Water deficits in the water economics complex of Crimea

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Abstract. In recent years, the natural and economic situation in the Republic of Crimea has developed in such a way that the amount of available water resources is less than the amount of water necessary for the socio-economic development of the peninsula. This article considers one of the main water management hazards for the territory of Crimea: a lack of water. The aim of this study was to assess the water deficit and determine ways to minimize the impact of risk exposures on the population, the economy and the ecosystem as a whole. Options are provided to ensure that (1) the water economic complex supplies water to consumers in sufficient quantity and quality, and (2) the ecological status of water bodies is maintained at a high level. For example, local wastewater treatment and desalination of sea water can be used in agro-industry and the water economic complex both for individual agricultural producers and for large enterprises. The economic efficiency of the use of technologies to reduce the environmental threats of the water economic complex was assessed using technologies to increase water availability. The analysis of the quality of water resources is given, and options for improving the indicators of raw water-pipe water are proposed.

Keywords: water economic complex, water quality, deficits, wastewater treatment, water desalination, drinking water

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1. Introduction

Risk assessment involves the determination of the qualitative and quantitative values of the risk associated with a particular situation (Shalikovsky 2011). The probability of occurrence and manifestation of the risk caused by the negative impact of water tend to increase, resulting in an increase in the anthropogenic load on ecosystems.

The problems of water economic complex research were worked out in different studies by many scientists (Gillham et al. 1976; Tarasenko 2003; Ohman et al. 2007; Kharitonov 2010; Alekseevsky, Frolova 2011; Terleev et al. 2015, 2016d; Huang et al. 2016; Lesnykh et al. 2016), and the questions of sea water desalination (Huang et al. 2005; Mosin, Ignatov 2012) and wastewater treatment (Razzak et al. 2017; Soltermann et al. 2017; Wang et al. 2017) are widely developed in the scientific literature.

According to their origins, the risks associated with the appearance of water deficit are divided into the following:

- natural-climatic risks, caused by the manifestation of natural forces and the influence of fluctuations in weather conditions on the operation of water management systems; and
- technogenic risks, caused by human economic activity and associated with hazards arising from technical facilities.

Changes in the volume of river flow and the levels of groundwater lead to risks for the population and economic objects. The indicator of sustainable development of the territory is the health of the population and the quality of the environment. Determining ways to reduce risk levels and implementing measures to eliminate them leads to an increase in the socio-economic and environmental sustainability of the territories.

The aim of this work is to assess the deficit of the water economic complex (*WEC*) of the Republic of Crimea and to determine ways to minimize the impact of risk exposures on the population, the economy and the ecosystem as a whole. The Crimean *WEC* is vital to the population and the entire social, economic, industrial, and recreational infrastructure. It is a complex aggregate of natural water resources that includes surface water (rivers, lakes, reservoirs and ponds, filled with natural runoff), groundwater, and hydraulic structures. The main consumers of water are housing (utilities and electricity, representing 79% of the total fresh water consumed), agriculture (only 5%), and industry (6%). This distribution is due to the stoppage of the external water supply (North Crimean Canal) to the peninsula, which previously provided more than 80% of the necessary water, as well as the lack of available natural water resources (*On the state and protection of the environment in the Republic of Crimea in 2016*). These causes determine the risks for the *WEC*, which are shortages of water resources, exacerbated by imperfect and deteriorating water consumption and transportation systems (water loss during transportation is on average more than 35%, including losses at water supply enterprises). In addition, the lack of water affects the supply of food to residents because of the difficulty of growing the required amount of agricultural products. To meet the water needs of the population of the peninsula, local surface and groundwater resources are used. Because of the insufficiency of these resources (Falkenmark index for the Crimea is less than 500 m^3 per person) (Falkenmark et al. 1989; Popovych, Dunaieva 2015; Terleev et al. 2016c)), their use can lead to resource depletion and deterioration of their characteristics. Thus, the excessive extraction of groundwater in Crimea (the volume of groundwater abstraction increased in 2017 by 25% over the previous year; report *On the state and protection of the environment in the Republic of Crimea in 2016*) led to the intrusion of saline sea water. To restore the natural balance, the wells were tamped. Due to these conditions, the *WEC* requires reorientation to the current level of water availability and conversion to the effective use of existing water resources.

