N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 6, Number 444 (2020), 186 – 193 **https://doi.org/10.32014/2020.2518-170X.146**

UDC 504.4.054

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APPLICABILITY ASSESSMENT OF NATURAL WATERS IN IRRIGATION OF AGRICULTURAL LAND ON THE EXAMPLE OF THE VAKHSH RIVER AND ITS TRIBUTARIES

Abstract. The results of chemical analyses of the Vakhsh river and its tributaries and the calculations of the main criteria for the water applicability for irrigation purposes are presented: the proportion of sodium cations capable of absorption, dissolution, ion exchange, and the proportion of magnesium. It was found that the waters of the Vakhsh river and its tributaries (Kyzylsu, Muksu, Obikhingou and Surkhob) are favorable for irrigation of agricultural land. On the values of the magnesium cations ratio to calcium cations the Vakhsh river and tributaries water correspond to the first class of «soft waters». It is shown that due to the surface and underground water exchange, underground water reservoirs are enriched by cations of alkaline and alkaline earth elements. The underground water reservoirs of the Vakhsh tributaries basin on the water quality terms are also suitable for irrigation purposes.

Key words: agriculture, underground water, solubility of cations, adsorbtion irrigation.

Introduction. The Vakhsh River is one of the main tributaries of the transboundary river Amu Darya that is formed by the confluence of the Surkhob and Obikhingou rivers.

The Vakhsh river basin by meteorological characteristics belongs to a dry climate with an annual rainfall of 143-297 mm and the distribution of the average annual precipitation by the seasons is as follows: in winter 40%, 48% in spring, 1.5% in summer and more than 10% in autumn [1].

The Vakhsh river by 691 km (from source to mouth) with a basin area of 39 160 km^2 is characterized by glacial-snow fed i.e. more than 40 % of the flow in the flood is meltwater glaciers.

The Vakhsh river basin potential energy resources are 15.0 Th. MWt by an electric energy generation of 53.4 TWt·h/year. From it more than 9.0 Th. MWt and 35.4 TWt·h/year of electric energy generation are correspond only to Vakhsh river [2]. By improving water quality and regulating part of the flow of the Amu Darya river, the Rogun Hydropower station will allow 90% irrigation of the Amu Darya basin on an area of 4.6 million ha and additionally develop more than 480 thousand hectare of land in the lower reaches. [3].

Water pollution is the leading cause of death and disease worldwide. Every year around the world, 6.000 children die from infectious diseases and 30 million people die from cancer caused by drinking contaminated water [4]. In developing countries, 80% of human diseases are associated with drinking water pollution.

Water quality deals with the physical, chemical and biological characteristics of water in relation to all other hydrological properties. The characteristics of water quality have become important in water resources planning, development for drinking, industrial, and irrigation purposes [5]

A number of indicators regulates the quality of water used in irrigation in order not to destroy the agrochemical properties of the soil.

The major concerns in terms of water quality and quantity are due to its inadequate distribution on the surface of earth and the rapid declining of fresh useable water [6]. Anthropogenic activities within river basins, erosion, and atmospheric depositions were also the main negative impacts on the water quality of most the reservoirs [7].

A wide review of the literature on the selection of optimal indicators for a comprehensive assessment of surface water quality and compelling facts about the need for systematic monitoring of the dynamics of the spread of pollutants for an objective assessment of water quality and in particular transboundary water basins and the establishment of criteria for assessing the quality of surface waters taking into account natural features are presented in [8,9].

The agriculture success is highly dependable on the quality of water applied in an agriculture area. Due to the application of poor or hazardous quality water the agriculture land/soil is affected and damages the crop yield in several waysThe presence of metals in irrigation water also has adverse effects on crop production. In addition, high concentration of salts can change the plant nutrients balance in the soil meanwhile some salts are toxic to certain plants [6,10].

Irrigation water quality alone is not sufficient to assess the potential salinity and hazards that irrigated agriculture may face. The concept of quality is not singular, but multiple. They can be so different that they can be compatible with each other, so it makes no sense to talk about quality as a single factor. It is more correct to talk about a high-quality profile. This means presenting multiple indicators instead of single ones in order to achieve a better understanding of the type of water. The quality profile is not a single one; it will also depend on the severity of the problem [11].

However, even water with considerably high salt concentration can be used for irrigation without endangering soil productivity, provided selected irrigation management. The key point is how to maintain existing salt balance in plant root zone [12].

