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DEVELOPMENT OF MEASURES TO INCREASE THE ECOLOGICAL SAFETY OF DRINKING WATER SUPPLY FOR POPULATION OF EASTERN UKRAINE DUE TO THE USE OF BUCHAK-KANIV AQUIFER GROUNDWATER

(представлено членом редакційної колегії д-ром геол. наук, проф. О. М. Карпенком)

In the article, measures to increase the ecological safety of population drinking water supply due to the use of Buchak-Kaniv aquifer groundwater from urban water intakes in Eastern Ukraine have been developed.

The ecological consequences of man-made intervention in Buchak-Kaniv aquifer drinking groundwater at the research territory have been assessed. The main pollutant elements of these groundwater have been traced. Water intakes (Poltava, Karlivka, Krasnograd, Lubny, Khorol, Reshetylivka), where the ecological consequences of technogenic intervention in the underground hydrosphere are the greatest, since here the target groundwater is partially or completely unsuitable for drinking purposes, have been identified. The key role of technogenesis (intensification of groundwater withdrawal and expansion of water intakes network; as a result – changes in the hydrodynamic conditions of operational aquifers and formation of their regional depression funnels) in these processes has been established. It is emphasized that the increased content of investigated pollutant elements in systematically consumed drinking water has a colossal effect on the human body, which can be expressed in a number of serious diseases.

In the paper, measures have been developed to minimize the established ecological consequences of technogenesis of Buchak-Kaniv aquifer drinking groundwater to increase the ecological safety of population drinking water supply from the Poltava city agglomeration water intakes, which are strategically important for the studied region. The system of groundwater hydrogeochemical monitoring at the region water intakes has been improved for the conditions of filtration of pollutants from the surface or their migration from below in the zones affected by tectonic faults associated with salt diapirs. This significantly shortens the time and reduces the cost of works in comparison with a full complex of hydrogeochemical studies within the entire territory. The allocation of promising areas for the construction of new water intakes to solve the problem of drinking groundwater lack of acceptable quality within the research territory has been substantiated. Estimated resources of high-quality drinking groundwater in a radius of 40 km around the Poltava city, the involvement of which will allow providing high-quality drinking water to the population of this urban agglomeration. The optimal general water withdrawal at the Poltava water intakes to stabilize the content of polluting elements in the composition of Buchak-Kaniv aquifer groundwater within different parts of the city has been justified.

Keywords: groundwater, pollution, environmental safety, water intakes, measures.

Statement of the problem. Creating conditions for reliable safety of people's lives and activities in terms of providing the population with high-quality drinking water is one of priority environmental problems for Ukraine. It is especially acute in the eastern regions of the country, where under the complex influence of significant man-made pressure on the geological environment (GE) and natural factors, significant quality and resource changes of surface and drinking groundwater are observed.

Currently, almost 80% of the country's drinking water supply is provided by the use of surface water. At the same time, according to the degree of pollution, most water objects are classified as polluted and highly polluted, and the technogenic pressure on them is only increasing.

Therefore, in order to increase the ecological safety of population drinking water supply, it is very important to switch to a wider use of groundwater, as the only current source of naturally high-quality drinking water.

One of the main sources of drinking water supply for settlements in Eastern Ukraine is the waters of Buchak-Kaniv aquifer (BKA), which historically have been noted for their high drinking quality and stable chemical composition. However, BKA is locally vulnerable to both man-made and natural pollution. Against the background of modern technogenesis and natural processes, the chemical composition of these groundwaters has recently undergone significant changes. Currently, these waters are partially or completely unsuitable for drinking purposes at about 20 powerful urban water intakes in the region.

The above-mentioned features determine the need to conduct a complex of geoecological studies aimed at finding and developing optimal forms of managing the ecological safety of drinking water supply in the studied region in modern geological and technogenic conditions.

