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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

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STRUCTURE OF THE INFORMATION SYSTEM OF KAZAKHSTAN FRESH GROUNDWATER RESOURCES

Abstract. Insignificant in general value of surface water resources, cross-border nature of major rivers, their almost complete exposure to impacts of technogenesis processes have predetermined wide use of fresh groundwater supply in Kazakhstan. Study of the groundwater resources demand engaging of large volumes of hydrogeological materials and data from related areas of expertise. Their accumulation and analysis were carried out within the frameworks of the unified geoinformation system of resources and reserves of fresh groundwater of the Kazakhstan Republic and allows systematizing and analyzing of data about groundwater resources, quality and its using.

The system's structure was development with account to interconnection of groundwater with all components of natural and man-made environment. Key information blocks distinguished in the system are the following: general information about hydrogeological object and environment; data of groundwater monitoring; fresh groundwater resources and reserves; groundwater deposits; man-made facilities; groundwater pollution; groundwater protection; availability of fresh groundwater resources.

All data are accommodated in graphic, semantic and documental database. Semantic data is presented in tabular form and represents attributive information for graphics objects comprising cartographical documents. The system was created in ArcGIS environment.

Data entered into the system was used for generating thematic maps of fresh

groundwater resources, as well as for calculating various characteristics of groundwater, areas with certain sets of parameters etc.

Operation of the information system demonstrates by the example of territory of West Kazakhstan.

Key words: groundwater, information systems, groundwater resources.

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ҚАЗАҚСТАНДАҒЫ ЖЕР АСТЫ ТҰЩЫ СУ РЕСУРСТАРЫНЫҢ АҚПАРАТТЫҚ ЖҮЙЕСІНІҢ ҚҰРЫЛЫМЫ

Аннотация. Жер үсті су ресурстарының құндылығы, ірі өзендердің трансшекаралық сипаты, олардың техногенез процестерінің әсеріне толық дерлік ұшырауы Қазақстандағы тұщы жер асты суларының қорларын кеңінен пайдалануды алдын ала анықтады. Жер асты суларының ресурстарын зерттеу гидрогеологиялық материалдар мен байланысты білім салаларындағы деректердің үлкен көлемін тартуды талап етеді. Оларды жинақтау мен талдау Қазақстан Республикасының тұщы жерасты сулары ресурстары мен қорларының бірыңғай геоақпараттық жүйесі шеңберінде жүргізілді және жерасты суларының ресурстары, олардың сапасы мен пайдаланылуы туралы деректерді жүйелендіруге және талдауға мүмкіндік береді.

Жүйенің құрылымы жер асты суларының табиғи және техногендік ортаның барлық компоненттерімен байланысын ескере отырып жасалды. Жүйеде бөлінетін негізгі ақпараттық блоктар: гидрогеологиялық объект және қоршаған орта туралы жалпы ақпарат; жерасты сулары мониторингінің деректері; тұщы жерасты суларының ресурстары мен қорлары; жерасты суларының шоғырлары; техногендік құрылыстар; жерасты суларының ластануы; жерасты суларын қорғау; тұщы жерасты сулары ресурстарының қолжетімділігі.

Барлық деректер графикалық, семантикалық және құжаттық мәліметтер базасында орналастырылған. Семантикалық деректер кесте түрінде ұсынылған және картографиялық құжаттарды құрайтын графикалық нысан-

дар үшін атрибутивті ақпарат болып табылады. Жүйе ArcGIS ортасында құрылды.

Жүйеге енгізілген деректер тұщы жер асты сулары ресурстарының тақырыптық карталарын жасау үшін, сондай-ақ жер асты суларының әртүрлі сипаттамаларын, белгілі бір параметрлер жиынтығы бар аудандарды есептеу үшін пайдаланылды. Ақпараттық жүйенің жұмыс істеуі Батыс Қазақстан аумағының үлгісінде көрсетіледі.

Түйін сөздер: жерасты сулары, Ақпараттық жүйелер, жерасты суларының ресурстары.

