Estimation of average long-term soil salinity of arable land Golodnaya Steppe in Kazakhstan

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Abstract. In the Syr-Darya River basin on the border between Kazakhstan and Uzbekistan there is an irrigation massif "Golodnaya Steppe". In its Kazakh part, the agricultural procedure of winter washing of fields is practiced for cleaning from secondary salinization. It is carried out in January-February by flooding saline fields. At the same time, water mirrors are formed on the arable land, which can be recorded using satellite data. In this study, based on satellite information from Landsat 8,9 and Sentinel 1,2 for the period January-February 2016-2022, masks of water mirrors were created, located on irrigated arable land in winter. These masks diagnose seasonal farmers' activity on cleaning arable land from secondary salinization. Analysis of the field washing frequency in the period 2016-2022 allowed to estimate the average long-term salinity of irrigated arable land in the analyzed region. The data obtained are of interest for the zoning of the territory of the irrigation massif "Golodnaya Steppe" in Kazakhstan according to the level of secondary salinization, which is important for optimizing the work to improve the irrigation and drainage infrastructure.

1 Introduction

In the Syr Darya River basin on the border of Uzbekistan and Kazakhstan there is a large irrigation massif "Golodnaya Steppe". About 140 thousand hectares of irrigated arable land belong to Kazakhstan from this massif, Fig.1. Agricultural lands in the river basin are subject to secondary salinization [1]. Groundwater in the region is saline, therefore, disturbances in the irrigation and drainage system lead to the accumulation of salt in the surface soil horizons. Soil salinization negatively affects crop production, reducing crop yields [2]. The issue of control over water use [3] and secondary salinization of fields is of great importance for the effective administration of agricultural production [4] and ensuring food security in the south of Kazakhstan.

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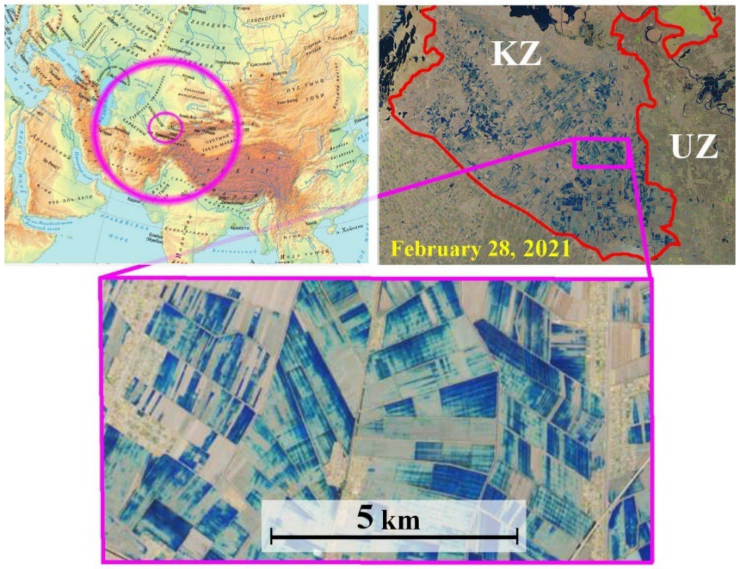

Fig. 1. Disposition of Kazakh part of agricultural "Golodnaya Steppe" area with example of satellite image during period of winter irrigation (January-February)

Secondary salinity of soil horizons on irrigated arable land is a very dynamic process [5]. During summer irrigation, the level of saline groundwater increases and may exceed the critical level of 150 cm, which leads to secondary salinization of soils. In unfavorable conditions there are the lands located in local lowlands, where the groundwater level is always higher.

Mapping the average long-term salinity of agricultural land is in high demand. This information is necessary for planning measures to combat secondary salinity of soil horizons. Ground survey of fields is very laborious, since it is necessary to drill the soil and take samples from different depths (up to 1-2 meters). Soil salinization is based on the physical process of liquid seeping through porous media. A spatial feature of the 3-dimensional seepage processes is the contrasting mosaic, which manifests on the land surface in the form of spotting of local salinization zones. Therefore, on the basis of ground surveys alone, it is difficult to carry out detailed mapping of significant areas of arable land.

The drainage system is designed to combat secondary salinization of fields. Nevertheless, to maintain the functionality of this system, regular cleaning of drains and the operation of numerous drainage wells are required. In the current conditions, these expensive procedures are not fully provided, which leads to a chronic problem in the form of secondary salinization of arable land for a significant part of the lands of the irrigation massif "Golodnaya Steppe" in Kazakhstan. The energy mode of operation of the main hydroelectric power plants on the Syr-Darya River, located in its upstream, leads to an increased river flow during the cold period. This feature, on the one hand, creates problems for irrigation agriculture of the middle and lower reaches, which lacks water resources in summer. But on the other hand, it allows to carry out large-scale measures for winter washing of fields from secondary salinization. Agrotechnologies adopted in the region under consideration recommend that in case of severe salinization in the period from December to March, from 8 to 12 thousand cubic meters of water per hectare should be supplied in 2-3 cycles. With an average degree of salinity, the water supply rate is reduced to 4 to 8 thousand cubic meters of water per hectare [6]. As a result of winter washing (January-February), water mirrors are formed in the fields, which can exist for a month or more.