Analysis of previous studies and publications. The papers of such outstanding scientists as A. L. Bryks (1983, 2013), E. S. Dzektser (1993), M. S. Ohnianyk (1985, 2013), N. K. Paramonov (2013), I. V. Udalov (2012, 2015, 2018), O. A. Ulytskyi (1998), E. O. Yakovlev (1994, 1998, 2001), O. N. Yartseva (1974), N. Dalla Libera (2017), A. Molinari (2019), E. Preziosi (2014) were directed to the development of methodology for studying the geological environment and, in particular, ecological-hydrogeological studies of drinking groundwater under the influence of active technogenesis *(Aziz et al., 2015; Dalla Libera et al., 2017; Kononenko et al., 2018; Molinari et al., 2019; Ohnianyk, 1985; Preziosi et al., 2014; Yakovlev et al., 1994; Yakovlev et al., 2001).* The main principles of their research are basic for modern developments in this direction.

Problems related to the development of measures to improve the ecological safety of drinking water supply and stabilize the quality of groundwater at existing and prospective water intakes in various regions of the world were dealt with F. M. Bochever (1972, 1979), N. N. Verygyn (1979), V. M. Goldberg (1976, 1984, 1987), S. R. Krainov (1973, 1991), N. N. Lapshin (1979), M. S. Ohnianyk (1985), A. E. Oradovska (1979, 1987), M. I. Plotnikov (1983, 1989), V. S. Sarkisian (1975), I. V. Udalov (2014, 2017, 2018), V. M. Shestakov (1973), V. V. Yakovlev (2008, 2016, 2018), M. Abtahi (2015), Y. Chen (2018), S. Nurani Zulkifli (2018), J. Szabo (2014), Y. Weiwu (2016) and some others.

These studies consider the methods of groundwater hydrogeochemical monitoring; methodology for assessing the quality of groundwaters in the conditions of their longterm exploitation is highlighted; measures of minimizing the ecological consequences of man-made intervention in the underground hydrosphere are developed.

In the papers of O. O. Serdiukova, V. I. Smoliar, G. I. Petrashenko, E. A. Nazarenko, Yu. B. Nikoziat, O. D. Ivashchenko, O. I. Popov, L. V. Podrigalo, G. N. Danylenko, N. G. Semko and others *(Levoniuk, 2019; Nazarenko et al., 2015; Popov et al., 2000; Serdiukova, 2013; Smoliar et al., 2007)* an assessment of ecological consequences of man-made intervention in the underground hydrosphere within the studied territory was carried out. Some aspects of impact of drinking groundwater polluting elements on the formation of centers of population non-infectious diseases within this region were investigated.

The purpose of article is the development of measures to increase the ecological safety of population drinking water supply within Eastern Ukraine due to the use of Buchak-Kaniv aquifer groundwaters.

In order to achieve this purpose, the **following tasks** were supposed to be solved:

- to assess the ecological consequences of man-made intervention in the BKA drinking groundwater;
- to develop measures for minimizing these environmental consequences.

Research results and their discussion. The authors investigated the general ecological condition of BKA groundwater at large water intakes of Eastern Ukraine during the period of GE active technogenesis (1960–2020). In the process of studies, the main groundwater pollutant elements, which have systematically increased over standards *(DSanPiN 2.2.4-171-10, 2010)* values at the investigated water intakes, were traced. They are organized into 2 groups:

- elements-pollutants of surface genesis (NH_4^+, NO_2^-), which are not characterized by a wide distribution (detected only at 3 large water intakes, such as Poltava, Khorol, Krasnograd);
- elements-pollutants of deep genesis (Cl^-, Na^++K^+, F^-, Fe_{total}, Br^-, B^{3+}, J^-, as a result – increased water mineralization). It was established that these pollutants are the predominant factor in the deterioration of target groundwater quality, as they were detected in most of the large water intakes within studied region (including Poltava, Karlivka, Kotelva, Dykanka, Opishnya, Zinkiv, Gadyach, Pyryatyn, Chornukhy, Shyshaky, Lohvytsia, Myrhorod, Khorol, Lubny, Velyka Bagachka, Reshetylivka, Chutove, Krasnograd, Bogoduhiv and some other less powerful).