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СТРУКТУРА ИНФОРМАЦИОННОЙ СИСТЕМЫ РЕСУРСОВ ПРЕСНЫХ ПОДЗЕМНЫХ ВОД КАЗАХСТАНА

Аннотация. Незначительная в целом величина ресурсов поверхностных вод, трансграничный характер основных рек, практически их незащищенность от воздействия процессов техногенеза предопределили широкое использование в Казахстане для решения проблемы водоснабжения населения пресных подземных вод. Изучение ресурсов подземных вод требует привлечения большого объема гидрогеологических материалов и сведений из смежных областей знания. В связи с этим их накопление и анализ проведены в рамках единой системы ресурсов и запасов пресных подземных вод. Она является основной частью геоинформационной системы ресурсов подземных вод Республики Казахстан и позволила систематизировать и анализировать данные о ресурсах, качестве подземных вод и их использовании.

Структура системы сформирована с учетом взаимосвязи подземных вод со всеми компонентами природной и техногенной среды. Основными информационными блоками, выделенными в системе, являются: общая информация о гидрогеологическом объекте и окружающей природной среде; данные мониторинга подземных вод; ресурсы и запасы пресных подземных вод; месторождения подземных вод; техногенные объекты;

загрязнение подземных вод; защищенность подземных вод; обеспеченность ресурсами пресных подземных вод.

Все сведения размещены в базах графических и семантических данных и базе документов. Семантические данные представлены в табличной форме и являются атрибутивной информацией для графических объектов, составляющих картографические материалы. Система создана в среде ArcGIS.

Введенные в систему сведения использованы для формирования тематических карт ресурсов пресных подземных вод Западного Казахстана, а также для расчетов различных характеристик подземных вод, площадей с определенными наборами параметров и др.

Работа информационной системы проиллюстрирована на примере территории Западного Казахстана.

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

Introduction. Modern information systems created on the basis of geoinformation technologies are used to resolving majority of hydrogeological problems. They are designed for management of spatially-distributed data and include databases and systems of their management (Yazvin, 2015:323). Capabilities of computing technology allow accumulating and collate large bodies of data, manage it, use in the mathematical modeling and in field surveys. Information systems are created to manage groundwater resources, estimating interaction groundwater with environment in different countries of the world.

Global Information System containing information about world where groundwater resources were created by IGRAC (International Groundwater Resources Assessment Centre) under the auspices of UNESCO (https://www.un-igrac.org/global-groundwater-information-system-ggis). Information water resources system in Europe - WISE provides access to data related to domestic and cross-border water resources of different countries (https://water.europa.eu/). Groundwater Database of the United Kingdom was presented by British Geological Survey (*https://www2.bgs.ac.uk/groundwater/datainfo/datainformation.html*). Information system for France groundwater management SIGES contains data about aquifer's condition and their interaction (https://www.brgm.fr/en/website/siges-aquifere-rhenan-information-system-groundwater-management). Substantial volumes of hydrogeological information about groundwater in Germany are processed with the use of artificial intelligence (https://www.bgr.bund.de/EN/Themen/Wasser/Informationsgrundlagen/informationsgrundlagen_node_en.html). The Spain groundwater information system (SIAS) contains monitoring databases, thematic hydrogeological maps and so on (*https://hispagua.cedex.es/documentacion/recurso/57867).m* National groundwater information system in Italy (SINTAI) aimed to protecting groundwater from contamination (https://www.sintai.isprambiente.it/). National groundwater information system (NGIS) created in Australia represents a spatial database according to states and territories (https://data.gov.au/data/dataset/national-groundwater-information-system). US Groundwater resource data is differentiated by states and include hydrogeological maps, initial data and its processing results (https://ecology.wa.gov/Water-Shorelines/Water-quality/Groundwater/Groundwater-resources). Information system developed by China Geological Survey is designed for groundwater integrated management (Liu et al., 2016: 21). Africa groundwater atlas includes digital hydrogeological maps for 51 countries, data about groundwater quality and its use, on-line library of documents (https://www2.bgs.ac.uk/africagroundwateratlas/index.cfm).

The above studies prove efficiency of information systems usage in groundwater resources management process.

