Bulgarian Journal of Agricultural Science, 25 (Suppl. 2) 2019
Agricultural Academy

Using brackish water to irrigate vegetable and fodder crops

Luiza Khasanova[1*], Rafil Abdrakhmanov[2], Radik Mustafin[1], Bakhytgaley Batanov[1], Nikolai Kavelin[1]

[1]*Bashkir State Agrarian University, 450001 Ufa, Russian Federation*
[2]*Russian Academy of Science, Ufa Scientific Center, Institute of Geology, 450077 Ufa, Russian Federation*
[*]*Corresponding author:* luizamaratowna@yandex.ru

Abstract

Khasanova, L., Abdrakhmanov, R., Mustafin, R., Batanov, B., & Kavelin, N. (2019). Using brackish water to irrigate vegetable and fodder crops. *Bulgarian Journal of Agricultural Science, 25* (Suppl. 2), 129–139

The Republic of Bashkortostan, being a major producer of agricultural products, is a risk farming area. Irrigation can significantly reduce these risks and increase crop yields. In western Bashkortostan, there is a lack of fresh water, so irrigation can be based on groundwater (fresh and brackish). The given paper analyzes the experience of irrigating perennial grasses and vegetable crops with brackish waters of different ion and salt composition. It estimates the irrigation properties of different types of natural waters by a number of empirical and natural methods. It is established that when there is drainage, sulphate calcium brackish waters can be successfully used even on heavy loamy and clay soils. In conditions of poorly drained solids, composed of poorly percolating rocks, it is necessary to arrange artificial drainage. In some cases, irrigation with brackish waters did not lead to soil salination but contributed to salt removal. The paper defines sources of impact on the underground hydrosphere in the areas of livestock waste water utilization as well as areas affected by oil extraction.

Keywords: irrigation; brackish groundwater; mineralization; soil solutions; irrigation properties; soil salinity; crop yields; irrigation rates; vegetable crops; fodder crops

Introduction

Irrigation farming is vital for increasing crop yields. It plays a particularly important role in cultivation of sugar beet, cotton plant, rice and vegetables. The yield of grain crops can grow 2-3 times (Pang et al., 2015; Rashed, 2016).

The economic feasibility of irrigation is evident in marginal lands. The Republic of Bashkortostan, being a risk farming area, is characterized by aridity of a large part of its territory. It has a certain impact on agricultural production indicators. Thus, they decreased to the level of the previous year during drought periods (1975, 1998, 2010, 2012). During these periods, agricultural producers experienced a serious shortage of working capital. They were forced to reduce the number of livestock, and, therefore, were not able to carry out expanded reproduction.

As of January 1, 2015 the area of irrigated land in Bashkortostan was 38 292 ha. Most of it is in good condition. Some part of it is in satisfactory condition. It should be noted that in 1991 irrigation was carried out on the area of 140 thousand ha with gross output being twice, two and a half times higher than the cost of gross output from the equivalent area of non-irrigated lands (Batanov, 2004). However, the dynamics of climate change leads to a reduction in freshwater resources (Ronco et al., 2017). Currently many countries have gained extensive experience in irrigation with brackish waters.

Foreign studies on brackish water irrigation (USA, Israel, Algeria, Morocco, Tunisia, Italy, India, China and others) have shown that a number of vegetables, grain and other crops can be irrigated with water having 1.5-2.0 to 5.0-8.0 g/l mineralization. As the result there are high yields often being higher when watering crops with fresh water.

According to the results of the Texas A & M University studies (J. Tahtouh, R. Mohtar, R), brackish ground water (BGW) is potentially attractive with higher shortage of fresh water worldwide (Tahtouh et al., 2019). Claims of some authors (N. Uri, Israel) about irrigation water rich in salt being one of the main causes of salination of arable lands are being challenged (Nachshonm, 2018).

Thus, the conducted analysis of limy clay soils in West Texas on the texture, salinity, acidity and carbon content indicates no problems (Tahtouh et al., 2019). Moreover, irrigation with treated waste water (TWW) also provides a positive conclusion with minor differences in the analysis results compared to BGW. Therefore, TWW and BGW are considered to be a viable replacement for freshwater irrigation in arid and semi-arid regions. A number of scientists consider that brackish ground water desalinated with reverse osmosis (RO) can be used to prevent soil salination if irrigation is planned (Sivakumar et al., 2015; Ozturk et al., 2018).

