 2010, as well as in the entire Volga Federal District [3, 4].

According to the results, there is a tendency to increase the average annual air temperature in Samara region.

Figure 1. Repeatability (%) of average excess moisture in June according to PAI.

Figure 2. Repeatability (%) of average drought in July according to PAI.
The linear trend of long-term changes in the summer PAI for 1954-2019, which was marked by an active phase of warming, is statistically significant and indicates an increase in the index for the entire growing season (Figure 3); in the XXI century there is a tendency to increase aridity, which must be taken into account in forestry and agricultural production. In addition, the PAI has a good relationship with yield [5].

In Samara region, the average value of the BEI indicator varies from 11 to 22 (Table 4). Its highest values are observed in the north of the region: Tolyatti (22.1) and Klyavlino (19.1). The lowest BEI values are observed in the south: the Aglos and Avangard stations, the grain farm (Figure 4). The value of the moisture coefficient (MC) varies from 0.49 (semi-dry conditions) per station (Avangard, grain farm) to 0.92 (semi-wet conditions) at Tolyatti.

**Table 4. Agro-climatic indicators in Samara region.**

| Station               | MC  | BEI  |
|-----------------------|-----|------|
| Tolyatti              | 0.92| 22.12|
| Novodevichye          | 0.70| 16.03|
| Syzran                | 0.65| 15.00|
| Bezenchuk             | 0.59| 14.3 |
| Chelno-Vershiny       | 0.73| 16.03|
| Klyavlino             | 0.89| 19.13|
| Sernovodsk            | 0.57| 13.19|
| Samara, OGMS          | 0.67| 16.46|
| Apos                  | 0.57| 13.89|
| Avangard, Grain Farm  | 0.49| 11.29|
Conclusions

According to the above assessment of the conditions of aridity and humidity in the growing season in Samara region, the following conclusions can be made:

1. The linear trend of long-term changes in the D. A. Ped summer index in the 1954-2019 period, in which an active phase of warming is observed, is statistically significant and indicates an increase in the index in the entire growing season.

2. The above analysis of the spatial and temporal variability of the agroclimatic characteristics shows that aridity is increasing on the territory of the region, especially during the warm period. This is most evident in the south and southwest, where droughts are more intense than in the other areas of the region.

3. The Ivanov-Vysotsky moisture ratio and the BEI index have almost similar dynamics. The above real-time analysis of these hydrothermal indicators has not revealed any significant changes.

4. The territory of Samara region currently has satisfactory agroclimatic resources with moderate and low productivity. In the Samara region, there are unfavorable moisture conditions due to droughts in 2010, 2011, 2015, and 2016 and extensive heat supply.

Acknowledgement

This work was supported by the Russian Foundation for Basic Research (grants 18-05-00087 A and 20-55-00014 Bel_a).

References

[1] Ped D A 1975 On indicators of drought and excessive moisture Proceedings of the hydrometeorological center of the USSR 156 19 – 39

[2] Zoidze E K, Zadornova O I, Khomyakova T V 2012 Experience of agroclimatic and operational monitoring of arid phenomena in Russia based on ground data Proceedings of the Voeikov Main Geophysical Observatory 565 152 – 64

[3] Cherenkova E A 2013 Quantitative estimates of atmospheric droughts in European Russia Izv. RAS. Geographical series 6 76–85

[4] Perevedentsev Yu P, Sharipova R B, Vazhnova N A 2012 Agroclimatic resources of the Ulyanovsk region and their impact on the productivity of grain crops Bulletin of the Udmurt University. Biology Series. Earth Sciences 2 130 – 36

[5] Ulanova E S, Strashnaya A I 2000 Droughts in Russia and their impact on the productivity of grain crops Tr. VNIISKhm iss 33 64 – 83