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Irrigation cooling effect: opportunities in task of estimation of international irrigation water usage in transboundary River Syrdarya basin, Central Asia

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Abstract. The aim of this research was the analysis of long-term and seasonal dynamics of Irrigation Cooling Effect (ICE) of irrigated arable lands in test sites of Kazakhstan and Uzbekistan in agriculture province “Golodnaya stepp”, located in transboundary River Syrdarya basin. The Land Surface Temperature (LST) FEWS NET (Famine early Warning System Network) product was used for calculation and monitoring (2002-2019) ICE values. The amount and efficiency of irrigation water usage significantly affects the ICE values. Therefore, long-term (2002-2019) ICE monitoring on arable land Kazakhstan and Uzbekistan in “Golodnaya stepp” is important as an objective characteristic of irrigation parameters and their changes during the observation period. Analysis of data from 2002-2019 showed that in the key period (May-June) Uzbekistan's arable land is in a better position. Review of two eras 2003-2010 and 2011-2019 it showed that changes in ICE values are directed at: an increase in May, approximately 2.5° in Uzbekistan and 1.3° in Kazakhstan; an increase in July, 1.3° in Uzbekistan and 2.5° degrees in Kazakhstan; and a decrease in September, approximately 1.5° in Kazakhstan, with stable values in Uzbekistan. Thus, ICE monitoring in arid climates is a useful tool for diagnosing water consumption on arable land in various countries, which is especially important in transboundary river basins.

1 Introduction

Central Asia region is located at the center of Eurasia, Fig.1. The distance from the oceans leads to significant variability in the seasonal precipitation in mountain systems in the center of Eurasia. Mountain systems of Eurasia, such as the Tien Shan, Pamir, etc. they are zones of river outflow formation of major rivers in Central Asia, including the Syrdarya river, which is the second rang in outflow volume. All the largest rivers in the region have

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ice and snow-ice nutrition and significant seasonal (2-3 times) variability in the annual outflow [1,2].

In the context of the water-scarcity climate of Central Asia, the distribution of transboundary river resources between the countries is an extremely important political issue. Agricultural production in arid climates depends entirely on irrigation. Thus, the food security of Central Asian countries that depend on irrigation agriculture is intricately linked to international agreements on the division of transboundary river resources and their actual implementation. The annual variability in the river outflow makes it difficult to create a transparent water allocation system for cross-border river outflow. Countries in the lower parts of transboundary basins have deficit objective tools to control the actual water use of countries in the upper parts of the basin.

Arable irrigation consumes the bulk of Central Asia's surface runoff. The issue of controlling agricultural water consumption on irrigated arable land according to satellite estimates is still far from being resolved. There are possibilities to control the size of irrigated arable land and assess the state of crops, for example, using vegetation indices [3]. But this is not enough to provide an objective quantitative description of transboundary water allocation. In this paper, we consider Land Surface Temperature (LST) [4] as another satellite parameter that characterizes water usage on irrigated arable land [5,6]. This research uses the Irrigation Cooling Effect (ICE), calculated on the basis of LST, which is the effect of cooling the surface of irrigated arable land, which occurs due to the evapotranspiration of water from the soil surface and vegetation cover, as a result of irrigation.

2 Study area

The 2nd largest transboundary river of Central Asia – Syrdarya pass through the territory of Kyrgyzstan, Tajikistan, Uzbekistan and Kazakhstan. River length of more than 2 thousand km, with an average annual flow of about 38 km^3 (variation from 19 to 72 km^3, maximum seasonal flow in July). At the same time, Kyrgyzstan and Tajikistan are in the upper reaches of the river basin, in the mountainous part of its basin. Uzbekistan occupies the middle part, while Kazakhstan is in the lower part of river basin. Irrigation agriculture is the basis of agricultural production in Uzbekistan. Kazakhstan has the main agricultural lands in the North part (more than 10 million hectares of non-irrigated arable land), and the irrigated arable land in the South of the Republic is important only in the regional aspect, Fig. 1.

