Assessment of the current state of irrigated lands in the Gissar Valley based on the use of GIS technologies

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Abstract. The Republic of Tajikistan is a country whose economy has a very high share of agriculture. The share of agriculture in the structure of the country's GDP for 2020 reaches 17.4%, providing GDP growth for the period of January-September 2020 by 2.1 percentage points out of 4.2 (where the remaining 2.1 percentage points are accounted for by the industry). To further ensure sustainable development of the agrarian sector, issues related to the effective and rational use of the country’s available land resources are of particular relevance. The article presents material that is aimed at solving one of the main tasks for the Republic of Tajikistan - the preservation and restoration of irrigated lands. This is based on the decision to form reliable and relevant information on the state and use of irrigated lands based on the use and processing of multispectral satellite images, obtaining hidden indicators and the development of digital map materials in the shortest possible time. The practical significance lies in the fact that the developed methodology can be used to predict and design the implementation of activities on irrigated lands.

1. Introduction

The issues of preserving and improving the ameliorative state of irrigated lands in Tajikistan occupy one of the main places in the ecological problems of the Republic. For the development and implementation of nature conservation measures, objective and reliable information is needed, which helps to assess, analyze and predict the state of land use problems. And on the basis of this data, management decisions should be made and a policy of sustainable land use development in the country should be implemented.

In this regard, there is a need to identify and assess existing environmental and socio-economic problems in the use of reclamation lands, timely reconstruction of reclamation systems, develop ways to solve the identified problems, as well as develop methodological recommendations to substantiate the effectiveness of the implementation of state programs for the management of agricultural lands with taking into account regional specificities [1]. We consider it necessary to note that assessing the state of irrigated lands and organizing their rational use is an important and urgent task not only for traditionally agricultural or industrial-agrarian countries, but also for world leaders. The introduction of modern gis-technologies for monitoring the state of land is considered in the works of many specialists [2, 3, 4].

The territory of the irrigated lands of the Gissar Valley of the Republic of Tajikistan was chosen as the study area. The territory is occupied by mountains and mountain ranges, flat areas are extended sections of river valleys and intermountain depressions. During the period of 1970-2019, the territory of
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the Gissar Valley underwent a significant anthropogenic transformation of natural landscapes, some of which passed into the category of anthropogenic [5].

The negative processes arising on the irrigated lands of the Gissar valley can be grouped into the following classes: natural, technogenic, social at the detailed, local, regional, subregional and state levels. Information support for assessing the state of land should be based on a set of information data reflecting the state of the entire natural environment [6]. Considering that the total number of monitoring indicators can reach 350 and more, it is necessary to form them into the most significant groups of indicators for the implementation of integrated monitoring of irrigated lands in the Gissar valley [7].

To analyze the state of irrigated lands in the Gissar valley, the main factors have been selected that have a negative impact on the state of the valley lands at the regional level, on the basis of which the most informative indicators were selected from the groups at the regional level at the local level. For this, first of all, the actual areas of irrigated lands in the Gissar valley were determined on the basis of multispectral satellite images from the Landsat 7 and Landst 8 satellites using the ArcGis software.

One of the goals of this work is to develop proposals for assessing the state of irrigated lands in the Gissar Valley based on the use of modern geoinformation technologies and aerospace images [8].

2. Materials and methods

For the research, the regulatory documents of the Republic of Tajikistan, materials of open press, Landsat satellite images, documents on the state of the environment of the Republic of Tajikistan and materials from other sources were used. The analysis of the state of irrigated lands in the Gissar Valley was carried out on the basis of the established factors that have a negative impact on the state of the lands of the Valley, on the basis of which hidden factors were identified and the actual areas of irrigated lands in the Hissar valley were determined based on multispectral satellite images of Landsat 7 and Landst 8 using the ArcGis software taking into account the indicators of hidden factors [9].

To determine the area of irrigated land, first of all, the areas of vegetation in the territory of the Gissar valley were determined using the analysis of multispectral satellite images from the Landsat 7 and Landst 8 satellites and the ArcGis 12 software according to formula (1), which determined the values in the range from -1 up to 1, while for areas covered with vegetation, values above 0.2 are taken [10]:

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

where \( \text{NIR} \) is the pixel values from the near infrared channel and \( \text{Red} \) is the pixel values from the red channel. The formula for this index is based on the fact that in the red region of the spectrum - \( \text{Red} \) (0.6-0.7 microns) there is a maximum absorption of solar radiation by chlorophyll by plants, and in the infrared region - \( \text{NIR} \) (0.7-1.0 microns) there is a region maximum reflection of the cellular structures of the leaf. Thus, the high photosynthetic activity associated with dense vegetation leads to less reflection in the red spectrum and more reflection in the infrared. The ratio of these indicators to each other makes it possible to clearly separate plant objects from all others. In the course of this analysis, \( \text{NDVI} \) maps were obtained for each month from 2010 to 2019. Then, on each map, only those pixels were highlighted that show vegetation, that is, with a value above 0.2 and tracked changes in the area of vegetation during 2010-2019.

As a result of the analysis, graphs of changes in the area of vegetation were obtained for the month of September of each year from 2010 to 2019 and for each month by years from 2010 to 2019 (Figs. 1 and 2).
Figure 1. Diagram of changes in the area of vegetation in September each year from 2010 to 2019 in the territory of the Gissar valley.

Figure 2. Diagram of changes in the area of vegetation cover by months from 2010 to 2019 in the territory of the Gissar valley.