The following pollutant elements are most prevalent at the above-mentioned water intakes: Cl^-, F^-, Fe_{total}, Br^-, B^{3+}, J^-. On the basis of this, the authors classified them as elements-indicators of quality composition transformation of BKA waters. It was determined that these components are characterized by a gradual increase in their content in the process of active exploitation of region's powerful water intakes. Also, authors in previous papers *(Levoniuk et al., 2018; Udalov et al., 2019)* established the key role of technogenesis (intensification of groundwater withdrawal and expansion of water intakes network; as a result, changes in the hydrodynamic conditions of operational aquifers and the formation of their regional depression funnels) in these processes. At the same time, "thanking" to the man-made factor, as well as the tectonic and geological conditions of this territory, deep hydrogeomigration processes were activated (upward migration of substandard waters through tectonic faults associated with salt diapirs to the waters of active water exchange zone).

According to the papers *(Levoniuk, 2019; Nazarenko et al., 2015; Popov et al., 2000; Serdiukova, 2013; Smoliar et al., 2007)*, the increased content of Cl^-, F^-, Fe_{total}, Br^-, B^{3+}, J^- in drinking water has a colossal effect on the human body. This can be expressed in a number of serious diseases of population that systematically consumes this water (Table 1).

Table 1

The influence of increased content of studied hydrogeochemical indicators on the human body (compiled by the author on the basis of *(Levoniuk, 2019; Nazarenko et al., 2015; Popov et al., 2000; Serdiukova, 2013; Smoliar et al., 2007)*, etc.)

Indicator name	Impact on the human body – possible diseases
Mineralization	Negative impact on pregnancy, fetus and newborns. Increases the likelihood of gynecological diseases. Negative influence on the secretory activity of digestive system, disrupts the water-salt balance, contributes to the development of diseases of circulatory system (ischemic heart disease, hypertension)
Cl^-	Negative influence on the functions of digestive system. It causes inflammation of mucous membranes, irritation of the skin and respiratory organs, has carcinogenic and mutagenic properties and increases the risk of some abnormalities of intrauterine development. Causes itching, irritation, a feeling of tightness and dryness of the skin, irritation of mucous membrane of eyes and respiratory tract, negative effect on the hair structure
F^-	Causes dental diseases – endemic fluorosis, tooth enamel hypoplasia, caries. Negative effect on the permeability of cell membranes. It reduces the exchange of phosphorus and calcium in bone tissues, disrupts carbohydrate, protein and other metabolic processes, inhibits tissue respiration, etc. It is a neurotropic poison that reduces the mobility of nervous processes
Fe_{total}	Gradual destruction of the liver, toxicosis, decrease in hematopoiesis. It is part of respiratory pigments, participates in the transfer of oxygen to tissues in the body of humans, stimulates the function of hematopoietic organs
Br^-	Negative influence on the permeability of cell membranes, reaction with the 8 group of cysteine and methionine. Causes: dry cough, conjunctivitis, runny nose, skin rash, diarrhea, chronic intoxication, nausea, slurred speech
B^{3+}	A chronic digestive problem – boron enteritis, intoxication will affect the kidneys, liver and nervous system. The body becomes dehydrated, severe symptoms appear: vomiting, diarrhea, scaly skin rash, anemia, confusion, lack of appetite, cachexia – sudden weight loss, disappearance of subcutaneous fat, atrophy of organs and muscles, hair loss and skin laxity
J^-	Negative influence on the permeability of cell membranes, reaction with the 8 group of cysteine and methionine. In the human body, it regulates: the speed of biochemical reactions; exchange of energy and body temperature; protein, fat, water-electrolyte metabolism; metabolism of some vitamins; differentiation of tissues, processes of growth and development of organism, in particular neuropsychological; induction of increased tissue oxygen consumption

During the researches, about 20 networks of powerful urban water intakes in the region were found, on which elevated values of above-mentioned indicator elements were traced. The most characteristic are water intakes of Poltava, Karlivka, Krasnograd, Lubny, Khorol, Reshetylivka cities. Within these territories, the ecological consequences of man-made intervention in the underground hydrosphere are the greatest, since here the BKA groundwaters are partially or completely unsuitable for drinking purposes.