The water supply of Kazakhstan population under conditions of ongoing surface water resources depletion of proper quality water making the extensively use fresh groundwater. Anthropogenic burden and climatic changes adversely impact on the environment in particular on groundwater conditions, its hydrogeochemical and hydro-geodynamic parameters (Smolyar, 2017: 7). Analysis of water quality changes, evaluating possibility of it using for domestic drinking water supply demanded involving a large volume of hydrogeological materials and data from related areas of knowledge. Usually used text documents represent a type of not structured descriptions, are presented in author's interpretation, the maps are created in different geographical projections, that makes their search and use very difficult. To resolve practical problems in hydrogeology, it is need to unify all available data, classify it according to form of information presentation, convert into forms convenient for analyzing. The most efficiently it is possible to implement within the frameworks of the unified groundwater resources and reserves information system.

The following described system created on the basis of geoinformation technologies in particular allowed accumulating materials and carry out their effective analysis, receive qualitatively new data during hydrogeological objects and processes studding. Possibility of simultaneous engagement of archive materials and results of their interpretation by different authors allowed raising the quality of such research.

Main part of the system is the subsystem of fresh groundwater resources and reserves allowing monitoring of water quality dynamics and evaluation of possibility to use it for utility and drinking water supply. Of especial relevancy the creation of such a system is for Kazakhstan, major part of territory of which experiences acute shortage of quality water.

Integrated use of data allowed the created by authors information system the provision of information support to any theoretical and practical hydrogeological studies.

Research materials and methods. The structure of the fresh groundwater resources information system of Kazakhstan was created with account to need in hydrogeological data, availability of cartographic information and capabilities of the geoinformation system tools (Yazvin, 2015: 323), (Smolyar et al., 2012: 125), (Veselov et al., 2004: 426). All information is accommodated in semantic, graphic and document databases.

Document database contains all collected data about hydrogeological object functioning. Low formalization of the subject area and considerable quantity of initial data are characteristic for hydrogeological documents. This fact explains the necessity of storing substantial volumes of both published and unpublished documents.

Semantic database servers for the collecting, storing and analyzing of systematized structured information presented in tabular format. It includes both baseline hydrogeological materials as well as results of their processing. All data is conditionally divided into general, used for resolving the majority of tasks, and special, required to resolve specific problems, for example, calculating groundwater resources and reserves, evaluating degree of groundwater contamination and others.

The graphic database includes cartographic documents allowing obtaining attributive information about graphical objects. They are generated with the help of the geographic information system (GIS) and represent a set of digital maps. As a rule, maps required for resolving a certain task are generated in a single geographical projection. Attributive information is related to all graphical objects.

The elements of graphic and semantic databases are interrelated. Records of semantic database tables act as attributes to graphical objects.

While studying fresh groundwater resources, it is taken into account that any changes in components of the environment cause changes in groundwater conditions (Zektser, 2001: 313). Results of interconnection of surface and groundwater is the intensification of the groundwater recharge during river flooding, change of groundwater regime while regulating surface run-off with water-storage reservoirs and others. Considerable impact upon groundwater resources affects by soil cultivation, irrigation and land remediation. Groundwater pollution accompanies operation of various man-made facilities (industrial enterprises, oil and gas fields, transport etc.). Amount of precipitation including contaminated causes change in groundwater regime and quality.

In its turn, groundwater impact environment's other components. Intense water intake affected to surface water, for example, to river flow rate. The large volume of groundwater intakes increases the probability of hazardous geological engineering and hydrogeological processes, activation of suffusion-karst processes. Besides, the groundwater table raise may result in underflooding of various man-made facilities, urban areas and agricultural lands.