The next stage in the research was to determine the area of water coverage on the territory of the Gissar valley using the analysis of multispectral satellite images according to the formula (2), in the range of values from -1 to 1, while the areas covered by water are taken as values above 0:

\[
MNDWI = \frac{(\text{Green} - \text{SWIR})}{(\text{Green} + \text{SWIR})}, \tag{2}
\]

where \text{Green} is the pixel values from the green channel and \text{SWIR} is the pixel values from the shortwave infrared channel. This formula is based on the fact that shortwave infrared bands are more sensitive to moisture content in both soil and vegetation, and in combination with a green channel, they can reliably separate wetlands from dry lands. In the course of this analysis, we received MNDWI maps for each month from 2010 to 2019 [12].
Next, we selected for each map only those pixels that show water, that is, with a value above 0 and tracked changes in the area of water coverage during 2010-2019.

The next step was to identify the plots related to irrigated land using the obtained data on vegetation and water coverage (Fig. 3).

![Irrigated land map in the Gissar valley](image)

**Figure 3.** Irrigated land map in the Gissar valley.

Thus, we obtained data on the area covered by water and the area of irrigated land for the period from 2010 to 2019 (Fig. 4).

The negative processes occurring in the Gissar valley can be grouped into the following groups: natural, technogenic, social, the analysis was carried out using the software "Statistica" v.10.0, JMP Statistic 15 and Minitab 19 [12].

The set of indicators was determined during the analysis of natural and man-made factors that have a negative impact on the state of irrigated lands in the Gissar valley.

The obtained indicators of the regional level were processed using the Statistica 10.0 software product. First of all, a description of the indicators is carried out and the normality of their distribution is established.

In this regard, for further analysis, nonparametric methods of analysis were used: correlation analysis based on the Spearman coefficient, the method of factor analysis.

The number of factors was determined on the basis of a matrix of eigenvalues with a percentage of total variance exceeding 10%. It was found that all the selected factors to one degree or another affect the variables in the database [13].
At the next stage, factor analysis was performed in the software "Statistica" v.10 and JMP Statistical Discovery to reduce the indicators. Factor analysis allows you to calculate factor loadings for each variable, i.e. determine the correlations between indicators and the most informative indicators in a given set of variables.

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Further, the obtained factorial loads, which have load values exceeding 0.7, were considered the most significant.

On the basis of factor analysis and correlation matrix, the choice of the most informative indicators for the Gissar valley was made. Thus, the system of monitored indicators for monitoring irrigated lands in the Gissar valley covers such main factors as: soil fertility, amelioration state, organization of the territory, constructive differences in the reclamation network and other significant factors [14]. These indicators were considered for water resources and vegetation of irrigated lands, which are influenced by climatic factors: average monthly temperature; average annual precipitation; average humidity; average annual wind speed; average number of sunny days per year [15].

The obtained indicators are processed using the statistical software JMP Statistical Discovery, Minitab 19, Statistica. First of all, the indicators are checked for the normal distribution of data to select a criterion for the purpose of further analysis. For this, the mean and standard deviations are calculated.

For further analysis, we will use Spearman's coefficient to calculate nonparametric data. As a result, a correlation analysis was carried out to identify the factors that most strongly affect the irrigated land and the area covered by water. In this case, these are temperature, humidity, wind and sun (Fig. 5).

Using the Holt-Winters method with a seasonal coefficient of 12 (monthly), the projected development of indicators for three years ahead was calculated for subsequent analysis by the ANOVA method and, based on the data obtained by the Holt-Winters method, using the ANOVA method, we calculate the effect of groups of indicators on irrigated land and the area covered by water in the next three years (Fig. 6 - 7).

It can be seen from these graphs that irrigated lands will be most strongly influenced by the following groups of factors: temperature and precipitation; temperature and humidity; temperature and wind speed; temperature and sun; humidity and wind speed; humidity and sun.

The studies carried out made it possible to establish that water resources will be influenced by: temperature and precipitation; temperature and humidity; temperature and wind speed; temperature and sun; precipitation and humidity; precipitation and wind speed; precipitation and sun; humidity and wind speed; humidity and sun. From the analysis, it was found that the indicator "wind" does not directly correlate with irrigated land and the area of water coverage, but when grouped with other factors, it also plays a large role, influencing these indicators.

Thus, the analysis of the qualitative state of land in the Gissar Valley shows that the development of processes of degradation of soil and vegetation cover is observed almost everywhere on the territory of the valley, which affects the efficiency of agriculture and causes the expansion of territories, the
ecological state of which is problematic or even in crisis. In many farms there is a deterioration in the condition of arable land.

Figure 5. Data correlation analysis plots.

Figure 6. Graph for building a model of the influence of each factor on vegetation.
Soils are a widely used resource that is exposed to negative factors. The main reason for the reduction in the area of fertile soils is imperfection of agricultural production. The fertile soil layer with an irrational organization of the territory is exposed to water or wind erosion. In addition, one of the most important reasons for the ecological disadvantage of irrigated agricultural landscapes is also the low quality of their management, as a consequence of the lack of information when making decisions. There is such information, it was collected and is being collected by various organizations, but the main problem is its integration, bringing together information flows from various suppliers or creating favorable conditions for information exchange between information holders. As a result of the study, proposals were made for obtaining hidden factors that affect the state of irrigated lands and forecasting the development of changes in their state and impact on irrigated lands in the Gissar Valley was made.

3. Conclusion

Thus, the proposed mechanisms for obtaining relevant and reliable information in a shorter time frame with high information content and reliability were considered on the territory of the Gissar valley using satellite images obtained from the Landsat 7 and Landsat 8 satellites. Using the statistical software JMP Statistical Discovery, Minitab 19 and Statistica obtained controllable indicators for monitoring irrigated lands in the Gissar valley. Using the Holt-Winters method, the predicted development of indicators for the next three years ahead for irrigated land and area of water coverage was calculated.

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