The issue of applying groundwater of higher mineralization is complex. In addition to the problems of soil science it covers a range of issues from the field of hydrogeology, agriculture, land reclamation and other sciences.

Special farm practices that provide “permanent living soil cover”, such as perennial grasses, farm forestry make it possible to improve the management of underground water resources (Sultanova et al., 2018). These methods increase the hydrological function of the soil, thereby preserving the ecological potential of the environment.

Applying recycling water being often of high salinity for landscape irrigation is very common in some countries (Wang et al., 2017) (China -34%). When irrigation methods are complied, additional nutrients of reclaimed water provide better turf quality due to the reinforced vegetation root system. The latter can perform a reinforcing action as well (Mustafin et al., 2018) thereby protecting the soil. Thus this practice is considered as environmentally desirable. It is expected that reclaimed water will be used not only for farming but also for landscape irrigation and urban use, as traditional water supply is becoming increasingly limited.

The relevance of our research is associated with the strong limitation and extreme unevenness of the distribution of fresh surface and groundwater resources in the Republic of Bashkortostan. As a result, the Bashkir Cis-Urals with the developed agro-industrial production is experiencing an acute shortage of fresh water. Thus, in many areas of western Bashkiria, groundwater of higher mineralization with abundant reserves can serve as the main source of irrigation water.

Changes in the properties of groundwater in the Cis-Urals under the effect of applied livestock and oil extraction waste water (Abdrakhmanov & Khasanova, 2018) as well as using these waters for irrigation have not been previously considered.

Materials and Methods

The studies were conducted in the western part of Bashkortostan, the total reserves of brackish waters are given in Table 1 (Abdrakhmanov, 2005).

Chemical composition of groundwater in the study areas, currently formed under the active influence of man-made processes, is very diverse both in composition of salts and in the level of mineralization (Table 2).

The research target was irrigated soils of the Cis-Urals, located in four districts – Ufa (140 ha, Fig. 2a), Aurgazy (100 ha, Fig. 3a), Diurtiuli (25 ha) and Sterlitamak (450-500 ha, Fig. 5).

Soil pits were laid in the most representative places of irrigated areas and dryland to a depth of 140-150 cm to the parent rock. Soil samples were taken every 25 cm. Water extract was analyzed on the basis of the Industry standard OST 46-52-76 methods of agrochemical soil analysis.

Determination of chemical composition of water extracts and groundwater for soil salination

The method is based on the extraction of soluble salts from the soil by water at relationship 1:5 Soil/Water fol-

Table 1. Natural reserves of ground brackish waters in western Bashkiria

Districts	Area km^2	Average power of water-bearing deposits, m	Water return	Natural reserves, billion m^3		Yield factor, million m^3/km^2	
				1-3, g/l	More than 3, g/l	1-3, g/l	More than 3, g/l
I	1100	15	0.2	3.3	–	3.0	–
II	1400	10	0.15	2.1	–	1.5	–
III	4100	20	0.15	12.3	–	3.0	–
IV	5200	60	0.015	1.5	3.1	0.3	0.6
V	26500	40	0.008	3.1	5.3	0.1	0.2
VI	4700	50	0.02	4.7	–	1.0	–
Total	43000			27.0	8.4		

Table 2. Chemical composition of brackish groundwater in the study areas

Sample section	Ingredients, mg/l; mg-Eq; %-Eq											pH
	HCO_3^-	SO_4^{2-}	CL^-	NO_2^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na+	K+	Na+, K+	NH_4^+	
1	2	4	5	6	7	8	9	10	11	12	13	14
The Urshak river, Bulgakovo settlement	256.2 4.2 14.3	1165 24.25 82.4	34.2 0.96 3.3	– – –	– – –	420 21.0 71.4	61.0 5.0 17.0	– – –	– – –	78.6 3.42 11.6	– – –	– – –
The Aurgaza river, Sultanmuratovo settlement	292.8 4.8 15.0	1253 26.1 81.8	35.50 1.00 3.2	– – –	– – –	516.0 25.75 80.7	54.72 4.50 14.1	37.9 1.65 5.2	– – –	– – –	– – –	– – –
Irrigation water of pig raising farm, Roschinsky settlement	580 9.51 37.4	12.4 0.26 1.0	553.3 15.6 61.4	0.4 0.01 0.04	2.8 0.05 0.2	98.2 4.9 19.3	28.0 2.3 9.1	111 4.83 19.0	44.3 1.13 4.5	– – –	220 12.19 48.1	7.6

