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SUITABILITY ASSESSMENT OF GROUNDWATER FOR IRRIGATION PURPOSE AT HIGH-RISK SITES OF THE ARARAT PLAIN

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Soil salinization, caused by natural and anthropogenic factors, is a pressing environmental issue in Masis Region, which is one of the important regions of irrigated agriculture in Armenia. To prevent this adverse process the groundwater quality in the region has been evaluated for agricultural uses. For this purpose, the water samples were collected from 27 extraction wells and analyzed for major quality parameters following standard test procedures. Other chemical indices, notably sodium adsorption ratio, permeability index and magnesium hazard, were derived from the measured quality parameters. During the studies the areas with good, permissible and unsuitable groundwater quality for irrigation were determined. According to results obtained for irrigation of agricultural lands in Masis Region (especially in its eastern and southern parts), the usage of highly saline groundwater from shallow horizons should be restricted as much as possible, and in Ranchpar Village, where the groundwater even from the high depths has a high salinity, it is required to use an alternative source of irrigation water.

***Keywords*:** irrigation, groundwater quality, hydrochemical indices, soil salinization, Masis Region.

Introduction. Land is an important and indispensable resource for society development. With rapid human population increase, the need for agricultural lands is continually growing, which causes various ecological problems, such as soil salinization, soil erosion, soil exhaustion etc., which ultimately leads to agricultural land degradation [1]. These problems have arisen in many countries, particularly in the developing countries. As the most common ecological problem, soil salinization is an essential process causing the reduction of crop yields, resulting in the crisis of world food shortages [2–6]. Salinization reduces soil productive capacity and degrades the chemical and physical properties of the soil. Therefore, the investigation of the factors leading to soil salinization has become an important research issue [7–9]. The ecological problem of soil salinization is especially actual in arid and semi-arid regions [10] such as the Ararat plain, particularly in Masis Region, where the precipitation is low and the production of agricultural lands mostly depends on irrigation. In case of insufficient quality of water used for irrigation purposes, changes in the physical and chemical structure of soil can be observed [11–13].

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Groundwater is a significant source of irrigation water supply in the Masis Region. The quality of groundwater depends on natural processes (chemical composition of soils and rocks through which water flows, nature of geochemical reactions, solubility of salts, and so on) and various human activities such as application of pesticides and fertilizers for increasing crop yields without understanding the chemical characteristics of soils [14–18]. The evaluation of groundwater quality is of utmost importance in Masis region as far as in this semi-arid area the groundwater has a social and economic importance. The attention to the quality, hydrogeology, and hydrochemistry of groundwater of Masis Region, is increasing now. The Ararat plain is one of the most important agricultural regions in Armenia where the need for groundwater is continually increasing due to agricultural development, which often brings to the deterioration of groundwater quality.

Therefore, the main aim of this study was the assessment of groundwater quality in Masis Region and of its suitability for irrigation purposes.

Materials and Methods.

Studied Area. Masis Region is situated in the southwestern part of Ararat Marz, in the Ararat plain. The climate is sharply continental, with dry, hot summers and cold winters. The average annual precipitation varies in the range of 200–300 *mm*. The average temperature is from +12° to +13°*C* [19]. The relief is flat, the altitude is about 800 *m* above sea level. The following soil types are mainly found in the study area: irrigated meadow-brown soils, irrigated residual-meadow-brown soils, moist meadow-brown soils, saline-alkali soils [20].

Groundwater Sample Collection and Analysis. Groundwater sampling was performed in April, 2019. The selection of sampling points was done taking into account the even spatial distribution as well as the depths of groundwater and the capacities of the pumping stations. During water sampling the coordinates of the sampling sites, the altitude of the sites above sea level, their microreliefs, and the depths of the wells were recorded by GPS and described in the registration book.

Sampling was performed in one-liter containers, immediately after the sampling water was sealed and stored under the cool conditions. The samples were labeled in the field during the sampling. In the laboratory the samples were stored in a refrigerator. The contents of Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-} ions and the pH were determined by means of laboratory ionometer (I-160 M), the TDS (total dissolved salts) was measured using the conductometer MARK 603.