For a comparative analysis of the ICE effect of irrigation arable land in Uzbekistan and Kazakhstan, the "Golodnaya stepp" agriculture province was used. A large agricultural province of irrigated arable land with an area of about 800 thousand hectares called the "Golodnaya stepp" is located on the left bank of the Syrdarya river. Most of it belongs to the territory of Uzbekistan (Syrdarya oblast) and a smaller part to Kazakhstan (Makhtaaral district of South Kazakhstan oblast), Fig.2.

Three test sites with a size of 24x18 km were identified for the study. Two polygons in the agricultural zone, on the territory of Kazakhstan (coordinates of the center- 40° 47'N; 68° 20' E) and on the territory of Uzbekistan (40° 37' N; 68° 00' E). As well as a polygon in the natural landscape zone (41° 20' N; 67° 00' E) located on the territory of Kazakhstan, see Fig. 2B

3 Materials and methods

FEWS NET products presented for the Central Asia region were used. The Early Warning Explorer (EWX) tool allows users to access the LST Collection 6 products, with a resolution of 3 minutes, which is approximately 5.5 x 4.3 km in the analyzed region. Ten-day renew composites for the period May-September (15 coverages per year) described the seasonal temperature regime of the test sites. The data archive contains information from the period 2002-2020, which made it possible to analyze the eighteen-year period.

ICE value this is LST difference between the natural landscape and irrigated arable land. The decrease in the surface temperature of arable land is a consequence of the irrigation [3]. Irrigation water evaporates, both directly from the capillaries of the soil layer, and through vegetation, and thus the temperature of the underlying surface decreases. The amount of temperature decrease primarily depends on the amount of water. The irrigation type, and cultivated crop varieties and the specifics of agricultural practices also play a role. In case if all other things being equal, the value of ICE depends on the level of water consumption on irrigated arable land.

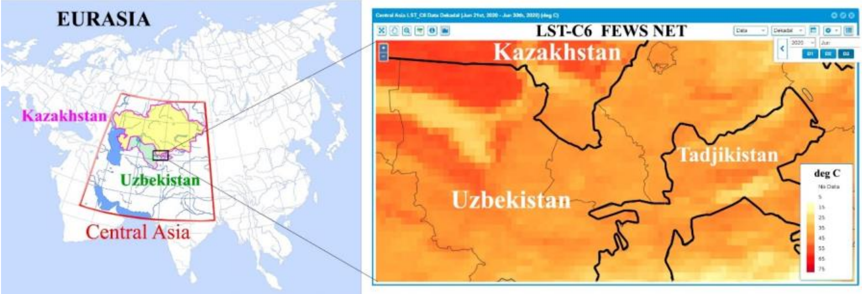

Fig. 1. Disposition of Central Asian region (FEWS NET) and Kazakhstan on Eurasia continent and example of decade "Land Surface Temperature" map of study area from FEWS NET.

Long-term monitoring, which in this research is a period of 18 years, makes it possible to determine the direction of the trend of ICE changes in the period from soil preparation for sowing in May to after harvesting in September. Of particular interest is the time of maximum vegetation, which is usually observed in the second half of July, since it is most closely related to crop yields. Trends in increasing ICE values indicate progressive development of agricultural land use, in which an increasing amount of water is brought to the surface and root layer of the soil.

Of particular interest are comparisons of long-term ICE regimes of irrigated arable land in different parts of the agricultural province [6], related to different countries. In this case, it is arable land of Uzbekistan or Kazakhstan. Access to irrigation water in transboundary river basins usually depends significantly on geographical location. The countries in the lower parts of the basin are most vulnerable. As part of this research, this is Kazakhstan. Long-term comparisons of differences in ICE values between the arable land of Uzbekistan and Kazakhstan characterize the actual water allocation and efficiency of agricultural water usage.