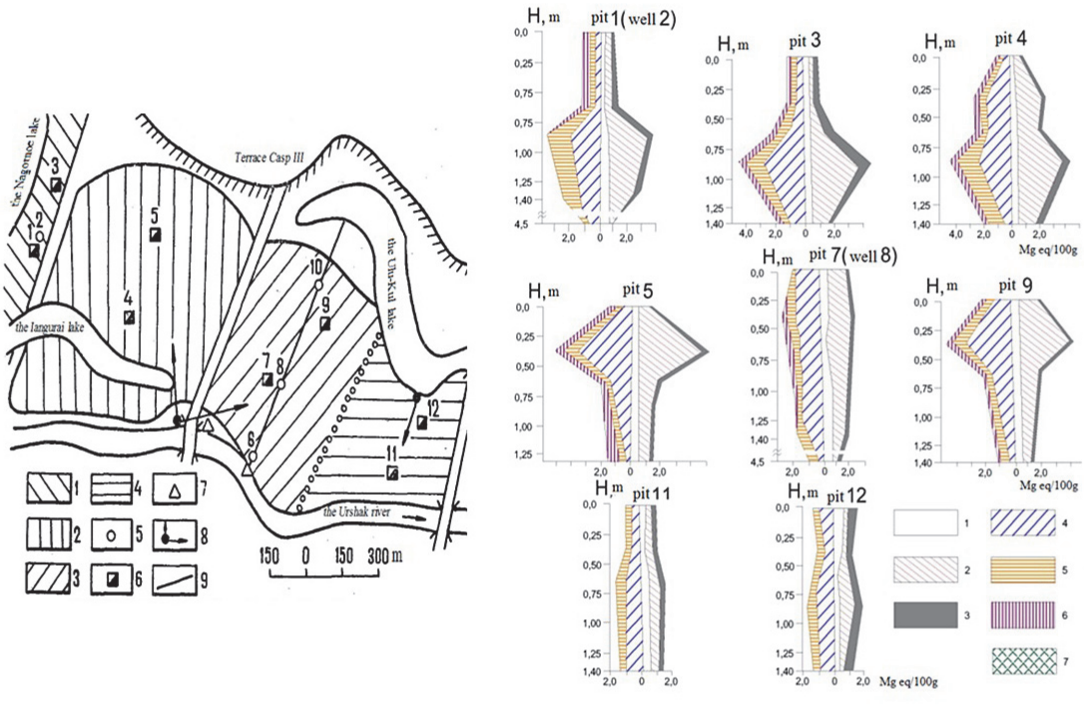

Fig. 2. Irrigation in the Urshak river valley: *a*) the scheme of the plot (*1* – non-irrigated land; *2* – land irrigated from the Urshak river for 10 years; *3* – the same for 20 years; *4* – land irrigated from the Ulu-Kul lake; *5* – well; *6* – pit; *7* – source; *8* – pumping station; *9* – profile line); *b*) soil salt profiles (ions: *1* -bicarbonate; *2* – sulphate; *3* – chloride; *4* – calcium; *5* – magnesium; *6* – sodium and potassium; *7* – nitrate)

lowed by finding ions in the studied extract CO^{2-}_3 , HCO^-_3 , Cl^- , Ca^{2+} , Mg^{2+} , Na^+, K^+, SO^{2-}_4.

Soil samples were air-dried, dispersed and passed through a sieve with round holes 1 mm in diameter. To get a water extract to the soil sample (weight 30 g), 150 ml of distilled water was dosed; the resulting suspension was filtered and extracted for analysis.