Due to evaluate groundwater resources and making of management decisions on its use, the fresh groundwater information system must contain data of hydrogeological object and its relations with natural and man-made environment. Such data shall include:

- hydrogeological maps and cross-sections that include areas of distribution of aquifers and aquifer systems;
- maps of factual material and data of groundwater regime;
- maps of groundwater head contours and flow path, groundwater depths and groundwater mineralization;
- maps of lithological structure for the creating of geo-filtration parameters maps;
- soil maps;
- hydrographic maps and river runoff maps;
- maps of surface water mineralization and chemical composition;
- climatic maps including the atmospheric precipitation data;
- topographical maps;
- layouts of groundwater, surface water and air monitoring networks and monitoring results;
- groundwater resources and reserves maps (groundwater reserves, groundwater resources (natural, estimated and mineable), endowment with water resources);
- groundwater deposits (sites) maps, data of reserves by categories and information about management;
- maps of groundwater pollution;
- layouts of facilities used for economic activities (industrial and agricultural enterprises, sites of intense water intake and water injection, induced recharge etc.) and information about their functioning.

Due to it seems advisable to emphasize the following key blocks of the information system (Fig. 1): general information about hydrogeological object and environment; data of groundwater monitoring; fresh groundwater resources and reserves; groundwater deposits; man-made facilities; groundwater pollution; groundwater protection; availability of fresh groundwater resources.

All data is accommodated in graphical and semantic databases and document database. The structure of the system is not rigid and can be supplemented or changed in the process of solving practical hydrogeological problems. Despite the fact that any hydrogeological analysis is based on the same set of initial data about the object, the resulting maps reflect the personal point of view of the researcher on the problem. Therefore, the system may contain ambiguous materials, for example, maps of hydrogeological zoning created in terms of "regions and basins" or "massifs and basins".

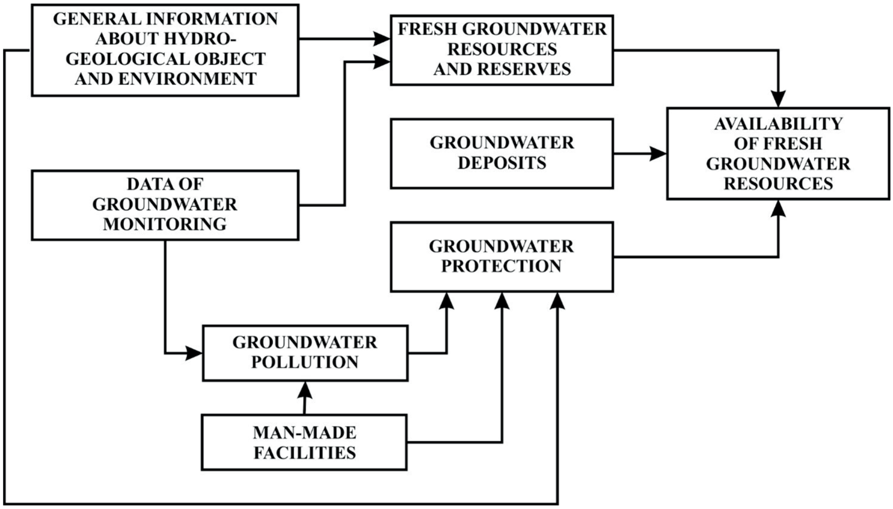


Figure 1 – Structure of geoinformation-analytical system of fresh groundwater resources

General information about a hydrogeological object and environment is represented by materials underlying any hydrogeological studies – hydrogeological maps and cross-sections; data of lithologic structure of aquifers and aquifer systems; maps of groundwater head contours and flow path; groundwater mineralization and chemical composition data; hydrographical, meteorological and topographic data etc. (Zektser, 2001: 313).

Data of groundwater monitoring includes information about groundwater regime and its quality and their temporally change. To obtain an integral hydrogeological information, archive and real-time data is required. It is usually presented in the form of maps of groundwater monitoring networks and groundwater regime and chemical analysis results tables.

Fresh resources and reserves groundwater information determine possibility of making some or other management decisions in hydrogeology. Their classification in the information system was made based on traditional subdivision into reserves (secular) and resources (natural, estimated, exploitable) (Murtazin et al., 2020 a: 8) (Fig. 2). It is necessary to note that maps of groundwater resources reflect subjective viewpoints of authors. Therefore, maps of various authors may be presented in the system.

Groundwater deposits are presented in the system in tabular and graphical formats. Such data as: location; genetic type; recoverable reserves by target purpose and categories; reserves approval date; water intake etc. for each deposit. Data is analyzed within borders of administrative districts, hydrogeological structures and hydro-economic basins.

