Spatial distribution of moisture deficit on the territory of the south of Western Siberia and Northern Kazakhstan

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Abstract. The article examines the spatial distribution of the moisture deficit for meteorological stations in the south of Western Siberia and in Northern Kazakhstan in the forest-steppe and steppe natural zones. To calculate the water equivalent of heat and power resources, empirical formulas were used and the water equivalent, moisture deficit and moisture coefficient were determined. In the course of research for specific years of recent decades, the dependence of the moisture deficit on heat and power resources and precipitation has been revealed. With an increase in atmospheric precipitation and a decrease in thermal energy resources of the climate, an increase in the coefficient of moisture in the territory was revealed.

1. Introduction
In the arid conditions of the southern forest-steppe and steppe natural zones of the south of Western Siberia and Northern Kazakhstan, the provision of the growing season with moisture and heat for the growth, development and productivity of agricultural crops is essential. Air temperature, precipitation and deficit (or excess) of moisture in the growing season (May-August) have a decisive influence on the yield of grain crops. The territory of the south of Western Siberia and Northern Kazakhstan as a whole is characterized by insufficient moisture during the warm period, due to an increase in heat and power resources with a decrease in latitude. However, there are wetter years with rare recurrence, when moisture can be increased.

2. Materials and methods
To determine the regularities of the spatial distribution of the total moisture content in the study area, the data of meteorological stations for specific years in the periods characteristic of moisture content (insufficient and excessive) are considered. The meteorological stations were chosen so that their location had latitudinal zoning (figure 1) and covered different natural zones (table 1). As the calculation
period, the interval from 1974 to 2019 was chosen, lasting 45 years, when both dry and high-water years were observed.

Table 1. Locations of meteorological stations.

| Meteorological stations | Locations                          | Geographical coordinates | Height above sea level, m |
|--------------------------|------------------------------------|--------------------------|----------------------------|
|                          |                                    | Latitude (N)              | Longitude (E)             |                            |
| Makushino                | Kurgan region, Russia              | 55°25´                   | 67°30´                    | 139                        |
| Blagoveshenka            | North Kazakhstan region, Kazakhstan| 54°37´                   | 66°97´                    | 153                        |
| Balkashino               | Akmola region, Kazakhstan          | 52°53´                   | 68°75´                    | 399                        |
| Atbasar                  | Akmola region, Kazakhstan          | 51°82´                   | 68°37´                    | 304                        |

Figure 1. Location of meteorological stations in the study area.

The moisture content of the territory is determined by the water cycle between the earth’s surface and the atmosphere, which occurs due to the continuous heat and moisture exchange between the active soil layer and the surface air layer. At the same time, it is obvious that the productivity of agricultural crops primarily depends on the ratio between heat and moisture resources. In accordance with this, heat-one-balance calculations were performed in the work. To determine the natural heat and moisture supply, data on average monthly air temperatures above 0 °C, monthly and annual precipitation amounts were used. The indicator of precipitation availability ($X_c$) is calculated by the ratio of actual annual precipitation ($X_f$) to the annual precipitation rate ($X_a$) for a given meteorological station:

$$X_c = \frac{X_f}{X_a}$$  \hspace{1cm} (1)

According to the method of hydrological and climatic calculations of V.S. Mezentsev, in the case of inequality of atmospheric humidification to the optimal value obtained using the water equivalent of heat and energy resources of evaporation, their difference expresses the amount of moisture deficits (or excess) [1,2]. Thus, the indicator of moisture content of the territory ($\Delta KX$) can be obtained as the difference between the value of atmospheric precipitation ($KX$) and the water equivalent of heat and energy resources ($Z_m$).

$$\Delta KX = KX - Z_m$$  \hspace{1cm} (2)

