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# ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
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OF THE REPUBLIC OF KAZAKHSTAN
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named after K. I. Satpayev

## ГЕОЛОГИЯ ЖӘНЕ ТЕХНИКАЛЫҚ ҒЫЛЫМДАР СЕРИЯСЫ

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## СЕРИЯ ГЕОЛОГИИ И ТЕХНИЧЕСКИХ НАУК

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# METHODS OF MAKING OF GEOINFORMATIONAL AND ANALYTICAL SYSTEM OF GROUNDWATER RESOURCES IN KAZAKHSTAN

**Abstract.** The tasks for groundwater resources managing become particularly relevant under the climate fluctuation and significant man-caused impact. A large volume of hydrogeological data and information from related areas of knowledge is used to solve these tasks. Increasing the studies' effectiveness is facilitated by the use of geoinformation and analytical systems, the development of which became possible in connection with the development of computer technologies. They enables the data accumulating, collation, analysing and using them for handling of applied problems. An overview of the studies conducted in different countries on the development of information systems make it possible to state their wide use in assessing the groundwater role in a single ecosystem.

The purpose of creation of the geoinformational and analytical system of groundwater resources in Kazakhstan is the accumulation of data on groundwater and related environmental objects and their use as an information basis for solving practical hydrogeological problems. Not only natural environments (climate aridity, variety of relief types, etc.) are taken into account when it is created, but also man-caused factors (large water intake, groundwater pollution, etc.).

The technique includes the collection of primary hydrogeological information, the accumulation of data in the formats of the geoinformational and analytical system, the evaluation of data, the solving of practical hydrogeological problems, the providing of recommendations, the reference information provision. The initial data, the results of their analysis and calculations are in the document database, databases of semantic and graphic data, the database of computational models. The solving of practical problems involves the thematic maps and computational models creation.

The developed technique can be used in the process of creating information systems of groundwater resources at the regional and local levels.

**Keywords:** groundwater, informational systems, groundwater resources.

At present, geoinformational and analytical systems in hydrogeology are becoming increasingly widespread. It became possible to integrate all the accumulated information on groundwater and their interaction with the environment due to the development of software tools for large amounts of data processing and analysing. The use of information systems in solving practical problems makes them an effective tool for groundwater studies.

The work [1] is devoted to methodological issues of using information systems for the estimation and management of raw materials potential. An information system is a system that includes an organizationally ordered set of data and management tools and that is designed for obtaining new quality information on the state of an object, process or phenomenon. They are used for storage, analysis and processing of groundwater studies' materials and include databases and management systems. In hydrogeology, it is advisable to use integrated information and analytical systems, the main elements of which are factographic and geographical information systems, as well as computerized mathematical simulation systems.

The Global Groundwater Information System, created by IGRAC (International Mountain Resource Assessment Centre) under the authority of UNESCO, presents an interactive web portal and contains data related to groundwater resources for the whole world. [2]

It is proposed in [3] to divide the groundwater information into four levels depending on the degree of data interpretation. Information analysis complex for the processing of groundwater monitoring data contains the monitoring observations data and it is used in hydrogeological and geoecological studies [4]. The structure of the information and analytical system for water resources quality management is proposed in [5], which allows to build optimization and simulation models. To simulate the environmental changes, depending on climate fluctuations, it is proposed to use the TGRASS GIS, based on space-time data sets (raster, vector, voxel) [6].

Kazakhstan gives importance to the data accumulation and collation in the field of hydrogeology. The official website of the Committee of Geology and Subsurface Use of the Republic of Kazakhstan notes that one of the main tasks of the Department of Hydrogeology and Engineering Geology is to improve the "Groundwater" information subsystem of the Mineral Resources State Data Bank [7, 8].The issues of Kazakhstan's water security in connection with the reduction of the stream run-off from the territories of neighbouring states and climate fluctuations are considered in [9, 10]. The water security system represents a set of parameters reflecting dependable water supply and human-caused disturbance of the water resource system. You need to analyse a large amount of data in order to implement it.