Evaluation of Irrigation Suitability of Groundwater. To estimate the suitability of groundwater for irrigation purposes we used the following indices derived from the measured water quality parameters: sodium adsorption ratio (SAR), permeability index (PI), magnesium hazard (MH). The classification of irrigation water, based on these statistical and physicochemical parameters, was performed in accordance with international standards (Tab. 1).

Sodium Adsorption Ratio (SAR). The sodium hazard of irrigation water is defined by the relative and absolute concentrations of cations and is expressed in terms of SAR. The SAR values were determined using the following equation:

$$\mathrm{SAR}=\frac{\mathrm{Na}^{+}}{\sqrt{(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+})/2}},$$

where the concentrations of ions are expressed in *meq*/*L*.

There is a considerable relationship between the irrigation water SAR values and the extent to which sodium is attracted to the soil.

Permeability Index (PI). The permeability of the soil is affected by long-term use of irrigation water. It is influenced by Na^+, Mg^{2+}, Ca^{2+} and HCO_3^- contents of the soil. To assess the suitability of irrigation water the determination of PI is also important. The PI value was defined by the given equation:

$$PI=\frac{Na^{+}+\sqrt{HCO_3^{-}}}{Ca^{2+}+Mg^{2+}+Na^{+}}\,100,$$

where the concentrations of ions are expressed in *meq/L*.

Magnesium Hazard (MH). Szaboles and Darab (1964) [21] offered MH to assess the quality of groundwater used for irrigation. MH was calculated by the following equation:

$$MH=\frac{Mg^{2+}}{Mg^{2+}+Ca^{2+}}\,100,$$

where concentrations of cations are expressed in *meq/L*.

Table 1

The irrigation water classification according to the listed physicochemical andstatistical parameters

Classification pattern	Categories	Ranges	Description
SAR [22]	excellent	0–10	no sodium hazard
	good	10–18	low sodium hazard
	fair	18–26	harmful for almost all types of soils
	poor	>26	unsuitable for irrigation
PI [23]	class-I	>75	good for irrigation
	class-II	25–75	suitable for irrigation
	class-III	<25	unsuitable for irrigation
MH [21]	suitable	< 50	suitable for irrigation
	unsuitable	> 50	unsuitable for irrigation
Total dissolved salts, TDS, *mg/L*, USDA Salinity Laboratory classification [10]	excellent	<150	low salinity hazard
	good	150–500	permissible for irrigation
	fair	500–1500	doubtful for irrigation
	poor	>1500	unsuitable for irrigation

Results and Discussion. During groundwater sampling in Masis Region 27 observation sites were chosen, taking into account the natural climatic conditions of the area, the depths, capacities, spatial distribution of the wells used for irrigation, as well as the the soil types and the crops irrigated by water from these wells. The data concerning the depths and coordinates of the wells from which water was sampled and the results of studies of some physicochemical parameters of groundwater are presented in Tab. 2. The deepest well was found in the observation point 15 N-2 with a depth of 200 *m*, which also had high throughput and was used by many farmers of the community. The well with the least depth (6 *m*) and small capacity was registered in the observation point 04 Ha. Groundwater of mentioned well was used only for irrigation of a single homestead land. Such a pattern was observed at all observations points, namely, the wells with a depth of 54 *m* or more were of high capacity and their groundwater was to irrigate relatively large agricultural areas, while groundwater of wells with lesser depth predominately was of private use and irrigated agricultural land with an area of no more than 2000 m^2.

Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^- and CO_3^{2-} contents were studied, as the most dangerous ions for soil salinization, which are also used in the calculation of evaluation indices of irrigation water properties that are widespread in international practice.

Studies have shown that the maximal contents of all ions were observed in groundwater of the observation point 23-A-2, with the exception of K^+, the maximal content of which was observed in the groundwater of observation point 24-M-2.

The lowest contents of Na^+, Ca^{2+} and HCO_3^- ions were observed in groundwater of observation point 28-Sis-1, while the lowest contents of K^+ and Mg^{2+} – in groundwater of sites 16-Kh and 29-Sis-2, respectively. CO_3^{2-} ion was not detected in any groundwater sample. It should be noted that the following pattern was revealed during the research: the higher contents of studied ions were observed in groundwater from not too deep horizons compared to the groundwater from deeper horizons. But there was a slight deviation from this general pattern in the case of groundwater from observation points 10-R-1, 11-R-2 and 12-R-3 located in Ranchpar Village. In the mentioned sites, the groundwater was situated at a great depth, but also had relatively high contents of studied ions, which may be conditioned by hydrogeological characteristics of the area.

