Evaluation of environmental safety of waterworks for urban water supply systems

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Abstract. Basing on the results of long-term research of currently functioning and constructing of waterworks known as ‘activity objects’ (‘AO’) as parts of natural-technical systems (NTS) ‘natural medium – activity object – population’ (‘NM-AO-P’) limited by basin geosystems of Kuban, Lower Don and Terek rivers, in this article are presented the methodological basics of evaluation of level of environmental safety affected by functioning ‘AO’, forming in their impact areas space-time environmental state of NM (surface stratum of the atmosphere, waterbodies of hydrographic river system limited by the water-taking territory where the surface water discharge is formed; higher layers of the lithosphere where the underground water discharge is formed; soil surface with underlying layer), what influences all the processes of life activity of biota, fauna and health of local population.

1. Introduction

Up-to-day environmental safekeeping activity becomes the main productive technological element in almost all types of economic activity [1] – especially in processing of water resources which are formed in limits of basin geosystems appearing to be elemental parts of global system – planet’s biosphere (Wₚₖ=1*10¹⁰km³). Space limits of local basin system (SLBG) where the water discharge (surface, underground) is formed in the limits of water-taking area of hydrographic network of water body includes surface stratum of the atmosphere (height less than 10 km), higher layers of lithosphere (depth less than 300m) which form a virtual cylinder as a model of basin geosystem (Figure 1).

Quantitative indicator of influence area on the surface depends of the square of water-taking territory (Fₚₖ, km²), and for the rivers of the Russian Federation which amount about 2 562 489 [6], is located in the limits not less than 10 km² – 40*105 km² (table 1.)
2. Materials & methods
Use of water resources in different branches of economy as a special kind of activity, is characterized by a big variety of technologies for managing the processes of forming the water discharge (surface, underground) in SLBG is conducted by functioning waterwork systems providing stable water supply of water consumers, for example, in residential sphere of urban households and settlements and water processors, for example, generation of electric energy by hydroelectric and storage hydroelectric stations, technical water supply systems of thermal, condensing and nuclear power stations. System interconnection of basin geosystem of main waterbody with basin geosystems of higher hierarchic level, for example, Azov-Black Sea basin, and analogically local basin geosystems inside of SLBG of main river works the principle of dominating role of the entire, where the systems of higher hierarchic level play leading role for local basin geosystems of lower hierarchic level [4,5].
Practical usage of water resources, as the national and foreign experience shows, is conducted by in-basin regulation or inter-basin redistribution of discharge with following take (irretrievable, retrievable) calculated consumption of natural water, their following transportation to the consumers or water processors with help of hydrotechnical construction complex (HTCC) being a technogenic component of a specific type of natural-technical system (NTS) ‘natural medium – activity object – population’ (‘NM-AO-P’) (Figure 2), where ‘AO’ is considered to be represented by HTCC and additional buildings. The natural component ‘NM’ is considered to be a natural medium (surface stratum of the atmosphere, hydrosphere represented by river hydrographic network limited by the water-taking area where the surface discharge is formed, higher layers of lithosphere geological medium, where the underground discharge is formed, and soil surface with underlying layers), interacting with ‘AO’ while using water resources. Component ‘P’ represents local population of areas impacted by ‘AO’.

Figure 2. NTS-Model ‘natural medium-activity object-population’

Existing NTS ‘NM-AO-P’ function in SLBG, where during the process of usage of water resources under the impact of ‘AO’ appear quantitative and qualitative indicators of the environmental state (ES) of ‘NM’ as a determining factor of environmental safety in areas impacted by ‘AO’.

3. Results & discussions

Basin geosystems, including NTS ‘NM-AO-P’ as a natural element of the biosphere, from the system view share the same abilities for transformation of in-coming substances, energy, information (SEI) from the environment of higher hierarchic level systems and so being their discharge and source, i.e. some kind of system mechanism controlled from the outside [1].