Thus, comprehensive river water quality monitoring is a helpful tool not only to evaluate the suitability of surface water for irrigation, but also to ensure an efficient management of water resources and the protection of aquatic life [13] Therefore, the monitoring of environmental parameters is one of the highest priorities in the evaluation of environmental status of water resources and in environmental protection policy [14]. Thus, it is imperative to have reliable information on the characteristics of water quality for assessing its safety for irrigation as well as an effective pollution control and water resource management [15]. These findings can be explained by the geology of the study area, in particular the variation of the mineralogical composition of the bedrock from upstream to downstream. A similar impact of the bedrock composition to the water quality has been also described by [16]. It is commonly known that the ionic composition of water is the result of several factors during water-rock interaction [17].

In fact, changes in the geochemical characteristics of salt waters can be caused by the interaction of water and rocks, including exchange reactions with clay minerals, adsorption on clay minerals, and carbonate dissolution – precipitation [18]. In particular, the main factors controlling the mineralization of water are the mineral dissolution of well-soluble salts and, no less important, ion exchange. The high content of chloride and sodium water is mainly due to the dissolution of anhydrite, gypsum, and halite [19, 20].

To assess the quality of water for irrigation purposes, an alkaline hazard is widely used, expressed by the coefficient of adsorption of sodium cations (CA), the percentage of sodium cations, the percentage of solubility of sodium, the coefficient of exchange of sodium, the coefficient of magnesium.

The purpose of this work is a comprehensive chemical analysis and determination of the degree of applicability of the waters of the Vakhsh river and its tributaries for irrigation purposes.

Objects and Methodology. The scheme for sampling water from the Vakhsh River and its tributaries is shown in figure 1.

After preserving the samples, physical and chemical analyses of water were performed in the laboratory using a «TaLab» Photocolorimeter at a temperature of 19-20 °C and a relative humidity of 44-49%.

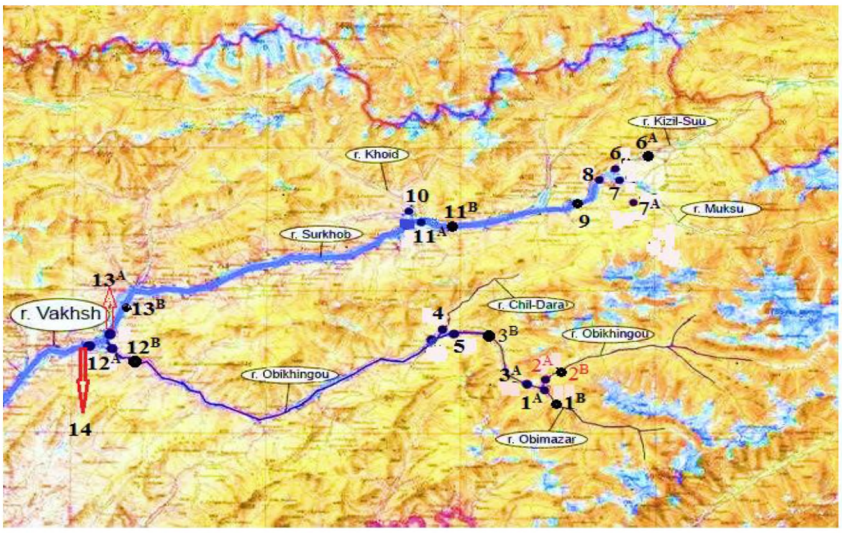

Figure 1 – Water sampling scheme from the Vakhsh river and its tributaries

At chemical analyses interpretation of results was guided by the normative document «Sanitary and epidemiological requirements to water sources, water intake sites for drinking purposes, drinking water supply and places of cultural and domestic water use and security of water facilities» (Order of the Minister of national economy of the Republic of Kazakhstan, March 16, 2015 No. 209). In addition, state standards were relevant: Na^+ (State standart 26449.1-85, п.17.1), K^+ (State standart 26449.1-85, п. 18.1), Ca^{2+} (State standart 26449.1-85, п. 11.1), Mg^{2+} (State standart 26449.1-85, п.12), NO_3^- (State standart 33045-2014).

Results and discussion. The results of the Na^+ adsorption ratios and the percentage of Na+ for the waters of the Vakhsh river and its tributaries (Kyzylsu, Muksu, Obikhingou, and Surkhob) are presented in figure 2 and figure 3, respectively.