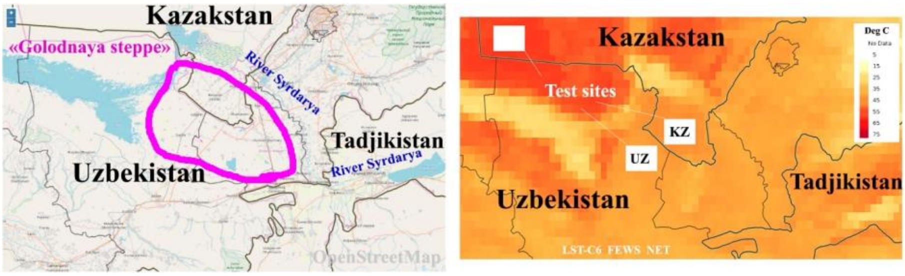

Fig. 2. Regional physical map with "Golodnaya steppe" agriculture province in River Syrdariya basin and test site disposition on fragment of LST FEWS NET map for Central Asian region (3 decade of June 2020).

The data processing technique was extremely simple. Initially, the average values of LST C6 FEWS NET (decadal composites) were determined for three test sites. Thus, time series of ICE values for arable land in Uzbekistan and Kazakhstan were formed. Satellite monitoring included the period from July 2002 to September 2019. Unfortunately, on May 1, 2020, the Sardobinsky reservoir collapsed [7,8]. The water supply regime of the analyzed arable land was distorted by this emergency, which made it impossible to include the 2020 data in the analyzed time series. The time series processing technique itself was based on a linear regression analysis of ICE data series for arable land in Uzbekistan and Kazakhstan, which allowed us to quantify the long-term dynamics of relative water use efficiency in the agricultural sector and national differences in this parameter.

4 Results

The calculated ICE values ranged from 5 to 21 degrees. The highest ICE values were recorded in the second decade of August, which is associated with a more intense warming of natural landscapes at this time. The monitoring results are showed in Fig.3-4.

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5 Discussion

The average long-term (2003-2019) seasonal profiles of ICE values for arable land in Kazakhstan and Uzbekistan in "Golodnaya steppe" agriculture province is shown in Fig. 3. In the period from May to mid-July, the ICE values for arable land in Uzbekistan are 3-4 degrees higher than in Kazakhstan. It seems that this is a consequence of the favorable geographical position of Uzbekistan, located upstream of Kazakhstan along the transboundary River Syrdarya. Uzbekistan provides the best water supply for its arable land during the key period (May-June) of the vegetation season. In July, there is a seasonal maximum water consumption in the River Syrdarya river, which makes it possible to equalize the water needs of irrigation arable land for both countries. In the late summer and early autumn (August-September), the ICE values for Kazakhstan's arable land, on the contrary, exceed the Uzbek values. At the end of the growing season, after harvesting some of crops, water requirements for arable land in Uzbekistan decrease, which automatically reduces the ICE values. Thus, the better water availability of irrigated arable land in Uzbekistan shifts the beginning of the growing season to an earlier date in comparison with Kazakhstan, see Fig. 4

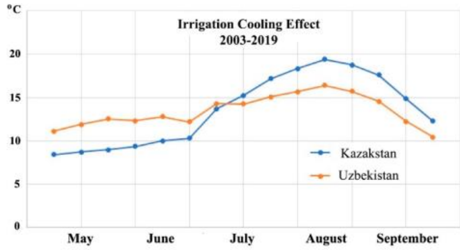

Fig. 3. Long-term average ICE seasonal profiles for test sites in irrigated arable land of Kazakhstan and Uzbekistan in “Golognaya steppe” agriculture province in River Syrdarya basin.

Figure 4a shows a long-term (2002-2019) profile illustrating changes in the ICE values of irrigated arable land in Kazakhstan and Uzbekistan in “Golodnaya steppe” agriculture province for mid-July. The Kazakhstan segment of the province's irrigated arable land shows steady development with an increase in ICE values from approximately 11.5° in 2002-2004 to 17.5° in 2017-2019. There are two abnormally high ICE values in 2005 and 2006, the cause of which is not clear.