System mechanism functioning in space limits of basin geosystems as well as in areas of impact of existing NTS ‘NM-AO-P’ ensures simultaneous changes and keeping of in-coming flows SEI through maintaining the directions of changes within the considerable space of these flows.

Consequently, one can stress that system mechanism works under the principle ‘everything changes and stays unchanged’, which concentrates all infinity and power of the space-time appearing as the multi-edged flow. For NTS ‘NM-AO-P’ multi-dimension flows of substance in form of surface and underground discharge, dissolved and not dissolved substances, minerals e.t.c., flows of energy, coming from the Sun, consumed organic fuel (oil, gas, coal) which transform under the impact of natural processes and functioning of ‘AO’ [8].

System mechanism, controlled form the outside, secures the evolutive development of natural processes in basin geosystem regarding life activity of biotic components and local population, abiotic components including ‘AO’ through developing the 3I-processes (interconnection, interaction and interrelation) between components, safekeeping the integrity of considerable basin geosystem and
Functioning NTS ‘NM-AO-P’. Functioning of this system mechanism is maintained by space-time movement of SEI-flows which get consumed and yet produce active and passive flows including flows of free energy (E.), related energy (E.), determining accordingly the proactive power (P) and power of loss (G), defining the fundamental law of power conservation:

\[ N_{\text{max}} = P + G \left[ L^3 T^{-3} \right] \]  

Management of system mechanism in SLBG in natural objectives 3I natural (biotic, abiotic) components between each other is conducted according to the existing principle of maintaining of development ensuring irreversible, regular and directed transformation which causes new qualitative state with certain level of entropy. Time (t) appears to be an important indicator in processes of development, determining the direction of the Development.

Long-term researches of existing and newly constructed NTS ‘NM-AO-P’ in SLBG of Kuban (SLBG-size W_{bg.k}=580 000 km³, water-taking square of river hydrographic network F_{w.hx}=58 000 km²), Terek (W_{bg.t}=430 000 km³, F_{w.hx}=43 000 km²), Lower Don (W_{bg.d}=1 100 000 km³, F_{w.hx}=101 000 km²) rivers, where about 23 million people (16.3% of the RF population) live and about 10 000 ‘AO’ function, including different types of hydrotechnical constructions, causing certain changes of natural processes between natural components forming ‘NM’ and local ‘P’ of areas impacted by ‘AO’. These changes of movement of SEI-flows form new environmental state in areas impacted by ‘AO’ which in the causative connection represents environmental safety as an important factor of life activity of living matter and local ‘P’. Limits of impact areas of ‘AO’ in ‘NS’ of basin geosystem are determined by an integrate research on the stage of drafting of exploitation of ‘AO’ as a part of NTS ‘NM-AO-P’ [2]. Consequently, it can be stressed that, basing on the definition of protection determining the state of object of protection (OP) under the impact of SEI-flows coming from the source of environmental danger – ‘AO’.

Character of movement of SEI-flows in space-time of ‘AO’ impact areas is determined by in-system 3I-processes of natural and technogenic components between each other as the parts of NTS ‘NM-AO-P’ as well as the by the processes of substance-energetic exchange with the environment, limited by the considerable basin geosystem of higher hierarchic level.

In generalized meaning environmental state in areas impacted by ‘AO’ is determined by a combination of conditions and factors of abiotic and biotic nature, forming under the influence of ‘AO’. As stated by the researches, these conditions and factors are characterized by quantitative of environmental indicators letting evaluate the environmental state as an important factor of environmental safety in areas of ‘AO’ impact.