The sodium adsorption ratio (SAR) was calculated by use of [21]:

$$SAR = \frac{Na+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (1)$$

The percentage of Na^+ is determined [22]:

$$\%Na^+ = \frac{(Na^+ + K^+)\cdot 100}{(Ca^{2+}+Mg^{2+}+Na^+ + K^+)} \quad (2)$$

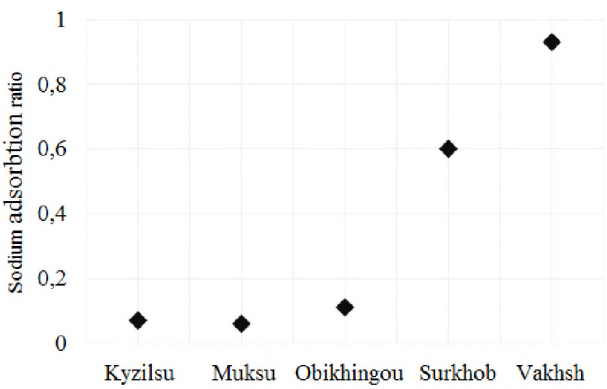

Figure 2 – Sodium adsorption ratio of the Vakhsh river and its tributaries

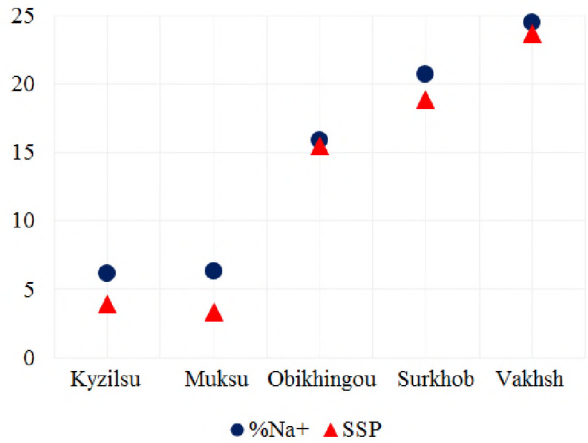

Figure 3 – The percentage Na^+ and soluble sodium percentage (SSP) of the Vakhsh river and tributaries

It can be seen from figure 2 that on the upstream tributaries of the Vakhsh river sodium adsorption ratio is not significant compared to the Vakhsh river and its tributary of the Surkhob river. The explanation of these phenomena can be found in figure 3 that shows the percentage of Na^+ in the waters of the Vakhsh river and its tributaries.

The content of sodium cations in the waters of the Kyzylsu and Muksu rivers in comparison with the Vakhsh and Surkhob rivers is much lower (figure3). Therefore, due to the low Na^+ content in the Kyzylsu and Muksu rivers ion-exchange reactions proceed weakly.

Another important parameter characterizing the applicability of water for irrigation purposes is the solubility sodium ratio (SSR) determined as [20]:

$$SSR = \left(\frac{Na^+}{Na^+ + Ca^+ + Mg^{2+}}\right) \cdot 100 \quad (3)$$

The percentage of soluble sodium calculation results by use of (3) for the Vakhsh river and its tributaries are shown in figure 3. Naturally, at small content of elements in the water, an insignificant percentage of its dissolution will be observed which is evidenced by the location of the values of soluble Na^+ for the Vakhsh river and its tributaries (figure 3).

The Mg^{2+} cation content is also an important indicator for determining the applicability of water for irrigation purposes.

Magnesium deteriorates soil structure particularly when waters are sodium dominated and highly saline. The Mg-ratio determined by use equation [23]:

$$Mg\text{-}ratio = \frac{(Mg^{2+}) \cdot 100}{(Ca^{2+} + Mg^{2+})} \quad (4)$$

Magnesium hazard value of more than 50 % would adversely affect the crop yield as the soils become more alkaline [22].

The Mg^{2+} ratio in the waters of the Vakhsh river and its tributaries as shown in figure 4 insignificant and does not reach 50%.

