Geosystem approach to using surface and groundwater in agricultural water supply

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Abstract. The water resources required for agricultural water supply in the zone of insufficient moisture in the south of the European part of Russia have been assessed based on the geosystem approach. Global warming has changed the conditions for the surface and groundwater formation, which leads to water resources shortage. To ensure irrigation and agricultural water supply, it is necessary to analyze the geosystem conditions of water exchange basins, assess the need for water and justify additional sources of water resources to overcome the shortage. To substantiate the use of water resources, the south of the European part of the Russian Federation was zoned in terms of water availability regarding the agroclimatic features, hydrogeological conditions, the river runoff regularity, the climatic changes influence. The analysis of the agricultural production characteristics, the assessment of the current volumes and the need for water resources for irrigation and agricultural water supply until 2035 with regards to agricultural production development, the population size and the dynamics of climate change are presented. For the conditions of the Republic of Kalmykia, the data of forecast calculations of the needs of agricultural water supply for multipurpose use have been presented. The possibility of complex use of surface and groundwater has been determined. The volumes of groundwater potentially available for use in acute arid periods for 1-2 years have been assessed. For the Republic of Kalmykia, the short-term groundwater reserve is 70.1 thousand m$^3$ per day, for the Krasnodar Territory – 3135.1 thousand m$^3$ per day, for the Astrakhan region – 19.9 thousand m$^3$ per day, for the Volgograd region – 519.1 thousand m$^3$ per day The results of studies carried out using the geosystem approach can provide the basis for developing long-term plans for water use and a detailed study of issues on increasing the water supply in the south of the European part of the Russian Federation with water resources.

1. Introduction
The territory of the south of the European part of the Russian Federation, where Samara, Saratov, Volgograd, Rostov, Astrakhan regions, the Republic of Kalmykia, Stavropol and Krasnodar Territories are located, is confined to the zone of insufficient humidification. The territory is located in the basins of the Lower Volga, Don and Kuban. This region is experiencing a shortage of water resources including agricultural water supply. A tense water balance has existed for more than 20 years even in moderately dry years. Under such conditions, water use is limited in the region, which negatively affects the development of irrigation [1].

Global warming has determined changes in the mode and volumes of river flow, the conditions for groundwater formation. The dynamics of the average annual resources of the surface waters of the
Volga, Don, Kuban has been noted [2]. High floods are occurring more often even in autumn, periods of drought are being aggravated and increased, and low-water runoff is increasing. An increase in air temperature in winter, changes in the atmospheric precipitation pattern cause an increase in the groundwater supply in winter. Groundwater resources are increasing [1,2].

When managing water resources in order to ensure irrigation and agricultural water supply, it is necessary to analyze the conditions for ground and surface waters formation, assess the need for water and justify additional sources of water resources to overcome the shortage. The geosystem approach simplifies the solution of these problems.

2. Objects and research methods
The objects of research were geosystems identified on the basis of water exchange basins [3] within the water-collecting areas of the Lower Volga, Don and Kuban. The water exchange basin includes a river basin and an underground (artesian) one, although there may be a discrepancy between the surface and underground boundaries of the water-collecting area. In artesian basins, fresh water necessary to ensure agricultural water supply (drinking and irrigation) is formed in the zone of active (free) water exchange. This is a zone of earth’s crust drainage by rivers, where fresh water is a part of the hydrological cycle conditioned by climate, landscape conditions, structural and hydrogeological features. The unity of the water collection determines the relations between surface and groundwater in resources formation. The water exchange basin has all the necessary features of a geosystem and they are as follows:

- integrity allowing all its elements to function as a whole;
- hierarchy possesses internal subsystems and at the same time obeys supersystems that determine its ecological resistance to technogenic impacts;
- structurality enabling to distinguish and consider individual elements of the water exchange basin and their interrelated functioning.

Based on the geosystem approach, the possibility of increasing the use of water resources for agricultural water supply and zoning of the south of the European part of the Russian Federation in terms of water supply was analyzed. Zoning regards the following:

- agroclimatic conditions,
- conditions for forming groundwater within artesian basins with regards to the modern dynamics of groundwater replenishment in the catchment area,
- conditions for forming surface waters within river basins with regards to the impact of climate change.

The taxonomic zoning scheme for the south of the European part of the Russian Federation is based on the geosystem approach. A GIS project including databases and thematic maps has been developed [4,5].

According to the moisture content, 2 agroclimatic zones being arid and dry (according to G.T. Selyaninov) are distinguished. Geologically, the south of the European part of the Russian Federation is confined to the East European platform and North Caucasian folds. To reflect water exchange geosystems, artesian basins of the second order were identified in accordance with the map of hydrogeological zoning of the All-Russian Institute of Hydrogeology and Engineering Geology. As a result, the GIS project includes digital and cartographic data on agro-climatic zones, artesian basins, the value of the average annual natural resources of surface waters, the amount of renewable surface water resources, groundwater reserves, groundwater reserves replenishment, the degree of anthropogenic pressure on water resources, groundwater resources potentially available for temporary withdrawal.

