ANNOTATION
on the dissertation for the degree of Doctor of Philosophy (PhD)
In educational program «8D07302-Geoinformatics»
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Development of remote sensing methods for zoning fields of irrigated agriculture (based on computational methods of machine learning)

General characteristics of the work. Climate change on a global scale has a significant impact on the agricultural sector. An increase in air temperature and decrease in precipitation increase the need for water and have a negative impact on agriculture. In this regard, it is advisable to consider the ways to adapt agricultural land to environmental changes using optimal irrigation systems.

The topicality of the research fully corresponds to the direction 2: «Development of the real sector» in the Message of the Head of State K.K. Tokayev to the people of Kazakhstan dated September 1, 2022. This message provides for the need to combine disparate information about the state of agricultural land, water resources and irrigation systems into a single digital platform. **Firstly,** taking into account the peculiarities of the environment from a scientific point of view and putting them into practice are prerequisites for sustainable agricultural development and will be inextricably linked with full digitalization. **Secondly**, the analysis of the dynamics of climate change in the water supply of agricultural land will prevent possible emergencies. **Thirdly,** the creation of an interactive map of irrigated agricultural lands will contribute to the formation of advanced technologies model for providing comprehensive and reliable geospatial information. Fourth, machine learning algorithms will provide relevant results in the processing and analysis of large amounts of remote sensing data, as well as in the zoning of irrigated agricultural land.

The dissertation corresponds to the policy of the «Strategic Development Plan of the Republic of Kazakhstan until 2025», «Green Economy and environmental protection», dated January 31, 2017. In his Address to the People of Kazakhstan in 2021, Head of State K.Tokayev noted the need to increase the irrigated land area up to 3 million hectares by 2030. It is necessary to conduct comprehensive studies of land and water resources in irrigated agricultural areas to achieve this goal. The research topic will contribute to the implementation of the long-term priorities of the strategy "Kazakhstan-2050" and the directions of development of the state program «Digital Kazakhstan».

The object of the research – Irrigated agricultural lands of Almaty and Zhetysu regions.

The subject of the research – Remote sensing using machine learning.

The aim and objectives of research are hydromodular zoning of irrigated agricultural lands in Almaty and Zhetysu regions based on remote sensing and machine learning. The following **tasks** are set to achieve this aim:

– to determine the theoretical and methodological foundations of hydromodule zoning with the systematization of scientific literature and information resources;

– classify and make maps of hydro-module areas, taking into account optimal irrigation regimes and methods, based on the geo-data database of irrigated agricultural lands of Almaty and Zhetysu regions' administrative units on a scale of 1:55 000-1:180 000.

– develop a model of hydro-module zoning of irrigated agricultural lands of Almaty and Zhetysu regions based on remote sensing and machine learning data;

– to analyze water resources and verified data of the Kazhydromet center based on satellite images, to determine climatic changes and ways of adaptation of water resources in irrigated agriculture in the territory of Almaty and Zhetysu regions;

– to develop a Web-GIS server application containing information from thematic maps of scale 1:55 000-1:180 000 based on remote sensing of the earth and machine learning for irrigated agricultural lands of Almaty and Zhetysu regions.

The information base was provided by the materials of the Al-Farabi Kazakh National University, the National Library of the Republic of Kazakhstan, National Center of Science and Technology Evaluation. Maps and satellite images used in scientific research: 1. Comprehensive land map of the Almaty region (1: 300 000); 2. «Placement Map of regular and estuary irrigation areas» (1: 3 000 000). 3. Sentinel 2A/2B multispectral images; 4. Digital terrain model provided by SRTM 1 Arcsceond Global; 5. Cartographic materials of the National Atlas of the Republic of Kazakhstan (2010). As **research materials**, 27 complex maps were compiled (an author's certificate was obtained) covering the territory of Almaty and Zhetysu regions, as well as administrative units.

Research methods that give optimal results in the agricultural land zoning in modern geo-informatics include field research, in-house data processing, the applied use of GIS technologies, cartographic research aimed at decrypting satellite images, as well as mathematical methods for data analysis. An important aspect is to determine the reliability and correlation of the results using statistical methods. The zoning of irrigated agricultural lands in the study area was carried out using the Google Earth Engine (GEE) using the geemap package in Python, which allowed for interactive geospatial analysis and data visualization.

The theoretical and methodological foundations of research were the works of domestic and foreign researchers in the field of agricultural and hydro-modular zoning of lands, climate change and water resources of the territory, research of agricultural landscapes and natural landscapes using GIS technologies. The above-mentioned directions were reviewed at the global level by the following scientists: V.I. Kiryushin, E. Tsoraeva, E. Karimov, N. Kapitulina, G.P. Geltser, A. Mirzaev, V. Nerozin, M. Khamidov, B.S. Mambetnazarov, S. Abdurakhmonov, G.V. Stulina, G.F. Solodky, K. Kurbanova and others. Domestic scientists whose research and works were guided by: K.B. Balgabekov, O.Zh. Ospanbayev, A. Kapashev, K.M. Zhanalieva, L.K. Veselova, Zh.N. Mukasheva, Zh.U. Mamutov, N.N. Kerimbay, A.G. Koshim, E.H. Kakimzhanov, A.A. Asylbekova, D.K. Shokparova, R.I. Galperin, M.J. Burilibayev, J.D. Dostay, S.K. Alimkulov, A.A. Tursunova, A.S. Amirgalieva, E.K. Talipova, etc. It should be noted that aspects of remote sensing compilation and machine learning methods in the zoning

of irrigated agricultural lands in Almaty and Zhetysu regions, climate change in the territory and adaptation to water resource reduction have not been studied.