In Russia HYDEC company developed a technique and technology for creating information and analytical systems for monitoring subsurface use, which is used as the basis for the information and analytical system of state monitoring of the groundwater in Russia, the information system of state accounting and the balance of resources and usable drinking and technical groundwater, the information system of the State Data Bank on the mineral resources (subsurface) use of the Republic of Kazakhstan, etc. [8, 11, 12]. Information and analytical systems include factographic and cartographic databases related to the mathematical simulation systems [1, 13]. A map of the raw materials potential of fresh groundwater in Russia has been developed [14, 15].

The "Geolink Consulting" company created the AquaBase information and analytical system for geoecological monitoring. It allows analysing and integrating data on the resources, regime and quality of groundwater and surface water and solving hydrogeological problems effectively [16].

The "Natural Resources of Perm Territory" information and analytical system was created on the basis of geoinformational technologies [17]. The "Tomskgeomonitoring" territorial centre created digital maps and collection of maps, including hydrogeological and geoecological maps, maps of hydrogeological zoning, etc. [18]. The Tatar Geological Survey created the inquiry and communications system for "Region" territory state of exploration [19].

The issues of the climate fluctuations impact on water resources in the countries of Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan) are discussed in [20]. The Uzbekistan National Information Agency established an information and analytical database on all aquifers, in accordance with the Program of Measures for Harmonisation of Control and Accounting for the Management of Groundwater Reserves for 2017-2021 [21]. The Information System for Water Management has been developed in Kyrgyzstan [22]. The State Service of Geology and Mineral Resources in Ukraine uses the "Groundwater" automated information system [23]. The automated information system for the use of water resources and water quality is being maintained in the Republic of Belarus [24].

The US Geological Survey established the National Information System for Groundwater Data. It includes data on the groundwater availability in various regions of the country, methods for assessing groundwater resources. The collection of US groundwater maps was created and it contains regime data, a description of the groundwater's response to climate fluctuations and various groundwater simulations, including mathematical ones. [25] The US National Groundwater Association developed a groundwater monitoring program. [26]. Local information systems for managing groundwater resources have been established almost for all states of the country [27-33].

The Groundwater Information Network has been established, including links to publications, in order to enhance the management level for Canada's groundwater by providing enhanced access to hydrogeological data [34]. The descriptions of the main aquifers of Canada are presented in [35, 36].

The Australian National Groundwater Information System is designed to manage groundwater resources under high man-caused loads [37, 38]. The collection of maps of Australian dependent aquatic ecosystems was created [39]. It is proposed to use GIS, remote sensing data and expert analysis during the ecosystems mapping process. [40]. A web-based data management system for groundwater was introduced [41].

Great attention is paid to the impact of climate fluctuations and human impact on water resources in Asian countries. The GIS of the groundwater of Thailand is designed to prove the possibility of using groundwater as an alternative source of water supply during periods of drought [42]. Information systems for identifying potential areas of groundwater concentration are created for the territories of Iran [43, 44, 45]. The maps of the main hydrogeological parameters of shallow aquifers of Laos form the basis of the groundwater geoinformational system [46].

The Geological Survey of China has developed a groundwater information system for assessing their resources, integrated groundwater management, exploring their relationship with the environment, developing measures to protect groundwater, etc. [47].

The IndiaWaterportal portal contains archival data on the quality and regime of groundwater for all the states of India. [48] Information systems are designed for different states of the country [49-51]. The Sri Lanka aquifer description system is designed to show changes in hydrogeological conditions in space and time in connection with man-caused impact [52].

The maps of groundwater resources were created for nine European countries (Belgium, Germany, Denmark, France, Ireland, Italy, Luxembourg, the Netherlands, Great Britain), including descriptions of aquifers, information on water intake, underground and surface water monitoring data, hydrographic network, etc. [53].

The UK's groundwater resources information system, developed by the British Geological Survey, reflects the use of groundwater now and in future [54]. The groundwater information system of Berlin (Germany) is created on the GeoDin platform [55]. The GIS of groundwater in Belgium is created in order to determine the areas of groundwater recharge [56].

The National Simulation of Water Resources of Denmark is operated in the ArcGIS environment [57]. A space-time approach is applied to assess the climate fluctuations impact on water resources in the groundwater information system of Romania [58]. The information system of the continental Spain territory is used to assess the climate fluctuations impact on renewable groundwater resources [59]. The GIS of the central Portugal describes aquifer systems containing mineral waters [60]. A web portal based on the i-SeLaR system for the management of water resources in Serbia was developed [61]. GIS is used to identify critical areas of groundwater imbalance for the territory of central Italy [62]. An information system for the assessment of groundwater resources in Greece includes maps, monitoring data, as well as earth remote sensing data [63].