The allocation pattern of studied cations and anions in the groundwater of the study area by average values (*mg*/*L*) was as $Na^+>Mg^{2+}>Ca^{2+}>K^+$ and $HCO_3^- > CO_3^{2-}$ respectively. TDS in the investigated area varied in the range of 405–3183 *mg*/*L*. The groundwater in the investigated area belong to the water types from fresh to brackish [24]. According to the classification of USDA Salinity Laboratory, the groundwater of only 2 wells belong to good category and are permissible for irrigation (150–500 *mg*/*L*), while the groundwater from 16 wells belong to the fair category (500–1500 *mg*/*L*) and are doubtful for irrigation. In the remaining 9 wells the water belong to the poor category (>1500 *mg*/*L*) and are unsuitable for irrigation. The high TDS increases the osmotic potential in the soil and complicates the water absorption by plants.

The SAR value gives helpful information about the groundwater sodium hazard for plants and agricultural lands and is used to predict the threat of sodium accumulation in soil. The SAR values indicate the degree when the groundwater used for irrigation has an impact on cation-exchange reactions of soil. Sodium replaces the exchangeable calcium and magnesium and harms the soil structure by making it dense and impermeable for water and air. Therefore, the investigation of sodium concentration in the groundwater is needful given the suitability for irrigation. The classification of irrigation water based on SAR values is given in Tab. 1. SAR values of studied samples varied from 1.19 to 5.03 with an average value of 2.74 (Tab. 3). All groundwater samples quality fell in the excellent category and had no sodium hazard.

The permeability of the soil is influenced by the long-term usage of insufficient quality water, and the affecting ions are the Na^+, Ca^{2+}, Mg^{2+} and HCO_3^-. The PI values of the groundwater of Masis region wells ranged between 23.37 and 57.85 with a mean value of 45.05 (Tab. 3). Hence, except the sample 02-H, which that belongs to the Class III (unsuitable for irrigation), the remaining samples of the groundwater of Masis Region wells fell within the Class II, which indicated that the groundwater was suitable for irrigation purposes (Tab. 1).

Table 2

Coordinates of wells, depths of groundwater and results of some physicochemical analyses *

Sample number	Depth of wells	Coordinates	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-
01-H-1	96	N 40° 06,422′ E 044° 19,975′	818	85.7	6.36	88.5	100.8	256.2
02-H-2	18	N 40° 06,369′ E 044° 19,339′	1329	95	3.02	170	188.4	378.2
03-H-3	148	N 40° 06,359′ E 044° 19,916′	890	97	6.24	88	125.9	325.7
04-Ha	6	N 40° 07,162′ E 44° 22, 479′	939	126	10.13	66	73.5	341.4
05-Da	10.5	N 40° 06,373′ E 44° 25,046′	1244	133	18.1	121	126.9	366
07-Dash	10	N 40° 05,977′ E 44° 23,544′	771	113.5	24.7	71.2	58.3	302.1
08-Z	12	N 40° 05,451′ E 44° 23,619′	1148	163	24.6	85.4	94.9	438.9
09-M-1	15	N 40° 04,393′ E 44° 25,873′	1389	215	9.61	130	117.7	471
10-R-1	100	N 40° 01,737′ E 44° 21,785′	1850	312	13.5	138	160.7	534.4
11-R-2	95	N 40° 01,551′ E 44° 22,308′	1928	232	13.3	149	182.2	549
12-R-3	160	N 40° 01,470′ E 44° 22,274′	2256	277	12.3	189	205.7	622.2
14-N-1	100	N 40° 01,988′ E 44° 24,666′	762	83.6	8.54	62.7	75.1	292.8
15-N-2	200	N 40° 01,429′ E 44° 25,432′	569	78.2	5.47	47.4	50.2	248.4
16-Kh	16	N 40° 05,306′ E 44° 28,492′	812	92.2	2.68	120	126.9	317.2
17-Mar-1	13	N 40° 03,785′ E 44° 28,171′	1829	316	10.01	174	213.6	451.4
18-Mar-2	8	N 40° 03,544′ E 44° 28,159′	2600	386	6.32	178	238.5	488
19-Mar-3	18	N 40° 03,257′ E 44° 27,941′	1937	292	14.7	145	167.8	427
20-Dz-1	54	N 40° 02,740′ E 44° 28,257′	1364	208	10.47	93.2	110.7	414.8
21-Dz-2	16	N 40° 02,761′ E 44° 28,532′	2378	291	14.1	173	204.4	427
22-A-1	100	N 40° 02,140′ E 44° 28,003′	1158	175	10.33	77.2	105.8	353.8
23-A-2	20	N 40° 02,183′ E 44° 28,392′	3183	400	17.3	258	283.5	646.6
24-M-2	8	N 40° 04,242′ E 44° 23,555′	2352	328	32.1	106.7	128.9	646.6
25-Sip-1	150	N 40° 04,919′ E 44° 21,096′	870	84.5	7.44	107.1	83.7	366
28-Sis-1	100	N 40° 03,792′ E 44° 22,788′	405	59.7	4.94	38.4	42.7	155.2
29-Sis-2	150	N 40° 03,364′ E 44° 23,248′	444	69.6	5.9	40.8	38	184
30-SN-1	150	N 40° 04,604′ E 44° 24,415′	661	113.4	6.85	53	59.4	290.4
31-SN-2	10	N 40° 04,596′ E 44° 23,914′	791	126	8.28	64.7	67.2	341.6