The man-made facilities, both directly impacting groundwater, as well as representing potential hazard for groundwater include in the information system. Man-made facilities are the industrial and agricultural enterprises, territories of intense water pumping and water injection, artificial recharge sites etc.

Groundwater pollution is displayed on maps of the ecological state of the environment as a zone within which the chemical (radiological) composition of groundwater does not meet sanitary requirements. Groundwater pollution maps are built using monitoring data and information on the pollution source's location.

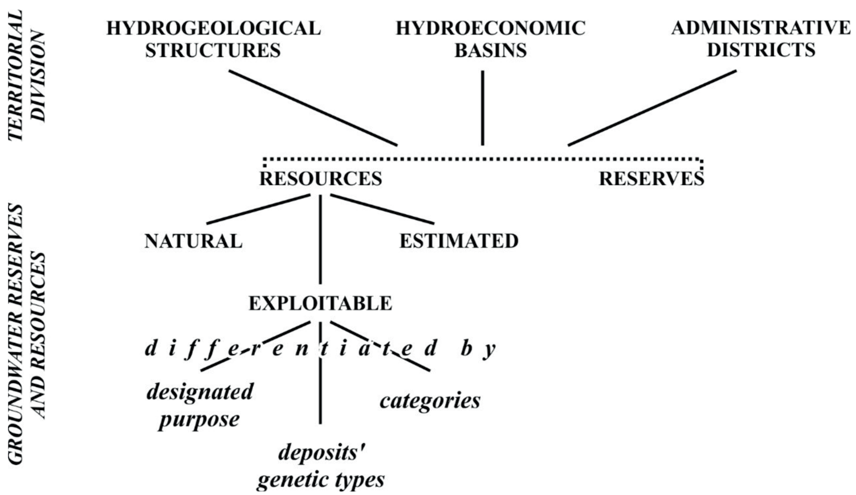


Figure 2 – Structure of information block of fresh groundwater resources and reserves

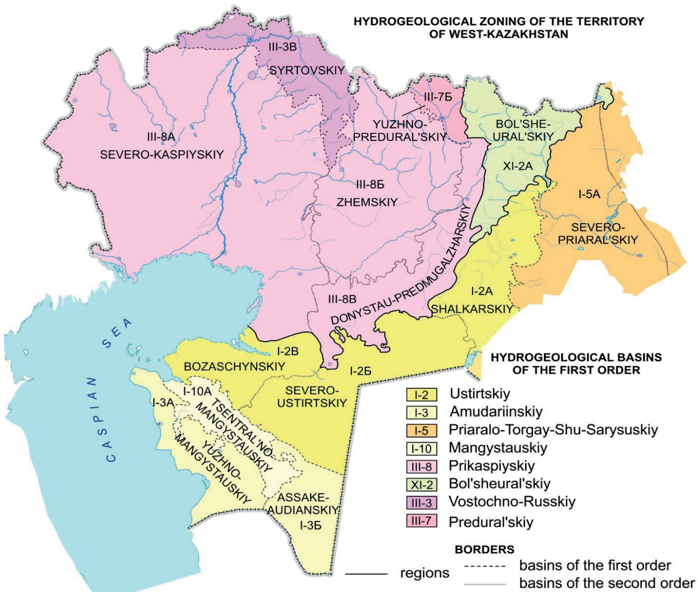
Groundwater protection is associated with the preservation of the natural hydro-ecological system in a state that allows maintaining the composition and quality of groundwater at the required level for a given time period (Zektser, 2001: 313). To creating integrated maps of groundwater protection against pollution hydrogeological and soil maps, data of man-made sources of impact upon environment and groundwater deposit locations, hydrogeochemical map and others are used.

The availability of fresh groundwater resources is defined as the degree to which the current and prospective needs of the population in the quality of drinking water are met at the expense of calculated and withdrawn groundwater resources (Smolyar et al., 2012: 125). Availability maps are formed on the basis of data on resources and reserves of groundwater, deposits, and taking into account the protection of groundwater (Murtazin et al., 2020 b: 9).

