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## **METHODOLOGY FOR CREATING A GEOINFORMATION-ANALYTICAL SYSTEM TO MONITOR IRRIGATED LANDS IN THE SOUTH-EAST OF KAZAKHSTAN**

### **ABSTRACT**

At present, the study of natural objects without modern information technologies is almost impossible. The use of GIS for monitoring spatial features of irrigation systems uncovers broad opportunities. The development of the organizational structure, the selection of the necessary software tools for the collection, storage, processing and analysis of semantic data integrated with spatial objects is an urgent task and has important scientific and practical value.

The irrigated lands located in the southeast of Kazakhstan within the Almaty region are the object of research. Monitoring of these land salinization is carried out, including hydrogeological and hydrological observations and soil reclamation studies.

The article discusses the methodology for creating a geographic information and analytical system to monitor irrigated lands, and describes its organizational structure. The content of the database, the composition of functional components, the basic properties and capabilities of laboratory processing and analyzes of field materials are described. The cartographic material component describes its basic properties, including properties intended for analysis of database objects and their spatial point analogues. Also, the possibilities for ArcGIS application modules to automate the process of constructing maps of the hydrogeological and reclamation conditions of irrigated objects, and the possibilities for automated calculation of areas in specified gradations of depth and groundwater salinity to assess the reclamation state of these lands are shown.

**KEYWORDS:** GIS, monitoring of irrigated land, database, groundwater level, salinization

### **INTRODUCTION**

At the present time, digitalization and informatization of processes, including the monitoring of environment, is gaining importance [Gostishchev *et al.*, 2001]. Process of monitoring of natural objects requires the use of modern tools and methodological approaches, as well as technological base for processing, data analysis, visualization and presentation of spatial and digital indicators [Zanosova, 2015].

GIS tools are used to monitor soil salinization, justify land reclamation and forecasting, and develop an agronomic strategy for farmers [Bouksila *et al.*, 2013]. The integrated use of GIS and satellite information to determine abandoned lands made it possible to identify the causes, pace, and scale of irrigated lands neglect at the Svetloyarskaya irrigation system [Gorokhova *et al.*, 2017]. An important role that GIS plays as a modeling and decision-making tool for managing water resources on irrigation systems is described by a number of researchers [Knox *et al.*, 1999; Kumar *et al.*, 2014].

The natural landscapes of southeastern Kazakhstan vary widely and are represented by mountain-folded areas, intermountain and foothill depressions and lowland territories with erosion

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basis towards the Lake Balkhash. Taking into account extremely continental climatic conditions and available surface water sources, irrigated agriculture is practiced here on a total area of 584 000 ha. Irrigation systems are present on scattered areas in all administrative regions of the Almaty region and are tied to various water sources. Hydrogeological observations of the salt regime level of groundwater in wells are carried, as well as hydrological and hydrochemical observations of irrigation and collector-drainage waters, soil reclamation for salinization of the soil cover, including laboratory studies of water and soils, and other related work.

Monitoring of irrigated lands involves collection and systematization of data on hydro geological, hydro-chemical, soil-reclamation, climatic, water and agricultural conditions and other indicators. The storage and analysis of such large amount of information requires a systematic arrangement and automation of the processing of many datapoints [Saxen, 2008]. Therefore, information support is an important part of monitoring, which should make it possible to systematize observational data, visualize spatial objects and comprehensively analyze the ongoing hydrogeological and ameliorative processes and phenomena [Panichkin *et al.*, 2014].

The given study analyzes the possibility of using ArcGIS 10.5 modules for monitoring the level of groundwater. The Karatal irrigation massif, characterized by active seasonal fluctuation of the groundwater level, was selected as the area for study.

## **MATERIALS AND METHODS OF RESEARCHES**

To conduct monitoring of irrigated lands in the Almaty region of southeastern Kazakhstan, a geographic information and analytical system (GIS) “Monitoring of irrigated lands” has been developed that provides storage and management of observation results [Shakibaev, 2014]. GIS is a multi-level system built along hierarchy levels and associated with management objects, irrigation and business entities. At each level, sources and nature of the input information are determined.