The authors have developed measures to minimize the ecological consequences of technogenic intervention in the BKA groundwater to increase the ecological safety of drinking water supply to the population from the water intakes of Poltava city agglomeration, which are strategically important for the studied region.

I. The system of groundwater hydrogeochemical monitoring at water intakes in conditions of pollutants filtration from the surface or their migration from below in the zones affected by tectonic faults associated with salt diapirs has been improved. These measures are based on the following:

- characteristic indicators of groundwater qualitative composition, according to which elevated values were established in the target aquifer waters, were determined. It is recommended to control their content on the basis of general (control of the entire complex of actual pollutants in the zones of influence of water intakes) and special monitoring (control of mineralization, Cl^-, F^-, Fe_{total}, Br^-, B^{3+}, J^- at the intersection of zones of powerful water intakes influence with territories in a radius of 5 km around tectonic faults). This significantly shortens the time and reduces the cost of works in comparison with a full complex of hydrogeochemical studies within the entire territory;
- proposed criteria for assessing the levels of groundwater pollution in the form of characteristic intervals of values for the above-mentioned hydrogeochemical indicators, which indicate the degree of water pollution (Tables 2, 3). This makes it possible to increase efficiency when making management decisions to improve the ecological safety of drinking water supply. These criteria are based on the use of average geological base content of polluting elements determined by the authors for the waters of studied area. The average geological base content (GBC) of elements is the content of chemical elements in the groundwater composition, which was determined from relevant values within the territories that are distant from sources of pollution and with minimal technogenic influence.

Table 2

The proposed levels of groundwater pollution for the general monitoring

Name of the indicator, units	The groundwater pollution levels			
	Unpolluted water		Relatively polluted water (*a time of making management decisions*)	Contaminated water
	Within the average GBC	Within the current standards (*DSanPiN 2.2.4-171-10, 2010*)		
Physical and chemical indicators				
Mineralization, mg/dm^3	≤ 1150	≤ 1000	1150-2300	≥ 2300
pH	6,6-7,6	6,5-8,5	6,0-8,5	≤ 6,0; ≥ 8,5
Cl^-, mg/dm^3	≤ 275	≤ 250	275-550	≥ 550
Fe_{total}, mg/dm^3	≤ 0,25	≤ 0,2	0,25-0,5	≥ 0,5
Sanitary and toxicological indicators				
Na^++K^+, mg/dm^3	≤ 300	≤ 200	300-600	≥ 600
F^-, mg/dm^3	≤ 2,0	≤ 1,5	2,0-4,0	≥ 4,0
NH_4^+, mg/dm^3	≤ 0,3	≤ 0,5	0,3-0,6	≥ 0,6
NO_2^-, mg/dm^3	≤ 0,1	≤ 0,1	0,1-0,2	≥ 0,2
Si, mg/dm^3	no data available	≤ 10	10-30	≥ 30
Physical and chemical+Sanitary and toxicological indicators				
Br^-+B^{3+}+J^- (total), mg/dm^3	≤ 0,5	≤ 0,55	0,5-1,0	≥ 1,0

Table 3

The proposed levels of groundwater pollution for the special monitoring

Name of the indicator, units	The groundwater pollution levels		
	Unpolluted water	Relatively polluted water (*a time of making management decisions*)	Contaminated water
Mineralization, mg/dm^3	≤ 1400	1400-1600	≥ 1600
Cl^-, mg/dm^3/ % equivalent	≤ 350 / 30	350-450 / 30-35	≥ 450 / 35
F^-, mg/dm^3	≤ 3,5	3,5-4,0	≥ 4,0
Br^-+B^{3+}+J^- (total), mg/dm^3	≤ 1,0	1,0-1,5	≥ 1,5
Fe_{total}, mg/dm^3	≤ 0,5	0,5-1,0	≥ 1,0