African countries are characterized by a strong impact of climate fluctuations on groundwater. A system has been developed that includes descriptions of all aquifers and reflects the impact of climate fluctuations on groundwater, in order to manage water resources in South Africa [64]. The National Groundwater Information System of the Republic of South Africa includes the National Archives of Groundwater, the Groundwater studies Database and etc. [65]. The hydrogeological mapping of the groundwater resources of Egypt is carried out within the framework of the National Water Policy [66]. The geoportal for accessing geographic and text data related to groundwater resources was created in Morocco [67]. The geoinformational system is used for the Kalahari Desert (Botswana) as a tool for integrating information and decision-making under insufficiency of data [68].The integrated water resources management system of Zanzibar is created on the GeODin platform [69].

An information system of groundwater for the countries of South America has been created, which includes all data on groundwater - hydrogeological and geological maps, hydrographic network map and etc. [70]. Mapping of problem regions was carried out using a combined GRACE/InSAR approach in order to solve the problem of groundwater depletion in Central Mexico [71].

Based on the review of the performed researches it can be concluded that information system of groundwater have been established in many countries of the world. The main purpose of their creation is the management of groundwater resources. Natural conditions largely determine the types of applied hydrogeological problems and, as a consequence, the specificity of any information system. Groundwater

study as a part of a single ecosystem requires the accumulation of information that reflects the processes of their interaction with the environment.

Geoinformational-analytical system can be useful for areas with significant anthropogenic loads and a high degree of climate impact on the state of groundwater resources. Such systems are very effective in terms of uncertainty of key parameters affecting the quantity and quality of groundwater.

The purpose of creation of geoinformational-analytical system of groundwater resources of Kazakhstan is the accumulation of data on groundwater and related environmental objects and using them as informational basis for solving practical hydrogeological problems.

The method of automatic formation of the geoinformational-analytical system of groundwater resources involves not only the collection and storage of primary hydrogeological data, but also the possibility of their generalization and analysis, and using as an information basis for solving various practical hydrogeological problems. The methodology is based on the principles outlined in [72]. The main approaches to hydrogeological zoning and regional evaluation of groundwater resources of Kazakhstan, illustrated in a large volume of map data that are presented in [73].

The methodology includes collection of primary hydrogeological information, accumulation of data in the formats of geoinformational-analytical system, assessing the data, the solution of practical problems of hydrogeology, recommendations, providing referral information (figure 1).