GIS structure is based on the administrative bottom-up principle, when compositional blocks are presented by administrative regions and its components: administrative and rural districts and then arrays, i.e., information flows (such as groundwater levels, chemical composition, volumes water supply and water consumption, irrigation water quality, reclamation condition, etc.) are introduced at the lowest level of the hierarchy, and, passing through higher hierarchical levels, are aggregated and entered into GIS. At the system input, the information corresponds to the main objects of the information blocks, and at the output it is determined by the needs of users and can take a variety of types and forms (text, graphic, tabular and cartographic).

Information in the GIS database is stored in the form of relevant information tables that contain information characterizing various objects (hydrogeological, soil, water, climate, etc.). Each object is expanded by several corresponding tables; in this case each table acts as a specific property of the object.

The GIS database consists of the following functional components:

1. Soil monitoring.
2. Groundwater monitoring.
3. Monitoring of surface and drainage waters.
4. Monitoring the use of irrigated land.
5. Climate.
6. Reports.
7. Charts and graphs.
8. Cartographic material
9. Administration.
10. Directories (fig. 1).

Each component includes information corresponding to its functional purpose.

## **RESULTS OF RESEARCHES AND THEIR DISCUSSION**

The interface of the Soil Monitoring component is intended for input, adjustment and analysis of information on wells, sections and sites that are collected during soil reclamation work on irrigated lands. The properties of the component are Salinization of Soils, Chemical Composition of Soils, Mechanical composition of soils and Water-physical properties of soils, Pesticides and herbicides Control and Content of Micro-components in Soil. The results of processing soil analysis data are presented in table 1.

Table 1. Results of the analysis of water extract from soil on Schengeldin irrigation system

№	Place of selection	Depth of selection	Date of selection	pH	mg-eq%-mg/dm <sup>3</sup>							Σk mg-eq	Salt content, %
					CO <sub>3</sub>	HCO <sub>3</sub>	Cl	SO <sub>4</sub>	Ca	Mg	Na+K		
1	1 (41)	0–30	03.09.2019	7,20	0,00	1,50	0,45	0,75	0,75	0,10	1,85	2,7	0,202
2		30–70	03.09.2019	7,10	0,00	0,09	0,02	0,04	0,02	0,00	0,04		
3		70–100	03.09.2019	7,00	0,00	1,00	3,55	15,05	3,85	2,45	13,30	19,6	1,320
4	2 (40)	0–30	03.09.2019	7,40	0,00	0,06	0,12	0,72	0,08	0,03	0,31	14,6	0,960
5		30–70	03.09.2019	7,40	0,00	0,06	0,10	0,52	0,08	0,04	0,16		
6		70–100	03.09.2019	7,40	0,00	1,20	0,20	0,90	0,55	0,15	1,60	2,3	0,173
7	3 (42)	0–30	03.09.2019	7,40	0,00	0,07	0,01	0,04	0,01	0,00	0,04	2,4	0,178
8		30–70	03.09.2019	7,30	0,00	0,07	0,01	0,05	0,01	0,00	0,04		
9		70–100	03.09.2019	7,40	0,00	0,90	0,25	0,25	0,45	0,30	0,65	1,4	0,103
10	4 (7)	0–30	03.09.2019	7,40	0,00	0,05	0,01	0,01	0,01	0,00	0,01	1,8	0,140
11		30–70	03.09.2019	7,30	0,00	0,07	0,01	0,02	0,01	0,00	0,03		
12		70–100	03.09.2019	7,40	0,00	1,10	0,20	0,50	0,55	0,15	1,10	2,2	0,169
13	4 (7)	0–30	03.09.2019	7,20	0,00	1,30	0,30	0,60	0,60	0,20	1,40	2,2	0,165
14		30–70	03.09.2019	7,20	0,00	0,08	0,01	0,03	0,01	0,00	0,03		
15		70–100	03.09.2019	7,20	0,00	1,10	0,30	0,60	0,75	0,10	1,15	2	0,149

For convenience, some calculations are automated, if possible. So, Salinization property provides automatic classification of soils by types of salinity according to the solid residue. While “Content of pesticides and herbicides” and “Content of microcomponents” properties enable to compare with the established Maximum Allowed Concentration (MAC) for these ingredients and calculate the percentage deviation from it.