II. Justification of selection of promising areas for the construction of new water intakes to solve the problem of acceptable quality drinking groundwater lack within the territory. The developed methodological approach to selection is complex and allows determining the degree of vulnerability of groundwater to pollution caused by each of the established groups of factors:

a) assessment of vulnerability to man-made pollution that enters groundwater in the process of downward vertical filtration and migration from the surface. It is based on the following ecological and hydrogeological indicators: the intensity of technogenic pressure on the GE and its changes within the territory; lithology-filtration protective capacity of barriers (sediment layers) that lie between the surface and BKA; parameter of filtration through a regional separate layer of poorly permeable sediments; thickness of water-bearing rocks of target aquifer. Each of these indicators is evaluated in accordance with specially developed scales, according to which its value is determined depending on local ecological and hydrogeological characteristics;

b) assessment of vulnerability to natural pollution factors (migration of deep substandard waters through tectonic faults). It is based on the parameter of influence of natural neotectonic factors on the quality of BKA groundwater; an indicator of current geodynamic activity of the earth's crust within the region.

The authors have identified promising areas for creation new water intakes in a radius of 40 km around the Poltava city with an area of 750 km^2 and have calculated using the balance method the forecast resources of high-quality BKA groundwater within their limits (54.5 thousand m^3/day). Using these resources the current water supply of urban agglomeration will gradually be replaced with water of high drinking quality.

III. As a result of comparison of general water withdrawal data and studied hydrogeochemical indicators, dependencies have been obtained that made it possible to calculate the optimal total water withdrawal at the Poltava water intakes:

- to stabilize the content of characteristic indicators of BKA water quality composition within the eastern part of city, where the most intense pollution of these waters is observed, within the following values: mineralization up to 1150 mg/dm^3 (up to 1 GBC), $Br^{-}+B^{3+}+J^{-}$ (in total) up to 0.5 mg/dm^3 (up to 1 GBC), Cl^{-} up to 400 mg/dm^3 (up to 1.5 GBC), F^{-} up to 3.0 mg/dm^3 (up to 1.5 GBC) – the total water withdrawal must be up to 16 thousand m^3/day;
- to stabilize the content of characteristic hydrogeochemical indicators in the BKA water composition within other parts of city, where less intense pollution of these waters is observed, within the following values: mineralization up to 1150 mg/dm^3 (up to 1 GBC), $Br^{-}+B^{3+}+J^{-}$ (total) up to 0.75 mg/dm^3 (up to 1.5 GBC), Cl^{-} up to 275 mg/dm^3 (up to 1 GBC), F^{-} up to 3.0 mg/dm^3 (up to 1.5 GBC) – total water withdrawal must be up to 40 thousand m^3/day.

Conclusions. The purpose of article was to develop measures to improve the ecological safety of population drinking water supply with groundwaters of Buchak-Kaniv aquifer from urban water intakes in Eastern Ukraine.

The ecological consequences of man-made intervention in the BKA drinking groundwater in the studied area have been assessed. The main pollutant elements of these groundwaters have been traced (Cl^{-}, F^{-}, Fe_{total}, Br^{-}, B^{3+}, J^{-}). About 20 networks of powerful urban water intakes in the region have been identified, on which elevated values of these elements have been traced. Within the water intakes of Poltava, Karlivka, Krasnograd, Lubny, Khorol, Reshetylivka cities, the ecological consequences of technogenic intervention in the underground hydrosphere are the greatest, as here the BKA groundwaters are partially or completely unsuitable for drinking purposes. The key role of technogenesis (intensification of groundwater withdrawal and expansion of water intakes network; as a result – changes in the hydrodynamic conditions of operational aquifers and the formation of their regional depression funnels) in these processes has been established. The increased content of Cl^{-}, F^{-}, Fe_{total}, Br^{-}, B^{3+}, J^{-} in systematically consumed drinking water has a colossal effect on the human body, which can be expressed in a number of serious population diseases.

