Principles of ensuring geosystem environmental sustainability under man-made impacts on water resources

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Abstract. The paper presents long-term interdisciplinary studies aimed at developing the methodology of ecosystem water use and applying it to supervise the use of water resources for ensuring the environmental sustainability of geosystems. The proposed approaches to justify and implement ecosystem water use are based on the provisions of sustainability theory of complex systems and risk management. Risk factors are defined by some general situation and water sector challenges accumulated over the past years. The paper deals with water use issues leading to violations in the ecological stability of geosystems, including organizational and legal, environmental, economic, technical, and social. As per risk management theory, the main methods of risk management are informational, organizational, regulatory, economic, engineering and technical. Based on theoretical provisions, improved principles of ecologically safe functioning of geosystems during water use are as follows: ecosystem services imply restoration and preservation of the functional and structural integrity of drainage basins, landscapes, water bodies; environmental friendliness implies compliance of water management activities with environmental requirements and restrictions; protection of water bodies prioritized over their use; utilization of water bodies for drinking and domestic water supply prioritized over other purposes of water use; equilibrium implies compliance with the balance of use and reproduction of water resources; optimality of technical and technological solutions. To assess the ecological state of geosystems and man-made impacts, it is necessary to control indicators, which provides a sound basis for the analysis and ongoing management of the environmental situation. An integral index for irrigated land is the hydrothermal coefficient otherwise referred to as radiation dryness index. Strengthening water supply involves improving water conservation, constructing and reconstructing irrigation systems, promoting innovative irrigation technologies; putting into service efficient water, primarily, drinking water treatment plants, drainage and effluent treatment, water accounting systems.

1. Introduction
A continuously growing man-made impact on the environment entails water pollution, degradation of natural and reclaimed landscapes, which significantly reduces their sustainability and productivity. Thus, according to the State of Ecology and Environment Report as of 01.01.2018, over 6,017.80 million m$^3$ of wastewater was discharged into surface water in the Russian Federation, of which about 1,708.10 million m$^3$ were contaminated [1]. Drainage basins of various kinds and landscapes within the area can be considered as open dynamic geosystems, the ecological stability of which is determined by the state and functioning of their components (subsystems). Such components are also water bodies containing surface water and groundwater. Water bodies forming drainage geosystems
are interconnected. Agriculture can affect the pollution of surface and underground waters, contributing to mineralization, which, primarily, causes a violation in aquatic biota. The use of saline waters or waters polluted by livestock waste for irrigation of lands causes re-salinization, unfavorable changes in soils, and declining productivity of agrocenoses. This means a decrease in the ecological stability of ecosystems to succeeding man-made impacts and environmental and, subsequently, economic risks in agriculture.

Water quality also causes social and environmental issues including unsatisfactory agricultural drinking water supply. Water that does not meet quality standards due to man-made or natural pollution is used by about 30 million people in rural areas. What is more, 16% of the rural population use, for household and drinking needs without appropriate treatment, underground waters with a salinity of 1 to 5 g/l and a hardness of 7 to 15 and above mg-eq/l, and 19% – with an excess of maximum permissible concentrations for iron and manganese.

Ensuring water use in line with preserving ecological stability of the geosystem and guaranteed provision of water resources for a favorable socio-economic development of the country is becoming an important task. First of all, it impinges on the state of water management system of the Russian Federation. The water management and reclamation system is made up of a set of engineering facilities and structures that provide solutions to environmental, technical, economic and social issues of water and land use [2-4].

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2. Objects and Research Methods

Environmentally sustainable water use within ecosystems depends on natural and man-made factors. The provision of water resources is complicated by uneven distribution of surface and groundwater across the territory of Russia. In a number of regions, there is a shortage of water, primarily, suitable for household and drinking water supply. There are not enough water resources in drought years for irrigation of lands. The situation is aggravated by the current climate change. Russia remains a region of the world where climate warming during the 21st century will be projected to significantly exceed the global average. There is a gradual aridization of the climate, primarily in the south of the European part of the country, which will make the issue of water supply to the regions particularly acute [5].

Challenges to bring about violations in the ecological stability of ecosystems during water use can be roughly divided into the following types:

- organizational and legal, including imperfection of management systems, oversight of water management, lack of a unified information basis for water use, deficiency and inconsistency of legal and regulatory arrangements for water use;
- ecological, including pollution, depletion, degradation of aquatic ecosystems and groundwater, uneven distribution of water resources, imperfection of environmental regulation of water use in terms of quantitative and qualitative indicators;
- economic, including imperfection of economic mechanisms to ensure the environmentally safe functioning of water use systems;
- technical, including deterioration and aging of fixed assets, imperfection of water use systems, non-productive costs and water losses; imperfection of technologies for water treatment, purification and regulation of water quality in the subsystems of water consumption and wastewater disposal; lack of a system of monitoring and control over the quantity and quality of consumed and discharged water;
- social, including a rise in morbidity, a decline in the living standard of the rural population, a fall in the quality of agricultural products.

Methodological approaches rest on modern theoretical and practical developments in the field of ecosystem water use, on agricultural principles of water resources utilization, regulatory documents of environmental activities.
To foster the water supply in regions experiencing a shortage of water resources, it is necessary to concentrate and strengthen water management in the country within a single framework [3,5-7]. Targeted management will streamline the systemic water use in the unified water sector of the country, and will allow the required integration of the main production water resources, concentrate efforts to improve the drinking water supply, eliminate the shortage of water resources in the regions, ensure the rational use of water, and improve the technical condition of production assets.