In each dialog box, it is possible to obtain a paper copy of the information fields for the selected object and for a given date.

The interface of the Groundwater Monitoring component allows you to enter, adjust and analyze background information on groundwater. The main properties of this component are “Observation Well Passport”, “Groundwater Monitoring Results”, “Chemical Composition of Groundwater” and Contaminant Content in Groundwater.

“Results of observations of the groundwater regime” property provides automated calculation, i.e. only the measured value of the groundwater level recorded, and the program itself calculates the true value of the groundwater levels and its absolute point. In the “Chemical composition of groundwater” properties, it is possible to automatically calculate the percentage ratio of anions and cations by the Kurlov formula (table 2). It is possible to compare the current MAC for each component with the properties of Pesticides and herbicides Control and Content of Microcomponents.

Also, in the property “Results of observations of the groundwater regime” aimed at analyzing information, it is possible to construct various, including combined, schedules. To do this, the “Chart” button is provided in the dialog box, which allows to get a graphical display of the relevant information indicators for a selected period of time or a group of information indicators.

The main properties of Monitoring of Surface and Drainage water’s component are Passport Gauging Station, Chemical Composition of Surface Water, Chemical Composition of Collector-Drainage Water, Contaminant Content in Surface Water, Contaminant Content in Collector-Drainage Water, Volume of Water Intake and Water Supply to Irrigated Lands and Volume collector-drainage water. The open dialog boxes allow to enter data and analyze conditionally constant information on surface and drainage waters.

Table 2. The results of a chemical analysis of groundwaters at Akdala irrigation system

№	c / o	Place of selection	Date of selection	mg-eq%-mg/dm <sup>3</sup>							Σk mg-eq	Mineralization	Kurlov's formula	Type of water	Name of water	SAR	Water quality assessment/	
				pH	CO <sub>3</sub>	HC O <sub>3</sub>	Cl	SO <sub>4</sub>	Ca	Mg								Na+K
1	Bakbaktv	Well 12v	11.04.2019	8,30	0,80	3,80	1,30	8,10	1,80	2,30	9,90	14	983,0,98 M	$\frac{SO_4 58 HCO_3 27 Cl 9 CO}{Na 71 Mg 16 Ca 13}$	fresh	Sulfate-hydrocarbonate sodium	6.9	average
			13.08.2019	7,70	0,00	3,80	0,80	2,40	0,50	1,00	5,50							
2	Bakbaktv	Well 17v	11.04.2019	7,90	0,00	4,20	1,40	9,40	7,50	2,50	5,00	15	1053,1,05 M	$\frac{SO_4 63 HCO_3 28 Cl 9}{Ca 50 Na 33 Mg 17}$	slightly saline	Sulfate-hydrocarbonate calcium so-	2.2	low
			13.08.2019	6,70	0,00	4,40	1,30	5,70	5,30	2,70	3,40							
3	Bakbaktv	Well 18	11.04.2019	7,90	0,00	3,20	1,60	0,60	1,60	1,40	2,40	5,4	385,0,38 M	$\frac{HCO_3 59 Cl 30 SO_4 11}{Na 44 Ca 30 Mg 26}$	fresh	Hydrocarbonate chloride sodium calcium	2.0	
					0,00	1,95	56,7	28,8	32,0	17,0	55,2							

In Chemical Composition of Surface and Drainage water property, the program automatically calculates the percentage ratio of anions and cations by the Kurlov formula, while the properties of “Pesticides and herbicides Control”, “Content of Micro-components” make it possible to compare results with the MAC for each component and calculate the percentage deviation from it.

To make graphical analysis of information, it is possible to build various graphs of indicators or a group of information indicators for a selected period of time.

The interface of Monitoring the Use of Irrigated Land Component allows you to access properties from other components of GIS. The structure of the component includes the properties Use of irrigated lands, Structure of Sown Areas, Productivity and Gross Harvest of Crops, Use of Water for Irrigation, Distribution of Areas by Depth of the Level and Salinity of Groundwater on Irrigated Lands. For graphical analysis of information, the “Chart” button is used to arrange the corresponding information indicators or groups of indicators in the form of diagrams for a selected period of time.