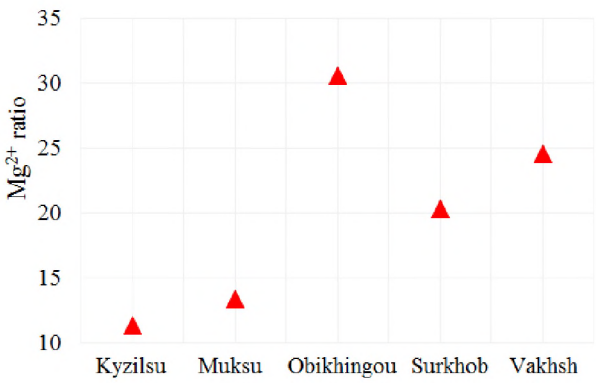

Figure 4 – Magnesium ratio of the Vakhsh river and its tributaries

The highest value is observed at the Obikhingou river exceeding more than 30% (figure 4). To explain the observed phenomenon, refer to table 1 that shows the content of alkaline and alkaline earth cations in the corresponding river waters.

Cation content in the waters of the Vakhsh river tributaries

Cations	Unit	Rivers			
		Kyzilsu	Muksu	Obikhingou	Surkhob
Na^+	mEq/dm^3	0.073	0.058	0.033	0.762
K^+	mEq/dm^3	0.059	0.056	0.002	0.094
Ca^{2+}	mEq/dm^3	1.786	1.456	0.125	2.613
Mg^{2+}	mEq/dm^3	0.228	0.225	0.055	0.665

From a comparison of the data presented in table, it follows that the Obikhingou river is characterized by the lowest content of cations of alkaline, alkaline earth elements and especially small values of Ca^{2+} according to (4) lead to an increase in the proportion of Mg^{2+} cations in the waters of the Obikhingou river.

The analysis of the chemical composition of river water and ground water in the river basins of Tajikistan revealed the processes of enrichment of underground water reservoirs by chemical elements of river water [24]. The sodium adsorption ratio (SAR) values for the surface water of the tributaries of the Vakhsh river (Kyzilsu, Muksu, Obikhingou, and Surkhob) and groundwater of the basin corresponding rivers is shown in figure 5. The percentage of Na+ in the groundwater of the Kyzylsu, Muksu, Obikhingou and Surkhob river basins and comparing it with values for the corresponding rivers are presented on the figure 6. The content of Na+ in groundwater of the three tributaries of the Vakhsh river (Kyzylsu, Obikhingou and Surkhob) is relatively lower than the surface, and in the case of Muksu appears anomalous, i.e. in the surface water Na+ is almost three times less than underground.

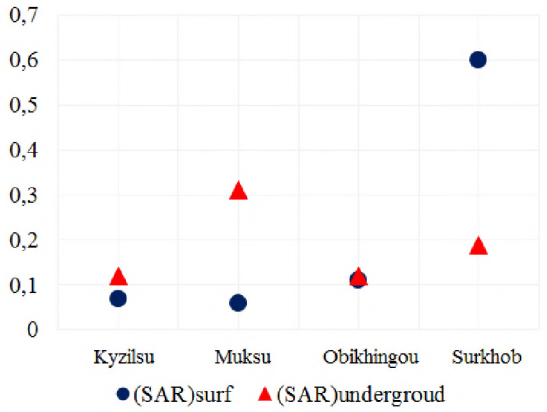

Figure 5 – Sodium adsorption ratio of the Vakhsh river tributaries and underground waters of rivers basins

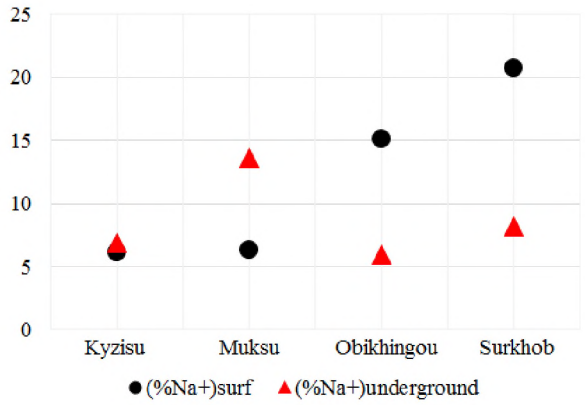

Figure 6 – The percentage Na^{+} of the Vakhsh river tributaries and underground waters of rivers basins

This naturally leads to large values of sodium ratio capable to dissolution (figure 7) and ion exchange (figure 8).

