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Monitoring the State of Ameliorated Agricultural Lands in the Arid Zone of Russia

Vladimir Alexandrovich Tarbaev[1], Petr Vladimirovich Tarasenko[1], Vyacheslav Mikhailovich Yanyuk[1], Alexander Anatolyevich Tkachev[1], Renat Barievich Tuktarov[2] and Irina Igorevna Demakina[3]
[1]Saratov State Agrarian University named after N.I. Vavilov, Teatralnaya square, 1, Saratov, 410012, Russia.
[2]Volzhsky Research Institute of Hydraulic Engineering and Land Reclamation, Gagarina Street, 1, Engels, Saratov Region, 413123, Russia.
[3]Research Institute of Agriculture of the Southeast, Tulaykova Street, 7, Saratov, 410010, Russia.

(Corresponding author: Vladimir Alexandrovich Tarbaev)
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ABSTRACT: The article presents the results of the monitoring studies (ecological-ameliorative state of irrigated agricultural landscapes of the arid Trans-Volga area, degradation of soil and the vegetation cover in them) performed based on the data of the Volga State Design and Survey Institute for Amelioration Systems and Water Facilities (Privolzhgiprovodkhoz), the Saratov Hydrogeological and Ameliorative Crew, the SE Volga Research Institute of Hydtrotechny and Amelioration (VolzNIIGiM), the Saratov State Agrarian University; the results of aerial survey (UHF, HF); satellite images (NDVI, freely available from the LP DAAC center as part of USGS), etc. As a result of the studies, three periods (1952–1981, 1981–1992, and 1993– 2018) of interaction have been identified between the changes in the irrigation load and the state of the interfluve-plain (land improving and irrigational), flood plain and water preserving agricultural lands, and the adjacent natural landscapes. It has been noted that the growth of the degradation processes (salinization, waterlogging) increases with the increase in the irrigated area and the water load, and with a drastic reduction of the water flow to the estuaries in the floodplains of the rivers. To save water resources, to increase the productivity, and to improve the ecological and ameliorative state of irrigated cultivated lands, the authors suggest creating associations of landowners and land users for obtaining grants and loans for renovating the engineering systems of basin irrigation aimed at using high-yield tiers with the area of 50 – 100 ha and the flooding norm of 2,000 – 3,000 m^3/ha.

Keywords: agricultural and environmental monitoring, cultivated land, engineering estuary, irrigation, flooding, groundwater, salinization, land degradation.

I. INTRODUCTION

In the arid soil and climatic conditions of the Russian Federation, basin irrigation is the most available source of guaranteed fodder production and improving the socio-economic living conditions of the local population [1].

In the eighties of the last century, great attention was paid to developing this method of land amelioration in the Saratov and the Volgograd Trans-Volga regions, Kalmykia, and Kazakhstan. In this period, large-scale construction and renovation of the engineering (artificial) estuaries took place on the territories with various types of cultivated lands (floodplain and water protection, land amelioration and irrigation [2]), which were focused on the guaranteed sources of irrigation — floodwaters of the steppe rivers and the water supply from irrigation and watering channels.

Large areas of the engineering estuaries flooding (2.6 – 11.0 thous. ha), in various conditions of groundwater outflow, had various effects on the ecological and ameliorative state of the lands in the arid Trans-Volga region.

The relevance of the analytical and monitoring studying the dynamics of changes in the state of irrigated lands is in the following:

– identification of the factors that influence the ecological and ameliorative state of integrated basin irrigation systems located on the flood-plains and water preserving and ameliorative-irrigated cultivated lands, and in adjacent areas;

– providing modern cartographical materials about the state and use of estuaries to the national system for monitoring observations, executive authorities, legal entities, and individuals, as well as to agricultural producers of all forms of ownership; and

– predicting the ecological and ameliorative changes, negative effects on the ameliorated lands, and developing recommendations for rational environmental management aimed at increasing the productivity of grasslands.

Conditions and objects. The study was performed in the Northern part of the Caspian depression in the zone of southern sagebrush-grass semi-desert steppes of the southeast (Aleksandrov Gai) part of the Saratov Trans-Volga region, which was characterized by the heterogeneity of the soil and the vegetation cover.

