Environmental monitoring of North-West Pre-Caspian liman lands using GIS technologies

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Abstract. Liman irrigation is an effective irrigation method in arid conditions of the Russian Pre-Caspian, which includes the territory of the Republic of Kalmykia ensuring the rational use of local surface runoff and other types of water resources and serving a reliable source of cheap and quality fodder. Based on the existing experience and experimental data, the paper states methodological bases and regulations of the regional monitoring system of ecological-reclamation state of lands and phytocenoses within limans, which ensure effective control of such indicators as fertility level (content of humus, nitrogen, phosphorus, potassium and heavy metals in soil); degree of salinization and alkalinization (using a zonal scale that takes into account the level of resistance of phytocenoses within limans to these negative processes); water-physical and structural properties (particle-size distribution, density, field moisture capacity, etc.), as well as species composition of vegetation (using the developed zonal classification scale) and productivity level and quality composition of fodder. The system of local environmental monitoring of Small Captain – the key section of liman irrigation system – is considered as an example. Based on the results of satellite image processing, the areas of liman zones with different NDVI levels in the time interval from 1985 to 2019 are calculated. The dynamics of the NDVI change of the Small Captain liman plant cover is shown, reflecting the true degradation picture of liman irrigation land during the considered period of study.

1. Introduction

The North-West part of the Caspian lowland is located in the south-east of the European part of the Russian Federation. Geographically, it is located between the Volga-Akhtubinsk floodplain, the Ergenin Elevation and the Kuma River Valley. The North-West Pre-Caspian includes the southern and central parts of the Astrakhan region, the main part of the Republic of Kalmykia (excluding the western zone), the northern part of the Republic of Dagestan, the south-east of the Volgograd region [1, 2].

The Republic of Kalmykia belongs to the depressed regions of North-West Pre-Caspian, and is characterized by arid and semiarid climate. The area of natural pastures in the territory of the republic is 5.2 million hectares, which is 83.5 % of all agricultural land [2–4]. The traditional agricultural industry of this region includes meat cattle breeding and sheep farming. However, natural pastures have low productivity and do not fully meet the animal needs.

Livestock production, as a dynamic agricultural sector, requires a strong feed base. In recent years, the total need for coarse fodders in all forms of economy in the republic has amounted to more than
700 thousand tons [2, 3]. Guaranteed production of fodder in arid regions of our country is only possible in areas with additional moisturization. Such lands allow obtaining sustainable fodder crops regardless of existing weather conditions.

Liman irrigation is the production of fodders in environmentally friendly manner, since it is the closest to a natural soil moistening cycle with the formation of a highly productive, sustainable agroecosystem. At present, there are more than 37 thousand hectares of liman irrigation engineering systems in the region. The channels of two large water-irrigation systems – Sarpinskaya and Chernozemelskaya serve the water source [2, 3].

The productivity of liman ecosystems significantly depends on the level of ecological and reclamation state of lands and natural fodder-producing areas.

2. Objects and methods of study
The assessment and forecasting of the ecological-reclamation situation within liman irrigation systems is carried out on the basis of soil-reclamation and salt surveys, geobotanical studies using publicly available remote sensing data (LANDSAT, SPOT, SENTINEL) and vectorization of cartographic documents.

The main indicators of ecological-reclamation state of irrigated lands within liman systems include the following:
• degree of salinization of soils and their underlying rocks in layers 0–1.0 and 0–2.0 m, total reserves of toxic salts;
• sodium absorption ratio of soils and their complexity;
• depth of formation, total dissolved solids and chemical composition of ground waters;
• degree of swampiness of liman massifs;
• soil fertility (humidity and nutrient content);
• extent of heavy metal pollution;
• hydrophysical indicators of soil (particle-size distribution, density and water permeability);
• quality of irrigation water.

The Small Captain liman located in the area of the Chernozemelskaya water-irrigation system was chosen as the object of geo-information analysis of ecological-reclamation state. The area of liman irrigation engineering system is 700 hectares, which consists of 6 tiers.

3. Results and discussion
The analysis of theoretical studies [5–11] and results of long-continued monitoring allowed developing a zonal assessment scale of ecological-meliorative state of liman irrigation lands (Table 1). It was established that many hydrotechnical structures within limans were found to be in unsatisfactory technical condition.

Negative processes, which are active in modern conditions on irrigated lands, require extensive monitoring over the development of these phenomena, their assessment, forecast, management and implementation measures to prevent and minimize the damage caused. Surface and remote monitoring techniques are urgently needed to implement rapid identification and accounting of degraded land. The technologies for the assessment and mapping of irrigated lands according to satellite data make it possible to determine the level and degree of degradation of vegetation and soil cover, the size and location of degraded areas, and to identify trends in their spatial distribution [5, 11].