The Climate component collects information on weather stations. To work with this component, the “Agro-climatic characteristics” property is selected from the component list and the corresponding dialog form appears on the screen, which allows you to enter reference information (Altitude, Latitude, Longitude) for climate stations, as well as operational information (Decade average air temperature, Total precipitation, Relative humidity) for each meteorological station.

The interface of Reports Component allows to generate and analyze information in the context of areas. The composition of the component includes the following properties: Distribution of Areas by depth of the level and salinity of groundwater on irrigated lands, Use of Irrigated Lands in Agricultural Production, which can be subsequently added by other properties.

The Chart Component is designed to build charts for a selected area for a given interval of years. The component consists of the following properties: Dynamics of the area’s distribution by depth of Groundwater Level on Irrigated Lands and Dynamics of Water Intake, Water Supply and Drainage Flow on Irrigated Lands, which can be added if necessary.

The Cartographic Material Information Component is applied to when Analysis, Updating and Creation of Point Graphic Objects Property is selected from the Component Composition list. It is intended for analysis on the correspondence between database information objects (observation wells, observation points, etc.) and their graphical point analogues in ArcGIS and MapInfo.

The Geographic Analysis of the Studied Objects Property is intended for the analysis of cartographic materials for the studied object (observation wells, platforms, sections, etc.). The functional element “Information Level” determines the system setting to the corresponding information level and then to the specific object under study corresponding to this level. Each level of information corresponds to a certain set of types of objects, such as observation wells, observation points, thematic layers, etc. Each type of object is characterized by a certain set of properties, which, in turn, are different quantitative, qualitative and spatial indicators of this type of object.

Also, this component contains “Construct Map” property that enables automated construction of special thematic maps. First of all, layers such as settlements, water bodies, irrigation canals, collector-drainage network, etc. are identified on a digital map. Then layers of observation wells and their numbers are fixed. From the existing database, data on groundwater levels or the results of chemical analyzes of wells for a given period of time are selected. A hydrogeological and reclamation state map is constructed using the Spatial Analyst ArcGIS 10.5 tool kit, which, in our opinion, correctly interpolates spatially remote data taking into account the topography of the area. In this case, the accepted gradation of isolines of the depths, hydroisogypsum or groundwater salinity is set. As shown by comparisons with hand-built maps, this method, with the selected tool, provides more reliable spatial information about the object. The results of constructing a map of the hydrogeological and reclamation conditions of the Karatal irrigation system are presented in fig. 2.

Also, when assessing the reclamation state of irrigated lands, it is necessary to have information on the area distribution of groundwater by the depth within the boundaries of economic entities. For this, the Zonal statistic module can be used as a tool for calculating areas with different depths or mineralization of groundwater, which allows you to calculate the distribution of areas according to the adopted scale (gradation) using depth and mineralization maps of groundwater. Preliminarily, this requires putting out a layer of farm boundaries on the constructed map, within

which a spatial calculation of the area should be made. The proposed technology allows you to create a series of cards for different periods of time, conduct analytical comparisons, accumulate and update them in a database.

The Administration Information Component includes the following components: Directory of Objects, Directory of Object Links, Directory of Object Types, Directory of Object Links Types and Directory of types of Objects Status, Directory of Types and Properties of Objects. The dialogue form allows you to enter, adjust and analyze administrative and reference information on the relevant objects. From a functional point of view, the form is designed in such a way that allows you to serve all available GIS directories by selecting bookmarks with the appropriate name. This component is primarily responsible for the proper functioning of the entire system.