The specialization of this agricultural region (livestock breeding) is appropriate for the semi-desert climatic conditions. Among the negative natural and anthropogenic processes that reduce the agricultural production, a special place is occupied by droughts, wind erosion, waterlogging, and secondary salinization — due to the rise (to 50 g/l) of mineralized groundwater [1]. The Aleksandrov Gai district is also characterized by manifestations of various desertification processes, such as decreasing the intensity of the anthropogenic load on the lands previously used for plowing, and increasing the pressure in the riverside zone, which leads to degradation of natural vegetation on the pastures [3-5].

The land reserves in the district amount to 227.1 thous.

ha. Farmlands make 97.2 % of the territory, which mainly (82.2 %) consists of the pastures and hayfields, some of which are irrigated (mostly by estuary) lands (3,085 ha, of which 20 to 60 % are flooded every year).

The objects of the research were two types of cultivated lands with engineering systems of basin irrigation on them.

On the interfluve-plain ameliorative-irrigation cultivated lands, the Burdinsk engineering system of basin irrigation (BSBI) with the flooded area of 2.6 thous. ha (9 tiers with the average tier area of 270 ha) was studied. It is located along the irrigation channel (with hydrotechnical structures — culverts), to which the irrigation water is supplied from the BolshoyUzen River by an electric pumping station.

In the flood-plain and water preserving cultivated lands in the floodplain of the MalyUzen River, the MalyUzen system of basin irrigation (MSBI) with the flooded area of 11.0 ha (28 tiers with the average tier area of 550 ha) was studied, to which water was supplied through three water channels with the throughput capacity of 10 m3/s each at the NPL (normal pond level) in the pond of 26.6 m. Given lower elevations, the water was supplied from the MalyUzen River by four electric plants.

In these estuaries, the soil complexes (meadow-estuary, meadow-chestnut, light-chestnut soils and solonetzes) were studied, the morphology of which was closely associated with the topography, the parent rock material, and the hydrological peculiarities of the territory.

The soils in question were formed in the Northern part of the Caspian lowlands. The thickness of the parent rocks (sediments of the Khvalynean tier) was 10 – 16 m. The distinctive features of the sodic Khvalynean sediments of marine origin were decreased permeability (due to their density), weak water transport capacity, and high content of salts.

II. PROPOSED METHODOLOGY

A. General description

The study was aimed at comprehensive monitoring and research of the ecological and ameliorative state of the irrigated cultivated lands in the Southeast of the Saratov Trans-Volga region, depending on their type and the degree of the anthropogenic load.

The tasks of the research were the following:

– studying the relationship between the changes in the hydrological and ameliorative state of flood-plain and water preserving cultivated lands and adjacent areas and the changes in the intensity of the irrigation load;

– using the methods of remote sensing of the ameliorated cultivated lands for monitoring the dynamics of the change in the area of flooding and the state of vegetation in the MSBI and the adjacent grazing lands; and

- developing recommendations for improving the ecological and ameliorative state of ameliorated lands.

The areas of the study were based on the following materials:

– analysis of the reasons for changes in the hydrogeological and ameliorative state of cultivated lands in the MSBI and the BSBI based on data of Kistanov [6, 7], the Saratov hydrogeological and ameliorative crew [9], Privolzhgiprovodkhoz, SE VolzhNIIGiM [1] and exploratory surveys of the Siberian State Agrarian University (SSAU) [8].

– the scale and the extent of flooding of the lands in the area around the MSBI and the BSBI were determined based on the results of complex microwave radiometric (scale 1:50000) and HF – radar photography (scale 1:100000) [9].

– degradation of pastures due to the natural and irrigation salinization and the deterioration of the water conditions, and the dynamics of changes in the area of flooding in the MSBI were studied by satellite images with daytime composite images of the NDVI data freely distributed by LP DAAC being part of USGS [10].

The research methodology was based on the methods of generalization, interpolation, observation, description, comparison, analysis, synthesis, and analytical modeling. The satellite images were processed, and thematic maps were made in the ENVI and ArcGIS software suites.