3. Results and discussion
To assess the volume of water resources currently used for agricultural water supply, the GIS project includes information on agricultural land use, the location of irrigation systems and the ecological state of reclaimed lands, irrigation rates, losses, discharge and water quality. A digital database of land
reclamation objects was formed using the official information resources of the Ministry of Natural Resources of Russia and the Ministry of Agriculture of Russia. The following information was compiled in xls-files: state irrigation and drainage systems; irrigation and drainage systems composition; separately located hydraulic structures; the assessment of the reclamation state of irrigated lands, irrigation modes, sown areas structure; the general indicators of water use [4].

The water supply of the zone characterized by insufficient moisture in the European part of the Russian Federation for the constituent entities of the Federation was studied with regards to the zoning results and materials analysis [6,7]. The works included the study of agricultural production characteristics; assessment of the current volume and demand for water resources for irrigation and agricultural water supply for the future until 2035, taking into account the development of agricultural production, population size and dynamics of climate change. It has been established that at present, 4.4 km³/year of water is used for irrigating 1.5 million hectares of land in the federal regions under consideration. Increasing the irrigated area by 2035 to 1.8 million hectares will require 6.7 km³ of water. In the long term, with the growth of irrigated land to 2.1 million hectares, about 8 km³/year of water is required. According to the forecast, basing on the demographic situation, the volume of drinking agricultural water supply by 2035 will have slightly increased from 274 to 288 million m³/year. The performed forecast calculations [7] of multipurpose agricultural water consumption for the conditions of the Republic of Kalmykia are shown in Table 1.

Table 1. Planned water consumption in the Republic of Kalmykia up to 2035

| No | Indicators                                                                 | Amount  |
|----|---------------------------------------------------------------------------|---------|
| 1. | Total area of irrigated land, thousand hectares                            | 106,6   |
|    | including:                                                                |         |
|    |   - forage crops                                                          | 76,1    |
|    |   - vegetables and melons                                                 | 12,2    |
|    |   - cereals                                                               | 8,0     |
|    |   - rice                                                                  | 6,1     |
|    |   - other cultures                                                        | 4,2     |
| 2  | Water demand for irrigation, million m³/year                               | 636,5   |
|    | including rice irrigation                                                 | 112,9   |
| 3  | Total area of watered pastures, million hectares                           | 3,9     |
| 4  | Water demand for pastures irrigation, million m³                           | 32,0    |
| 5  | Household drinking water supply for the rural population, million m³       | 12,0    |
| 6  | Water supply for livestock complexes and processing facilities, million m³| 10,0    |
| 7  | Water demand for pond fish establishments, million m³                      | 130,0   |
| 8  | Reservoirs filling                                                        | 545,0   |
| 9  | Channel filling                                                           | 31,5    |
|    | Total: general demand for water resources, mln.m³                          | 1696,8  |

As studies have shown, an increase in water availability is possible, first of all, due to an increase in the selection of artesian and complex use of surface and ground waters [6]. At present, the degree of groundwater development in the south of the European part of Russia is about 15% of the approved operational reserves. Groundwater reserves are more stable when analyzed for the period of many years. Their use can significantly increase the water supply in the regions.

The main positive aspect of the groundwater use is the possibility of extracting them in the maximum allowable volumes during severe arid periods with subsequent replenishment of their reserves during relatively high-water periods. Groundwater is recharged through filtration or injection of surface water into aquifers [8]. The volumes of groundwater potentially available for being used in acute arid periods for 1-2 years have been assessed. For the Republic of Kalmykia, the short-term
groundwater reserve is 70.1 thousand m$^3$/day, for the Krasnodar Territory – 3,135.1 thousand m$^3$/day, for the Astrakhan region – 19.9 thousand m$^3$/day, for the Volgograd region – 519.1 thousand m$^3$/day.

The results of assessing and zoning the territory of the south of the European part of the Russian Federation in terms of the amount of groundwater resources available for temporary withdrawal are shown in Figure 1.

Taking into account different geosystem conditions of the territory, a system of measures aimed to increase agricultural water supply has been developed. The measures are as follows:

- improvement of the substantiation and implementation of water distribution in irrigation systems using optimization mathematical modeling and GIS technologies;
- planning, management and provision of innovative technologies and equipment for water supply, water disposal, water treatment, irrigation, water supply, water distribution;
- justification and implementation of reconstruction, restoration of reclamation systems based on modern methods of survey, design and construction, ensuring conditions for the reuse of drainage flow;
- automation of geosystems ecological monitoring;
- introduction of remote observation methods and remote control of reclamation systems.

4. Conclusion
The application of the geosystem approach enabled to estimate the water resources required for agricultural water supply in the zone of insufficient moisture in the south of the European part of Russia. In the process of research, the water resources volumes relevant for 2014-2020 have been
analyzed and the requirements for water resources until 2035 as well as long-term requirements in water resources for irrigation within the southern regions of the European part of the Russian Federation have been identified. The possibility of integrated use of surface and groundwater for irrigation has been determined, and the volumes of groundwater resources potentially available for use in the acute dry period have been estimated. The territory of the southern regions of the European part of the Russian Federation has been zoned, which enables to establish general patterns of water resources formation and to assess the possibility of obtaining additional volumes for being used in agriculture through measures for the rational use and protection of ground and surface waters.

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