Conceptual basis of methodology of improving the technology of water use for irrigation and watering systems

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Abstract. The paper studies the formation and use of water resources on existing irrigation and watering systems (IWS) of Stavropol territory in cause-effect relation with the global problems of Energy, Water and Food defining the tendency of modern development of agricultural production thus meting the vital food needs in social development. Both at the level of the global system “Nature-Society-Person” within terrestrial biosphere and at its hierarchical levels of river basin geosystems, where water resources are formed, agricultural production is carried out on existing IWS, on the example of the Kuban, Terek and Lower Don rivers and with the population of over 23 million people, the modern social development is characterized by a stable tendency towards water finiteness in limited conditions for further development. The analysis of formation of water resources within the spatial limits of basin geosystems and their subsequent use on IWS determines the technological scheme of water use on irrigated lands. The problems of Energy, Water and Food in agricultural production on irrigated lands, as it was established in the processes of their systemic interconnection, interaction and relationship on current IWS of the Great Stavropol Canal have identified the dominant problem, according to which there is a need to take into account the geomorphological characteristics of the earth’s surface topography, geological zoning of the Stavropol territory, development of the methodology to improve energy efficiency of water resources using both non-renewable and renewable sources of energy in accordance with system principles: “system integrity”, “reflection of objective reality”, “ecological suitability”, “vital purposeful activity”. Seven conceptual statements of Ecological Suitability contributing to new ideas for the creation of new and improvement of existing IWS were developed within the concept of “ecological suitability” for IWS operating within NTS “NE – IWS – P” based on basic system principles.

1. Introduction
Modern social development at the level of the global system “Nature – Society – Person” in spatial borders of terrestrial biosphere ($W_{TB} = 10 \cdot 10^{10}$ km$^3$) and at its hierarchical levels of basin geosystems where water resources are formed as surface and ground water runoff and almost all types of economic activity are conducted, including agricultural production on the basis of irrigation and watering systems (IWS) [1]. The use of water resources in agricultural IWS within spatial limits of basin geosystems of the Kuban Rivers ($W_{KB} = 596370$ km$^3$), the Terek ($W_{TB} = 66847$ km$^3$), the Lower Don ($W_{LDB} = 1030000$ km$^3$) with over 23 million people (16.3% of the total number of residents of the Russian Federation) is characterized by a stable trend of limited water resources for further development [1, 2], which defined the relevance and the purpose of the study to improve the use of natural water resources.
The analysis of the sequence of water resources formation within spatial limits of the considered basin geosystem, their further intrabasin regulation and redistribution, selection of design flowrates (Q m³/s) from a water object, transportation to IWS, intrasystem distribution to IWS and final supply to rooting soil layer of plants with the specified irrigation rate determines the technological scheme of formation and use of water resources in agricultural production on irrigated lands [2, 3].

The analysis of cause-effect relation of 10 major global problems of the present with a particular focus on the first three core problems – Energy, Water and Food, which contribute to the dominant problem, without which it is impossible to solve the remaining 7 problems, including the problem of “Ecology”, which holds the first (fourth) place in order of importance [4].

The system role of the dominant problem of the use of water resources, which quantitative and qualitative indicators are formed within the spatial limits of basin geosystems, is characterized by the focus of interrelation, interaction and relationship (IIR) of Energy, Water and Food in their strive to achieve the set objective thus ensuring a stable trend towards the rational use of natural resource potential in the form of solar radiation, water resources, climatic, geomorphological, geological and hydrogeological factors in the top layers of a lithosphere, soil cover with basement rocks, available biodiversity in flora and fauna, as well as social and economic conditions in the considered space and time. The assessment of the key role shall consider the fact that all energy phenomena related to the transformation of forms of energy on Earth, except sea access and recess, represent the product of the radiative flow of energy arriving from space from its primary source – the Sun, which, in fact, defines the leading place of Energy within the key role in IIR between Energy, Water, Food [5-7].