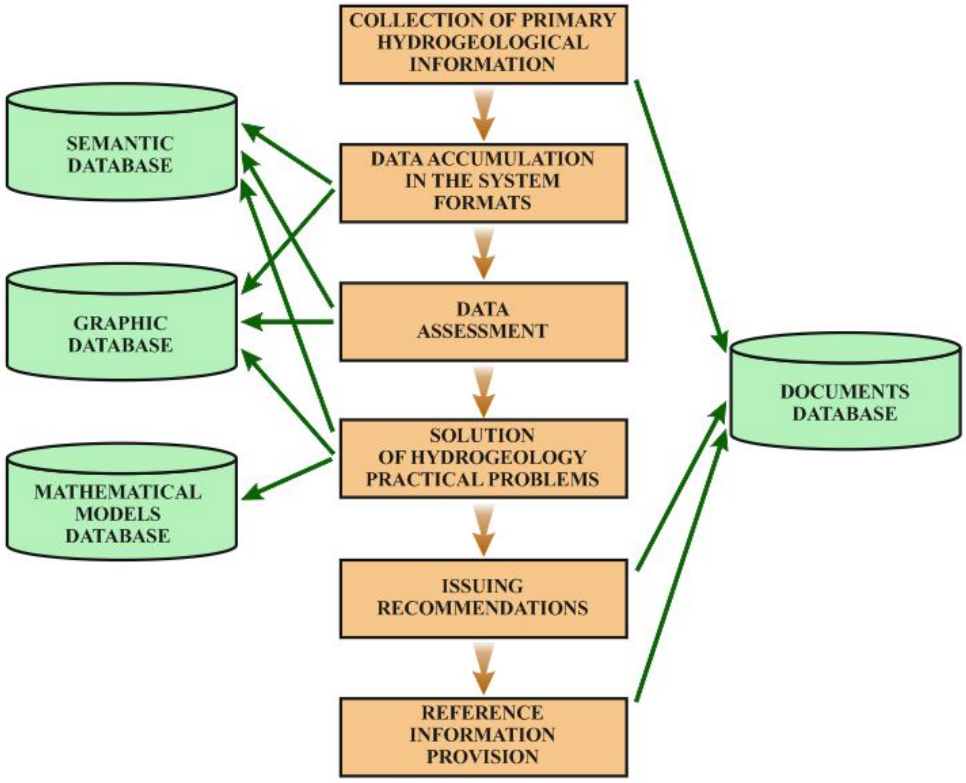


Figure 1 – Methodology for the automated formation of geoinformational-analytical system of groundwater resources

The collection of primary hydrogeological information consists in scanning the paper documents, the accumulation of documents in digital form, compilation a tabular, cartographic and unstructured documents. Sources of primary materials are archival data (scientific and industrial reports, publications, published maps, regulatory documents, etc.) and operational data (the data of water withdrawal and groundwater monitoring, sinking and unwatering, irrigation regime, etc.). In accordance with the form of the original data – digital or paper - realizing their collection or scanning. Primary materials contain structured or unstructured text data, cartographic and other graphic materials. The system splits the documents on the table, map and unstructured. The step of collecting primary hydrogeological information accomplishes by creation a document database.

The accumulation of data in the formats of geoinformational-analytical system implies creation of the semantic database structure for text data, specifying the structure of each table, input or data conversion. The structure of the graphical data database is created, projection and structure of each layer are set, the digitization of cartographic materials or data conversion are performed to carry out data mapping (figure 2).

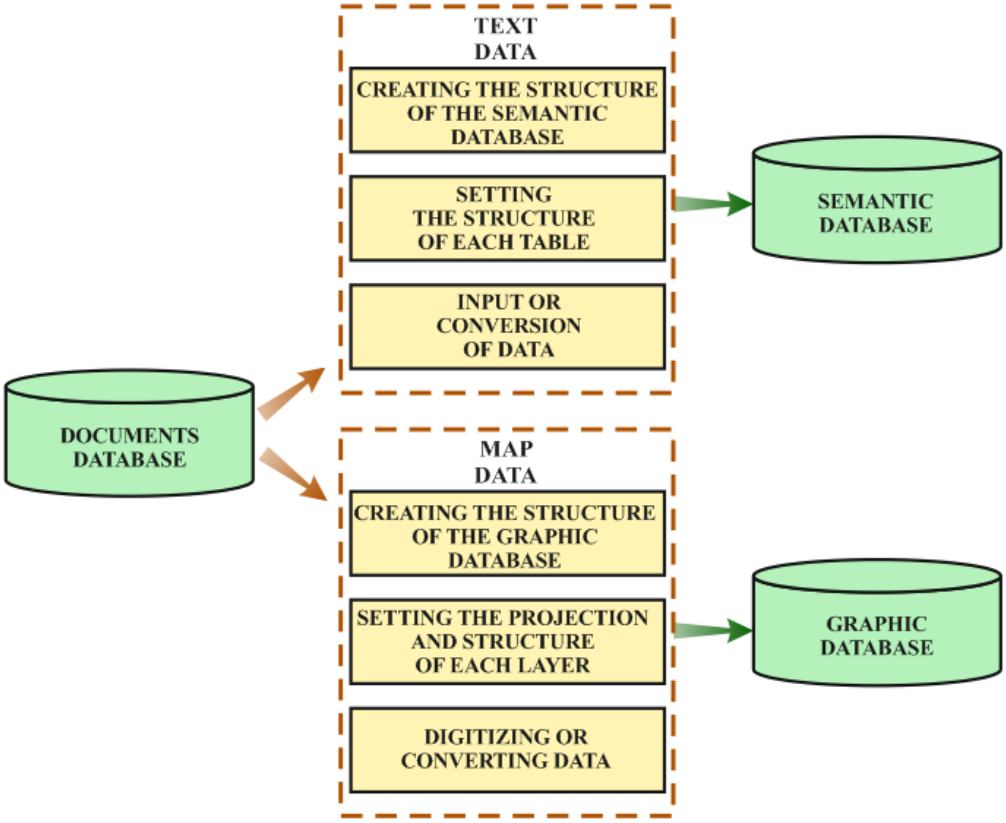


Figure 2 – Data accumulation in the formats of geoinformational-analytical system

Bases of graphic and semantic data are created based on the information contained in the document database. Their structure is created on the basis of the purposes of creating the geographical information analytical system and the possibility of dividing the hydrogeological information into sections. In the process of specifying the structure of each table defines the names and types of fields. Data input is carried out manually or by converting text data from the document database into the required formats.