The theoretical significance of the work. Conclusions on hydraulic engineering, climatology and agriculture were analyzed on the basis of GIS, remote sensing and programming, including from the point of view of hydromodule zoning of irrigated agricultural lands. Theoretical concepts will be complemented by the concepts of agricultural landscape studies in geographical science, GIS technologies, remote sensing and Web mapping.

The practical significance of the work. Firstly, the result serves as an important material in the application of optimal methods and ways of agricultural fields irrigation in arid regions, optimal management of water resources and their adaptation to climate change. Secondly, GIS technologies, remote sensing of the Earth and machine learning, as well as Web programming can be used in conducting in the courses as «Fundamentals of remote sensing», «Analysis and visualization of geospatial data», «Thematic mapping», «Design and mapping in the GIS program», «Database design and development data for GIS», «Fundamentals of Web programming», «Development of Web GIS applications». Thirdly, it can be used as a basis for compiling a specialized atlas of irrigated agricultural land.

The scientific novelty of the work. Irrigated agricultural lands of Almaty and Zhetysu regions, the dynamics of climate change and water resources, as well as ways to use remote sensing in machine learning were studied for the first time in the domestic scientific environment. The main scientific results were obtained in the process of analyzing specific objects. Previously, the hydro-module zoning of irrigated agricultural lands in Almaty and Zhetysu regions, in accordance with the objectives of the research work, it had its own original and relevant character. The scientific novelty of the research work is determined by the following **results**:

– the areas of irrigated agriculture of the administrative units of Almaty and Zhetysu regions on a scale of 1:55 000-1:180 000 were classified according to the optimal irrigation method into hydromodule areas for the first time and maps were implemented based on GIS technologies;

– a model of hydromodular zoning of irrigated agricultural lands in Almaty and Zhetysu regions based on the decryption of satellite images and machine learning has been created for the first time;

– verification of climatic indicators and adaptation of water resources to agriculture were determined, for the first time based on a comparison of open databases and information from the national hydrometeorological service of Kazhydromet on the territory of Almaty and Zhetysu regions;

– the territory of irrigated agricultural lands of Almaty and Zhetysu regions, climate, surface, groundwater; type and mechanical composition of soils; relief, slope, exposure and other factors, for the first time, were integrated into a Web-GIS server application.

The main provisions submitted for defended:

1. Theoretical and methodological aspects of algorithms for the combined study of irrigated agricultural lands in Kazakhstan based on remote sensing and machine learning make it possible to achieve substantiated and reasoned results in

determining irrigated agricultural lands; in hydro-module zoning according to irrigation regime and methods; in drawing up complex thematic maps.

2. Hydro-modular zoning of irrigated agricultural lands and automation of the classification model of irrigation methods in the processing of remote sensing data and the development of algorithms in machine learning make it possible to optimize the irrigation system for research scientists engaged in agriculture in agricultural science.

3. Indicators of the national hydrometeorological service Kazhydromet and open climate data (average and total precipitation, maximum and minimum air temperature) and water resources (GRACE Tellus Monthly Mass Grids, JRC Global Surface Water Mapping) are effective in the development of agricultural landscape farming systems, as well as in determining the vector of development of adaptive landscape farming systems.

4. The development and illustration of geovisualization of physical and geographical conditions, climate, surface and groundwater, type and mechanical composition of soils, relief, slope, exposure and other factors of irrigated agricultural lands of Almaty and Zhetysu regions in Web-GIS are the new foundation of our research on the intensity of development and flexibility of Web products in the digital environment of the world technological space and Kazakh agricultural science.

The connection of the thesis topic with the plans of scientific research. The dissertation work was carried out on the basis of a scientific and technical programs under program-targeted financing of the Ministry of Agriculture of the Republic of Kazakhstan for 2021-2023 BR10764908 «To develop a farming system of cultivation of agricultural crops (cereals, leguminous, oilseeds and industrial crops) using elements of cultivation technology, differentiated nutrition, plant protection products and machinery for profitable production on the basis of a comparative study of different cultivation technologies for the regions of Kazakhstan».

The contribution of the author in obtaining a scientific result. The research work carried out within the framework of the doctoral dissertation proposed by the author is based on scientific articles by domestic and foreign publishers. The data and practical results of the published articles were summarized, systematized and subjected to desk processing based on an individual scientific search, which allowed us to draw our own conclusions.

Approbation of the results of the research work results was published at international and republican practical conferences (2021-2024), held in domestic (Almaty, Taraz), as well as in foreign (Kursk, Russia and Istanbul, Turkey) cities: «Advancing Institutional Capacity for Sustainable Groundwater in Central Asia», «Materials of the international scientific and practical conference «Problems of the development of natural sciences and education in the context of sustainable Development Goals», «Adaptation of crop production to the conditions of global climate change: problems and solutions», «Problems and prospects of scientific-innovative support of the agro-industrial complex of the regions», «The academic months from 1st October 2023 until 30th November 2023 at the Yildiz Technical

University at Intensive Staff», International Scientific Conference of students and young Scientists «FARABI ALEMI» (April 4-7, 2022).

Discussion and approval of the research work have been published in 11 scientific papers of Kazakhstan and foreign scientific publications, international scientific and practical conferences, also methodological recommendations. Among these, 2 articles are included in the Elsevier, Web of Science, Scopus databases, 2 articles in the list of scientific publications submitted by the Committee for Quality Assurance in the field of science and higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan. Also, the applicant's Hirsch index based on Scopus and Web of Science is 2.

The volume and structure of the dissertation. The dissertation work consists of an Introduction, 4 sections, a conclusion and 148 references, 10 tables, 71 figures, 23 appendices. The number of pages is 188.