2. Materials and methods

The methodology of the risk assessment was developed in the Water Cycle Safety Plans and Prepared Adaptation Initiatives Matrix[1].

In this research qualitative and quantitative methods of analysis were used (Dunaieva et al. 2011). Qualitative methods were used to assess possible hazards and record their precise description. The water quality parameters pH, conductivity (*EC*), total dissolved solids (*TDS*), and temperature were analyzed using a Hanna Combo pH/Conductivity/TDS Tester[2], and laboratory methods were used to determine chemical compounds.

The quantitative approach is based on an analysis of economic efficiency. The statistical and economic methods for obtaining statistical materials, conducting economic comparisons, grouping data, and graphically representing economic indicators were used. The calculation of economic efficiency was used to determine the effectiveness of using water treatment and desalination plants to obtain additional volumes of water for various economic sectors of the Republic of Crimea. At the same time, the cost parameters of the saved energy and water were calculated, as well as the total cost of the installations. In the calculations, materials from the State Committee on Prices and Tariffs of the Republic of Crimea were used (*On the establishment of tariffs for drinking water, technical water and wastewater disposal to the State Unitary Enterprise of the Crimea "Water of the Crimea" for 2017*). In addition, the tap water was assessed (the analysis of tap water in Simferopol) before and after the application of the Aquaphor household filter. The need to use household filters has arisen because of the deterioration of drinking water quality after treatment facilities due to the old water transportation systems. The total hardness of fresh water (H_{tot}) was determined by the formula (Fomichev et al. 2010):

$$H_{tot} = \frac{[Ca^{2+}]}{20.04} + \frac{[Mg^{2+}]}{12.16} \tag{1}$$

where 20.04 and 12.16 are the equivalent masses of calcium and magnesium, respectively.

3. Results and discussions

Currently, one of the main problems with the development of the *WEC* of the Republic of Crimea is the lack of water resources, especially for drinking water supply

[1] http://aim.prepared-fp7.eu/home?mid=1
[2] HANNA Instruments Deutschland GmbH company, https://hannainst.com/

in the northern and eastern regions and for irrigated agriculture. Ways to overcome the problems of water scarcity include the following: (1) improving the economic efficiency of water resources used in the economic sphere, (2) reducing the damage to aquatic and terrestrial ecosystems in the ecological sphere, and (3) engineering and technological works related to the modernization of hydraulic structures and the prevention and elimination of pollution in the natural environment. Important directions for the Republic of Crimea are the use of seawater desalination, water purification and post-treatment of wastewater. For example, in 2015 the volume of wastewater in surface water bodies amounted to 131.3 million m^3 (*On the state and protection of the environment on the territory of the Republic of Crimea in 2016*), which corresponds to 69.3 m^3 per person in Crimea.

3.1. Wastewater treatment

Regarding the usage of sewage for irrigation purposes, in accordance with the legislation of the Russian Federation, the use of this technology is impossible without the designation of special areas: the agricultural irrigation fields (Terleev et al. 2016b). In addition, a list of cultivated crops and plantations that are allowed to irrigate with such water is necessary. It is permissible to irrigate grassland, perennial grasses, garden grass, etc., where the product of cultivation does not have direct contact with water. In the case of vegetables and fruits, watering with sewage water is not allowed because of the risk of gastrointestinal diseases and poisoning.

In accordance with the requirements for use of sewage for irrigation and fertilization (Terleev et al. 2016a), household, industrial and mixed wastewaters from cities, towns, farms, and agricultural processing enterprises can be used for these purposes.

The quality of wastewater and its sediments, used for irrigation, is regulated by chemical and sanitary-bacteriological indicators. If the concentration of microelements, including heavy metals, in water does not exceed the Maximum Permissible Concentration (*MPC*) for household and drinking water use, this water can be used for irrigation purposes without restrictions. Subsoil and intrasoil irrigation are the most appropriate irrigation methods for wastewater in terms of compliance with hygiene regulations (Terleev et al. 2017b).

