Monitoring of the Gissar Valley`s irrigated lands in the Republic of Tajikistan based on the use of GIS technologies

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Abstract. Land use in the Republic of Tajikistan is characterized by very difficult conditions for conducting useful economic activities. The crop industry is experiencing a shortage of suitable arable irrigated land (total arable land, according to various estimates, makes up about 5% of the total area of the country), which is clearly expressed in the decline in gross agricultural production. Scientists and practitioners have noted negative trends, indicating a decrease in specific indicators of per capita provision of agricultural land. All this necessitates the development of mechanisms and methods for a qualitative study of the current state of land use and the development of recommendations to prevent its further degradation. The article sets forth material that relates to the current state and prospects of obtaining and processing updated data on irrigated lands of the Republic of Tajikistan using modern information and communication technologies and GIS. It is shown which factors are constraining and which factors are stimulating in the republic. The practical significance lies in the fact that the results of the study can be useful in the study of the condition and use of irrigated lands, as well as in the effective management of these lands.

1. Introduction

The solution of problems related to the updating and reliability of obtaining data on the state and use of natural and man-made landscapes is based on the use of various data and, above all, remote sensing of the Earth (ERS). At the same time, the problem of monitoring various territories is one of the main problems that are based on the use of remote sensing methods and GIS technologies. Organization of a system for monitoring irrigated land based on the use of geoinformation technologies, which includes means of intelligent information processing and development of forecasts and recommendations, as well as a system of geoinformation support for optimizing management decisions in the field of land reclamation and land use.

The analysis of the state of land use, land and water policy, the state of irrigation systems in the Republic of Tajikistan at different times was carried out by such researchers as Frederike Klümper, Insa Theesfeld, Thomas Herzfeld (2018), Tobias Hoeck, Roman Droux, Thomas Breu, Hans Hurni, Daniel Maselli (2007), Marie-Charlotte Buisson, Soumya Balasubramanya (2019) and other.

The development and implementation of a monitoring system for irrigated lands must begin at the local level, since it is the local level that is closest to the real conditions that provides all the necessary information: collection of primary material, forecast changes and scientifically based recommendations [1].
Each territory under study has its own characteristics that are specific only to this territory. The availability of open access to satellite images in various ranges obtained from QuickBird, EROS, SPOT, TERRA (ASTER), Landsat, etc., provides great opportunities for their use for various tasks.

The territory of the irrigated lands of the Gissar Valley of the Republic of Tajikistan was chosen as the study area. The Republic of Tajikistan is located in the inner part of the large continental massif of Eurasia. The territory occupied by mountains and mountain ranges makes up 93%, which belong to the Tien Shan and Pamir-Altai mountain systems. Plain spaces are extended sections of river valleys and intermontane depressions. The altitudes above the sea level of the territory of Tajikistan vary from 300 to 7495 meters, in addition, the territory of the republic is divided into 7 cadastral zones: Sogd, Verkhne-Zeravshan, Gissar, Kurgan-Tyubinsk, Rasht and GBAO. During the period 1970-2019, the territory of the Gissar Valley underwent a significant anthropogenic transformation of natural landscapes, some of which went into the category of anthropogenic [2]. In particular, the area of agricultural land has changed most significantly; the area of vegetation has also undergone changes (Fig. 1).

![Figure 1. The study area of the Gissar Valley of the Republic of Tajikistan](image-url)
climatic region with a belt of insufficiently humid climate with very warm summers, mild and moderately mild winter.

The development of erosion processes depends on a complex of natural and anthropogenic factors. Of the many causes of soil erosion, in each case, the prevailing ones are distinguished, but it is always the result of the impact of geomorphological, geological, climatic, soil-plant and economic conditions. The nature of their combinations determines the danger and intensity of the manifestation of a particular type of soil erosion [3].

In this regard, the study and consideration of regional, landscape-typological and paradigmatic features of natural-territorial complexes that form the territory of the Gissar Valley, which will allow to establish their landscape-geoecological state, development trends, the degree of transformation under the influence of natural and anthropogenic factors, becomes particularly relevant.