B. Algorithm

In selecting satellite images for assessing the changes in the state of pastures, the peculiarities of working with the NDVI index were taken into account. Preference was given to the images taken in May and June. Correspondence of the NDVI values to the overall projective coverage and the levels of pasture degradation were assessed by four indicators (Table 1) [11].

Table 1: Correspondence of the NDVI indicators to the overall projective coverage (OPC) and the levels of pasture degradation.

The level of degradation	OPC, %	NDVI
Very strong (disaster)	0 – 20	< 0.4
Strong (crisis)	20 – 40	0.4 – 0.5
Medium (risk)	50 – 60	0.5 – 0.7
Weak (norm)	Above 60	> 0.7

Identification and mapping of the area of the MSBI flooding were made using satellite images from KA "Landsat" from March through June 1986, 2009, 2011, 2014, and 2018.

III. RESULT ANALYSIS

The performed analytical and monitoring research of the changes in the state of flood-plain and water preserving (MSBI), ameliorative and irrigation (BSBI) cultivated lands identified three periods when the scale, the intensity, and the frequency of irrigation loads significantly changed, thus affecting the hydrological and the ameliorative state of the studied cultivated lands and the adjacent areas.

The first period (1952–1981) was associated with the commissioning and operation of the MSBI with the total area of 32.6 ha, and consisting of separate shallow and deep-water estuaries: "Zarya", "Urusov", "Khrenovy", "Churikov", "Krutoy", etc. in the floodplain of the MalyUzen River that were flooded by the spring runoff waters. The meltwater was propped by the dam, then spread on both sides of the riverbed, and accumulated in depressions, which created favorable conditions for the development of meadow vegetation.

According to Kistanov [6, 7], after 15 years of the MSBI operation, its state was assessed as relatively favorable. In the central parts of estuaries, low (0.2 – 5.5 g/l) salt content was noted in the groundwater (GW), which increased (to 26 g/l) closer to the peripheral part of the estuaries. The general regularity of the hydrological and ameliorative state for most estuaries in the MSBI was desalinization of the profile from soluble salts in the zone of constant flooding. On the elements of the slopes of meso-depressions in the estuaries, differences in the content and the alkalinity of the absorbed sodium were noted. In long-flooded estuaries ("Khrenovoy", "Zarya"), processes of sodium carbonate salinization and solonization were observed.

The main disadvantage of the MSBI was the irregularity of flooding, which caused deterioration of ecological and ameliorative state in some parts of the flood-plain and water preserving cultivated lands: waterlogging in the lower parts of the terrain, and salinization in the elevated parts.

The second period (1981 – 1992) was associated with increasing the scale, the intensity and the frequency of irrigation load on the cultivated lands in the area due to the guaranteed (mechanical) water supply, including the water from the Volga River via the Saratov Watering and Irrigation Channel n.a. E. E. Alekseevsky. The guaranteed water supply contributed to increasing the ameliorated areas. For this purpose, new systems of basin irrigation were built, and the existing ones were renovated.

After the renovation (1976 – 1981), the MSBI started annually flooding the area over 11 thous. ha, whereas before the renovation, this system (32.6 thous. ha) had been intended for complete flooding by the runoff at 25 % of the water supply, and at 80 %, blind drainage had prevailed.

In 1984, the Burdinsky engineering estuary located on the interfluve-plain ameliorative-irrigation cultivated lands was commissioned (2.6 mln ha).

The magnitude of the irrigation load of the MSBI and the BSBI on the natural lands involved extensive grounds into the water-and-salt streams adjacent to the estuaries. Large areas of irrigation development and significant water load with a weak GW outflow caused their raise outside the estuaries on large areas. According to the results of microwave radiometric and HF-radar surveillance performed in 1991, in the area of 90 thous. ha, the groundwater level (GWL) was less than three meters from the surface, and in the area of 38 thous. ha (12.5 % of the territory), it was less than one meter from the surface (Fig. 1). Thirty percent of the territory or 35 % of its cultivated land and several settlements – Varfolomeyevka, Vetelki, Baiguzha, and Aleksandrov Gai – were flooded. The epicenters of flooding were the MSBI, the BSBI, and the Bolshoi estuary. Calculations show that the share of irrigation factors of flooding was 74 thous. ha or 24.7 % of the the entire area of the district. The environmental state of the lands in the area in terms of waterlogging was assessed [6] as the maximum allowable.