The layers of the graphic database are highlighted in accordance with the type of represented information on the maps. Geographical projection and the structure of the attributive data are set for each layer. Data are entered by the method of digitizing or conversion of cartographic materials from the document database. The result of the data accumulation step is creating and filling the bases with semantic and graphic data.

Data evaluation includes formal and expert verification of the data contained in the bases of semantic and graphic data, correction and addition of the data. The data accuracy, completeness and consistency are evaluated in the course of assessment. The results are stored in the databases.

The solution of practical problems of hydrogeology involves the creation of thematic maps and mathematical models. The necessary information is extracted, classification of data is carried out, calculations are performed, maps are made and analysis of the results is carried out in order to create a thematic map. Extracting of the required information, converting data into the formats of the mathematical modeling system, creation of the mathematical models and performing calculations, conversion of the simulation results into formats of graphic database, presentation and analysis of the results are carried out in developing mathematical models (figure 3).

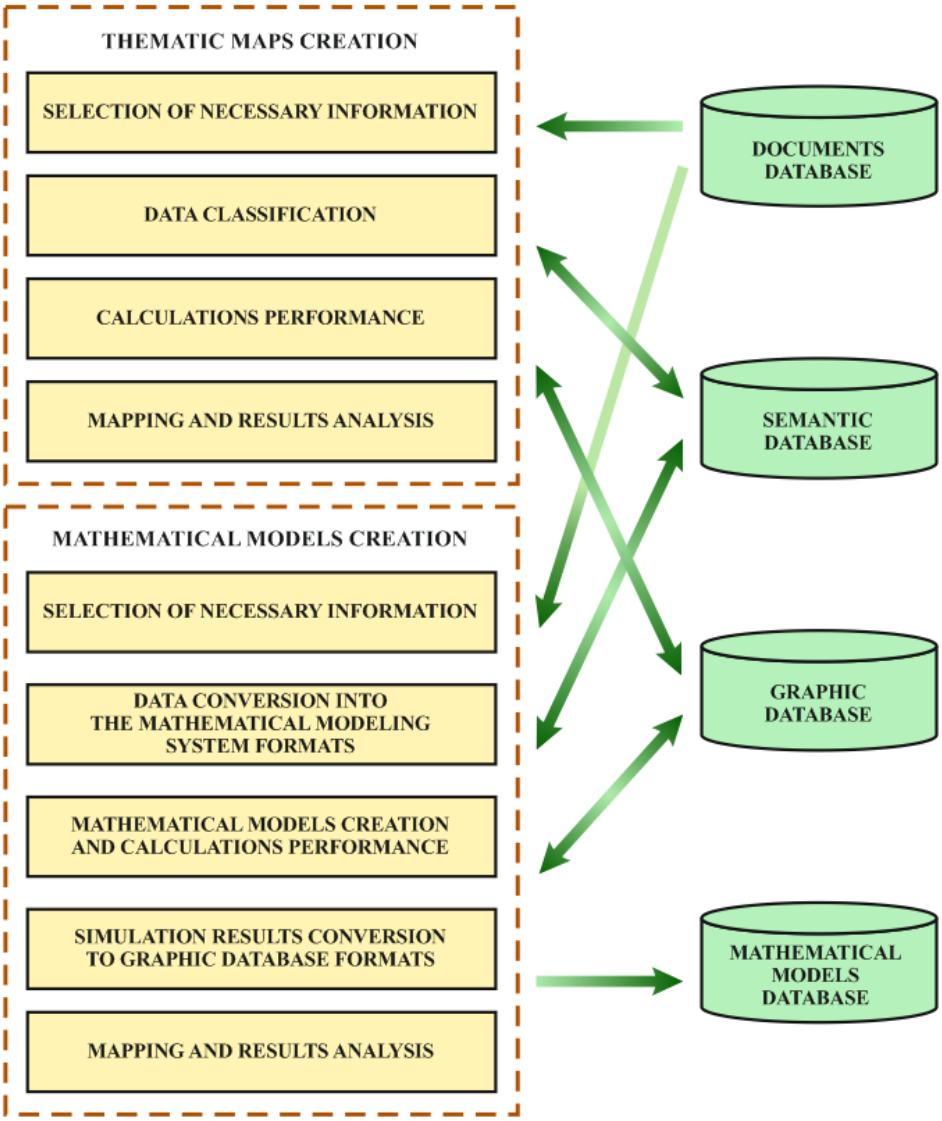


Figure 3 – The solution of the practical problems of hydrogeology

All the information accumulated in the bases of semantic and graphic data and in document database is used in order to solve practical hydrogeological problems. Thematic maps collect data (graphical and semantic) obtained from different sources. Solution of most hydrogeological problems requires an information differentiation based on any characteristic. Uniformity of information that represented in databases allows you to use different modes of classification. Thematic maps are used not only for visualization of the geographically dispersed data. Additional calculations allow creating qualitatively new maps. Their appearance is made in accordance with the forms of representation of hydrogeological information. Analysis of the results is carried out from the point of improving the efficiency of solving practical problems.

The source information is selected not only from the database of graphical and semantic data, but also from the document database in order to create mathematical models. The data conversion into the formats of mathematic modeling system may require changing the form of presentation of the specific parameters. Creating models and calculations are performed within the modeling system. The limited forms of results' representation require their conversion into formats of graphical database. Depending on the application task coming the realization of the results. For their analysis can be involved additional materials contained in the databases. The results of solving practical problems are placed in the database of graphic and semantic data as well as in the mathematical models database.