The structure of the relationship between heat resources and moisture resources determines the level of moisture (natural or anthropogenic); therefore, an indicator of the area's moisture content for any intra-annual interval of an average year is the ratio:

$$\beta_x = \frac{KX}{Z_m}$$  \hspace{1cm} (3)
The boundary of the optimal ratio of heat and moisture is spatially expressed by the isoline of a single value of the moisture coefficient, zero moisture deficit and soil moisture in fractions of the lowest moisture capacity equal to unity. This boundary is the upper limit of optimal moisture for most crops [3]. A single isoline of the humidification coefficient is usually associated with the boundary dividing the regions of humidification, in one of which there is an overconsumption of heat for the processes of total evaporation due to excess precipitation, and another region where, due to a lack of moisture, an increased turbulent heat exchange of the underlying surface and the atmosphere occurs, and overheating and drying of the active layer is also observed. The zero isoline of the moisture deficit divides the territory into areas where drainage or irrigation amelioration is required, and the magnitude and sign of this absolute moisture characteristic determine for these areas the size of the excess and deficiency of moisture of the necessary reclamation effects [4].

3. Results and discussion
In the works of O. V. Mezentseva determined the norms of the elements of the heat and water balance and the characteristics of natural heat and moisture supply within the economic optimum of moisture in Western Siberia. According to these standards, in an average long-term year, the amount of precipitation (KX) should be within 400 ... 600 mm, the water equivalent of heat and energy resources of evaporation (Zm) - 600 ... 700 mm, the deficit of atmospheric moisture (ΔKX) within 0... -280 mm, moisture coefficient (βx) 1.0 ... 0.65 [5,6].

In the present study, years have been identified that have deviations from the norm in terms of heat and moisture supply, i.e., years with parameters exceeding the norms of the average long-term period and years with significantly low compared to the norm for each of the considered meteorological stations. According to the Makushino weather station for the period from 1975 to 2019, years with an insufficient provision and with a provision of precipitation above the norm have been identified (table 2). For this period, we selected years with a precipitation rate below 75% and above 125% of the multiyear norm. Years in which the moisture deficit is less than -280 mm and with a moisture coefficient below 0.65 are classified as arid years. Years corresponding to the norms of atmospheric moisture deficit in the range of -280 ... 0 mm, the moisture coefficient in the range of 1.0 ... 0.65 are attributed to precipitation provided above the norm [7,8]. To identify the recurrence of humid and dry years, the entire studied time range was divided into periods with an interval of 5 years.

Table 2. Calculation data of moisture provision by meteorological station Makushino for 1975-2019.

| 5-years periods | Years with insufficient rainfall (very dry) | Years with higher than normal rainfall |
|-----------------|------------------------------------------|--------------------------------------|
|                 | Years | X, mm | Xa, % | KX, mm | Zm, mm | ΔKX, mm | βx (prop | un.) | Years | X, mm | Xa, % | KX | Zm | ΔKX, mm | βx (prop | or.un.) |
| I (1975-1979)   | 1975  | 204   | 53    | 277    | 756    | -479    | 0.37    |       | 1979  | 486   | 127   | 575  | 683 | -108    | 0.84    |         |
|                 | 1976  | 271   | 71    | 334    | 738    | -404    | 0.45    |       |       |       |       |       |     |       |         |         |
| II (1980-1984)  | 1981  | 246   | 64    | 306    | 784    | -478    | 0.39    |       |       |       |       |       |     |       |         |         |
|                 | 1989  | 268   | 70    | 361    | 765    | -404    | 0.47    |       |       |       |       |       |     |       |         |         |
| III (1985-1989) | -     | -     | -     | -      | -      | -       | -       |       |       |       |       |       |     |       |         |         |
| IV (1990-1994)  | -     | -     | -     | -      | -      | -       | -       |       |       |       |       |       |     |       |         |         |
| V (1995-1999)   | 1996  | 270   | 71    | 332    | 700    | -368    | 0.47    |       |       |       |       |       |     |       |         |         |
| VIII (2010-2014)| 2010  | 249   | 65    | 334    | 821    | -487    | 0.41    |       |       |       |       |       |     |       |         |         |
| IX (2015-2019)  | -     | -     | -     | -      | -      | -       | -       |       |       |       |       |       |     |       |         |         |
Analysis of the data obtained for the Makushino meteorological station (table 2), with an average precipitation rate of 382 mm, during the study period shows the appearance of dry years, with a provision below 75% of the norm in periods I, II, IV, V, VIII (1975, 1976, 1981, 1989, 1996, 2010), and high-water years, with a supply above 125% of the norm - in periods I, IV, IX (1979, 1993, 1994, 2018). The greatest moisture deficit (-487 mm) was noted in the VIII period (2010), the smallest value of the moisture deficit (-79 mm) was noted in the IX period (1994). At the same time, the moisture coefficient in dry years varied from 0.37 to 0.41, and in years with increased moisture it varied in the range from 0.82 to 0.90. The calculation results for the Blagoveshchenska meteorological station for the studied period are shown in table 3.

