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FORECAST OF POTENTIAL CHANGES IN EXPLOITABLE GROUNDWATER RESERVES UNDER THE INFLUENCE OF NATURAL AND ANTHROPOGENIC PROCESSES AT DEPOSITS EXPLORED FOR IRRIGATION

Abstract. The article analyzes the direction of anthropogenic changes in hydrogeological conditions, it is revealed that groundwater in Kazakhstan is not threatened by the depletion of its reserves in the process of their exploitation. No groundwater pollution has been established in the deposits explored for land irrigation in the territories of South and East Kazakhstan. Changes in the hydrodynamic regime at deposits confined to river valleys, cones of removal, and foothill plains were noted. The degree of groundwater reserves availability in the mentioned deposits at the expense of their formation sources was assessed in order to determine the reliability of operation under the influence of natural and anthropogenic processes, and the coefficient of groundwater reserves availability for each deposit was determined.

Keywords: operating reserves, groundwater deposits, land irrigation.

Introduction. In the modern period, a complex problem is the assessment of the impact of possible climatic changes and anthropogenic processes on the formation of natural and forecast resources and operational reserves of fresh and slightly brackish groundwater in deposits explored for irrigation. Taking into account the diversity of natural and hydrogeological conditions of Kazakhstan, changes in the value of natural resources, and in some cases natural reserves, can lead to both positive and negative consequences [1, 2].

Global warming predicted in recent years could also cause significant climate change that could result in impressive impacts to regional surface and groundwater resources [3-5]. At the same time, many researchers note that global warming [6-8], if it occurs, does not necessarily mean a one-step warming. Possible climate changes are expected to be heterogeneous across landscapes. Along with warming in some regions, there may be significant cooling in others. Not everything is unambiguous with temperature cycles either. The currently observed warming is believed to be occurring against the background of a global long-term cycle of significant cooling.

The above-mentioned problems of climate change are also very important for hydrogeologists when considering the peculiarities of influence of possible climatic changes on the formation of groundwater resources. This is natural, as the main source of groundwater formation is precipitation. Consequently, scientifically based forecasts of changes in precipitation and river runoff in relation to possible climatic changes, i.e. climate models, are needed. Such climatic models should be the basis for projected changes in hydrogeological and, above all, hydrodynamic conditions. Based on this, given any increase or decrease in the norm of atmospheric precipitation and river runoff, it is quite easy to predict the change of groundwater flow in one or another direction, i.e. the natural resources of the upper aquifers.

It should be noted that the contribution of precipitation changes to the predicted changes in groundwater levels and discharges is only 10-30%. In addition, climatological forecasts do not provide quantitative insights into the intra-annual distribution of precipitation and evaporation. Thus, the planned climate change scenarios under any assessment will not lead to any significant changes in the estimated values of natural and predicted exploitable resources [1].

In the process of research on the impact of anthropization processes on the underground hydrosphere, the trend of anthropogenic changes in hydrogeological conditions was revealed mainly in two directions.

The first is a change in the hydrogeodynamic regime of groundwater causing a decrease in the level and depletion of groundwater reserves or an increase in the level causing the formation of technogenic waterlogging of territories [1, 2, 9]. Analysis of the current state of exploitation of groundwater deposits on the territory of Kazakhstan has shown that groundwater use of explored deposits occurs in insignificant quantities. Of the total amount of explored groundwater reserves, less than 20% is utilized during this period. There are very few groundwater deposits in Kazakhstan whose reserves would be used more than 40-50%. Consequently, groundwaters of Kazakhstan are not threatened by the depletion of their reserves in the process of their exploitation.