The authors have developed measures to minimize the above-mentioned ecological consequences of the BKA drinking groundwater technogenesis:

- the system of groundwater hydrogeochemical monitoring at the water intakes of region has been improved in conditions of filtration of pollutants from the surface and their migration from below in the zones affected by tectonic faults associated with salt diapirs;
- the allocation of promising areas for creating new water intakes to solve the problem of potable groundwater lack of acceptable quality within the research territory has been substantiated. Prospective areas within a radius of 40 km around the Poltava city have been identified (total area – 750 km^2). Involvement of the calculated forecast resources of drinking groundwater (54.5 thousand m^3/day) will provide high-quality drinking water for the population of this urban agglomeration;
- optimal general water withdrawal at the Poltava water intakes has been substantiated: to stabilize the content of characteristic indicators in the BKA waters composition within the eastern part of city (up to 16 thousand m^3/day); to stabilize the content of characteristic indicators in the BKA waters composition within other parts of city (up to 40 thousand m^3/day).

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РОЗРОБЛЕННЯ ЗАХОДІВ ДЛЯ ПІДВИЩЕННЯ ЕКОЛОГІЧНОЇ БЕЗПЕКИ ПИТНОГО ВОДОПОСТАЧАННЯ НАСЕЛЕННЯ СХІДНОЇ УКРАЇНИ ЗА РАХУНОК ВИКОРИСТАННЯ ПІДЗЕМНИХ ВОД БУЧАЦЬКО-КАНІВСЬКОГО ВОДОНОСНОГО КОМПЛЕКСУ

Розроблено заходи для підвищення екологічної безпеки питного водопостачання населення за рахунок використання підземних вод бучацько-канівського водоносного комплексу з міських водозаборів Східної України.

Оцінено екологічні наслідки техногенного втручання в питні підземні води бучацько-канівського водоносного комплексу території робіт. Виявлено основні елементи-забруднювачі цих підземних вод. Визначено водозабори (м. Полтава, Карлівка, Красноград, Лубни, Хорол, Решетилівка), на яких екологічні наслідки техногенного втручання в підземну гідросферу є найбільшими, оскільки тут цільові підземні води частково або повністю не придатні для питних цілей. Установлено ключову роль техногенезу (інтенсифікація водовідбору підземних вод та розширення мережі водозаборів і, як наслідок, зміни гідродинамічних умов експлуатаційних водоносних комплексів та утворення їхніх регіональних депресійних лійок) у цих процесах. Підкреслено, що підвищений вміст досліджених елементів-забруднювачів у систематично споживаній питній воді має колосальний вплив на організм людини, що може виражатися у низці серйозних захворювань.

Розроблено заходи з мінімізації встановлених екологічних наслідків техногенезу питних підземних вод бучацько-канівського водоносного комплексу для підвищення екологічної безпеки питного водопостачання населення із водозаборів Полтавської міської агломерації, які є стратегічно важливими для дослідженого регіону. Удосконалено систему гідрогеохімічного моніторингу підземних вод на водозаборах регіону для умов фільтрації забруднюючих речовин із поверхні або їх міграції знизу в зонах впливу тектонічних порушень, пов'язаних із соляними діапірами. Це значно скорочує час і зменшує вартість робіт порівняно з повним комплексом гідрогеохімічних досліджень у межах усієї території. Обґрунтовано виділення перспективних ділянок під закладання нових водозаборів для розв'язання проблеми нестачі питних підземних вод прийнятної якості в межах території робіт. Розраховано прогнозні ресурси питних підземних вод високої якості в радіусі 40 км навколо м. Полтава, залучення яких дозволить забезпечити високоякісною питною водою населення цієї міської агломерації. Обґрунтовано оптимальний загальний водовідбір на Полтавських водозаборах для стабілізації вмісту елементів-забруднювачів у складі вод бучацько-канівського водоносного комплексу в межах різних частин міста.

Ключові слова: підземні води, забруднення, екологічна безпека, водозабори, заходи.