* Concentrations of all ions and TDS were reported in *mg/L*, depth of wells in meters, CO_3^{2-} ion wasn't detected in any groundwater sample.

Table 3

Statistical representation of hydrochemical parameters characterizing the groundwater irrigation properties

Sample number	SAR	PI	MH	Sample number	SAR	PI	MH
01-H	1.47	34.89	65.50	17-Mar-1	3.77	40.90	67.17
02-H	1.19	23.37	64.88	18-Mar-2	4.42	43.05	69.07
03-H	1.55	34.16	70.45	19-Mar-3	3.90	45.22	65.86
04-Ha	2.52	52.63	64.99	20-Dz-1	3.43	50.82	66.44
05-Da	2.01	36.74	63.61	21-Dz-2	3.53	39.91	66.32
07-Dash	2.41	53.62	57.71	22-A-1	3.02	49.38	69.55
08-Z	2.87	50.71	64.94	23-A-2	4.07	38.29	64.68
09-M-1	3.27	47.27	60.14	24-M-2	5.03	57.74	66.82
10-R-1	4.26	48.81	66.00	25-Sip-1	1.48	38.26	56.57
11-R-2	3.00	40.00	67.08	28-Sis-1	1.57	51.90	64.95
12-R-3	3.30	39.44	64.46	29-Sis-2	1.88	57.85	60.82
14-N-1	1.68	44.72	66.63	30-SN-1	2.53	56.76	65.13
15-N-2	1.88	54.43	63.84	31-SN-2	2.61	54.81	63.38
16-Kh	1.39	30.55	63.80				

Mg^{2+} and Ca^{2+} are important ions for the growth of crops, but large amounts of magnesium have an adverse effect on the soil structure and may decline the crop yield. Such detrimental impact of irrigation water could be revealed by means of MH. All studied samples of groundwater from Masis Region wells according to this index fell within the unsuitable category (Tabs. 1, 3) and in case of prolonged irrigation with such groundwater the magnesium hazard on the soil could be detected.

Conclusion. Our studies have shown that groundwater used for the irrigation in Masis Region differs not only in its horizons, but also in its chemical composition. According to spatial distribution, groundwater with relatively high salinity is most commonly found in the eastern (Marmarashen, Jrahovit, Arevabuyr villages, and eastern part of Masis Town) and southern (Ranchpar Village) parts of Masis Region. But in the Ranchpar village area an increase in salt content observed parallel to the depth. Consequently, in order to prevent the soil salinization process or to impede its further deepening, for the irrigation of agricultural territories in Masis Region (especially in the eastern and southern parts) the use of groundwater from shallow horizons should be restricted as much as possible, and in Ranchpar village, where groundwater even from high depths has high salinity, it is required to find an alternative source of irrigation water. It was also found that the long-term use for irrigation of all studied groundwater does not present a sodium hazard for the soil, but may has a magnesium hazard, and only groundwater from observation point 02-H can have a detrimental effect on soil permeability.