Environmental indicators in ‘AO’ impact areas include locations of concentrated environment-polluting ingredients – intensiveness of temperature, wet, sound, gravitation factors; gas and dust pollution; increasing populations of animals; changes of flora; growth/death-rate of particular population. In causative connection of forming environmental state in ‘AO’ impact areas, environmental safety becomes dependent on environmental state, which is classified into four types (table 2.):

Basing on the results of complex analysis [3] of long-term research (2005-2017) of waterworks of basin geosystems of Kuban, Lower Don and Terek rivers, the conceptual reasoning for the definition of environmental safety in areas of ‘AO’ impact as a part of NTS ‘NM-AO-P’:

1. Environmental safety in areas of ‘AO’ impact has a system interconnection with life processes of ‘P’ and ‘NM’;
2. Environmental safety in areas of biota and ‘P’ life activity are inherently connected with the energy consumption, determining the production, storage and transformation of all forms of energy;
3. Danger of breaching the environmental safety appears as a result of uncontrollable discharge of energy or substance, collected in ‘AO’ into the environment – for example, in case of destruction of pressure front of water-collecting hydrological unit;
4. Breaching of environmental safety in ‘AO’ impact areas in SLGB is caused by prerequisites determined by drafting, constructing and functioning, what results the discharge of energy and substance from 'AO';
5. Initiators and links of causative connection of environmental safety and ‘AO’ can become ‘AO’ that does not correspond to the ecological demands.

Table 2. Classification of environmental state by level of its trouble under the impact of ‘AO’

| № | Relatively satisfactory | The concentration index of harmful substances does not exceed the MPC, MPL, MPE |
|---|------------------------|---------------------------------------------------------------------------|
| 1 | Tense                  | The concentration index of harmful substances within 10 indices of MPC, MPL, MPE |
| 2 | Critical               | The concentration index of harmful substances is 20-30 MPC, MPL, MPE         |
| 3 | Crisis-emergency situation | The concentration index of harmful substances exceeds the MPC, MPL, MPE 50 times or more. Persistent negative changes in the environment, the extinction of certain types of plants, animals, and the threat to human health. |
| 4 | Catastrophic (ecological disaster) | Irreversible changes in the natural environment. Disruption of the natural balance, degradation of flora and fauna, loss of the gene pool, a significant deterioration in human health. |

Methodology of evaluation of level of environmental safety in ‘AO’ impact areas is based of the evaluation of changes brought into the natural processes of transformation of SEI-flows in space and time by ‘AO’ or environment which affect the generation of environmental state of ‘NM’ and, accordingly, environmental safety, what justifies the necessity of special conducting of system complex environmental monitoring (SCEM), including combination of modern methods and ways of obtaining timely and reliable information about environmental state and tendency of ongoing transformations of ‘NM’ under the impact of ‘AO’.

Basing on modern nature-protecting demands, environmental safety created by SCEM, should meet following requirements: obtaining the reliable information about environmental state in ‘NM’ impacted by ‘AO’; conducting the monitoring observations in selected locations of hydrographical river network with help of both general indicators in ‘NM’ and special indicators during the period of conducting construction or repair works – noise, pollution of air by working mechanisms, dust etc.; SCEM for currently working and constructed ‘AO’ should be created under the unified methodological and metrological principles.

Created SCEM for ‘AO’ functioning as a part of NTS ‘NM-AO-P’ in order to provide the environmental safety in areas of its impact, as the results of monitoring research of river basins of Kuban and Lower Don rivers shows, environmental safety in certain degree depends on technical state of hydrotechnical system which is determined by relevant types of safety – hydrological, constructive, hydraulic, filtration, exploitation. Timely and reliable information on technical state of ‘AO’ requires implementation of modern automatized information system with using of open system technology (GOST 28906).

4. Summary

1. Basing on the results of the research, the definition of environmental safety of waterworks is determined by the state of considerable objects of protection under the ‘AO’ impact on life activity of ‘NM’ and ‘P’;
2. Basing on the results of the complex analysis of the results of monitoring research of the 3I-processes of ‘AO’ as a part of NTS ‘NM-AO-P’ limited by considerable basin geosystems, conceptual definition of environmental safety in areas of ‘AO’ impact formulated;
3. For the evaluation of environmental state in areas of ‘AO’ impact as a dominating factor in maintaining the environmental safety, a classification scheme SCEM was developed, including modern methods and ways of obtaining timely and reliable information about direction of tendency of ongoing changes in ‘NM’ under the ‘AO’ impact.

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