Unlike the natural landscapes adjacent to the estuaries, in the MSBI and the BSBI, the relatively favorable ecological and ameliorative state was noted in this period.

The soil cover in the lands in the MSBI, which had been formed in the natural conditions determined by inundations of the Small Uzen River, consisted mostly of meadow-brown and meadow-estuary dark soils. The soils were leached of salts to the depth of one meter or more. The "cushion" of fresh groundwater was located at the depth of 2.0 – 3.0 m, and was used for water supply to perennial grasses.

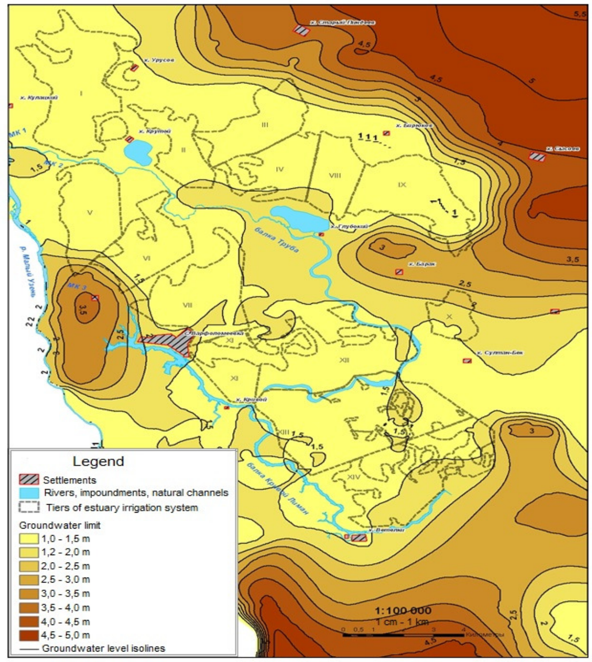


Fig. 1. Groundwater occurrence in the MSBI and adjacent areas.

Comparison of the results of analyzing water extracts in 1976, 1984 (the data of Privolzhgiprovodkhoz), and 1998 – 1999 [9] showed that the cover and the salt conditions of the soils in the BSBI had improved (Fig. 2). On meadow-chestnut, weakly solodized and meadow-inundated soils, the amount of salts did not change. On solonized alkaline and light chestnut soils, the salt content decreased 2.0 – 2.4 times. Alkaline-saline soil differences disappeared from the soil complex.

Deterioration of the ecological and ameliorative state of a part of the estuary was due to the uneven flooding of the tiers. In the lower parts of the terrain, the water stagnated, which resulted in waterlogging, and in microelevations — to salinization.

During this period of intensive operation, all estuaries were very important for fodder production in the area. The hay yield reached 2.0 – 2.2 t/ha.

In the third period (1993–2018), the changes in the hydrogeological and ameliorative state of the studied cultivated lands in the estuary were associated with the violation of the water-and-salt conditions that had existed for decades.

As a result of the ongoing political, social and economic transformations in the country aimed at developing market relations, payment for water use was introduced. The lack of state funding for the irrigation and watering systems, the collapse of collective farms and the emergence of numerous unorganized smallholders with insufficient financing and physical infrastructure [12-15] resulted in reduced water flow to the estuaries.

In the BSBI located on the interfluve-plain ameliorative-irrigative cultivated lands, a weak outflow of groundwater towards the downstream areas was noted. The factor of draining mineralized GW from the irrigated area and the areas adjacent to the estuary allowed maintaining relatively good ecological condition.