Issues of maintaining and improving the reclamation status of irrigated lands in Tajikistan occupy one of the main places in the environmental problems of the Republic [4]. The development and implementation of environmental protection measures requires objective and reliable information that helps to assess, analyze and predict the state of land use problems. Based on these data, managerial decisions should be made and a policy of sustainable development of land use in the country should be implemented. This requires, first of all, good knowledge of the specifics of local natural landscapes, and therefore requires the creation of an extensive spatial and thematic information base.

One of the goals of this work is to develop proposals for providing sustainable information support on the state and use of reclamation lands based on the use of modern geographic information technologies and aerospace images. In the process, an analysis of the state of irrigated lands and an analysis of the provision of relevant maps and information on the ecological state of irrigated lands in the Gissar Valley was performed.

2. Materials and methods

This study was based on normative documents of the Republic of Tajikistan and the Russian Federation, scientific and public press materials, Landsat satellite image databases, materials of conferences, symposiums, meetings, documents of the Ministry of natural resources and environmental protection of the Republic of Tajikistan, reports on the state and protection of the environment of the Republic, etc. As a result of data analysis, the main problems of information support are identified, suggestions are given for obtaining up-to-date information based on the use of modern information and communication technologies and data monitoring using GIS technologies.

3. Research on the development of monitoring of irrigated lands in the Republic of Tajikistan using GIS technologies

The most important degradation processes in irrigated agricultural landscapes that lead to the deterioration of their reclamation status are the rise of ground water and secondary salinization. Therefore, the most important components of a digital map are layers that reflect the level of ground water and salinity of irrigated lands and adjacent territories. In this regard, the information system has requirements that should ensure the receipt of such information as [5, 6]:

1) compliance with organizational structures for the operation of irrigated land;
2) reflection of the structure, properties and the relationship of the observed objects and processes in them;
3) presentation of reclamation lands as an integral part of such an element of the environment as agrolandscape;
4) ensuring security and confidentiality of information, as well as free access to subscribers;
5) organizational, software, technical, mathematical, methodological, linguistic, metrological and legal support;
6) prompt provision in an accessible form of information for the entire observation period for various models of analysis and forecasting.
This zone is characterized by low-cloud, dry hot weather in summer and rainy cool weather during autumn and winter. Long-term national research in the field of rational use of irrigated land has established that currently salinization of irrigated soils occurs where the ground water level is closer than 2.0 m from the earth's surface, and their salinity is more than 2-3 g/l. In order to ensure optimal water-salt regime on irrigated lands, a sufficiently developed open collector-drainage network was built [7]. The specific length of this network on individual irrigated lands varies from 13 to 50 m / ha. However, due to the fact that this network is often in a non-working state (silted and overgrown with vegetation), it cannot cope with the diversion of discharge and infiltration water outside the irrigated areas, which leads to a rise in the level of ground water, increased evaporation, as well as an increase in the intensity of salinization processes.

Another aspect that causes huge damage in agricultural production is irrigated soil erosion. Erosion processes that are widespread on irrigated, especially newly irrigated lands of the Gissar valley of Tajikistan, cause huge economic damage and annually reduce the area of agricultural land. Therefore, suspension of erosion processes requires the immediate application of science-based practical measures aimed at preventing their further development. To plan, design and conduct anti-erosion measures and rational use of irrigated land, it is necessary to study the regularity of soil erosion, factors of its development, and determine the amount of soil washed away.

The main common soils in the irrigated territory of the Gissar valley are dark gray soils (39016 ha or 56%), meadow – gray soils (6797 ha or 9.8%), light gray – gray meadows (7512 ha or 10.9%), dark gray - gray meadows (3840 ha or 5.5%), alluvial meadows (1608 ha or 2.3%), meadow – marsh (135 ha or 0.2%), mountain – brown carbonate (9602 ha or 14.6%) and other soils that occupy a small area. The main zone of early potato growing in the Gissar Valley is the piedmont plain and piedmont hilly arid zone with narrow valleys of lateral mountain slopes and rivers, where the main widespread soils with the most favorable water-physical properties for potato growing are old-irrigated dark gray soils and mountain-brown carbonate soils.

The main condition for ensuring the stable development of the agro-industrial complex and the most important source of expansion of agricultural production are conservation, reproduction and rational use of irrigated land. Soil fertility contributes to an increase in productivity and gross harvest of crops, which is why the state of soil fertility deserves special attention.