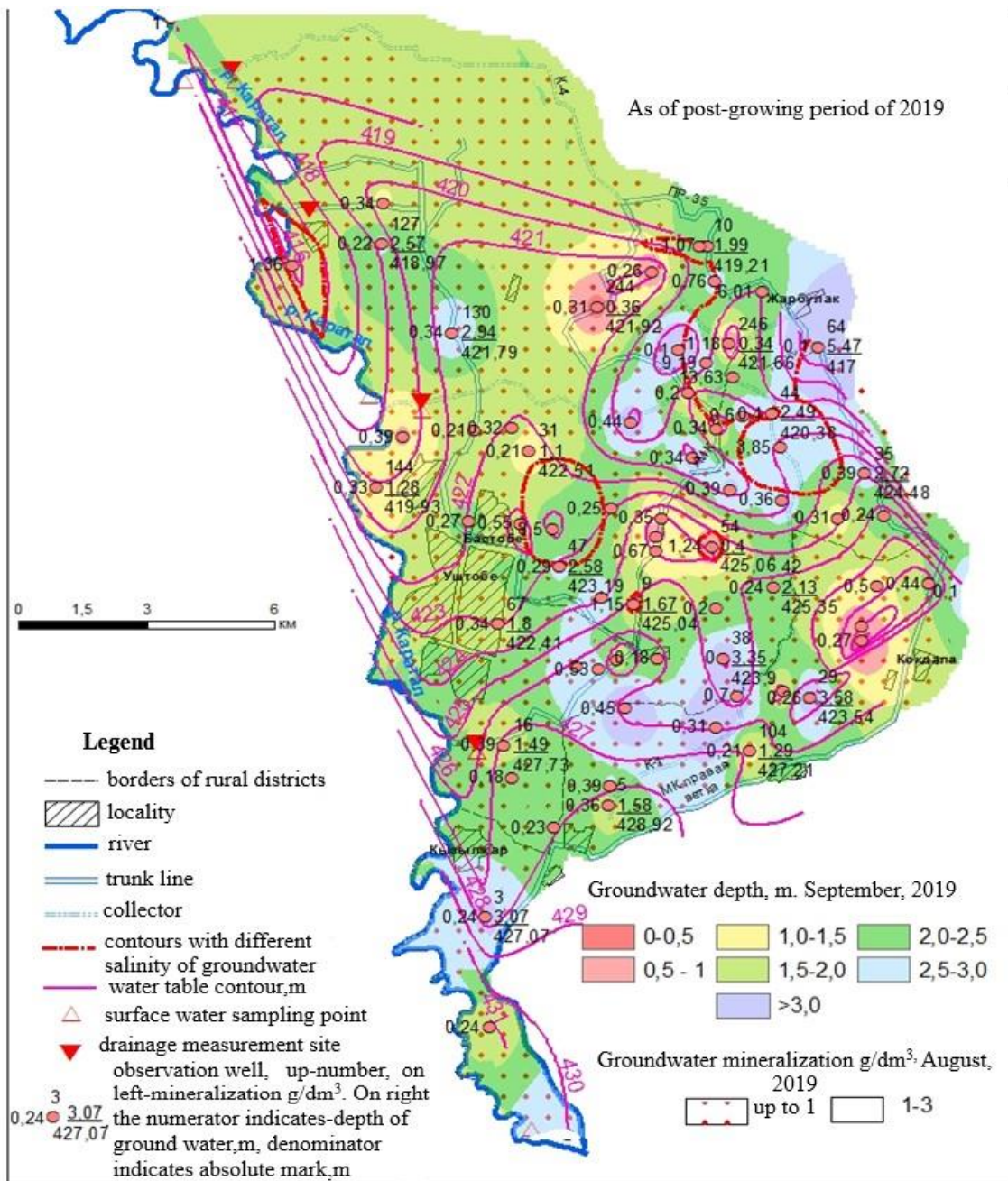


Fig. 2. The results of constructing the hydrogeological and reclamation conditions map of the Karatal irrigation system in an automated mode