Based on the study of the use of water resources on IWS of the Great Stavropol Canal (GSK) 666 km long (1700 km as per the design) on the area of 3666.6 thousand hectares it was found that the role of the dominant problem over the problems of Energy, Water and Food is fully underestimated thus causing vulnerability in the development of various branches of economic activity in the IWS zones of influence. Thus, on the example of the use of water resources within the limits of IWS zones of influence of GSC the interrelation of problems of Energy, Water and Food in the production of the necessary crop and livestock production on irrigated lands with their subsequent processing to receive foodstuff – Food requires a certain amount of Energy and volumes of Water, which in system consideration demonstrates the role of the dominant problem within the IIR of three major problems. The studies (2015-2018) revealed that on the operating IWS GSC (GSC – 1, GSC – 2, GSC – 3, GSC – 4) there are about 6 thousand various types of intrasystem hydraulic engineering structures (HES) with differences between fore and tail bays from 2 m to 30 m where it is possible to build small hydroelectric power stations with the total capacity of about 600 million kWh. Some IWS, for example GSC – 4, almost do not consider geomorphological characteristics of a terrestrial relief expressed by the difference of margins (from 70 m and above) between the water supply canals and the irrigated sites of IWS.

2. Methods and materials
Spatial borders of Stavropol Krai include parts of basin geosystems of the Kuban Rivers, the Terek, Western and East Manych, Kuma and the interflue area of the Kuma-Mulka in quantitative terms making the following: area of water-collecting territory $F_{ac} = 66.2$ thousand km²; volume of surface layers where rainfalls in the form of rain and snow are formed. $W_{at} = 662$ thousand km³; volume of top layers of a lithosphere with hydrographic network $W_{lt} = 19.86$ thousand km³; total volume of spatial limits makes respectively 681.86 thousand km³.

On the volume of the use of water resources formed within spatial limits of parts of river basin geosystems of the Kuban Rivers, the Terek, the Kuma, the Western and East Manych and the interflue area of the Kuma-Mulka the basin geosystem of the Top Kuban (52.8% of the selected expenses is domineering, further the basin geosystem of the Terek (29.7% of tap discharge rate), then goes the basin geosystem of the Kuma (17.3% of tap discharge rate) and 0.6% is the interflue area of the Kuma-Mulka. The water balance formed within Stavropol Krai is characterized by an average annual layer of rainfall making 615 mm (49.5 km³), river drain making 88 mm (7.0 km³), evaporation making 527 mm (42.5 km³), which defined the need for creation and development of artificial hydrographic network in
the form of water supply canals filling 53 large reservoirs with a total capacity of about 2.5 km$^3$. The cumulative water production in artificial hydrographic network of the Kuban Rivers, the Terek, the Kuma, the Kuma-Mulka and the Podkumk makes 485.1 m$^3$/s thus ensuring sustainable development of all economic branches, including agricultural production within IWS. Five hydrological structures presented in Fig. 1, which are used to solve water environmental problems, are defined based on the analysis of water resources formation, their use in economic branches and according to the applied scheme of hydrological division of the North Caucasus into districts for the considered spatial borders of Stavropol Krai [4, 6, 8].

![Figure 1. Scheme of the structural-hydrological zoning of basinal geological systems of Stavropol krai: 1 – Azov-Kuban artesian basin, 2 – Terek-Kuma artesian basin, 3 – Hydrologic region of Stavropol swell, 4 – Artesian basin of the East-Manych downfold, 5 – Artesian slope of the North-Caucasus monocline.](image)

The spatial borders of Stavropol Krai ($W_{St.krai} = 681.86$ thousand km$^3$) occupy low hierarchical level in the global system of terrestrial biosphere, which defines the direction of the development vector within systems functioning at lower hierarchical levels, which causes the basic principle in creation and development of fundamentals to study the consequences of water environmental problems from the standard statement “to think globally and to work locally” [2].