An analysis to determine CO^{2-}_3 and HCO^-_3 ions was carried out on the basis of successive titration of water extract with sulfuric acid solution first to pH 8.3 and then to pH 4.4. The CL^- ion was found by mercurimetry based on the titration of chloride ions with mercuric nitrate (II). As the result $HgCl_2$ compound with a low degree of dissociation appears. The applied trilonometric method to determine Ca^{2+} ion is

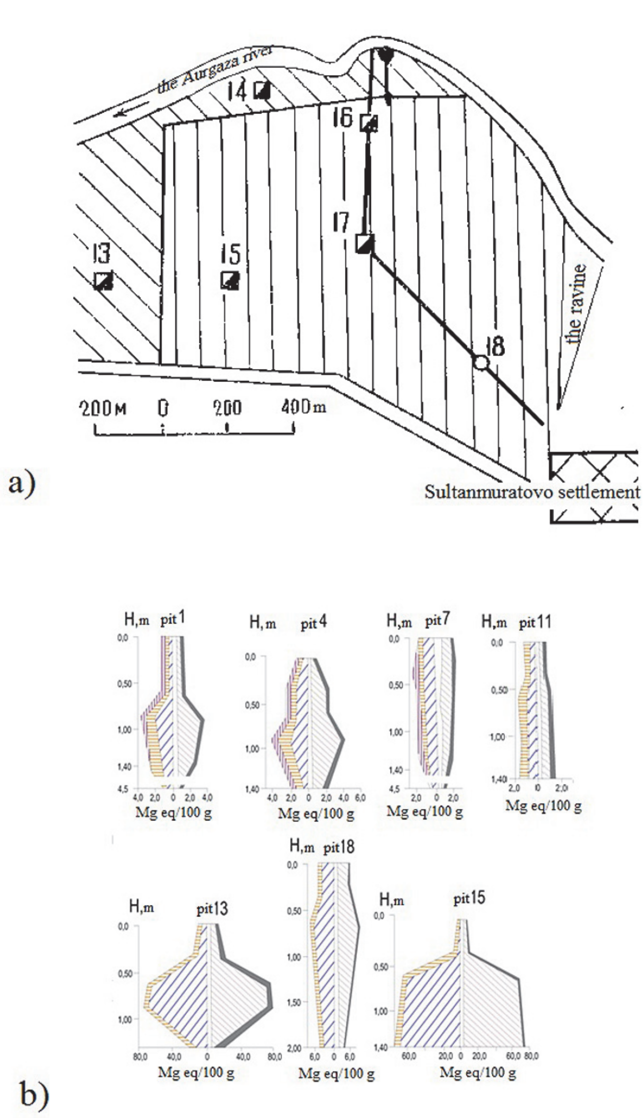

Fig. 3. Irrigation in the Aurgaza river valley:
***a*) the scheme of the site;**
***b*) soil salt profiles (refer Fig. 1 for legend)**

based on the titration of calcium ions by trilon B in a highly alkaline medium in the presence of murexide as a metal indicator. The content of Mg^{2+} ions was calculated with the trilonometric method of determining the amount of Ca^{2+} and Mg^{2+} ions. Na^{+} and K^{+} ions were found by the flame photometryic principle, SO^{2-}_{4} ions by the weight method of sulphate ion deposition by barium chloride and by weigh-

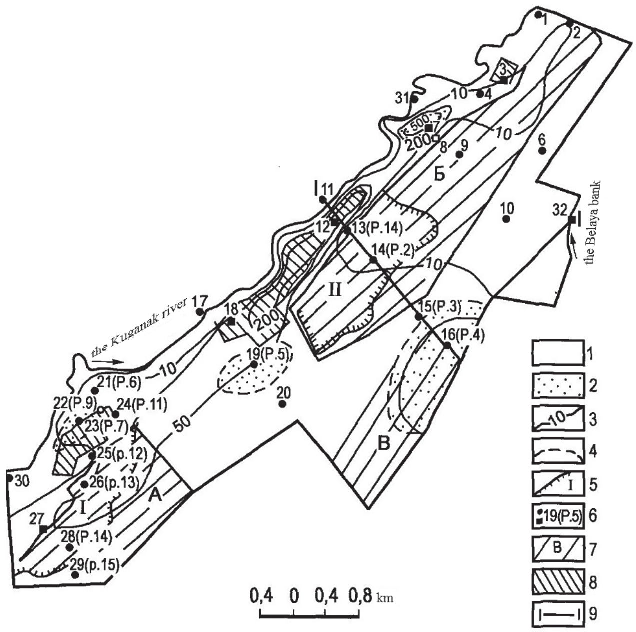

Fig. 5. Hydrogeochemical map of the site irrigated with wastewater of the pig raising farm (Diurtiuli district, Roshchinsky village) (Abdrakhmanov, 2005)

ing the heat-treated sediment in the form of $BaSO_4$. To find the total amount of water-soluble substances (dry residue) the method based on the gravimetric estimation of water-soluble substances after extract sample evaporation by heated bath.