3. Results and Discussion
Certain measures to improve the efficiency of the country’s water management system have been developed and are being implemented within the framework of the Federal Target Program for the Development of the Water Management Complex. Thus, due to the implementation of program measures, unproductive water losses are expected to be halved, while water intensity of GDP is likely to reduce by 40%, which will undoubtedly reduce the environmental risk [1,5]. It is planned to reduce man-made impacts through measures to reconstruct treatment facilities, based on modern technological breakthroughs in the field of wastewater treatment. Subsequent upon the program measures, it is planned to reduce water pollution by 2.5 times. Many aspects of the program also touch upon the problems of water supply to farming enterprises.

To increase the economic efficiency and environmental safety of the use of water resources, it is necessary to take a set of measures enabling the most economical and efficient water consumption [2-4,8]. In this regard, the core principles promoting ecologically safe geosystems in zones of insufficient moisture in the light of ongoing climatic changes are:

- ecosystem services that imply reconstructing water and land use management, aimed at restoring and promoting the functional and structural integrity of drainage basins, landscapes, water bodies;
- environmental friendliness that expects water management to meet environmental requirements and restrictions;
- protection of water bodies prioritized over their use, i.e. operation of water bodies should not have a negative impact on the environment;
- use of water bodies prioritized for drinking and domestic water supply over other purposes of water use;
- equilibrium, providing for a delicate balance of use and reproduction of water resources including surface, underground, etc. and protection of waters from pollution and depletion;
- optimality of technical and technological solutions, which implies the need to switch to new environmentally friendly and cost-effective water management systems, technologies and structures that ensure water conservation, protection of terrestrial and aquatic ecosystems from pollution and degradation, and safety of the population and economic facilities from harmful effects produced by water.

Water management activities performed by irrigation/water distribution systems and economic systems are based on the principles of ecosystem water use. A coherent approach has been proposed to ensure ecologically sound use of water, land and biological resources within geosystems, tailored with due account for landscape features and a strict focus on preventing pollution of water and other ecosystems [3-6].

The system of water use in irrigated areas is based on the use of standard quality water for irrigation (on black soils and dark chestnut soils, mineralization should not exceed 1 g/l) and its economy. For specifying the ecologically permissible value of water load on the irrigated agricultural landscape, it is fundamental to create a hydrothermal regime that provides the most favorable conditions for soil formation and productivity of agrophytocenoses. An integral indicator here is the hydrothermal coefficient – radiation dryness index ($\bar{R}$). Environmentally favorable parameters of hydrothermal regime, which must be sustained in the conditions of the republic, to ensure energy-substance equilibrium are: $\bar{R} = 0.8–1.2$ [2,4].
Table 1. Parameters of hydrothermal regime in natural and climatic zones of the southern regions of Russia

| Parameters                      | Level           | steppe | dry-steppe | semiarid | arid     |
|---------------------------------|-----------------|--------|------------|----------|----------|
| Radiation balance (R), kJ/cm² a year | natural         | 183    | 183-185    | 183-190  | 190-193.5|
|                                  | actual (when irrigated) | 194    | 194-195    | 194-201.5 | 201.5-205|
| Radiation dryness index (R̄)     | natural         | 1.7    | 2.0-2.5    | 2.6-3.2  | 3.1-3.7  |
|                                  | actual          | 0.8-1.2| 0.9-1.3    | 0.8-1.3  | 1.1-1.4  |
|                                  | advantageous    | 0.8-1.2| 1.0-1.2    | 1.0-1.2  | 1.0-1.2  |
|                                  | critical        | <0.8; >1.7| <0.8; >1.8 | <0.8; >1.9| <0.8; >1.9|
| Indicator of soil formation energy (Qs), kJ/cm² a year | natural         | 63     | 30-40      | 18-30    | 14-30    |
|                                  | actual          | 90-100 | 85-100     | 70-88    | 50-63    |
|                                  | advantageous    | 83-110 | 73-120     | 93-125   | 63-105   |
|                                  | critical        | 63     | 50         | 56       | 54       |
| Irrigation rate (M), mm/year     | actual          | 300-600| 350-510    | 400-630  | 400-610  |
|                                  | advantageous    | <415   | >600       | >640     | >700     |
|                                  | critical        | 0      | <95        | <105     | <160     |

Water supply systems for agricultural enterprises (livestock complexes, poultry farms, watering of hayfields and pastures) and water disposal facilities should rely on sanitary-and-epidemiologic and veterinary principles, which provide for the strictest provision of public health protection and the creation of favorable conditions for human and animal life (based on compliance with the conditions and norms of legal and regulatory documents on environmental safety) by using high quality water ensured by modern technologies for its purification. A sufficient number of watering points must be equipped.

The system of water use for fish farming should be developed through the more efficient employment of numerous basins (ponds, reservoirs, lakes) in line with a set of measures to improve the quality of water and with existing standards.

Thus, in order to improve water supply in the regions in the field of technical development of agricultural water supply, it is necessary:
- promotion of water saving, construction and reconstruction of irrigation systems, integration of innovative irrigation technologies, which in recent years have been actively developing based on a synergy of drip and fine-dispersed irrigation;
- construction of efficient installations for water treatment, primarily drinking water, including individual installations, since about 40% of the population use substandard drinking water;
- treatment of drainage water for reuse, primarily for irrigation;
- widespread application of a system for accounting for the quantity and quality of consumed and discharged water.

4. Conclusion

Compliance with the principles of ecosystem water use will facilitate water availability, improve the socio-economic situation, advantage production, efficient use of water resources and save them up to 20% together with promoting the ecological stability of geosystems to water management impact. Moreover, water of the sufficient quality will be provided to the population, irrigation and watering of areas in regions with the most acute shortage of water resources. The obligation to comply with environmental restrictions on water use is necessary to preserve environmental sustainability to water management impact, protect water resources from depletion and pollution, preserve a favorable ecological state of water and land resources for future generations.
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