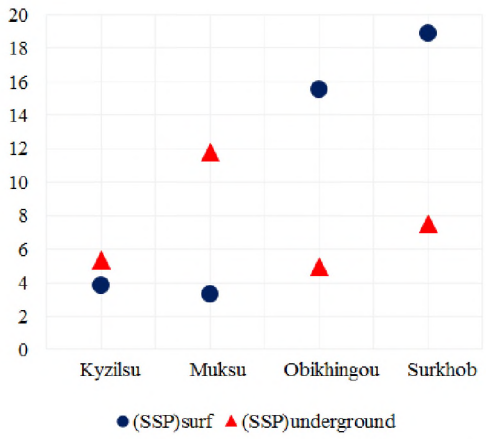

Figure 7 – The soluble sodium percentage (SSP) of the Vakhsh river tributaries and underground waters of rivers basins

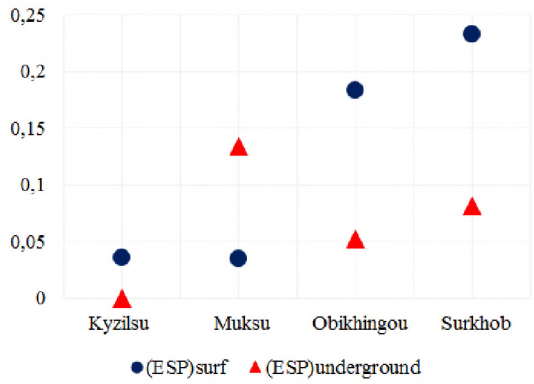

Figure 8 – The exchangeable sodium ratio of the Vakhsh river tributaries and underground waters of rivers basins

Conclusion. It was found that the concentration of cations in the Vakhsh river and its tributaries does not fit within any regularity and is mainly determined by the processes of rock washing out by the flow of the corresponding rivers. On the upstream of the Vakhsh river tributaries (Kyzylsu, Muksu) the share of

sodium cations adsorption is not significant compared to the Vakhsh river and tributary Surkhob river, and due to the low content of Na^+ in the Kyzylsu and Muksu rivers ion exchange reactions are weak and, of course, the proportion of sodium capable of dissolution is insignificant. A high proportion of Mg^{2+} in the waters of the Obikhingou river was found to be associated with low levels of Na^+, K^+,Ca^{2+}.

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ВАХШ ӨЗЕНІ МЕН ОНЫҢ САЛАЛАРЫ НЕГІЗІНДЕ АУЫЛШАРУАШЫЛЫҒЫ ЖЕРІН СУАРУДА ТАБИҒИ СУДЫҢ ҚОЛДАНЫЛУЫН БАҒАЛАУ

Аннотация. Судың сапасы – судың белгілі бір суды пайдалану түрлеріне жарамдылығын анықтайтын су құрамы мен қасиеттерінің сипатамасы. Судың сапасын бақылау – су сапасының көрсеткіштерінің белгіленген нормалар мен талаптарға сәйкестігін тексеру. Табиғи суды ирригациялық мақсатта пайдалану тиімділігін арттыру және олардың сапасын бақылау – су ресурстарын сақтаудағы басым бағыттарының бірі болып саналады. Осыған байланысты судың суаруға жарамдылығын кешенді бағалауды қамтамасыз ету үшін зерттелетін аумақтағы санитарлық-гигиеналық жағдайды және қоршаған ортаны қорғауды қамтамасыз ету қажеттілігін ескере отырып, су сапасын анықтайтын агрономиялық, техникалық және экологиялық өлшемдер негізге алынды.

Мақалада трансшекаралық Амудария өзенінің негізгі саласы, Сурхоб және Обихингоу өзендерінің қосылуы нәтижесінде пайда болған Вахш өзені суының химиялық талдау нәтижелері келтірілген. Вахш өзенінің ауданы мұз және қар жамылғысымен сипаттағанда 39 190 км^2 қамтиды, ұзындығы – 691 км. Вахш өзені алабының гидроэнергетикалық әлеуеті жылына 50 ТВт-тан асады. Вахш өзенінің ирригациалық потенциалы жақсы, қазіргі уақытта 15 ауданның суармалы жерлерін сумен қамтамасыз етеді және қосымша 480 мың гектардан астам жерді игере алады. Сонымен қатар, Тәжікстан Республикасының сушаруашылығында ауылшаруашылығының суармалы егіншілігі мен энергетика қажеттілігіне тұтынған су көлемі 92% қамтыса, ал өнеркәсіп және коммуналдық шаруашылыққа 4 % жұмсалады. Сондай-ақ суару үшін су жарамдылығының негізгі критерийлерінің есебі жүргізілген: натрий катионының адсорбцияға, ерітуге қабілетті қатынасы, иондық алмасу және магний қатынасы. Вахш өзені мен оның салаларының (Қызылсу, Мұксу, Обихингоу және Сурхоб) сулары ауылшаруашылығы алқаптарын суаруға қолайлы екендігі анықталды. Сонымен бірге, Вахш өзені салаларының жоғарғы ағысында өзеннің өзімен және оның Сурхоб саласымен салыстырғанда натрий адсорбциясының коэффициенті аз болатындығы анықталды. Қызылсу және Муксу өзен суларындағы натрий катионының құрамы Вахш және Сурхоб өзенімен салыстырғанда едәуір төмен, бұл ион алмасу реакциясының әлсіз жүруінің негізгі себебінен болады. Магний катиондарының кальций катиондарына қатынасының мәні бойынша Вахш өзені мен оның салаларының суы бірінші класқа «жұмсақ суға» жатады. Жерүсті және жерасты су алмасу есебінен жерасты суы сілтілік және сілтілік жер элементтері катиондарымен байытылатыны көрсетілген. Сондай-ақ Вахш өзені алабының жерасты суының сапасы суаруға жарамды.