Irrigation properties of water are examined based on the methods considering the permissible limits of soluble salts in water by Stebler (Fig. 1), the American method (SAR), the method of Mozheiko and Vorotnik (K), the method of Antipov-Karataev and Kader, the method of Budanova (K_1 K_2 K_3) (Kostyakov, 1951; Posokhov, 1985; Gorev & Peleshenko, 1991; Abdrakhmanov, 2005; Zanosova & Molchanova, 2017).

According to the studies of Kostiakov at low watering and irrigation rates water with salt content up to 1-3 g/l can be applied on well-drained soils with the required farm machinery (Abdrakhmanov, 2005).

Salts of monovalent ions Na_2CO_3, NaCl, Na_2SO_4 at a ratio of 1:3:10 respectively have a particularly adverse effect (Posokhov, 1985).

Calcium sulphate ($CaSO_4$) base water cannot be rejected for irrigation purposes in contrast to hydrogen carbonate salts ($NaHCO_3$) base water. In this case, you should look for

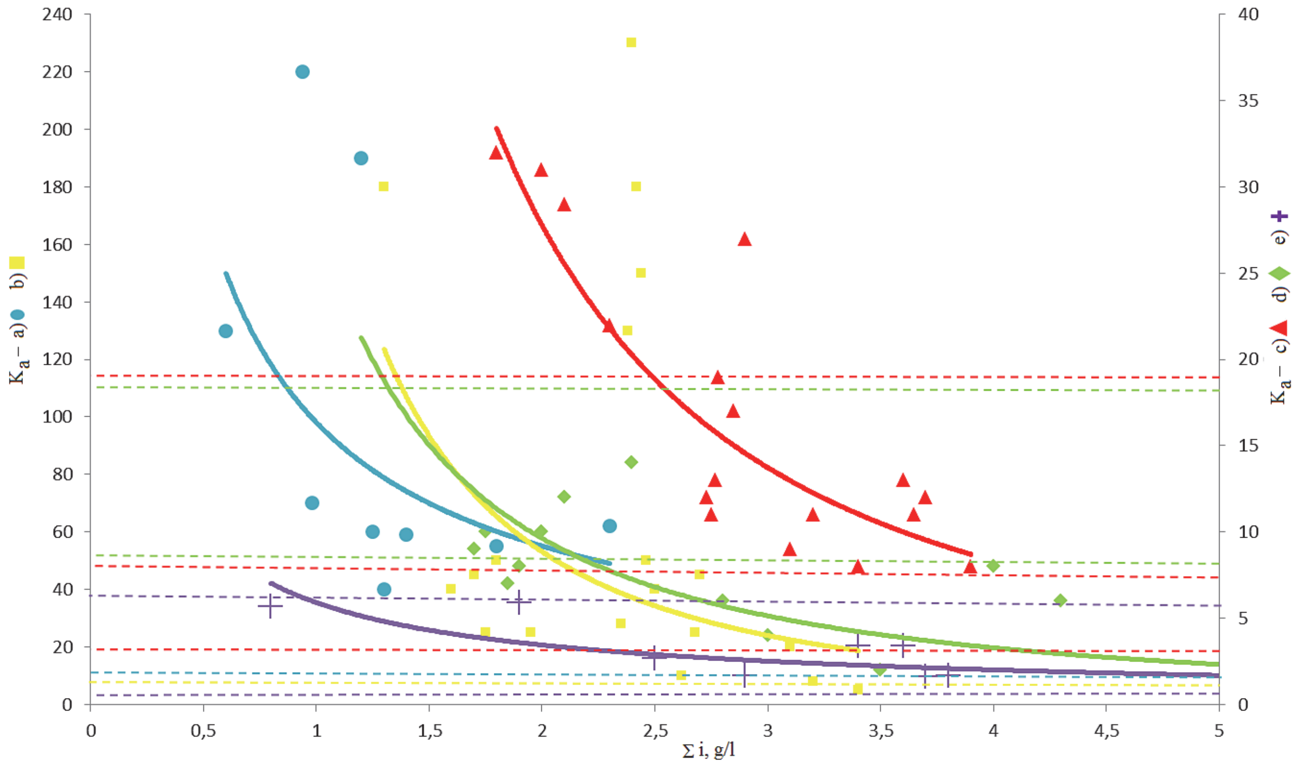

Fig. 1. The relationship between the irrigation coefficient by Stebler and groundwater mineralization; composition of water: *a*) – hydrocarbonate-calcium sulphate; *b*) – calcium sulphate; *c*) – calcium sulphate-sodium; *d*) – sodium sulphate; *e*) – chloride-sulphate-calcium-sodium