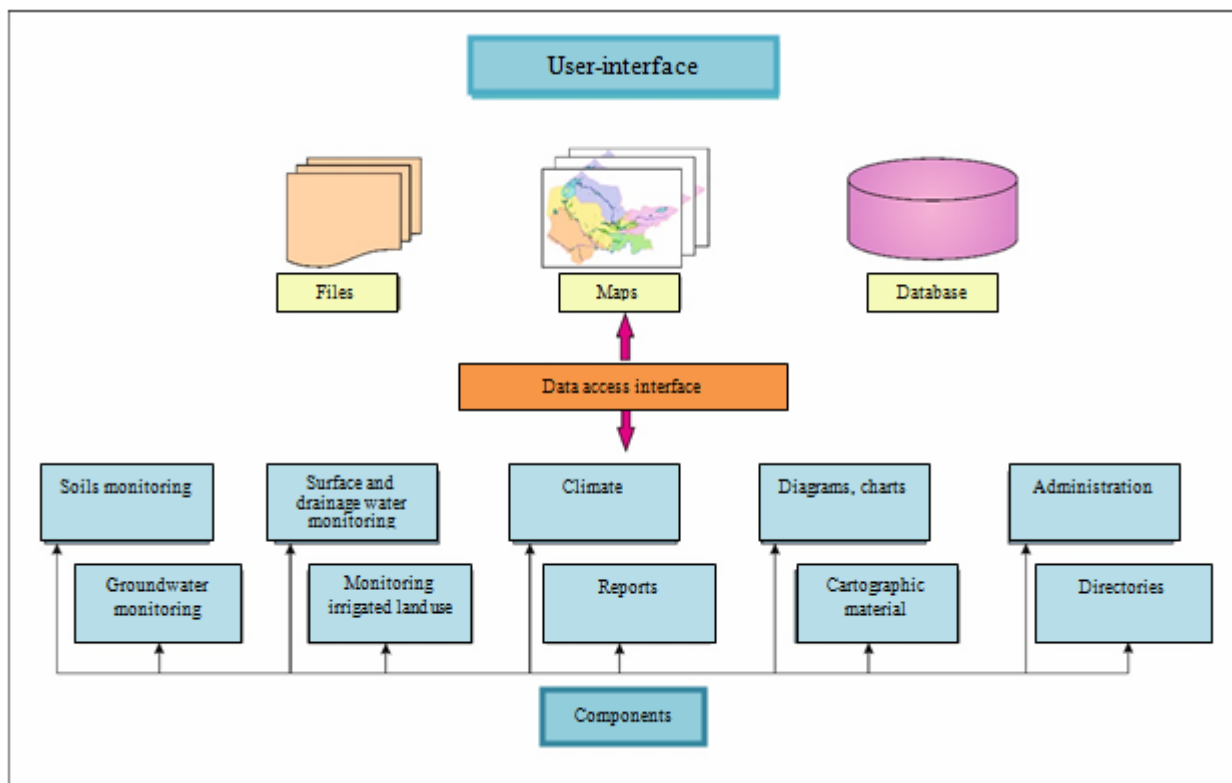


Fig.1. Structure of Monitoring Irrigated Lands GIS

GIS runs on the WINDOWS operating system, ACCESS DBMS and the service programs included in the standard Microsoft Office suite. For the cartographic database, ArcGIS and MapInfo programs were used. GIS software enables to display the information contained in the database in the following ways:

1. Dialogue forms (tables) to enter, adjust, view and analyze the source data in the tables, as well as to view and analyze aggregated data;
2. Reports to receive a paper copy;
3. Charts and diagrams for viewing and analyzing information in graphical form;
4. Thematic layers, working sets, maps for viewing and analyzing information in a cartographic form.

## CONCLUSIONS

GIS monitoring of irrigated lands has significantly expanded the capabilities for conducting and processing the results of observations of the salt regime levelsof groundwater, hydrological observations of runoff and chemical compositions of irrigation and drainage waters, soil and land reclamation observations and other works when monitoring irrigated lands in the southeast of Kazakhstan. Digital maps of hydrogeological and soil conditions of monitored objects have been built and systemicstorage is provided. The use of separate ArcGIS modules enables to automate the construction of maps measuring depths and hydroisohypses, groundwater salinity and calculates areas with different depths and groundwater salinity for their subsequent analysis and assessment. Currently, the existing GIS database is undergoing integration with modeling systems for predicting hydrogeological and reclamation processes, as well as using satellite information to obtain more reliable data to increase the efficiency of irrigated land use.

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