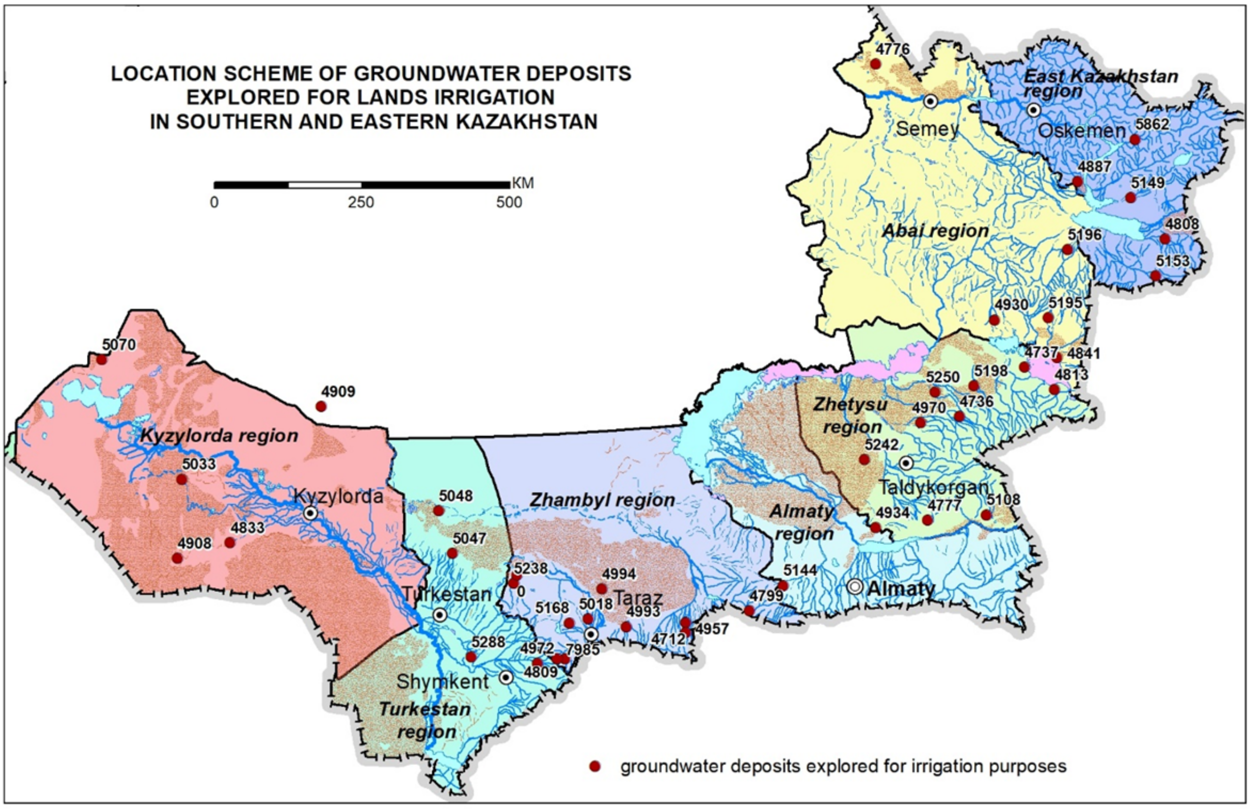
The second is hydrogeochemical changes in groundwater caused by contamination of the latter with gas, liquid and solid wastes from transportation, industry, agriculture, energy and life support facilities. Such changes can capture both significant changes and be local in nature. Pollution of fresh groundwater is of particular concern. Freshwater is a limited and vulnerable resource. It is difficult to overemphasize the significance of pollution of another environment that provides humans with the ability to survive, which could be compared to water pollution. At the same time, field studies have not established groundwater contamination in deposits explored for irrigation in the territories of South and East Kazakhstan. There are no sources of possible groundwater contamination in the vicinity of these deposits [10].

In future, under significant increase of regular irrigation area and intensive exploitation of groundwater deposits explored for irrigation, the following changes are possible: decrease of their natural (capacity) reserves; redistribution of main sources of supply, i.e., decrease of the role of infiltration of atmospheric precipitation due to increase of depth of level occurrence; filtration of surface (river) water will be carried out mainly in winter period only in rivers with permanent flow; increase of surface water filtration on irrigation fields and from irrigation and main canals as a result of increase of their areas and length of canals).