**Table 3.** Data of calculations of moisture provision according to the Blagoveshchenska meteorological station for 1975-2019.

| 5-years periods | Years with insufficient provision by rainfall (very dry) | Years with higher than normal provision by rainfall | βx (propor un.) |
|-----------------|---------------------------------------------------------|--------------------------------------------------|-----------------|
| I - (1975-1979) | 1975254 73 | 317 779 -462 0.41 | 1977437 125 530 789 -259 0.67 |
| II - (1980-1984) | 1981212 61 | 250 805 -555 -0.31 | - - - - - |
| III - (1985-1989) | 1988237 68 | 293 810 -517 -0.36 | - - - - - |
| IV - (1990-1994) | 1991184 53 | 234 865 -658 0.24 | 1994464 133 560 748 -188 0.75 |
| V - (1995-1999) | 1995241 69 | 308 830 -522 0.37 | - - - - - |
| VI - (2000-2004) | - - - - - | - - - - - | 2001469 134 564 756 -192 0.75 |
| VIII - (2010-2014) | 2010196 56 | 279 835 -556 -0.33 | 2011450 129 523 781 -258 0.67 |
| IX - (2015-2019) | 2017251 72 | 295 753 -458 0.39 | - - - - - |

The annual precipitation rate at the Blagoveshchenska meteorological station for the period from 1975 to 2019 was 349 mm. The calculation results showed that the rainfall rate below 75% of the norm was observed in periods I, II, III, IV, V, VI, VIII, IX (1975, 1981, 1988, 1991, 1995, 2010, 2017), and above 125% corresponded to periods I, IV, VI, VIII (1977, 1994, 2001, 2011, 2013). The most significant moisture deficit (-658 mm) was noted in 1991, and the smallest moisture deficit (-121 mm) was noted in 2013. Moisture coefficients in years of insufficient provision varied from 0.24 to 0.41, and from 0.67 to 0.84 - in years with high provision. At this meteorological station in each period, except for the VI-th, one dry year was repeated every 5 years. Calculation data for the provision of humidification at the Balkashino and Atbasar meteorological stations for the period from 1975 to 2019, are given, respectively, in tables 4 and 5.

**Table 4.** Calculation data of moisture provision by meteorological station Balkashino for 1975-2019.

| 5-years periods | Years with insufficient provision by rainfall (very dry) | Years with higher than normal provision by rainfall | βx (propor un.) |
|-----------------|---------------------------------------------------------|--------------------------------------------------|-----------------|
| I - (1975-1979) | 1975 223 56 289 745 -456 0.39 | - - - - - | - - - - - |
| II - (1980-1984) | 1976 229 57 272 713 -441 0.38 | - - - - - | - - - - - |
| III - (1985-1989) | 1986 295 74 371 675 -304 0.55 | - - - - - | - - - - - |
The average long-term rainfall at the Balkashino meteorological station is 400 mm. During the period under consideration (1975 ... 2019), precipitation levels below 75% of the norm were identified in periods I, III, IV, V, VI, VIII, IX (1975, 1976, 1986, 1988, 1991, 1995, 1996, 1997, 1998, 2008), excess rainfall over 125% of the norm was revealed in the IV, V, VI, VIII periods (1992, 1993, 1994, 1999, 2001, 2013). The most significant moisture deficit was noted (-486 mm) in 1997, and the largest excess moisture was noted in 1992 (+1787 mm). The ratio of a large amount of precipitation over 125% of the norm was noted in 1992 (+1787 mm). The ratio of a large amount of precipitation over 125% of the norm was noted in 1992 (+1787 mm). The ratio of a large amount of precipitation over 125% of the norm was noted in 1992 (+1787 mm). The ratio of a large amount of precipitation over 125% of the norm was noted in 1992 (+1787 mm). The ratio of a large amount of precipitation over 125% of the norm was noted in 1992 (+1787 mm). The ratio of a large amount of precipitation over 125% of the norm was noted in 1992 (+1787 mm).