Вахш өзені мен оның салаларының суындағы катиондар концентрациясы қандай да бір заңдылыққа сәйкес келмейді және негізінен ол өзендер ағынымен тау жыныстарының шайылу процестері арқылы анықталды.

Түйін сөздер: ауылшаруашылығы, жерасты суы, катиондар ерігіштігі, адсорбция, суару.

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ОЦЕНКА ПРИМЕНИМОСТИ ПРИРОДНЫХ ВОД В ОРОШЕНИИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЗЕМЕЛЬ НА ПРИМЕРЕ РЕКИ ВАХШ И ЕЕ ПРИТОКОВ

Аннотация. Качество воды – характеристика состава и свойств воды, определяющая пригодность ее для конкретных видов водопользования. Контроль качества вод – проверка соответствия показателей качества вод установленным нормам и требованиям. Повышение эффективности применения природных вод в ирригационных целях и контроль их качества – это приоритетные направления в сохранении водных

ресурсов. В этой связи для обеспечения комплексной оценки применимости качества воды для орошения были учтены агрономические, технические и экологические критерии, которые определяют качество воды с учетом необходимости обеспечения безопасности санитарно-гигиенической обстановки на исследуемой территории и охраны окружающей среды.

Таким образом, в статье представлены результаты химических анализов воды одной из главных притоков трансграничной реки Амударьи, образованной слиянием рек Сурхоб и Обихингоу реки Вахш и ее притоков. Площадь реки Вахш, характеризуясь ледниково-снежным покровом, составляет 39 190 км^2, а ее длина – 691 км. Гидроэнергетический потенциал бассейна реки Вахш составляет более 50 ТВт.ч/год. Река Вахш имеет хороший ирригационный потенциал, в данное время обеспечивает водой орошаемые площади 15- ти районов и дополнительно может освоить более 480 тыс.га. При этом в водном хозяйстве Республики Таджикистан на нужды сельского хозяйства с орошаемым земледелием и в энергетике расходуется 92% объема потребляемой воды, а на промышленность и коммунальное хозяйство – 4%. Выполнены также расчеты основных критериев пригодности воды для орошения: соотношение катионов натрия, способных к адборбции и растворению, ионный обмен, соотношение магния. Установлено, воды реки Вахш и ее притоков (Кызылсу, Муксу, Обихингу и Сурхоб) благоприятны для орошения сельскохозяйственных угодий. При этом выявлено, что в верховье притоков реки Вахш коэффициент адсорбции натрия незначителен по сравнению с самой рекой и ее притоком Сурхоб. Содержание катионов натрия в водах рек Кызылсу и Муксу по сравнению с реками Вахш и Сурхоб значительно ниже, что явилось основной причиной слабого течения ионнообменной реакции. По значениям отношения катионов магния к катионам кальция вода реки Вахш и ее притоков соответствует первому классу «мягких вод». Показано, что за счет поверхностного и подземного водообмена подземные воды обогащаются катионами щелочных и щелочноземельных элементов. Подземные воды бассейна притоков Вахша по качеству воды также пригодны для орошения.

Установлено, что концентрация катионов в реке Вахш и ее притоках не укладывается ни в какие закономерности и определяется в основном процессами вымывания горных пород потоком соответствующих рек.

Ключевые слова: сельское хозяйство, подземные воды, растворимость катионов, адсорбция, орошение.

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