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ՍՏՈՐԵՐԿՐՅԱ ՋՐԵՐԻ ՊԻՏԱՆԻՈՒԹՅԱՆ ԳՆԱՀԱՏՈՒՄԸ ՈՌՈԳՄԱՆ ՆՊԱՏԱԿՈՎ ԱՐԱՐԱՏՅԱՆ ԴԱՇՏԻ ԲԱՐՁՐ ՌԻՍԿԱՅՆՈՒԹՅԱՆ ՇՐՋԱՆՆԵՐՈՒՄ

Ամփոփում

Հողերի աղակալումը, պայմանավորված բնական և մարդածին գործոններով, լուրջ բնապահպանական խնդիր է Հայաստանի ոռոգվող գյուղատնտեսության կարևոր տարածք հանդիսացող Մասիսի տարածաշրջանում: Այս անբարենպաստ գործընթացը կանխելու համար գնահատվել է տարածաշրջանի ստորերկրյա ջրերի որակը գյուղատնտեսության ոլորտում օգտագործելու համար: Այդ նպատակով 27 հորից հավաքվել են ստորերկրյա ջրի նմուշներ և վերլուծվել համաձայն ստանդարտ փորձնական ընթացակարգերի` որակի կարևորագույն պարամետրերը որոշելու համար: Որակի չափված պարամետրերից հաշվարկվել են այլ քիմիական ցուցանիշներ, մասնավորապես նատրիումի ադսորբցիայի գործակիցը, թափանցելիության ցուցանիշը և մագնեզիումի վտանգը: Ուսումնասիրությունների ընթացքում առանձնացվել են ոռոգման համար լավ, թույլատրելի և ոչ պիտանի որակ ունեցող ստորերկրյա ջրերի տարածքներ: Ստացված արդյունքների համաձայն, Մասիսի տարածաշրջանում (հատկապես դրա արևելյան և հարավային մասերում) գյուղատնտեսական հողերի ոռոգման համար բարձր աղայնություն ունեցող ոչ մեծ խորությունների ստորերկրյա ջրերի օգտագործումը պետք է հնարավորինս սահմանափակվի, իսկ Ռանչպար գյուղում, որտեղ նույնիսկ մեծ խորությունների ստորերկրյա ջրերը ունեն բարձր աղայնություն, անհրաժեշտ է օգտագործել ոռոգման ջրի այլընտրանքային աղբյուր:

К. А. КАЗАРЯН

ОПРЕДЕЛЕНИЕ ПРИГОДНОСТИ ДЛЯ ОРОШЕНИЯ ПОДЗЕМНЫХ ВОД АРАРАТСКОЙ ДОЛИНЫ В РАЙОНАХ ВЫСОКОГО РИСКА

Резюме

Засоление почв, вызванное природными и антропогенными факторами, является актуальной экологической проблемой в Масисском регионе – одном из важных районов орошаемого земледелия в Армении. Для предотвращения этого неблагоприятного процесса было оценено качество подземных вод региона для использования их в сельском хозяйстве. Для этого из 27 скважин были отобраны пробы воды и проанализированы основные параметры качества в соответствии со стандартными опытными процедурами. Другие химические показатели, в частности коэффициент адсорбции натрия, индекс проницаемости и опасность магния, были рассчитаны на основании измеренных параметров качества. В результате исследований были выявлены районы с хорошим, допустимым и неподходящим качеством подземных вод для орошения. Согласно полученным результатам, для орошения сельскохозяйственных земель в Масисском регионе (особенно в его восточной и южной частях) использование сильно засоленных подземных вод с неглубоких горизонтов должно быть максимально ограничено, а в деревне Ранчпар, где подземные воды даже с больших глубин имеют высокую степень минерализации, для орошения необходимо использовать альтернативные источники воды.