Results and discussion. On the example of the territory of the West Kazakhstan, the functioning of the fresh groundwater resources and reserves information system is illustrated. The territory includes four administrative regions: West-Kazakhstan, Atyrau, Aktobe and Mangystau.

General information about hydrogeological object and environment for the territory of West Kazakhstan is contained in graphical database and includes hydrographic network map, hydrogeological map, map of hydrogeological zoning and others. Hydrographic network map (rivers, lakes, swamps etc.) is executed in the form of linear and area facilities, each facility name is connected with them. Hydrogeological map was built in scale 1:2500000. For area facilities corresponding to hydrogeological subdivisions (aquifers and aquicludes and systems), deposition age acts as attribute.

On the zoning map, polygons distinguish hydrogeological regions and basins of the first and second order (Fig. 3), areas of distribution of waters of various salinity, etc. Linear objects display fracture zones, groundwater pressure contours, etc. It should be noted that the zoning map was built by comparison and analysis of data layers already available in the GIS: the area of hydrogeological units, the location of watersheds and hydrographic objects, data on the age and chemical composition of waters, etc.



Note. The names of second order hydrogeological basins are displayed on the map

Figure 3 – Map of hydrogeological zoning of the territory of West Kazakhstan

The groundwater monitoring results for 2021 are included in the semantic database of the information system. The tables contain fields with information about sampling sites, sampling date, pH values, salinity, water hardness, concentrations of various chemical elements. The corresponding layer of the inspection wells graphical database was generated in the WGS 1984 coordinate system using GPS data obtained during the field survey. Associated with each test site is a semantic database chemical analysis results table record.

Groundwater resources and reserves in the information system are displayed on groundwater mineable reserves maps, groundwater estimated resources, fresh groundwater estimated resources extent of exploration etc. Data is displayed by diagrams related to area facilities representing administrative regions, hydro-economic basins or hydrogeological structures. Map of West Kazakhstan groundwater mineable reserves reflecting distribution of mineable reserves values in general by administrative regions and values of mineable reserves with mineralization of up to 1 g/l is create.

Map of groundwater estimated resources was prepared with the use of related values of estimated resources modules and groundwater prevailing mineralization in major aquifers and aquifer systems. Compiled information by administrative regions about potable groundwater estimated resources values and estimated resources modules can be derived automatically (Yazvin, 2015:323), (Nurabayev et ai., 2019: 426).

Resource potential of West Kazakhstan fresh groundwater shown on the map of estimated resources extent of exploration. Based on ratio of values of mineable and estimated resources, groundwater use prospects for various territories were evaluated.

Groundwater deposits data is presented in the shape file containing represented by point objects created in the graphical database. A deposit cadastral number is associated with each object. Tabulated information: administrative region; administrative district; name; information about deposit belonging to second order hydrogeological basin; deposit genetic type; geological index; designated purpose; limits of groundwater mineralization; water chemical composition; mineable reserves by categories (A, B, C_1, C_2); date and authority to approve reserves; protocol number were entered into the semantic database.

Records of the table of semantic database in the field of "Cadastral number" (Fig. 4) are connected with all graphics object representing groundwater deposits.

Thematic maps created based on semantic database information, displaying the distribution of groundwater mineable reserves according to assigned purpose, deposit genetic types etc. Data of water mineralization was taken into account while classifying deposits by value of fresh groundwater mineable reserves. Presenting data of deposits in the form of thematic maps has considerably increased information efficiency of documents required for making groundwater use decisions.

Based on information system data, it is possible to calculate the number of various class deposits distinguished by designated purpose or genetic type, and value of their mineable reserves for each administrative region.

Man-made facilities distribution map in the territory of West Kazakhstan contains a set of point layers corresponding to mine openings, operated hydrocarbon deposits, sites of radioactive and technogenic wastes storage, nuclear reactors etc. Man-made industrial and agricultural systems are represented as polygons. To display railroads and motor roads, oil- and gas pipelines, lines were used. In spite of that not all man-made facilities threaten groundwater at present, they are potential sources of environmental pollution, in general, and groundwater in particularly.