According to this statement it is possible to note that the whole Water in the solar system is generated from a huge primary cloud of gas and dust, which compressed more than four billion years ago having formed the solar system. Hydrogen and oxygen constituting Water (H$_2$O) were present in this cloud. The World Ocean occupies over 70% ($F_{WO} = 361$ million km$^2$) of the Earth ($F_E = 140.1$ million km$^2$), which weight is about 0.02% of the Earth’s mass ($M_E = 5.976 \cdot 10^{24}$ kg), and taking into account water in its mantle – 0.04% [1]. The global moisture circulation under the influence of solar energy flows (35000 TW) within the biosphere of Earth ($W_{B.E.} = 1 \cdot 10^{10}$ km$^3$) makes 577 thousand km$^3$, from which 72 thousand km$^3$ come from land basin geosystems ($F_L = 149$ million km$^2$), and from the World Ocean –
505 thousand km$^3$ ($F_{WO} = 361$ million km$^2$). All types of natural Waters on Earth are interconnected and are used and renewed in the course of global moisture circulation. It shall be noted that the uniqueness of Water (H$_2$O) as a natural mineral is that Water does not lose its physical importance but only changes the qualitative structure from pollutants when used in various technological processes of economic activity [4, 5].

3. Results and discussion

Proceeding from objectively operating limited conditions of water resources formation in the form of surface and underground runoff within spatial limits of river parts of basin geosystems of Stavropol Krai and a stable trend of agricultural development on the basis of operating and created IWS there is a need to improve available and create new technologies of water resources use in the limited conditions. In turn, new technologies for water resources use in IWS require New Ideas contributing to the growth of social opportunities thus satisfying vital and necessary needs for Food of present and future generations according to functional laws of Nature and ecologically sustainable development (ESD) of the considered branch of economic activity.

The problem of water resources use in agriculture causes the system character and requires New Ideas and new knowledge from the adjacent fields of science and practice utilizing system and convergent approaches [4, 9, 10].

The system approach to modern problems of water resources use on operating and created IWS is considered as orderliness and integrity where the integrity of a system is caused by the dominating role of integrity over natural and social (population) components interacting with IWS as a technogenic component as part of the “Natural Environment – IWS – Population” natural and technical system (NTS) (NTS “NE – IWS – P”) [2, 6].

Proceeding from objective operating system principle of the key role of the whole in the considered NTS “NE – IWS – P” in the context of the dominant problem of Energy, Water and Food the suggested New Ideas shall form a stable trend of more comprehensive use both inside system and external potential resources with the energy flow arriving from the primary source of the Earth-Sun being the major one [9]. Under the influence of solar energy flows within spatial limits (atmosphere, hydrosphere, top layers of lithosphere, soil cover) of the IWS zones of influence as part of the NTS “NE – IWS – P” almost all processes connected with the transformation of forms of Energy take place, as a result of which (in particular) crop and livestock products are created. What is the role of the principle of the key role of the whole here?

The key role of the whole in the considered NTS “NE – IWS – P” connected with formation and use of water resources is expressed in IIR of water resources formation at a hierarchical level of the global system of the Earth’s biosphere and spatial limits of parts of river basin geosystems of Stavropol Krai, where IWS function with the use of water resources as integrally connected systems. Such IIR of a global system of the Earth’s biosphere with local river basin geosystems determines the principle the key role of the whole, according to which the formation of water resources at the level of a higher system defines the formation of a water drain in the systems of lower hierarchical level as the zones of influence of the NTS “NE – IWS – P” within local river basin geosystems.