At present, a peculiarity of Crimea's agricultural development is the presence of a large number of small agricultural enterprises and farms, for which the availability of local treatment facilities is beneficial both from the point of view of irrigation of agricultural crops and the use of treated sewage for household needs. It is also advisable to use local treatment facilities with high productivity for large enterprises for agricultural production and processing. There are three types of ultraviolet disinfection facilities in the local market that can be used for irrigation purposes: horizontal type, vertical type, and container type.

Table 1. Calculation of the efficiency of wastewater treatment by saving water and electricity in the Republic of Crimea*

	Input data			
Daily discharge of sewage	[m^3/day]	0.7	20	72
Average cost of water supply in the Republic of Crimea	[rubles/m^3]	36.2	36.2	36.2
Average cost of water disposal in the Republic of Crimea	[rubles/$m^{3]}$	35.6	35.6	35.6
Cost of electric power	[rubles/kW]	5	5	5
	Calculation results			
Payment for water disposal	[rubles/day]	25	712	2 563.2
Number of persons	[pers.]	4	100	360
Consumption of electrical energy by installation per day	[kW/day]	0.4	12	43.2
Cost of installation of electrical energy	[rubles/day]	2	60	216
Savings per month				
due to absence of water disposal	[rubles]	690	19 560	70 416
due to use of purified water	[rubles]	760.2	21 720	78 192
Savings per year:				
due to absence of water disposal	[rubles]	8 395	237 980	856 728
due to use of purified water	[rubles]	9 122.4	260 640	938 304
Total savings per year	[rubles]	17 517.4	498 620	1 795 032
Cost of installation	[rubles]	62 900	689 500	no data
Payback	[year]	3.5	1.4	0

* Calculations were made under the condition of wastewater discharge throughout the year

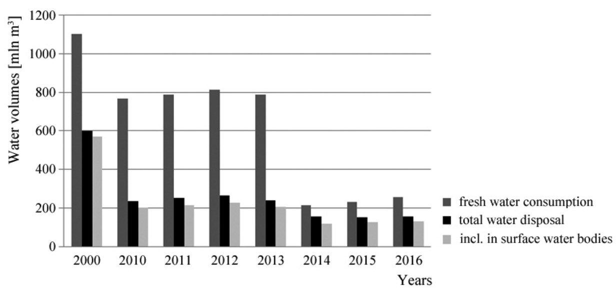

Fig. 1. Volumes of consumption and water disposal in the whole of Crimea

Table 1 includes an example calculation of the economic efficiency of the operation of such treatment plants with different levels of daily discharge of sewage; these plants are produced directly in Crimea and can be used for both individual housing estates and large enterprises (Lihach et al. 2017). The efficiency of such plants is achieved because of the additional volume of water, obtained after treatment (otherwise, this volume must be payed for) and the cost savings due to the absence of water disposal.

Table 1 provides data for small volumes of wastewater. In general, a large amount of sewage is discharged annually in Crimea. In the last two years, the sharp decrease in water volumes was associated with the cessation of water supply through the North-Crimean Canal (Fig. 1, Tab. 2) (*On the state and protection of the environment on the territory of the Republic of Crimea in 2016*).

The purification and further use of disposal water, especially in the least secure water sectors (i.e., agriculture and industry), is the main direction needed to solve the water problem in Crimea (Gonopolskii et al. 2008).

3.2. Desalination of sea water

The second direction for solving the problem of water supply in the Republic of Crimea is desalination of sea water. The high salt concentration in sea water (mainly NaCl) up to 35 g/l makes it unsuitable for drinking and household purposes. Data on the content of other chemicals in sea water are given in Table 3 (Ginocchio et al. 2017).

There are several ways to desalinate sea water that are used in world practice, such as:

- thermal desalination or distillation;
- desalination by freezing (crystallohydrate);
- electrochemical desalination (electrodialysis);
- desalination by reverse osmosis, or by hyperfiltration;
- chemical desalination.

Desalination of water is more expensive than most other methods of obtaining fresh water. The cheapest desalination method is the reverse osmosis method, which is supposed to be used for seawater desalination in Crimea. The first desalination plant in Crimea was opened on September 10, 2013 in the village NovySvet for a hotel complex, which used imported water at a price of $10 per cubic meter. The capacity of the plant with two modules is 1 m^3 of water per hour for each module. To obtain 1 m^3 of fresh water, 5 m^3 of water should be taken from the sea, 4 m^3 of which is discharged back into the sea.