Groundwater pollution maps is contained in graphical database. Groundwater may be polluted from different chemical, biological and physical sources. In this case, any quality degradation shall be understood as groundwater pollution (Beshentsev et al., 2013: 48).

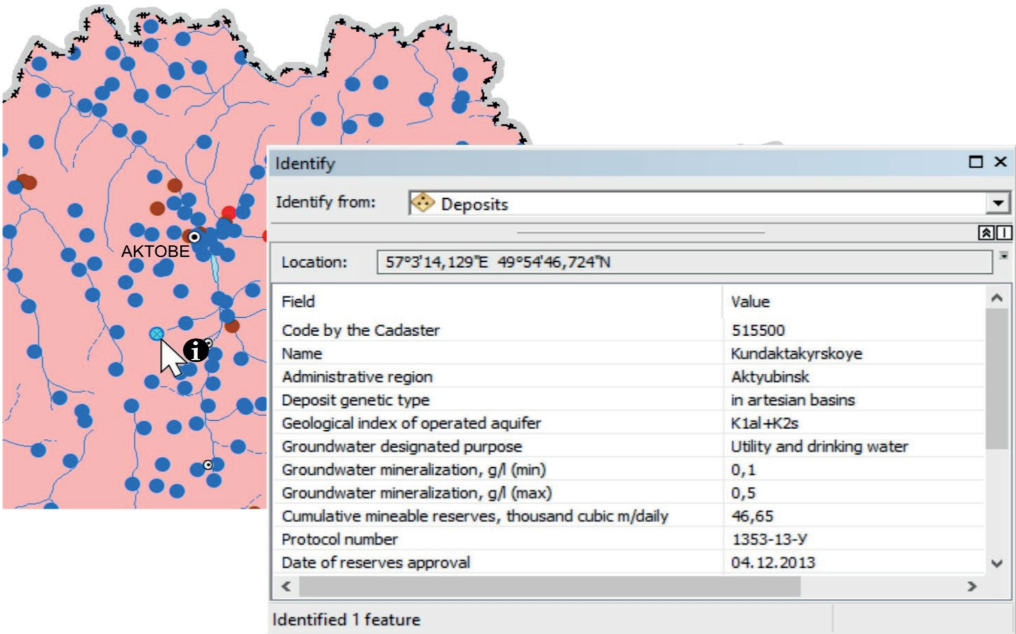


Figure 4 – Presentation of attributive information related to West Kazakhstan groundwater deposits

Pollution maps show areal and focal pollution in the areas of groundwater deposits impact. Pollution area boundaries are emphasized, as well as hydrogeochemical provinces with abnormal concentrations of standardized components and groundwater deposits. Large pollution foci (dangerous and moderately dangerous) are shown. The most hazardous types of pollutants (oil and oil products, radionuclides, strontium, chromium and others.) are identified (Fig. 5).

On maps of groundwater protection from pollution, polygons are plotted corresponding to the following degrees of protection: protected; conditionally protected; underprotected and unprotected. It is also rational to display groundwater deposits on these maps. Based on the data entered, using GIS tools, the areas of territories of varying degrees of protection within the boundaries of the West Kazakhstan were calculated. The main area is occupied by territories where groundwater is not protected or has little protection from pollution (44.48 and 34.49%). Conditionally protected areas occupy less than a fifth of the region (18.99%), and protected areas - 2.04%.

While preparing the availability of fresh groundwater resources map of the West Kazakhstan, sites depending on groundwater grade of suitability for utility and drinking water supply and possible capacity of production wells were distinguished. The map also displays areas with prevailing depth of production wells. To carry out effective analysis, the map contains a layer of groundwater deposits with mineralization of up to 1 g/l. Information about provision of administrative regions population with potable water is given as well as information about regions areas and population size. Based on date of geoinformation system, areas with different degree of endowment by groundwater resources were calculated. Area of territories of West Kazakhstan with endowment by groundwater resources suitable for drinking water supply with prevailing mineralization of up to 1 g/l is 144.2045 thousand km^2, or 19.79% of the West Kazakhstan total area. With endowment by groundwater resources limitedly suitable for drinking water supply without desalination and commonly with desalination up to 3 g/l the area is 142.4958 thousand km2 (19.56%). Area with endowment by groundwater resources suitable for drinking water supply with preliminary desalination higher than 3 g/l is 269.4296 thousand km^2 (36.98%). Area of sites of prevailing location of non-perspective aquifers and groundwater with mineralization of more than 10 g/l and almost waterless territories consists 172.4848 thousand km^2 (23.67%).