The NTS “NE – IWS – P” defines the complex of intrasystem transformations in natural structural formations (hydrographic river network, top layers of lithosphere, ground layers of atmosphere, soil cover, plant and animal life, etc.), where the natural environment plays the leading role in IIR with IWS. The leading role of the natural environment is possible in case of the optimum reflection of objective reality of the environment. The objective reality is understood as objectively operating mechanism of management from the outside (systems of higher hierarchical levels) to preserve the development in IWS zones of influence and respectively to ensure through the preservation of the key role of the whole such development mainly performed by hydrological processes, which form the water runoff in spatial limits of river basin geosystems being parts of basin geosystems of higher hierarchical levels. For the NTS “NE – IWS – P” connected with agricultural production the concept of the key role of the whole determines the dominating impact of natural moisture circulation processes within spatial limits of basin
geosystems of higher hierarchical levels within the Earth’s biosphere on the formation of water runoff in IWS zones of influence and its purposeful use in technological processes of irrigation systems. There is a complex and ambitious problem of energy efficient New Technologies for water resources within IWS within the context of new and improvement of existing technologies of water resources use in IWS [4, 11].

The creation of energy efficient technologies of water resources use in IWS becomes possible in the presence of a stable trend of New ideas connected with the improvement of existing and creation of new constructive and technology solutions on the use of water resources with “Energy efficiency” using both non-renewable and renewable sources of Energy in accordance with system principles: “system integrity”, “reflection of objective reality”, “ecological suitability”, “vital purposeful activity” [1, 11, 12].

The principle of “system integrity” on operating and created IWS as part of the NTS “NE – IWS – P” within the spatial limits of local river basin geosystems is caused by integrity with its internal structure consisting from IIR of natural (biotic, abiotic) components, technogenic components in the form of various types of hydraulic engineering structures (HES) and the population living in IWS zones of influence [4, 6].

The principle “reflection of objective reality” is defined by the ability of IWS to adapt to natural external environment of spatial limits of a local river basin geosystem thus forming the ecological state (ES) in zones of its influence [4, 6].

The IIR processes of IWS with natural environments are characterized by the unity of functional actions of its system elements in the form of HES watering unit with transformation processes in natural environments, for example, in water-collecting hydrographic river network during the formation of surface and underground water runoffs. The reflection of reality of natural transformation processes is defined by the depth of knowledge and skills to reproduce similar actions in structural elements and technological schemes of water resources use within IWS. It shall be noted that if there are positive achievements in the knowledge, then the formation of skills of reflection of reality of natural transformation processes in water resources technologies, for example in IWS, faces certain problems connected with imperfection of constructive decisions, insufficient use of renewable energy sources (RES), insufficient use of morphometric characteristics of the land surface within IWS, etc. [5, 13, 11].

The principle of “vital reality” of IWS as part of the NTS “NE – IWS – P” of local river basin geosystem functioning in spatial limits as the systems of higher hierarchical level is caused by deactivation of the “ES” vector in IWS zones of influence from the “ES” vector of the system of higher hierarchical level. In case of considerable deviations of ecological indicators in IWS zones of influence as part of the NTS “NE – IWS – P” from ecological indicators of the “maternal” ecosystem of the local river basin geosystem accompanied by the withdrawal from coevolution (adaptation) band to natural factors of external environment may later cause irreversible processes of degradation of life-supporting natural environment [4, 6, 8].

According to the studies, the concept of the “key role of the whole” in the NTS “NE – IWS – P” is defined by the processes of integral IIR between components of the considered system with natural components of basin geosystems of higher hierarchical levels interconnected with the global moisture circulation defining a natural component of the “key role of the whole” over natural and technogenic components. The technogenic component of the principle of the “key role of the whole” in purposeful functioning of IWS as part of the NTS “NE – IWS – P” is in complete dependence on constructive and other characteristics of IWS, the used energy sources and is defined by IIR intrasystem processes of IWS with “NE”, living “P” thus defining the IWS zones of influence. In methodology the concept “ecological suitability” (“ES”) defined by perfection of used constructive solutions, use of “RES” and “NRES”, morphometric characteristics of the land surface in IWS and other indicators is especially important.