In the task of mapping soil salinity, the most effective is considered to be the use of remote sensing data [7], which means UAV survey, aerial photography, or satellite data [8]. Due to the high practical significance of the task of assessing the salinity of territories, a large number of different methods have been described in the scientific literature [9-10]. http://www.scirp.org/journal/PaperInformation.aspx?PaperID=41262 Aerial photography was popular back in the former USSR [11]. Currently, the emphasis is on satellite information or UAV survey [12].

Secondary salinization of arable land in the studied region has a natural intra-seasonal dynamic [13]. The typical seasonal regime of the secondary salinization degree of arable land includes minimal salinity at the beginning of the growing season, after winter washing and cleaning of the soil from secondary salinization of fields. As crops grow and develop against the background of summer irrigation, saline groundwater penetrates into the upper soil horizons and salines them. The maximum salinity is reached by the end of the growing season, by the beginning of the cold period. If, after harvesting crops, according to farmers, the harmful threshold of secondary soil salinization has been passed, the fields are sent for salt purification. After the removal of salts from the arable and sub-arable soil horizons with the help of winter washing, the level of soil salinity decreases. Same or similar dynamics of changes in the secondary salinization level of irrigated arable land during the season is typical for any region practicing irrigation farming [14].

Remote sensing in most methods of assessing soil salinity includes satellite imagery and synchronous subsatellite ground survey. The methods developed in this way for assessing soil salinity are not universal. They are applicable only to the place of the study and the local time of the analysis. Therefore, despite the almost 50-year history of using remote sensing data, it has not been possible to develop universal and robust methods for assessing the salinity of agricultural land.

Salinity maps of cultivated agricultural lands reflect the state of the soil at the time of satellite or UAV survey. At the same time, in conditions of water scarcity, years of different water content produce significantly different hydrological conditions. The interrelationships between the spectral characteristics of the underlying surface and its salinity in low-water and high-water years can radically differ [5]. Meanwhile, objective, average long-term information on soil salinity is necessary to solve many practically important tasks. For example, to maintain the functionality and development of an irrigation and drainage system, or to optimize crop rotations and other management decisions.

The purpose of this study was to assess the average long-term level of salinity of arable land of the irrigation massif "Golodnaya Steppe" in Kazakhstan. The more often the field was washed during the long-term satellite monitoring (2016-2022), the higher its average long-term salinity was considered. Such results are of practical interest for the tasks of planning measures to improve irrigation and drainage infrastructure, since they allow to identify the most problematic, in terms of average long-term secondary salinity of soils.

2 Materials and Methods

Thematic processing of satellite data was carried out in Google Earth Engine (GEE). This study analyzed satellite data from Landsat-8,9 (30 m resolution) and Sentinel 1,2 (10 m resolution) for the period January-February 2016-2022. The purpose of thematic processing of satellite data was to estimate the frequency of winter washing of fields during the monitoring period. To solve this problem, satellite masks of water mirrors were built. Seasonal masks were built according to data for January-February, which allowed to determine the fields selected by farmers for cleaning from secondary salinization before the growing season. In this study, a mask of arable lands of the studied region was used, taken from the work [16].

In the generally accepted concept of research, the analysis of average long-term conditions of salinization of arable land requires the availability of long-term satellite data and synchronous ground surveys. Currently, quite extensive satellite data archives have been accumulated that allow to characterize multi-year periods in a homogeneous way, for example, daily MODIS data available since 2000. Nevertheless, there are no ground surveys of comparable detail. This is probably why scientific research based on remote sensing data, with rare exceptions [5, 13, 16], does not pose the task of analyzing average long-term conditions.

The only way out of this situation may be to replace the data of long-term ground surveys with information on the activity of farmers in cleaning soils from secondary salinization. In this case, the financial feasibility of winter flushing is a factor that ensures the comparability of information from different years. It is assumed that farmers minimize their financial costs and decide to carry out winter soil washing from secondary salinization only if there is a real need. Satellite monitoring of water mirrors in the period from January 1 to February 28 allowed registering fields sent by farmers for washing from secondary salinization after the end of the growing season. Recognizing a water mirror from satellite data is not a difficult task. In this study, simple threshold algorithms were used to construct masks of water mirrors. According to the optical channels Landsat-8,9 and Sentinel-2, the NDWI index (Normalized Difference Water Index) was calculated [17-21] and a mask of the water surface was formed through its threshold value. Sentinel-1 radar data with two polarizations VV and VH made it possible to distinguish a water mirror on the basis of weak reflection, considering the filtration of residual speckle noise [22]. Masks constructed from optical and radar data were combined in the required time window. For January-February data, seasonal masks of water mirrors were formed, i.e. 7 masks were generated for each year in the period 2016-2022.