In recent years, Tajikistan has sharply intensified the process of land development for the construction of houses, industrial buildings, roads. The area of arable land per capita is also being intensively reduced due to population growth.

In order not to reduce the area of irrigated land per capita, about 10-12 thousand hectares of new land should be developed annually. There are such lands for development in the Republic. This is, first of all, unproductive slope, rocky, sandy saline lands, development of which will require a major reclamation and the necessary investments for this purpose.

Therefore, at the present stage of development of the state, the main thing is the rational use of arable, especially irrigated lands, increasing their fertility, ensuring the ecological state, protecting soils from erosion and improving the ecological state of the environment of irrigated lands.

Intensification of the use of irrigated lands is associated with unacceptable loads on natural landscapes, which lead to an imbalance in them. Creating a sustainable interaction of technogenic and natural systems is one of the most important tasks of science and practice.

Research in the field of land reclamation, previously conducted by such scientists as: Dobrovolsky G. V., Orlov D. S, Grishina P. L., 1983; Israel Y. A, 1990; Glushko E. V., 1992; Derzhavin L. M., Frid A. S., Yanishhevsky F. V., 1999; Pronko N. A., Falkovich A. S., Korsak V. V., Holudeneva O. Yu., 2003; Gafurov R. R., 2004 showed that for timely prevention of negative processes, prevention of degradation of irrigated land and environmental pollution by chemical means, as well as improving the quality and safety of products, it is necessary to create a system of integrated, discrete and continuous monitoring of components of the natural environment. Such a system would not only monitor the current state of the natural environment, but also predict their changes in the future based on observations. The implementation of such a system, according to Pronko N.A. et al. (2003), is especially necessary for the
rational use of irrigated lands, since the danger of environmental degradation always accompanies irrigation, as one of the most intensive human activities interfering with natural ecosystems. The studies conducted by Pronko N.A., Fomin G.I., Kopsak V.V., Holudeneva O.Yu. (2002) showed that such a system is possible only with the organization of land use based on the results of monitoring of irrigated agrolandscapes or ecological reclamation monitoring designed to solve resource, reclamation and environmental problems [8].

Thus, ensuring the preservation of favorable environmental conditions in the conduct of any human activity is the most urgent task of the environmental management system. According to N.I. Moiseev [9] at the turn of the 20th century, the 3rd stage of the interaction of man and nature began, at which the anthropogenic influences acquired a global character.

The implementation of monitoring makes it necessary to solve many issues: the creation of a geographical network for tracking the parameters of the state of irrigated land, conducting expedition, laboratory and vegetation studies, creating an information Bank of soil data and a system for their use.

The objectives of monitoring of irrigated lands are: timely identification of changes, their assessment, forecast, timely prevention and elimination of consequences of negative processes and phenomena under the influence of melioration; rationalization of land use; control over the use of irrigated lands; control of the functioning and effectiveness of irrigation measures; information interaction with monitoring structures at the regional and state levels; information support for the management of irrigated lands.

In this study, the goal was to improve the methodological provisions of analysis, assessment and forecasting of the state of irrigated lands based on the use of modern geoinformation technologies and aerospace images of the Gissar valley of the Republic of Tajikistan, to justify the system of measures and conditions for sustainable agricultural development, increasing incomes, solving economic and social problems in the use of agricultural land.

To date, one of the most urgent tasks in the field of monitoring of irrigated land is to improve the quality and scientific validity of management of irrigated agriculture, including through the development and use of modern software and information tools to support decision-making. Their main task is to provide all decision-makers on the management of such lands with detailed, complete, timely and high-quality information in a form that is easy to understand, and to ensure its mathematical and heuristic processing. At the same time, it is very important to link heterogeneous in origin, but spatially interconnected information flows.

The use of GIS technologies for land monitoring allows you to create maps directly in digital form based on coordinates obtained from field measurements or by processing remote sensing materials. In creating digital maps in a GIS environment, the emphasis is on creating a structure of spatial relationships between objects. At the same time, the concepts of exact and inaccurate border matching are clearly distinguished, which is easy to implement with the use of previously digitized borders when creating adjacent objects. In this case, the relations of connectivity, neighborhood, adjacency, nesting, intersection, and other spatial relationships that are necessary for solving a wide range of analytical and practical problems are easily and explicitly fixed.