Materials and Methods. Conducted in 2023-2024, field studies within South Kazakhstan (Almaty, Zhetysu, Zhambyl, Kyzylorda and Turkestan regions) and East Kazakhstan (Abai and East Kazakhstan regions) have not revealed clearly expressed trends in the influence of climatic changes on groundwater resources in general, as well as on exploitable reserves of specific deposits explored for land irrigation. Some changes in the hydrodynamic regime (5-15 m lowering of the level) at such deposits, confined to river valleys, outflow cones, foothill plains, are related to the low-water period, which to some extent affected precipitation and surface water resources. Location of deposits of groundwater explored for irrigation within the territory of South and East Kazakhstan is reflected in figure.

Thus, under changes in hydrogeological and hydrodynamic conditions, the value of natural (capacitive) reserves may change, which is caused by a decrease in the thickness of aquifers. Natural (renewable) resources under groundwater exploitation for irrigation may be redistributed, filtration from rivers will decrease, filtration from irrigation systems and irrigation massifs will increase.

In these cases, it is important to assess the extent to which the exploitable groundwater reserves of the deposits in question are secured from the sources of their formation: natural resources, natural reserves, elastic reserves in the case of the use of pressurized groundwater and the impossibility of reliably determining natural groundwater resources.



Location scheme of groundwater deposits explored for lands irrigation in Southern and Eastern Kazakhstan

For the study area, the analysis of groundwater storage capacity at each deposit explored for irrigation was carried out to determine the possible impact of groundwater level reduction by 5-15 m on the size of groundwater storage capacity. Earlier, in the process of hydrogeological exploration works on specific deposits of groundwater explored for irrigation of lands, the assessment of the availability of exploitable groundwater reserves was carried out taking into account the genetic type of the deposit and lithology of water-bearing rocks, general hydrogeological and natural conditions.

Results. In order to assess the availability of operational groundwater reserves in deposits explored for irrigation, for each deposit, taking into account its genetic type, lithology of water-bearing rocks, general hydrogeological and natural conditions, natural reserves, natural resources, elastic reserves for pressure water, and in some deposits the groundwater recharge is due to precipitation were determined [11, 12].

Natural reserves represent the mass (volume) of groundwater contained in the considered element of the underground hydrosphere (reservoir, reservoir section, reservoir system, etc.). In turn, they are subdivided into the so-called *capacitive* reserves, determined by the amount of water that is extracted during drainage of the reservoir, and *elastic* reserves, which are formed when the piezometric level (reservoir pressure) of pressurized groundwater decreases due to water expansion and compaction of the mineral skeleton of the reservoir.

Capacitated natural reserves were determined by the formula:

$$V_e = FH\mu \;, \tag{1}$$

where V_e – natural (capacitive) reserves, m^3; F – area in the contour of the reduced radius of influence, m^2; H – weighted average thickness of the aquifer, m; μ – specific water yield of water-bearing rocks.

The value of elastic natural pressure water reserves is determined by the formula:

$$V_e = \mu F H_{wa} \,, \tag{2}$$

where V_e – elastic groundwater reserves, m^3; μ – elastic water yield; F – area of aquifer distribution, m^2; H_{wa} – weighted average head above the overlying layer, m.

Water withdrawal availability at the deposit due to natural reserves development without taking into account replenishment was determined by the formula:

$$Q_r = \frac{a \cdot V_r}{t}, \quad (3)$$

where Q_r – water withdrawal due to natural reserves development, m^3/day; V_r – value of natural reserves, m^3, a – extraction coefficient (taken from 0.3 to 0.5); t – water intake operation period, days.

A natural resource is a fed inflow or outflow of groundwater. Natural resources of an aquifer within a certain area of distribution are characterized by the amount of its supply in undisturbed balance-hydrodynamic conditions (infiltration of atmospheric precipitation, overflow from adjacent aquifers, filtration from their surface watercourses and reservoirs).

Natural resources are formed under the influence of numerous natural factors: climatic characteristics, conditions of aquifer occurrence, composition and thickness of aeration zone rocks, capacity and permeability of water-bearing sediments, boundary conditions of the deposit, etc.

Natural resources were determined by the following methods:

– By groundwater flow rate, using Darcy's formula:

$$Q_e = km \cdot J \cdot B \cdot cos \cdot \alpha , \quad (4)$$

where J – the average slope of the groundwater flow; km – average water permeability of the reservoir, m^2/day; B – length of the design profile, m; α – angle of flow meeting with the design section (if any).