Irrigation arable land in Uzbekistan has a more complex evolution of ICE values. There is a ten-year (2007-2016) stability period characterized by an ICE value of approximately 13.5°. The last years of 2017-2019 with high ICE values, about 17°, coincide with the start of operation of the new Sardoba reservoir with a volume of about 1 km^3. This reservoir intercepted winter water passes from the Toktogul reservoir (Kyrgyzstan), which operates in an energy mode. May 1, 2020 the Sardobia reservoir was destroyed as a result of the dam breakout [7,8]. There was also a three-year period 2004-2006 with high volatility of ICE values (from 10 to 16 degrees), the reason for which is not known.

Figure 4b shows changes in seasonal profiles of ICE values between two epochs: 2003-2010 and 2011-2019. The difference between these values shows that there is an increase in ICE values in May, both in Uzbekistan and Kazakhstan. However, it is more significant in Uzbekistan: 2.4°C contrary to 1.3°C in Kazakhstan. Also, for arable land in Kazakhstan, a significant increase in ICE values is registered in July, about 2° C, and a decrease in September. The characteristics of Uzbekistan's arable land in the summer-autumn period are generally stable, with some growth in July. The ICE values variations (June-September) almost do not exceed the level of (± 0.5° C).

3 Conclusion

The satellite product "Land Surface Temperature" collection 6 FEWS NET with a decade renew, a spatial resolution of 3´ (5,5 x 4, 3 km) and an archive from 2002 it allows to calculate and monitor Irrigation Cooling Effect values for irrigation arable land in countries located in arid climates. The dynamics of long-term changes of ICE values provides a basis for evaluating the effectiveness of irrigation water usage in Kazakhstan and Uzbekistan in the “Golodnaya steppe” agriculture province (Central Asia). There appears the possibility to diagnose the accessibility of transboundary water resources of the River Syrdarya for irrigation arable land of different countries and changes in the long-term aspect. Such estimates are most interesting for countries in the lower parts of transboundary river basins, since there is a lack of objective tools for controlling irrigation water usage in the upper parts of the basin, because the natural significant variability of river outflow in arid climates makes the situation significantly uncertain.

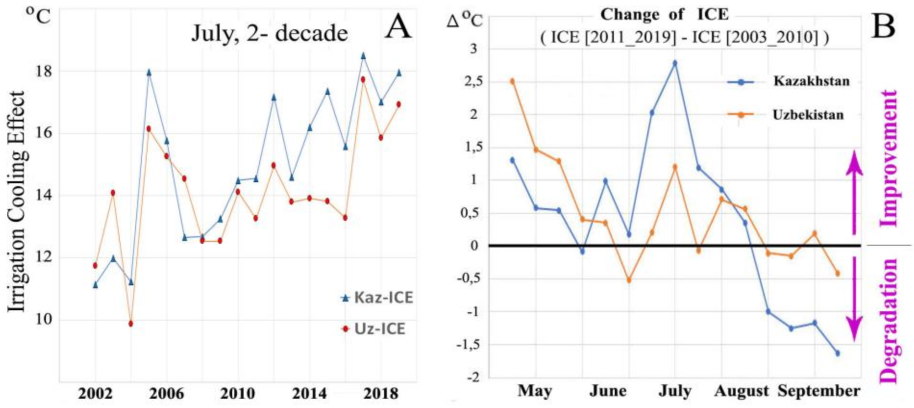

Fig. 4. A - Long-term evaluation of July's ICE values of national test sites in the agricultural province "Golodnaya steppe" in transboundary River Syrdarya basin: B - Modern directions of seasonal ICE value change in national test sites in the agricultural province "Golodnaya steppe" in transboundary River Syrdarya basin.

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