Since the adaptation of all components of irrigated agriculture systems requires complete and systematic information about the properties of soils, ground water, irrigation network, etc. for specific areas of farms, the information support should be based on local integrated GIS monitoring [10].

A mandatory problem of monitoring agricultural landscapes is the transition from point-based data on the state of indicators of irrigated lands and their soil fertility to digital models of spatial distribution of these indicators in layers of digital maps. Our task was to select optimal methods and develop algorithms for their application in specific conditions of irrigated land in Tajikistan [11].

For example, using earth remote sensing data, changes in water resources and vegetation areas in 2019 were measured from Landsat 8 satellite images using the modified standardized water difference index (MNDWI), which uses the green channel and the SWIR channel to improve the display of open water features. It also reduces the values of built-up areas, which are often correlated with open water areas in other indexes [12]:
MNDWI = (Green – SWIR)/(Green + SWIR),

- Green - pixel values from the green channel,
- SWIR - pixel values from the short-wave infrared channel.

In turn, NDVI processing creates a single-channel data set that mainly represents vegetation density and intensity. Different reflection in the red and infrared (IR) channels allows you to control the density and relative intensity of vegetation using the spectral reflection of solar radiation. Healthy vegetation usually shows better reflection in the near infrared than in the red region of the visible spectrum. If the leaves are deficient in moisture, wilting or dead, they become more yellow and reflect significantly less in the near-infrared range. The infrared range is absorbed by clouds, water, and snow, and is reflected by rocks and bare soil in much the same way as the red range of the visible spectrum.

NDVI is often used around the world to monitor drought, monitor and forecast agricultural production, help forecast dangerous zones of fires and map desert progress. NDVI is preferable for global monitoring of vegetation, as it helps compensate for changes in lighting conditions, surface slope, exposure and other external factors (Lillesand 2004).

The expression used to calculate the default NDVI looks like this:

\[
\text{NDVI} = \frac{(\text{IR} - \text{R}_0)}{\text{IR} + \text{R}}
\]

- IR = infrared pixel values,
- R = pixel values from the red channel

These scientific output values range from -1.0 to 1.0, which indicates the density and intensity of the vegetation cover. Negative values come mainly from clouds, water and snow, values close to zero mainly come from stones and bare soil. Very small values (0.1 or less) of the NDVI function correspond to empty areas of rocks, sand or snow. Moderate values (0.2 to 0.3) represent shrubs and meadows, while large values (0.6 to 0.8) indicate temperate and tropical forests.

Thus, to compile maps with NDVI and MNDWI indices, we need channels 3, 4, 5 and 6 of the Landsat 8 satellite images.

![Figure 2. Changes of the vegetation cover a) and of the water surface b), by months on the territory of the Gissar Valley in 2019](image-url)
Figure 3. Monthly coverage area of vegetation and water on the territory of the Gissar Valley in 2019

The studies performed using these indices for the study area for 2019 allowed us to obtain the data that are presented in Figure 2 as changes in the area of vegetation and water surface. A diagram was plotted and the correlation between the indicators of water areas and vegetation was calculated, which turned out to be -0.46, which shows that the relationship between them is inverse (fig. 3).

The combination of GIS and Internet technologies allows you to find the necessary maps and further work with them in an interactive mode, as with ordinary desktop GIS.

The use of GIS technologies in such systems makes it possible to combine spatial geographic data, aerial and space images, as well as thematic information on a variety of agricultural parameters presented in cartographic and tabular forms. By superimposing on the collected information other obtained data, such as, for example, soil quality, irrigation conditions, meteorological and satellite monitoring data, etc., derivative maps can be obtained to analyze and detect plant degradation, crop forecasting, and control the development of adverse natural - technological processes (soil erosion, desertification, flooding, waterlogging, etc.). In information systems in the European classification, the Land Cover class is one of the highest priorities.

Methods of creating an information base for monitoring agricultural land - there are direct types of work that differ in scale, scope and scope (Fig. 4).
Depending on the type and task of monitoring agricultural land (fertility monitoring, phytosanitary, geobotanical, irrigated land monitoring and other types), the methods for obtaining data can be divided into several groups based on the use of remote sensing, including the use of unmanned aerial vehicles (UAVs)).