– Due to infiltration of atmospheric precipitation in some cases were determined by the formula:

$$Q_{pi} = \frac{F \cdot h \cdot 1000}{t}, \quad (5)$$

where Q_{pi} – value of infiltration of atmospheric precipitation, m^3/s; h – precipitation layer, mm; F – area of aquifer supply, km^2; t – the time of the greatest infiltration of precipitation, s.

To assess the availability of exploitable reserves for groundwater deposits explored for land irrigation within the territories of South, West and East Kazakhstan, the coefficient of availability of exploitable groundwater reserves $K_{availability}$ was used, which is the ratio of the total value of natural reserves and natural resources $Q_{availability}$ to the value of exploitable groundwater reserves explored for land irrigation $Q_{exploitable}$ at each groundwater deposit ($K_{availability.} = Q_{availability} / Q_{exploitable}$).

All calculations made on availability of operational groundwater reserves explored for land irrigation were summarized in Table.

Analysis of the table shows that the coefficient of availability of operational groundwater reserves ($K_{availability}$) varies depending on hydrogeological conditions within significant limits and characterizes the resource potential of a particular groundwater deposit. The larger the value of the coefficient of availability of operational groundwater reserves, the more reliable are the resource components of a given groundwater deposit (GWD).

Discussion. In Almaty region, the $K_{availability}$ value varies from 1.12 (Karadala GWD) to 4.17 (Yuzhno-Kopinskoe GWD). In general, all fields of the region are reliably provided with natural resources and reserves, but at Karkarala GWD there is no possibility of reserves increase in the process of exploitation.

In the Zhetysu region, the $K_{availability}$ value ranges from 1.26 (Aksu GWD) to 3.83 (Karatal GWD). All deposits are reliably supplied with natural resources and reserves; there is no possibility of increasing exploitable reserves in the Aksu GWD.

The $K_{availability}$ value in the deposits of Zhambyl region ranges from 1.23 (Biylikol GWD) to 18.8 (Yuzhno-Kopinskoe GWD). In principle, all explored exploitable groundwater reserves at all fields are reliably secured, but there is no significant exploitable potential for increasing reserves at Biylikol GWD.

In Kyzylorda region the $K_{availability}$ value at groundwater fields is within 2.56-6.10 and only at Tolagai GWD it sharply increased up to 60. This indicates that the Tolagai GWD has significant groundwater resources and, if necessary, this can be proved by reassessment of exploitable reserves. Exploitable groundwater reserves of the region are reliably provided at all fields.

In Turkestan region at groundwater deposits, the $K_{availability}$ value ranges from 1.33 to 5.56. Exploitable reserves of all fields are secured.

Availability of exploitable groundwater reserves in deposits (ERG)