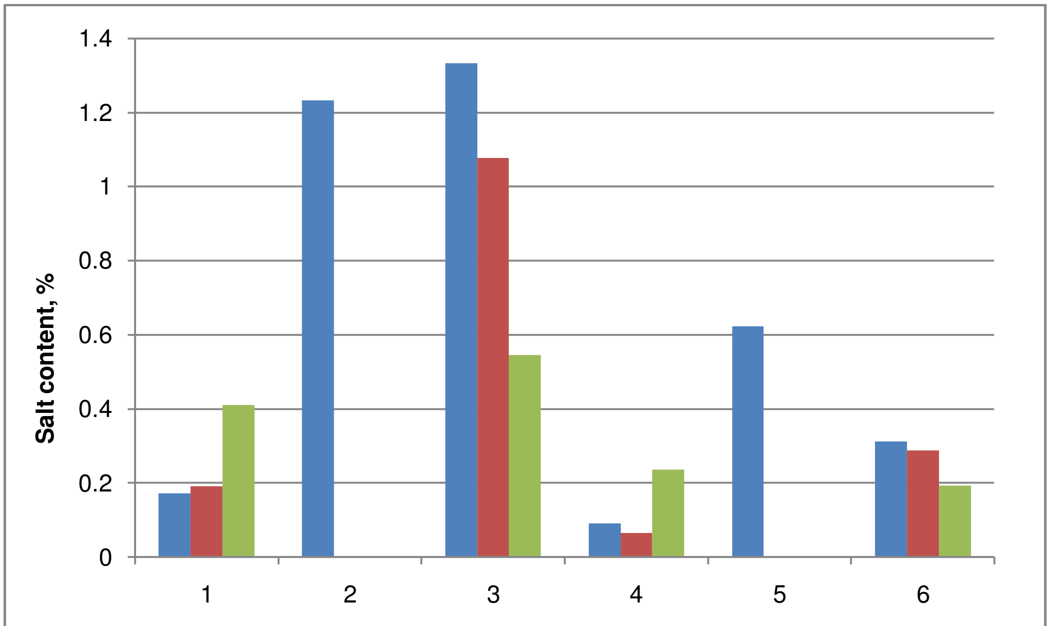


Fig. 2. The dynamics of changes in the salinity of the 0 – 1.0 meter layer of soil in the BSBI in 1976 (Row 1); 1983 (Row 2); and 1999 (Row 3).

Unlike the BSBI, in the MalyUzen system of basin irrigation located in the fluvial plain, there were no conditions for the outflow of mineralized GW. The mechanism of the estuary soil desalination that had existed for decades was based on moving salts outside the estuary under the pressure of irrigation water due to the irrigation norm of 3.5 – 5.0 thous. m^3/ha and subsequent exudation conditions of their localization in the soils outside the territory of the estuary. While earlier, a "hill" of GW formed every year after flooding, which then spread to sides, redistributing the salt outside the estuaries, in the absence of flooding, the well-developed root system of perennial grasses started absorbing the desalinated "water cushion" of GW like a pump. The level of desalinated GW in the tiers fell below the groundwater level outside, which caused the reverse current of the GW brine (40 – 50 g/l) toward the estuaries.

Identification and mapping of the flooding area at the MSBI performed with the use of satellite images from KA Landsat showed that the flooded area at the MSBI in 1986 amounted to 9,320 ha. In 2009, 2011, 2014 and 2018, it decreased to 589, 5,421, 1,695, and 1,920 ha, respectively (Fig. 3).