The needed electric power is approximately 6.5 kW. For the hotel, the acquisition of this desalination plant cost 78 thousand dollars (on average, the cost of a desalination plant is 50 thousand dollars).

The effect of desalinated water on public health and its possible risks are under investigation by physicians and scientists worldwide (Török et al. 2000; Wetstein 2000; Somlyai 2002). However, most of the works are devoted to the effect of heavy hydrogen on the body. Detailed studies of the connection between the use of desalinated water and the onset or development of cancer were not conducted.

The ecological risk from desalination lies in the fact that the removal of salt from sea water leads to the formation of concentrated sludge, so-called brine, which is two times heavier than salty sea water and contains impurities that can affect marine life when discharged back into the sea. In the case of removal of the brine on land, it can seep through the soil, penetrating into the groundwater. In addition, desalination plants produce a huge amount of carbon dioxide emissions because they utilize fossil fuels.

According to the results of Degtyareva et al. (2016), Nikonorov et al. (2016, 2017), Badenko et al. (2016) and Skvortsova et al. (2016), a transition to new technologies, technical modernization, land reclamation in arid zones, and the adoption of additional support measures in

Table 2. Dynamics of consumption of fresh water (including freshened) and water disposal per inhabitant of the Republic of Crimea

Parameters	Year							
	2000	2010	2011	2012	2013	2014	2015	2016
	[m^3]							
Consumption of fresh water for one person	537.1	394.1	405.2	416.8	403.1	114.7	122.8	135.8
Volume of water disposal for one person	293.1	122.7	129.9	136.6	124.6	84.6	81.3	82.5
Including: volume, disposed in surface water bodies for one person	278.1	104.9	111.0	116.7	106.3	63.8	69.3	70.5

Table 3. Chemicals contained in sea water in concentrations above 0.001 g/kg (1 ppm) by weight

Chemicals	Content [g/kg sea water]	Concentration [mol/l sea water]
Chlorides Cl^-	19.35	0.55
Sodium Na^+	10.76	0.47
Sulfates SO_4^{2-}	2.71	0.028
Magnesium Mg^{2+}	1.29	0.054
Calcium Ca^{2+}	0.412	0.010
Potassium K^+	0.40	0.010
Carbon dioxide CO_2	0.106	$2.3 \cdot 10^{-3}$
Bromides Br^-	0.067	$8.3 \cdot 10^{-4}$
Boric acid H_3BO_3	0.027	$4.3 \cdot 10^{-4}$
Strontium Sr^{2+}	0.0079	$9.1 \cdot 10^{-5}$
Fluorides F^-	0.001	$7 \cdot 10^{-5}$

unfavorable climatic conditions are necessary in order to reduce natural and climatic risks (Arefiev et al. 2015a, b, c; Makarov et al. 2015; Terleev et al. 2016a; Nikonorov et al. 2017; Nikonova et al. 2017; Orlova et al. 2017; Pavlov et al. 2017; Terleev et al. 2017a, c).

3.3. Quality of drinking water

One of the important factors determining the well-being of society is access to clean drinking water. The lack of natural water resources in the Republic of Crimea requires the search for alternative sources of water to meet the needs of the population. However, the search should take into account the quality of raw water and the possibility of its use for drinking needs.

According to the Sanitary rules and norms (S-R-N 2002), the term "high quality drinking water" means:

- water with the corresponding organoleptic indicators: transparent, odorless and with a pleasant taste;
- water with pH of 7-7.5 and hardness not higher than 7 mmol/l;
- water in which the total amount of useful minerals is not more than 1 g/l;
- water in which the concentrations of detrimental chemical impurities are either 0.1% or less of their MPCs or not detected (that is, their concentrations are so small that they are beyond the capabilities of modern analytical methods);
- water in which there are practically no pathogenic bacteria or viruses.

The quality of surface water, the state of water bodies, and the direction of the processes occurring in them, as well as the quality of tap water for consumers, are water risks that need to be minimized (Lyashevsky, Dzhaparova 2015).

To assess the quality of tap water (after passing through the old water pipes), the analysis of tap water in Simferopol was carried out before and after the application of the Aquaphor household filter. The results are shown in Table 4.