Administrative region. Cadastre GWD code	Name of GWD	Geological index of aquifer (complex)	Mineralization, g/l
1	**2**	**3**	**4**
Almaty	**South Kazakhstan**		
4849	Issyk-Turgen	apQ	0.1-0.7
4878	Karadala	N_2 K	0.2-0.7
4881	Karoi	apQ_I	0.1-0.3
5056	Talgar	apQ	0.2-0.4
5089	Uzun-Agach	apQ_{I-II}	0.1-0.9
5112	Chilik	apQ	0.2-0.7
5144	Yuzhno-Kopinskoe	apQ_I/ N_1	0.2-0.9
Total GWD and reserves	7		
Zhetysu			
4736	Aksu	$apQ_{I -II}$	0.1-0.5
4737	Alakol	apQ-alQ_{I-II}	0.2-0.4
5250	Baskan	apQ	0.2-0.8
4777	Bashi	dp Q_I-ap Q_{II}	0.1-0.8
4813	Djungar	Q_{I-II}	0.2-0.4
5242	Karatal	Q_I / N_2	0.8-0.9
4934	Kerbulak	Q_{I-II} / N_2	0.5-0.8
4970	Molaly	aQ_{I-II}—apQ_{I-II}	0.4-0.7
5108	Khorgos	apQ_{I-II}-aQ	0.2-0.3
5198	Shilikta	apQ_{I-II}	0.2-0.6
Total GWD and reserves	**10**		
Zhambyl			
5238	Akzhar	₽$_1$- ₽$_2$	0.4-0.6
4712	Aspara	Q_I apQ_{II-III}-N	0.2-0.4
5168	Biylikol	aQ_{III}-N_2	0.3-0.7
4799	Georgievskoye-Talapty	aQ_{III-IV}	0.3-0.5
4809	Zhualyn	apQ_{II-III}	0.2-0.5
4957	Merken	apQ_{II-III}	0.1-0.2
4993	Podgornenskoye	apQ_{II-III}	0.2-0.8
4994	Predpeskovoe	aQ-N_2	0.3-0.8
4944	Lugovskoye	apQ_{II-III}	0.2-0.8
5018	Talas-Assin (North)	apQ_{III-IV}- N_2	0.4-0.7
5144	Yuzhno-Kopinskoe	apQ_I - N_1	0.2-0.9
7985	Shakpakata	C_1	0.3-0.5
Total GWD and reserves	12		
Kyzylorda			
4833	Zhanadarya	K	1.0-2.0
4908	Kuvandarya	K_2	1.3-1.4
4909	Kyzylkum	K_2	1.6-2.0
5033	Sarybulak	K_2	1.5-3.0
5070	Tolagai	₽$_2$	0.5-1.0
Total GWD and reserves	5		
Turkestan			
5288	Bugun	Q_{II}- N_2	0.6-2.0
4972	Michurinskoe	apQ_{II-III}	0.5
5048	Suzak	N_2-₽$_2^{1-2}$, K_2	0.3-1.8
5047	Suykbulak-Intymak	K_2	0.5
Total GWD and reserves	4		
East Kazakhstan	**East Kazakhstan**		
4808	Dairov	aQ_{II} N_2-Q_1	0.2-0.7
5149	Kalgutin	apQ	0.2-0.8
4887	Kuludzhun	apQ	0.2-0.8
5862	Narym	aQ_{II-III}	0.2-0.4
5153	Chilikta	apQ_{II} -N_2-Q_1	0.2-0.3
Total GWD and reserves	5		
Abai			
4776	Balapanovskoye	aQ_{II-III} N_2-Q_1, ₽$_{2-3}$	0.2-0.6
4841	Zharbulak	apQ_1, apQ_{II-III},	0.1-0.5
4930	Karakol	aQ-apQ	0.4-1.0
5195	Katynsu	aQ-apQ_{I-IV}	0.2-0.5
5196	Kurailin	aQ-apQ_{I-IV}	0.3-0.8
Total GWD and reserves	5		