The concept of “ES” of operating and created new IWS as part of the NTS “NE – IWS – P” represents a certain “copy” of the natural system with processes of Energy transformation into a stable decreasing trend of entropy growth rates expressed by the perfection of applied constructive solutions and
magnitude relation of the efficiency factor \( \eta \) determined by the relation of free energy \( E_{\text{free}} \) to total energy \( E_{\text{total}} \) coming to the considered system \( \eta = \frac{E_{\text{free}}}{E_{\text{total}}} \).

According to studies, in the considered NTS “NE – IWS – P” the ES of “operating IWS” can be characterized by the following conceptual statements.

1. ES of IWS relies on the perfection of used constructive solutions on HES, corresponding devices in the form of fish-protecting (FP), fish-passing (FP) facilities, etc.
2. ES of IWS appears in IIR processes of IWS with “NE” forming ecological state (ES) in the zones of influence as a factor of environmental safety (ES).
3. ES of IWS depends on resource intensity, energy efficiency in construction and operation.
4. ES accompanies the processes of system self-organization as a universal model of transformations in “NE” under the influence of IWS as part of the NTS “NE – IWS – P”.
5. The leading system indicator in cause-effect logic of IIR processes of IWS with “NE” and “P” in IWS zones of influence in the assessment of ES is the ecological state as the dominating environmental safety factor.
6. ES of IWS ensures a stable decreasing trend of the system entropy growth rates.
7. ES constructive solutions on different operating HES, FP, FP as part of IWS are assessed by system complex environmental monitoring (SCEM).

Within system consideration of the NTS “NE – IWS – P” within river basin geosystems, IWS monitoring results in Stavropol Krai and 7 ES conceptual statements of operating IWS as part of the NTS “NE – IWS – P” it is possible to conclude that the ES in cause-effect interrelation is defined by the IWS functional perfection of its constructive solutions and in general. The methodology of improving the technology of water resources use proceeding from the system principle of the “key role of the whole” in the NTS “NE – IWS – P” with IWS as a technogenic component requires continuous constructive and technological improvement regarding the decrease of NRES with their replacement on RES and elimination of unproductive losses of resources, in particular water, considering the increasing ecological requirements [10, 14, 15].

In compliance with the system principle of the “key role of the whole” and the ES concept as the dominating factor of environmental safety and formation of New Ideas on IWS improvement as part of the NTS “NE – IWS – P” the most promising New ideas are determined:

1. Use of RES in technological processes of water resources use in IWS;
2. Improvement of HES design by using new construction materials;
3. Use of natural water runoff processes within the water-collecting territory with engineering measures on its intrabasin regulation for further IWS use;
4. Creation of closed IWS where the losses of irrigation water on filtration and evaporation will be approximately reduced to 5%;
5. Use of intrasystem HES on IWS for electric energy generation on small hydroelectric power stations;
6. Creation of intrasystem power clusters on the basis of operating reservoir hydrosystems for electric energy generation small hydroelectric power stations located near dams, use of kinetic wind power on wind electrical units (WEU), wind turbine of water supply systems in rural settlements;
7. Use of solar batteries in control systems of surface runoff within the water-collecting territory of a water object used as a water source in IWS.

4. Conclusion
1. Based on the study of existing IWS on the area of 3666.6 thousand hectares the role of the dominant problem over three main problems of Energy, Water and Food was defined with the particular focus on Energy within IIR problems of Energy, Water and Food, without which it is impossible to solve another 7 key problems.
2. IWS as part of the NTS “NE – IWS – P” was studied on the basis of the system principle of the “key role of the whole” within the concept of “Ecological suitability” as an important factor in the creative process of New Ideas to improve the technology of water resources use in agriculture on irrigated lands.
3. Long-term experience of creation and improvement of technologies of new resources based on IWS shows that to achieve a system positive effect the New Ideas shall give an opportunity to make the way from “a drawing board” to practical application.

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