Recommendations are performed by the data selection and analysis, representation of the recommendations. Information that extracted from graphic and semantic database includes both primary data and the results of their processing. Recommendations include suggestions for optimizing the use of groundwater resources, their protection from pollution and decrement, improvement of monitoring system of groundwater, etc. They are based on data comparison, their analysis, building new maps, making calculations, including the using of mathematical models, etc. Making recommendations depends on the application task and includes, as a rule, a text description, maps and other graphical data. Work suggestions are added to the database of documents.

Support information includes sampling data, conversion of data to a single standard, the formation of the documents. Referral information contains the information of the bases of graphic and semantic data. The possibility of bringing data to a single standard allows you to create documents in accordance with the needs of the various interested organizations. The resulting documents may include original data, results of analyses and calculations, expert assessment information, etc. Reference data is presented in form of the documents that are added to the document database.

Based on the results of the research, the following conclusions can be drawn. Described technique reflects all the steps of the hydrogeological object study process in the context of climate fluctuations and intensive human intervention.

Original materials are accumulated in database of documents in an unchanged form, which allows you to avoid the mistakes of their processing and use them during the pursuance of the researches both present and future.

Collected primary data refers not only to the field of hydrogeology but also to the related fields of science (geography, topography, meteorology, etc.). This allows you to use the informational system in studying dependent on groundwater ecosystems.

Formation of graphic and semantic databases is based on structuring the collected information. The possibility of their analysis and calculations allows solving different applied hydrogeological problems within the system.

The using of mathematical modeling methods allows raising a traditional study to the new level. So the mathematical models database, along with databases of graphic and semantic data, takes up equal place in the information-analytical system.

The reasonability of establishing information systems of groundwater is confirmed by the analysis of the experience of previous studies in different countries of the world. Therefore, the developed method may find wide application in the organization of geoinformational-analytical system of groundwater resources.