The essence of the remote study of soils (and vegetation) is to decrypt (recognize) photographs using photogrammetry and a visual method. The theoretical basis of remote sensing methods is the law of correlation between the properties of soils, plant communities covering them, and environmental conditions. The surface of the soil is almost always covered to some extent by vegetation. Therefore, the composition and state of vegetation primarily affect the nature of the image.

To develop managerial decisions in the field of land relations, it is not enough to accumulate the amount of information; it is necessary to have tools for analysis, processing, visualization and forecasting.

Currently, such tools are represented by various geographic information systems. A high level of computer technology can provide a solution to almost any tasks associated with the use of the territory with the help of GIS technologies.

The need to manage irrigated lands in the emerging socio-economic conditions require widespread use of geographic information systems in creating a unified information field, including for the entire agricultural industry.

Today, an important role in management is given to resource-saving technologies, one of the basic elements of which is precision farming.

In order to save resources and automate the tasks of managing agricultural land, local monitoring using GIS is required.

A unified technology for managing information resources will ensure the creation of a common information space that combines and structures all the main performance indicators of several enterprises within the framework of the use of irrigated land, which will allow:
- accumulate data on the state and use of irrigated land;
- ensure the formation of information on all types of resources of land users, agricultural producers and, as a result, provide strategic and ongoing control over their use, as well as assess the effectiveness of their use;
- generate data for a strategic forecast and assessment of the state of the irrigated land management system (Fig. 5).

In this system, you can collect, store, process, analyze and compare any information necessary for making management decisions, including cartographic data and data on any objects located on the relevant maps.

The use of UAVs in agriculture has a huge potential and interest in their use is growing every year. UAVs are equipped with multispectral cameras, whose high-definition image allows you to accurately identify problem areas of the field with a variety of sensors, satellite navigation systems, small-sized onboard computers and equipment for the study of irrigated land. At present, remote monitoring (primarily satellite-based) allows you to obtain timely and objective information on the entire territory occupied by irrigated land, the update time of which is from a few days to 1 year, depending on many factors, including its spatial resolution.

### 4. Conclusion

The paper analyzes the current state of irrigated lands of the Gissar Valley of the Republic of Tajikistan. The development of rural areas of the republic is impossible without an integrated approach to the development of the use of irrigated land in the context of the popularization of rural lifestyles. Thus, for the full development of such territories, it is necessary to conduct monitoring and constant updating of data, so that the data in the management system are provided in a timely manner and updated according to the monitoring results.

In this regard, a special role in ensuring the functioning of the GIS of irrigated lands is assigned to the district level of management, where the bulk of information is generated for making managerial
decisions in the context of each business entity. In this regard, the primary task is to connect districts to this system.

Figure 5. The main components of the local GIS of irrigated lands

A special feature of the formed system is the ability to work via the Internet without purchasing and installing special software for certain jobs. With access and appropriate rights, you can work in the system from any computer connected to the Internet with a good data transfer speed.

Currently, with the help of this system, local governments will be able to:

1) conduct continuous monitoring of the ownership of the fields to specific agricultural producers;
2) conduct continuous monitoring of the process of registration of fields in ownership or lease, monitor changes in tenants and users of each field;
3) regularly monitor the process of registration of each field for each agricultural producer (after uploading to the system relevant data on the final registration and cadastral registration of each field or part thereof, in the future);
4) monitor information on the structure of irrigated areas for each farm based on the data of agricultural producers or on the basis of objective control, thus knowing what field is grown or not grown for each year;
5) have in the system any necessary data for each agricultural producer (production, financial, economic, social and other indicators) and for each irrigated field (characteristics of the field and its fertility, results of agrochemical surveys, etc.);
6) analyze and compare the results of the farms' work on the basis of the indicators loaded into the system, evaluate the level of their effectiveness and the level of return on funds invested in their development, including state support;
7) have full information on the implementation of investment projects in the field of production and social projects in the region, including photos and video reports;
8) identify unused land, facilities, production facilities, etc., and provide the necessary information about them for potential investors in open access via the Internet.

All information generated at the regional level in the geographic information system can be instantly available at the regional level to management bodies and other interested structures and organizations.

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