Soil cover in the Small Captain liman is represented by zonal meadow average loamy, heavy loamy and clay soils, the agrochemical indicators of which were formed under the influence of the flooding schedule. The degree of salinization of the soil layer is 1.0 m high (sum of salts is 0.4–0.7 %), and alkalinity – low and average. Depending on the fertility level of soils, the yield of the natural herbal plant also varies. The highest productivity (2.0–3.0 t/ha of hay) is observed in the population of couchgrass growing in regular flooding zones within 20–30 days. In other liman belts with shorter or longer duration of water standing the yield drops to 1.0–2.0 t/ha and less [2, 3].
Table 1. Zonal assessment scale of ecological-meliorative state of liman irrigation lands

| No. | Estimated figures | Gradation of lands according to ecological-meliorative state |
|-----|-------------------|---------------------------------------------------------------|
| 1   | Content of water–soluble salts in soil layer 0–1.0 m, % of soil mass | good 0.16–0.28, satisfactory 0.28–0.60, unsatisfactory more than 0.60 |
| 2   | Share of exchangeable sodium in cation exchange, % | up to 5.0, 5.0–10.0, more than 10.0 |
| 3   | Depth of salic horizon, m | deeper than 1.0, 0.5–1.0, less than 0.5 |
| 4   | Soil dispersion coefficient | less than 5, 5–15, more than 15 |
| 5   | Humus content in soil layer 0–0.4 m, % | more than 3.0, 1.0–3.0, less than 1.0 |
|     | Nutrient content in soil layer 0–0.2 m (mg/kg): | |
|     | – easy hydrolysable nitrogen | more than 10.0, 5.0–10.0, less than 5.0 |
|     | – labile phosphorus (P2O5) | more than 15.0, 10.0–15.0, less than 10.0 |
|     | – exchange potassium (K2O) | more than 300.0, 100.0–300.0, less than 100.0 |
| 6   | Soil density in layer 0 m (m3/t) | less than 1.5, 1.5–1.7, more than 1.7 |
| 7   | Water permeability of soil layer 0–1.0 m (m3/ha per 1 h) | 500–750, 250–500, less than 250 |
|     | Ground water depth level (m) at their salination (g/l): | |
|     | – less than 1.0 | more than 1.8, 1.5–1.8, less than 1.5 |
|     | – 1.0–3.0 | more than 2.2, 1.8–2.2, less than 1.8 |
|     | – 3.0–5.0 | more than 2.8, 2.2–2.8, less than 2.2 |
|     | – 5.0–10.0 and more | more than 3.2, 2.8–3.2, less than 2.8 |
| 8   | Total dissolved solids, g/l | less than 1.0, 1.0–2.0, more than 2.0 |
| 9   | Water resources, % | 50.0 and more, 25.0–50.0, less than 25.0 |
| 10  | Degree of swampiness, % of liman area | less than 10.0, 10.0–20.0, more than 20.0 |

The study used multi-spectral images of medium density from Landsat and Sentinel 2 spacecraft from 1985 to 2019 from the open archives of the Internet portals of the US Geological Survey (USGS) and The Copernicus Open Access Hub of the European Space Agency (ESA). Digital processing of ERS data was carried out in QGIS geographic information system using the installed Semi-Automatic Classification Plugin [5, 11].

The plant cover of the studied area was used as an indicator to display the ecological-meliorative state of liman lands at the moment of ground surface survey by a spacecraft. This component of the landscape, as the most dynamic in terms of signs of ecological-meliorative state of liman land, shows the level of adverse processes that lead to the reduction of agricultural productivity. Liman herbal productivity depends on moisture conditions and soil fertility level.

The researchers worldwide use spectral reflective properties in separate channels and a variety of vegetation indices to produce qualitative and quantitative indicators of growing vegetation based on remote sensing data. Currently, there are about 160 options for calculating vegetation indices. Our study uses the most popular and frequently used vegetation index – NDVI (Normalized Difference Vegetation Index) calculated by the formula:

\[
\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}},
\]

where NIR – near-infrared reflectance; RED – red reflectance

The NDVI index is calculated in the range from −1 to +1. Due to the characteristic of NIR-RED reflectance in the spectrum regions, the natural objects unrelated to vegetation have a fixed NDVI value, which allows using this parameter to identify open soil, water surface, etc.

Changes of photosynthetically active biomass of the vegetation of the liman irrigation area were recorded in the phase of grass maximum vegetation by a series of multilayer images from artificial
The dynamics of the NDVI change of the vegetation cover of the Small Captain liman is shown in Figure 1 reflecting the true picture of liman irrigation land degradation during the studied period.

The observations showed that high NDVI index in the range of 0.4-0.8 corresponding to normally vegetating grass biomass almost throughout the liman were only found in 1985, 1990 and 1996. Since 2000, the NDVI values were declining and reached its minimum in 2010.

The areas of liman zones with different NDVI levels within the time interval from 1985 to 2019 were calculated based on the results of satellite image processing. According to the data obtained in the period from the mid-1980s to the early 1990s at this irrigation site, the occupied area of normally growing vegetation was at a quite high level, close to 100% of the total liman area.

Thus, in 1990, the prevalence of the area of NDVI zones in the most productive range from 0.4 and more reached the maximum over the entire monitoring – 674.2 hectares, which amounted to 99.6 % of the total studied area of the irrigated area. Next, there was a trend towards the reduction of the productive area, as a result of which in 2010 the lowest productive liman area was recorded – 452.1 hectares, which amounted to only 66.8 % of the total plot. In the following years, the situation slightly improved with the area of 557.2 hectares in 2019 corresponding to 82.3 %, with a relatively large number of non-flooded areas, as opposed to which there are also overwatering areas with a long water standing time.

**4. Conclusion**

The results obtained during the study confirm the feasibility and necessity of using remote methods to monitor the ecological-meliorative state of liman irrigation lands. These methods make it possible to assess promptly and reliably the nature and direction of negative processes and to develop measures for the restoration of degraded soils caused by the disruption of the technological regime of flooding and resulting in the disruption of the natural water balance and the deterioration of the ecological and meliorative state of limans.

The study of space-time formation and change of natural and technical systems is currently one of the main tasks of modern science. Cartographic materials based on earth remote sensing data are
needed to provide a common methodology for combating land degradation and improving hay grasses, as well as more accurate assessment and inventory of irrigated agricultural lands.

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