The results showed that the tap water hardness is higher than the permissible level (7 mmol/l), and the pH of tap water is higher than the S-R-N value. To minimize the risk to health, the use of household jar filters is recommended, which is the simplest and most available water treatment facility. As can be seen from Table 4 and from the calculations, the hardness of water decreases severalfold, and the amounts of magnesium and calcium ions, which are necessary minerals, remain in the filtered water and after post-cleaning. The disadvantages of this method include a low rate of filtration and the need for periodic replacement of the filter cartridge.

Note that the quality of tap water in Simferopol has deteriorated in index of hardness (by 1.5 times) and pH (by 1.2 times) compared with 2006, which indicates deterioration of water quality and an unsatisfactory condition of the water economic infrastructure.

According to the manufacturer's documentation, a standard domestic quality level is given for filtration of approximately 300 liters of water. However, the obtained data showed that the effectiveness of this type of equipment begins to decline after passing the 50-liter line. After more than 90 liters, the quality of the filtration is halved. That is why a cassette with an active component is recommended to be changed at least once every 1.5 to 2 months. Note that the cost of a single cartridge when

Table 4. Results of the analysis of tap water

	Electrical conductivity [mmS]	pH	HCO_3^-	Cl^-	Ca^{+2}	Mg^+	K^+	Na^+
			[mg/l]					
Tap water	0.45	8.4	244	19	136	30	1.5	8
Filtrate water	0.24	6.35	61	28	42	20	2	6.5
MPC according to (cost-benefit analysis Sanitary rules and norms (S-R-N 2002)	-	7-7.5	1 000	350	200	100	-	200

According to formula (1)

H_{tot} for tap water is (136/20.04) + (30/12.16) = 9.25 mmol/l

H_{tot} for filtrate is (42/20.04) + (20/12.16) = 3.73 mmol/l

Table 5. Calculation of the payback period of domestic cartridges in jar filters

April	1	2	3	4	5	6	7	8	9	10
Amount of drinking water per day [l]	2.5	0.0	1.0	2.0	3.0	4.0	3.5	2.5	1.0	1.0
Cost of a cartridge	Average cost of domestic cartridge: 275 Rub.									
Average cost of bottled water (1 l:15 Rub.)	38	0	15	30	45	60	52	38		
	278 Rub. (achieving the payback of cartridge)									

recalculating the cost of bottled water pays off in one week (see Table 5).

In addition to the "Aquafor" filter (Russia-USA), the products of other manufacturers are found in the retail network: "Brita" (Germany), "Kenwood" (Great Britain), and "Barrier" (Russia). Their main difference is in the types of absorbent used. "Aquaphor" filters through a patented aqualene, and "Barrier" filters through activated carbon. Jug-filter "Brita" is equipped with a cassette with ion-exchange resin, which enriches water with useful hydrogen ions. "Kenwood" uses a combination of food grade resin, activated carbon, and a grid that retards mechanical impurities.

4. Conclusion

The use of new types of equipment and methods for obtaining fresh water can minimize environmental risks in the water sector. Partial use of sewage after treatment contributes to a significant reduction in the risks of the water economic complex in the water supply and agricultural irrigation sectors by obtaining additional water resources for agricultural production. The use of desalinated seawater in the water-deficit regions of Crimea will significantly reduce the deficit of drinking water, especially in settlements using delivered water.

Calculations showed that wastewater treatment and desalination installations, despite the relatively high cost (for example, desalination: 0.6-1.5 dollars per m^3), can sufficiently provide consumers with drinking water and water for irrigation of crops, for which watering is possible according to sanitary requirements. The use of additional methods for cleaning potable water (filters for additional purification of drinking water) makes it possible to eliminate the risks associated with the deterioration of water quality (in comparison with 2006, the quality of tap water in Simferopol deteriorated by a factor of 1.5 in index of hardness and a factor of 1.2 in pH.

To minimize the impact of hazard exposures on the population and sectors of the peninsula's economy, it is necessary to develop mechanisms for regulating the structure of land use of territories, improve the monitoring system, and develop forecasting methods and implement them to prevent the occurrence of water deficits and their impact on humans and the ecosystem as a whole.

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