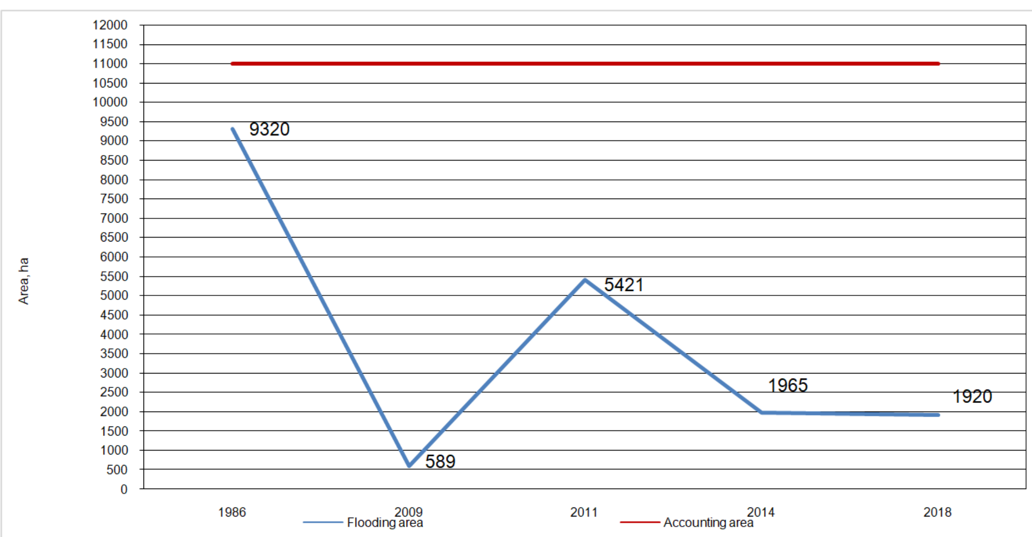
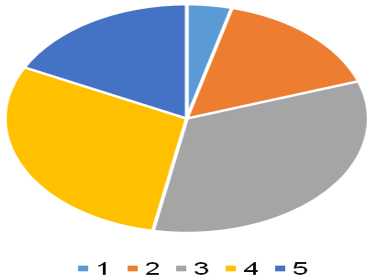


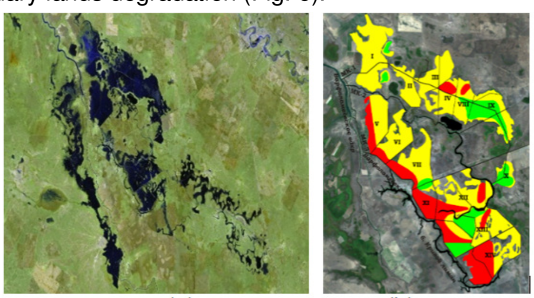
Fig. 3. The dynamics of the MSBI flooding area in 1986 – 2018.

According to the VolzNIIGiM [16], up to 25 % of the MSBI area was completely degraded, the rest of the soils in the estuary were salinized to varying degrees (Fig. 4, 5).



Degree of salinization: (1) not saline (2) weakly saline (3) medium saline (4) highly saline (5) very highly saline.
Fig. 4. Distribution of soils at the MSBI by the degree of salinization of the 0 – 1.0 meter layer based on the test results in 1997 – 1999, %.

Analysis of the environmental changes in the ecological and ameliorative state of the MSBI located on the flood-plain and water preserving cultivated lands in the period of the abrupt change in the water-and-salt conditions of the GW migration flow (between 1986 and 2007), performed with the use of the Normalized Difference Vegetation Index (NDVI) in the form of mapping the territory of the MSBI, allowed to assess the reduction in the biological productivity of the cenoses involved in estuary lands degradation (Fig. 6).



(a) (b)

– contours of solid strong salinization;
– contours of waterlogging;
– contours in the satisfactory condition.

Fig. 5. The MalyUzen system of basin irrigation (a) the scanned image from the Lands at 7 satellite (b) the map of the manifestations of the soil degradation processes.

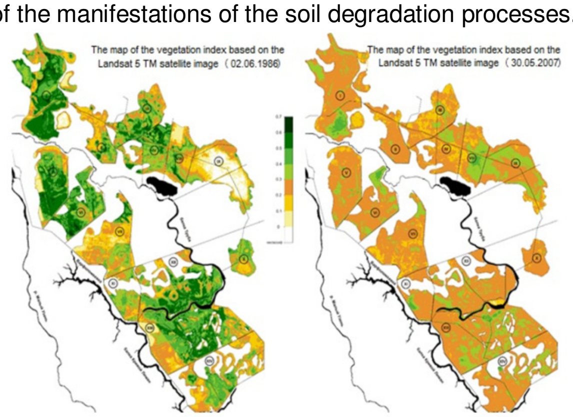


Fig. 6. Assessment of the bioproductivity of the lands at the MalyUzen system of basin irrigation by the method of NDVI mapping.

The monitoring studies of the satellite multispectral images of the changes in the photosynthetic active biomass of the vegetation of the estuaries in the Urusov MSBI confirmed that normal vegetating biomass of the grass stand had been observed until 1993. Starting with 2000, the NDVI values had decreased to the minimum in 2009.