explored for land irrigation in South and East Kazakhstan

ERGW value for irrigation			Availability of ERGW		The total value of ERGW availability, $Q_{availability}$, m^3/s	Coefficient of ERGW availability $K_{availability} = Q_{availability}/Q_{exploitable}$
thous. m^3/day	km^3/year	m^3/s	with natural reserves, m^3/s	with natural resources, m^3/s		
5	**6**	**7**	**8**	**9**	**10**	**11**
South Kazakhstan						
583.2	0.2128	6.75	4.83	10.64	15.47	2.29
776.1	0.2832	8.9826	6.7	3.358	10.058	1.12
12.9	0.0047	0.1493	0.09	0.47	0.56	3.75
288.72	0.1053	3.3416	3.44	10.49	13.93	4.17
257	0.0938	2.9745	2.69	3.46	6.15	2.06
1341	0.4894	15.5208	14.27	14.61	28.88	1.86
73	0.0266	0.8449	1.4	2.3	3.7	4.37
3331.92	**1.2158**	**38.5637**				
1497.5	0.5465	17.3321	2.8	19.06	21.86	1.261
864.7	0.3156	10.0081	3.79	22.66	26.45	2.64
259.2	0.0946	3.0	1.32	4.88	6.2	2.06
116.6	0.0425	1.3495	0.63	3.7	4.33	3.21
802.6	0.2929	9.2893	2.3	10.75	13.05	1.40
311	0.1135	3.5995	11.5	2.3	13.8	3.83
140.2	0.0511	1.6226	1.92	1.5	3.42	2.11
457.7	0.167	5.2874	2.3	5.8	8.1	1.53
2643.9	0.965	30.6006	16.7	28.2	44.9	1.47
755.1	0.2756	8.7395	3.5	10.564	14.064	1.61
7848.5	**2.8643**	**90.8286**				
43.2	0.0157	0.5	0.67	0.378	1.048	2.09
129.6	0.0473	1.5	2.2	7.97	10.17	6.78
293.7	0.1072	3.3993	3.12	1.07	4.19	1.23
46.6	0.017	0.5393	0.190	0.647	0.837	1.55
292.1	0.1066	3.3807	0.083	7.5	7.583	2.24
116.7	0.0425	1.3506	2.6	8.28	10.88	8.05
330	0.1204	3.8194	0.07	5.8	5.87	1.54
294.9	0.1076	3.4131	4.8	3.17	7.97	2.33
500	0.1825	5.7870	13.4	8.4	21.8	3.76
228.1	0.0832	2.64	6.97	4.6	11.57	4.38
18.3	0.0066	0.2118	1.7	2.13	3.83	18.08
0.740	0.00027	0.00856	0.01	0.020	0.03	3.50
1 793.94	**0.6543**	**20.7627**				
21.6	0.0078	0.25	0.7	0.18	0.88	3.52
72.5	0.0264	0.8391	1.724	0.17	1.894	2.56
71.5	0.026	0.8275	3.92	0.26	4.18	5.05
21.1	0.0077	0.2442	1.3	0.19	1.49	6.10
4.8	0.0017	0.0555	2.65	0.69	3.34	60.0
191.5	**0.0696**	**2.2163**				
302.4	0.1103	3.5	1.94	2.72	4.66	1.33
42.9	0.0156	0.4965	0.8	1.75	2.55	5.13
138.6	0.0505	1.6041	3.7	4.316	8.016	4.99
23.3	0.0085	0.2696	0.8	0.7	1.5	5.56
507.2	**0.1849**	**5.8702**				
East Kazakhstan						
667.3	0.2435	7.7233	0.5	10.2	10.7	1.38
45	0.0164	0.5208	0.3	1.8	2.1	4.03
136.7	0.0498	1.5821	0.08	2.7	2.8	1.77
85.7	0.0312	0.9918	0.089	1.00	1.089	1.09
139.1	0.0505	1.6099	0.4	3.22	3.62	2.25
1073.8	**0.3914**	**12.4279**				
85.794	0.0313	0.9929	0.3	0.942	1.242	1.25
1071.3	0.391	12.3993	19.3	3.8	23.1	1.86
216	0.0788	2.5	1.2	2.07	3.27	1.30
483.8	0.1765	5.5995	1.9	6.5	8.4	1.5
380.12	0.1387	4.3995	1.22	6.68	7.9	1.79
2237.01	**0.8163**	**25.8912**				

The $K_{availability}$ value in the fields of East Kazakhstan region ranges from 1.0 (Narym GWD) to 4.03 (Kalgutin GWD). Exploitable reserves are secured. There is no prospect of possible increase of groundwater reserves in the Kalgutin GWD.

In the Abai region, the $K_{availability}$ value at the fields varies insignificantly: from 1.25 to 1.86. Exploitable reserves are secured, but there are no significant prospects for their increase in the future.