Table 5. Calculation data for the provision of moisture according to the Atbasar weather station for 1975-2019.

| 5-years periods | Years with insufficient provision by rainfall (very dry) | Years with higher than normal provision by rainfall |
|-----------------|-------------------------------------------------------|---------------------------------------------------|
|                 | X, mm | Xa, % | KX, mm | Zm, mm | ΔKX, mm | βX (prop or un.) | X, mm | Xa, % | KX, mm | Zm, mm | ΔKX, mm | βX (prop or un.) |
| I - (1975-1979) | 1976 | 189 | 61 | 262 | 759 | -497 | 0.35 | - | - | - | - | - | - |
| IV - (1990-1994) | - | - | - | - | - | - | - | 1990 | 434 | 140 | 557 | 781 | -224 | 0.71 |
| VI - (2000-2004) | - | - | - | - | - | - | - | 1993 | 411 | 132 | 528 | 717 | -189 | 0.74 |
| VIII - (2010-2014) | 2010 | 189 | 61 | 300 | 853 | -553 | 0.35 | 2013 | 511 | 164 | 654 | 770 | -116 | 0.85 |
| IX - (2015-2019) | - | - | - | - | - | - | - | 2015 | 404 | 130 | 519 | 769 | -250 | 0.67 |

With a precipitation rate at the Atbasar meteorological station of 311 mm, the analysis of table 4 showed that for the considered time interval, precipitation provision below 75% of the norm was detected in periods I, VIII (1976, 2010), while excessive precipitation (above 125% of the norm) was identified in periods IV, VI, VIII, IX (1990, 1993, 2001, 2013, 2015, 2018). The most significant moisture deficit (-553 mm) was noted in 2010, the smallest moisture deficit (-116 mm) was noted in 2013. The moistening coefficient was 0.35 in years with insufficient precipitation and from 0.63 to 0.85 in years with above normal precipitation.

4. Conclusion
As a result of the study of the spatial distribution of the moisture deficit in the south of Western Siberia and Northern Kazakhstan, it can be concluded that precipitation and heat and power resources have a
significant effect on moisture. Thus, based on the calculations and the analyzed data for 1975-2019, the following conclusions can be drawn:

- in all the studied meteorological stations, except for Atbasar, severely dry years were identified in periods I, II, III, IV, V, VI, VIII, IX, years with precipitation above the norm in all meteorological stations in periods IV, V, VI, VIII. Thus, the frequency of dry years is more than twice that of water supplied. At the Atbasar meteorological station, insufficient precipitation was noted only in periods I and VIII. Despite the more southerly location of the city of Atbasar in comparison with other points, the significant difference in water availability was influenced by local conditions, such as the terrain. The relief characteristic of this territory is represented by hummocks, along with which hilly-ridged areas are widespread;
- in years with insufficient precipitation in all studied meteorological stations, a high level of moisture deficit was determined from -304 to -658 mm;
- in years with excessive (above normal) provision of atmospheric humidification in the studied meteorological stations Makushino, Blagoveshchenka and Atbasar, the level of humidity deficit decreased and ranged from -79 to -279 mm;
- for the Balkashino meteorological station in 1992, a significant excess of the annual precipitation rate (428%) was noted, the excess moisture was +1787 mm;
- the moisture coefficient in all the studied meteorological stations in dry years was at the level of 0.24-0.55;
- in years with excessive precipitation in the area of the Balkashino meteorological station, a high moisture coefficient was observed above 1;
- the ratio of a large amount of precipitation with relatively low thermal energy resources, for example, as in 1992 and 1999 for the Balkashino meteorological station, leads to excessive moisture in the territory;
- the recurrence of dry years once every 5 years is clearly visible at the Blagoveshchenka meteorological station, where in each period, with the exception of the VIth, one dry year occurs every 5 years.

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