The frequency of winter flushing acted as a quantitative indicator of the average long-term level of secondary salinization of the analyzed territory. Nevertheless, the dimension of the legend of the obtained map of the average long-term salinity level of arable land differed from the generally accepted ones. Instead of the salt content in the soil or the electrical conductivity of the water extract from the soil or the standard 5 FAO classes for soil salinity (unsalted – weakly – medium – strongly – very strongly saline), the average long-term frequency of cleaning fields from secondary salinization was used.

3 Results and Discussion

Figure 2 shows the final map of the average long-term secondary salinity level of arable land of the irrigation massif "Golodnaya Steppe" in Kazakhstan.

Mapping of soil salinity based on remote sensing data is almost always based on indirect data. A direct sign of salinization, in the form of white crusts on the soil surface for agricultural land, is extremely rare. Most often, vegetation depression or radar signal reflection features from a soil layer with increased electrical conductivity due to salinization or other objective signs of the underlying surface are used as salinization signs.

In this study, a subjective parameter was used as a salinization sign, farmers washing the field from secondary salinization. The frequency of soil cleaning from salinization, other things being equal, is directly related to the amount of salts removed from the soil layers to maintain the necessary fertility of arable land. It is clear that in case of a separate field, the decision may be erroneous and unreasonable. But with a long-term review of the region as a whole, an objective picture was expected. It was assumed that the preservation of the general business conditions should guarantee the comparability of estimates of individual years. The key parameters in this issue were the availability of a payment system for the use of water for winter flushing and the sufficiency of the winter river runoff volume. The winter flow of the Syr-Darya River is formed by the energy mode of operation of the upstream hydroelectric power plants. At the same time, the countries of the upper part of the river basin need to generate a certain amount of electricity in winter and use a certain amount of water accumulated in reservoirs for this purpose.

Thus, it seemed that the formed map of the average long-term secondary salinity level of arable land of the irrigation massif "Golodnaya Steppe" in Kazakhstan, Fig.2, is objective. Zoning of the territory of the region on its basis can be useful for improving the efficiency of the irrigation and drainage infrastructure restoration.

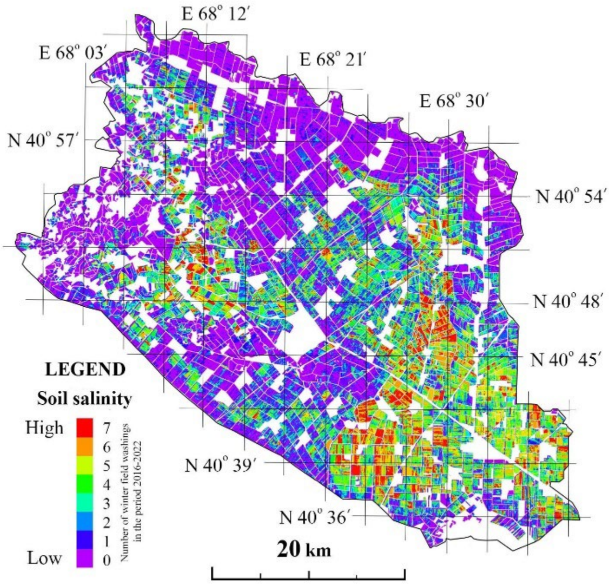

Fig. 2. Long-term secondary soil salinity of irrigated arable land of «Golodnaya Steppe» in Kazakhstan on base of satellite winter irrigation monitoring during 2016-2022

4 Conclusion

Features of regional agrotechnologies in the irrigation massif "Golodnaya Steppe" within Kazakhstan territory, include seasonal cleaning of soils from secondary salinization by means of winter washing. Washing is accompanied by the formation of water mirrors on the arable land in January-February. Water mirrors are easily registered by remote sensing data. Thus, winter soil cleaning from secondary salinization of arable and sub-arable horizons can be effectively monitored using satellite monitoring. Satellite monitoring of the agricultural procedure of winter washing of arable land from secondary salinization in the irrigation massif "Golodnaya Steppe", carried out in this study, allowed to quantify the average long-term frequency of field washing. The frequency of long-term cleaning of fields from secondary salinization is directly related to the average long-term secondary salinization level of arable land. The more often the field is washed, the higher its average long-term level of secondary salinization. The obtained estimates of the average long-term level of soil salinity can serve as a basis for the zoning of territories and be useful in the task of administering the irrigation and drainage infrastructure of the studied region.

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