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## ҚАЗАҚСТАННЫҢ ЖЕРАСТЫ СУЛАРЫ ҚОРЫНЫҢ ГЕОАҚПАРАТТЫҚ-ТАЛДАУ ЖҮЙЕСІН ҚҰРУ ӘДІСТЕМЕСІ

**Аннотация.** Жерасты суларының қорларын басқару міндеттері климаттың өзгеруіне байланысты және ауқымды антропогендік жүктемелер жағдайында ерекше өзектілікке ие болып отыр. Оларды шешу үшін өзара сабақтас білім салаларынан алынған гидрогеологиялық деректер мен мәліметтердің ауқымды көлемі тартылып отыр. Компьютерлік технологиялардың дамуына байланысты қазіргі кезде әзірлеу мүмкіндігі пайда болған геоақпараттық-талдау жүйелерін пайдалану зерттеулердің тиімділігін арттыруға ықпал етеді. Олар деректерді жинау, оларды бір жүйеге келтіріп, талдау үшін және қолданбалы міндеттерді шешу мақсатында пайдалану үшін қызмет етеді. Ақпараттық жүйелерді құру бойынша түрлі елдерде өткізілген зерттеулер шолуы бірыңғай экожүйеде жерасты суларының рөлін бағалайтын кезде олардың кеңінен қолданылуы туралы айтуға мүмкіндік береді.

Жерасты сулары және олармен байланысты қоршаған орта нысандары туралы деректерді жинақтау, оларды тәжірибелік гидрогеологиялық міндеттерді шешу үшін ақпараттық негіз ретінде пайдалану Қазақстанның жерасты сулары ресурстарының геоақпараттық-талдау жүйесін құрудың мақсаты болып табылады. Оларды құратын кезде табиғи жағдайлар ғана емес (климаттың қуаңшылығы, рельеф түрлерінің алуан түрлілігі және т.б.), техногенді факторлар да (ауқымды су іріктеу, жерасты суларының ластану және т.б.) ескеріледі.

Әдістеме бастапқы гидрогеологиялық ақпаратты жинауды, геоақпараттық-талдау жүйесінің пішімдерінде деректерді жинақтауды, деректерді бағалауды, гидрогеологияның тәжірибелік міндеттерін шешуді, ұсынымдар беруді, анықтамалық ақпарат ұсынуды қамтиды. Бастапқы деректер, оларды талдау және есептеу нәтижелері құжаттар базасында, семантикалық және графикалық деректер базасында, математикалық үлгілер базасында орналасқан. Тәжірибелік міндеттерді шешу тақырыптық карталарды және математикалық үлгілерді құруды көздейді.

Әзірленген әдістеме аймақтық және жергілікті деңгейлердегі жерасты сулары ресурстарының ақпараттық жүйелерін құру барысында қолданылуы мүмкін.

**Түйін сөздер:** жерастысуы, ақпараттық жүйе, жерастысуыресурстары.

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## МЕТОДИКА СОЗДАНИЯ ГЕОИНФОРМАЦИОННО-АНАЛИТИЧЕСКОЙ СИСТЕМЫ РЕСУРСОВ ПОДЗЕМНЫХ ВОД КАЗАХСТАНА

**Аннотация.** Задачи управления ресурсами подземных вод приобретают особую актуальность в условиях изменения климата и значительных антропогенных нагрузок. Для их решения привлекается большой объем гидрогеологических данных и сведений из смежных областей знания. Повышению эффективности исследований способствует использование геоинформационно-аналитических систем, разработка которых стала возможной в связи с развитием компьютерных технологий. Они служат для накопления, систематизации, анализа данных и использования их для решения прикладных задач. Обзор проведенных в разных странах исследований по созданию информационных систем позволяет говорить об их широком использовании при оценке роли подземных вод в единой экосистеме.

Целью создания геоинформационно-аналитической системы ресурсов подземных вод Казахстана является накопление данных о подземных водах и связанных с ними объектов окружающей среды и использование их в качестве информационной основы для решения практических гидрогеологических задач. При ее создании учитываются не только природные условия (аридность климата, разнообразие типов рельефа и др.), но и техногенные факторы (большой водоотбор, загрязнение подземных вод и др.).

Методика включает сбор первичной гидрогеологической информации, накопление данных в форматах геоинформационно-аналитической системы, оценку данных, решение практических задач гидрогеологии, выдачу рекомендаций, предоставление справочной информации. Исходные данные, результаты их анализа и расчетов расположены в базе документов, базах семантических и графических данных, базе математических моделей. Решение практических задач предполагает создание тематических карт и математических моделей.

Разработанная методика может быть использована в процессе создания информационных систем ресурсов подземных вод регионального и локального уровней.

**Ключевые слова:** подземные воды, информационные системы, ресурсы подземных вод

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