other sources of irrigation water. The negative impact of easily soluble salts on cultivated crops is determined by the following equation:

$$K_a = \frac{288}{5rC^-}, \quad (1)$$

where $rC^- + rSO_4^{2-} > rNa^+ > rCl^-$

$$K_a = \frac{288}{rNa^+ + 4rC^-}, \quad (2)$$

where $rNa^+ > rCl^- + rSO_4^{2-}$

$$K_a = \frac{288}{10\ rNa^+ - 5rC^- - 9SO_4^{2-}}. \quad (3)$$

The calculation results are shown in Table 3.

Results and Discussion

In Bashkortostan, due to the lack of fresh water in some districts (Aurgazy, Ufa and others), there is an experience of irrigation with brackish water. Thus, in the farm named after Tsyurupa located in the Ufa district (Fig. 2a) salty calcium sulphate water (2.1 g/l) of the river Urshak has been used to irrigate vegetables (potatoes, cabbage – an area of 40 ha) and perennial grasses (an area of 100 ha) for 20 and 10 years, respectively. Field studies with drilling and mining operations were carried out at the sites. Water extract samples from 4 wells and 8 pits (2 non-irrigated areas and 6 irrigated ones) were taken to identify their physical and mechanical properties.

According to the farm experts watering and irrigation rates are respectively 300-500 and 900-2000 m^3/ha on the plot of perennial grasses and 500-600 and 4500-6000 m^3/ha on the vegetable plots.

During irrigation, fertilizers (superphosphate, potassium salt, urea or sodium nitrate) are introduced at the rate of 3-4 dt/ha on the plots of perennial grasses and 10 dt/ha on the plots of vegetables.

All plots are located in the same geomorphic conditions (the second terrace above the floodplain of the Urshak River) with 789 mm precipitation per year according to the long-

Table 3. Mineralization of groundwater salinity (Σi) depending on irrigation rate of Stebler (K_a)

Item No	Water									
	a) hydro-carbonate-calcium sulphate		b) calcium sulphate		c) calcium sulphate-sodium		d) sodium sulphate		e) chloride-sulphate-calcium-sodium	
	K_a	Σi, g/l	K_a	Σi, g/l	K_a	Σi, g/l	K_a	Σi, g/l	K_a	Σi, g/l
1	130.4	0.67	184.2	1.3	32.1	1.8	9.8	1.7	5.7	0.8
2	220.7	0.94	40.5	1.6	31.8	2.10	10.6	1.75	5.9	1.9
3	71.8	0.98	45.2	1.7	29.1	2.12	7.7	1.85	2.7	2.5
4	191.6	1.21	25.1	1.75	22.6	2.3	8.2	1.9	1.7	2.9
5	61.7	1.25	53.2	1.8	12.9	2.73	10.8	2.82	3.4	3.4
6	42.3	1.31	25.1	1.95	11.4	2.75	12.1	2.1	3.4	3.6
7	59.5	1.39	28.6	2.35	13.2	2.77	14.1	2.4	1.6	3.7
8	55.8	1.84	131.2	2.38	19.8	2.78	6.7	2.8	1.7	3.8
9	62.1	2.37	229.1	2.4	17.7	2.85	4.9	3.13	2.1	5.5
10	–	–	178.3	2.42	27.2	2.9	2.6	3.5	1	5.8
11	–	–	52.8	2.46	9.8	3.1	8.5	4.0	–	–
12	–	–	39.7	2.5	11.1	3.2	6.5	4.3	–	–
13	–	–	10.4	2.62	8.2	3.4	2.1	6.1	–	–
14	–	–	24.9	2.68	13.8	3.6	3.8	6.3	–	–
15	–	–	46.5	2.7	11.7	3.65	2.1	7.7	–	–
16	–	–	24.1	3.1	12.7	3.7	0.6	8.1	–	–
17	–	–	7.6	3.2	6.1	3.9	0.4	8.3	–	–
18	–	–	5.1	3.4	–	–	–	–	–	–
19	–	–	148.9	2.44	–	–	–	–	–	–

term data (Ufa weather station). 420 mm of these comes to the warm season (IV-X months).