Conclusion. The analysis of the results of the completed study allowed us to draw the following conclusions:

– the trend of anthropogenic changes in hydrogeological conditions occurs mainly in changes in the hydrogeodynamic regime of groundwater and hydrogeochemical state of groundwater;

– groundwater contamination has not been established by field studies at deposits explored for irrigation;

– some changes in the hydrodynamic regime (5-15 m lowering of the level) at deposits confined to river valleys, outflow cones, foothill plains, are related to the low-water period;

– if hydrogeological and hydrogeochemical conditions can be changed, the value of natural (capacity) reserves may change due to a decrease in the thickness of aquifers. In these cases, it is important to assess the extent to which the exploitable groundwater reserves of the deposits in question are secured from the sources of their formation;

– to assess the availability of exploitable reserves for groundwater deposits explored for land irrigation, the coefficient of availability of exploitable groundwater reserves $K_{availability}$ was used, which is the ratio of the total value of natural reserves and natural resources to the value of exploitable groundwater reserves explored for land irrigation $Q_{exploitable}$;

– on all groundwater deposits explored for land irrigation in the regions of South and East Kazakhstan, operational reserves are fully secured with natural resources and reserves;

–climatic changes in the groundwater level regime of individual deposits, due to low water years, will not significantly affect the values of exploitable reserves of groundwater deposits explored for irrigation.

– the conducted studies allow for a timely assessment of possible changes in the sources of formation of operational reserves of groundwater and to determine the most rational mode of exploitation of a groundwater deposit explored for irrigation of lands, allowing for continuous exploitation of groundwater during the growing season.

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СУАРУ ҮШІН БАРЛАНҒАН ЖЕРЛЕРДЕ, ЖЕРАСТЫ СУ КЕНОРЫНДАРЫНДАҒЫ ТАБИҒИ ЖӘНЕ ТЕХНОГЕНДІК ПРОЦЕСТЕРДІҢ ӘСЕРІНЕН ЭКСПЛУАТАЦИЯЛЫҚ ҚОРЛАРЫНЫҢ ӨЗГЕРУ МҮМКІНДІГІНІҢ БОЛЖАМЫ

Аннотация. Мақалада гидрогеологиялық жағдайдағы антропогендік өзгерістердің бағытына талдау жасалып, Қазақстанның жерасты суларына оларды пайдалану кезінде олардың қорларының сарқылу қаупі болмайтыны анықталды. Оңтүстік және Шығыс Қазақстан аумақтарындағы жерлерді суару үшін барланған кен орындарында жерасты суларының ластануы анықталған емес. Гидродинамикалық режимнің өзгерістері өзен аңғарларында, аллювийлік желдеткіштерде және тау етегіндегі жазықтарда орналасқан кен орындарында байқалды. Табиғи және техногендік процестердің әсерінен пайдалану сенімділігін анықтау мақсатында аталған кен орындары бойынша жерасты суларының пайдалану қорларымен олардың пайда болу көздері бойынша қамтамасыз етілу дәрежесіне бағалау жүргізілді, әрбір кен орны бойынша жерасты суларының пайдалану қорымен қамтамасыз ету коэффициенті анықталды.

Түйін сөздер: пайдаланылатын қорлар, жерасты суларының кен орындары, жерді суару.

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ПРОГНОЗ ВОЗМОЖНЫХ ИЗМЕНЕНИЙ ВЕЛИЧИНЫ ЭКСПЛУАТАЦИОННЫХ ЗАПАСОВ ПОД ВЛИЯНИЕМ ПРИРОДНЫХ И ТЕХНОГЕННЫХ ПРОЦЕССОВ НА МЕСТОРОЖДЕНИЯХ ПОДЗЕМНЫХ ВОД, РАЗВЕДАННЫХ ДЛЯ ОРОШЕНИЯ ЗЕМЕЛЬ

Аннотация. Приведен анализ направленности антропогенных изменений гидрогеологических условий. Выявлено, что подземным водам Казахстана не угрожает истощение их запасов в процессе эксплуатации. Не установлено загрязнение подземных вод на месторождениях, разведанных для орошения земель в Южном и Восточном Казахстане. Отмечены изменения гидродинамического режима на месторождениях, приуроченных к долинам рек, конусам выноса, предгорным равнинам. Произведена оценка степени обеспеченности эксплуатационных запасов подземных вод на указанных месторождениях за счет источников их формирования с целью определения надежности эксплуатации под воздействием природных и техногенных процессов. Определен коэффициент обеспеченности эксплуатационных запасов подземных вод для каждого месторождения.

Ключевые слова: эксплуатационные запасы, месторождения подземных вод, орошение земель.