It should be noted than the created information system presents information about hydrogeological conditions of West Kazakhstan, groundwater resources and reserves, groundwater pollution and protection, endowment of population by water resources. The system based on ArcGIS tools family having a wide set of graphical data analysis functions.

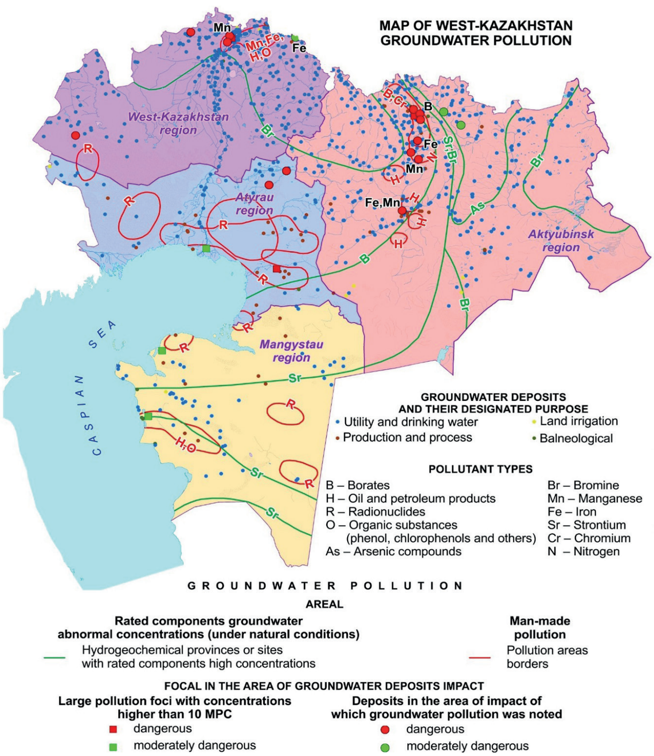


Figure 5 – Map of West Kazakhstan groundwater pollution

Review of data in interconnection, engagement of semantic tabulated information, and materials generated with the help of other geoinformation systems, allowed to present of all the volume of accumulated data as the systemic unified whole having features. This provides an opportunity to obtain principal new information about state and prospects of groundwater using, its interconnection with surrounding natural and man-made environment. The created system is open both in terms of its extension by including data about groundwater in other regions, as well as in terms of development by entering new types of hydrogeological materials.

Conclusion. The fresh groundwater resources information system is the part of the hole unified Kazakhstan groundwater resources system that is created for all administrative regions of the Republic. The fresh groundwater resources information system contains a characteristic of the groundwater conditions and its interrelation with natural and man-made environment. The system includes general information about a hydrogeological object, groundwater monitoring results, materials about groundwater deposits, resources and reserves, information about man-made facilities, groundwater pollution and protection, as well as data of endowment with fresh groundwater.

Data of fresh groundwater resources is displayed on maps of mineable reserves and extent of exploration of groundwater estimated resources. Creating the thematic maps of groundwater deposits differentiated by designated purpose, genetic type and value of mineable reserves along base on the data from semantic database may be very useful.

Groundwater pollution maps are made with the use of monitoring data, maps of man-made facilities and deposits distribution, as well as materials from general information block. Groundwater protection against pollution maps made it possible to calculate areas of the territory with various levels of protection of West Kazakhstan.

Analysis of information about endowment by groundwater resources allowed calculating areas with different extent of endowment in the territory of West Kazakhstan.

All maps included into the system are presented in a single geographical projection which greatly facilitates its use in the area of hydrogeology, geography and ecology. Accumulated data can be used in the process of resolving of practical and theoretical hydrogeological problems and making optimal decisions in potable fresh groundwater management.

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