Geological and hydrogeological data of the plot are as follows: coefficient of loam soil transmission (4.0-4.5 m depth) as well as sand and gravel deposits (1.5-4.0 m depth increasing to the river) is 0.2-0.7 m/day and 5.0-10.0 m/day respectively. At a depth of 8.5-9.0 m sand and gravel deposits are underlied by dense, relatively waterproof grey clays.

According to Katz scheme (Katz & Pashkovsky, 1988) this profile of irrigated plots in terms of its layer structure, filtration properties and drainage degree refers to a two-layer cross-section. The groundwater level is in the cover clay layer (3.8-4.0 m), natural drainage is high.

The groundwater table rise under the effect of irrigation has not been observed. A small groundwater mound of one meter high near one of the wells, being developed during the period of intensive irrigation, runs out after the irrigation cessation in autumn and winter.

According to the results of studies of water extracts from deposits of plots irrigated with calcium sulphate water with mineralization of 2.0 g/l for 10-20 years, there was no salt accumulation in soils. The same is observed on the non-irrigated plot being in the same conditions. The highest level of $CaSO_4$ and $MgSO_4$ salts (0.224–0.269%) are found at a depth of 0.75–1.0 m Fig. 2b, pit I) being lower with depth. It's 0.063% at the level of 4.5 m.

When irrigating with brackish water, salts are washed out of the cover deposits of the aeration zone with irrigation water and transferred to groundwater (the salt content in soils ranges from 0.052 to 0.33% (pit 4, pit 7), that is lower than in the non-irrigated plot). The results of studies show (pit 11) that irrigation with fresh water keeps up to 0.11% of water-soluble salts in soils.

Thus, it should be noted that irrigation with calcium sulphate brackish water does not lead to salt accumulation at the rooting depths if there is drainage.

The next plot is located on the first terrace above the floodplain of the Aurgazy river (area ~100 ha) in the Aurgazy district (Fig. 3a). The source of irrigation was the water of the river Aurgazy of calcium sulphate composition with mineralization of 2.2 g/l.

The hydrogeological profile of the studied plot is single-layered, represented by clay rocks without gravel-pebble horizon with a filtration coefficient of 0.1 m/day. Sulphate calcium groundwater with 2.5–3.0 g/l mineralization is at a depth of 2.0–3.0 m.

Soils here are of high salinity being 1.2 to 5.0% even in natural conditions (Fig. 3 b, pit 13) due to the presence of gypsum in the form of powdery material or crystals. In some cases, gypsum interlayers reach 5.0-10.0 cm. The highest gypsum fixation is at a depth of 0.5–1.0 m.

Irrigation of these plots, located near the river with a depth of groundwater more than 3.5 m and good conditions for their outflow with calcium sulphate water does not contribute to additional salt accumulation. Salt concentration is 0.076-0.90% (<1%). Moreover, irrigation provides soil desalination (2-3 times).

There is some desalination (up to 0.2–1.2%) of the upper layer (up to 1.0 m) as well as secondary salination up to 5.0-5.4% of the underlying layer (0.75-1.5 m) with more distance of irrigated plots from the river and shallower depth of groundwater (up to 2.5-3.0 m) (Fig. 2, pit 15). Therefore, irrigation with brackish water in these hydrogeological and reclamation conditions should be preceded by artificial drainage.

Studies on salinity in irrigated and non-irrigated plots at a depth of groundwater more than 3.5 m show that the salt content in the irrigated site with washing regime is up to 1.5-3.0 times less than in the non-irrigated plot. Hence, irrigation with brackish water did not result in soil salination but contributed to salt removal.

When there is weak natural drainage with groundwater depth less than 2.5-3.0 m, brackish water irrigation also caused some desalination of soils in the upper layer (up to 0.5-1.0 m) from 0.0681-4.76% to 0.118-1.19%. But in the underlying layer (0.75-1.5 m) salinity increased to 5.4%. Irrigation with brackish water in these hydrogeological and reclamation conditions should be preceded by artificial drainage. However, it should be noted that the depth of groundwater with no regard to its outflow cannot be a criterion in assessing land reclamation for irrigation purposes.