By 2009, the major part (73.5 %) of the initial area of the vegetation cover exposed to "weak" degradation had decreased by 73.1 %. With that, its degradation had increased with the shift to the "average" (14.8 %) and "strong" (58.3 %) level.

Deterioration of the ecologic-ameliorative state of irrigated lands affected the agricultural production in the Aleksandrov Gai District. From 1990 to 1999, the acreage had decreased from 94 to 20 thous. ha; the area of hayfields — from 19.4 to 9.0 thous. ha; the amount of hay — from 12.75 to 3.35 thous. t; the population of cattle — from 18.98 to 9.82 thous. animals; and the population of sheep and goats — from 179.11 to 32.64 thous. animals [17].

Currently (2018), the Burdinsk system is not flooded. The area of annual flooding in the MSBI is insignificant (Fig. 7).

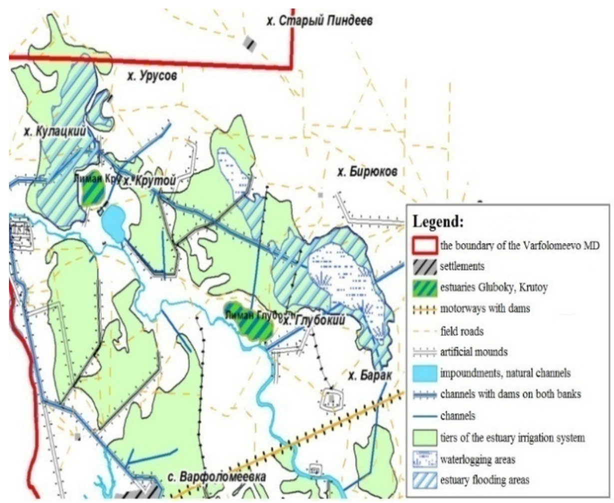


Fig. 7. A fragment of a land use map in the MalyUzen system of basin irrigation according to the remote sensingdata (2018).

The existing fodder base in the Aleksandrov Gai district does not allow keeping a cattle population of more than 21 thous. livestock units [18]. The development of sustainable fodder production in the area requires improving the ameliorated agriculture focused on water-and-resource preservation.

SSAU scientists suggest increasing the fodder base in the area and improving the efficiency of water use and the ecological and ameliorative state of engineering systems for basin irrigation:

–uniting the ameliorated landowners and users in a general organization for obtaining governmental grants, loans for retrofitting the system of basin irrigation to ensure sustainable and effective fodder production;

– retrofitting the most productive tiers of the estuaries by reducing the size of the tiers up to 50 - 100 ha, and by their uniform flooding and reducing the irrigation norm up to 2,000 – 3,000 m^3/ha; and

–reducing two times the irrigation load on the territory of the flood-plain and water preserving (MSBI) and ameliorative-irrigation (BSBI) cultivated lands by reducing the total area of basin irrigation in the district to 6 – 7 thous. ha.

IV. CONCLUSION

Irrigation in the arid zone of Russia plays a substantial role in ensuring fodder provision for livestock breeding. It should be focused on using local water resources in sufficient quantities in such a way that the total irrigation load of the ameliorated and natural agricultural landscapes does not exceed the defined limits with which the balance of the water and salt conditions in the soils and the ecologic-ameliorative state of the soils become deteriorated.

Systems of basin irrigation without or with very weak GW outflow are most prone to salinization and waterlogging, which is especially true for flood-plain and water preserving cultivated lands for which initially long and high irrigation load and its subsequent termination contribute to the lowering of groundwater level due to the suction of the GW "desalinized cushion" by the root system of the grasses and the occurrence of reverse flow of salinized GW from the periphery to the center of the estuary.

Improving the system of basin irrigation (improving the efficiency of the water use, improving the ecological-ameliorative state) in the modern conditions is impossible without unifying individual landowners and users into a general organization for obtaining governmental grants, loans for retrofitting engineering systems of basin irrigation for the following purposes: reducing the area of the tiers to 50 – 100 ha, reducing the irrigation norms to 2,000 – 3,000 m^3/ha, and improving the grass stand at the roots and on the surface.

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