The other studied plot (Diurtiuli district) is exposed to oil field waste water. In consists of chloride, calcium and sodium and have 2.0–6.5 g/l and more mineralization. In this case, irrigation with water from ponds on the rivers Mancharka and Nazi resulted in soil salination on some plots (up to 25 ha) under the water table being 0.75 m above critical (Fig. 4, well 17). With increased depth of the groundwater table (2.5 m, and 3.5–4.0 m in most parts of the studied horizon) there are no sharp changes in water-salt composition of the soil (Fig. 3, wells 16, 18).

The site under consideration, located on the right gentle slope of the Nazi river valley, is composed of simple Pliocene clays and loams with soil transmission coefficient of n•10^{-1} – n•10^{-2} m/day. Its geofiltration profile is represented by interchanged low permeable rocks. It refers to a stratified scheme with a weak filtration outflow. That is, according to the natural drainage the plot is characterized as poorly drained.

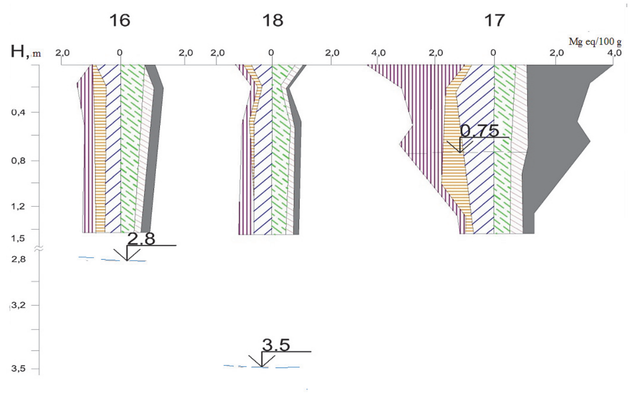

Fig. 4. Effect of irrigation with sodium chloride waters (up to 2.5 g/l) on the composition of pore solutions of soils depending on the depth of groundwater (refer Fig. 3 for legend)

As a result of observations, it was found that groundwater being above the "critical" level and irrigation with water with favourable indicators at higher watering and irrigation rates (up to 3000 m^3/ha) groundwater participates in the soil formation process. There is evaporation of groundwater, followed with increase in its mineralization (up to 3.1 g/l) and, consequently, a change in the chemical composition (to chloride calcium-sodium).

Intensive accumulation (up to 2.7 mg-eq/100 g) of NaCl salts in the soils of the aeration zone occurs at a depth of 1.0 m (0.19–0.23%). There are also Na_2SO_4 and $MgSO_4$ (0.2 and 0.16 mg-eq/100 g), $CaCO_3$ (0.82 mg-eq/100 g) salts. Starting from a depth of 1.3 m the concentration of soil solutions drops sharply (to 0.10%): the content of chloride ion (Cl^-) is less than 0.1 mg-eq/100 g, and sodium ion (Na^+) – 0.2–0.4 mg-eq/100 g.

At irrigation of plots with groundwater at the level below "critical" with irrigation rate of 1200-1500 m^3/ha there is no salt accumulation.

The mineral content of soil solutions is 0.07-0.09%: chloride ion (Cl^-) is 0.007-0.15 mg-eq/100 g, and sodium ion (Na+) – 0.2–0.4 mg-eq/100 g. Most of all there are $Ca(HCO_3)_2$ (up to 0.7 mg-eq/100 g), $CaSO_4$ (0.2 mg-eq/100 g) and $MgSO_4$ (0.3 mg-eq/100 g) and some quantity of $MgCl_2$ (0.06 mg-eq/100 g) and NaCl (0.06– 0.13 mg-eq/100 g).

The irrigation plot is represented by leached chernozem, heavy loam, medium-sized with humus content from 5.7 to 9.4%. As a result of the irrigation, carbonates were dissolved at a depth from 0.6 m to 0.85 m, accompanied by an increase in soil pH from 6.1 to 7.6. There is an increased and high soil supply by labile phosphorus (P) from 132 to 184-477 mg/kg, medium and soil supply by potassium (K) from 92-105 to 270 mg/kg. Among the divalent cations Ca^{+2} prevails over Mg^{2+} (22.2 and 3.1 mg-eq/100 g), the specific weight ranges within 1.20–1.69 g/cm^3, the total soil space is 36-53%. On the nonirrigated plots, the specific weight is 1.10–1.15 g/cm^3, and the soil space is 55-60% that is close to the optimal indicators for crops. The following soil indicators were obtained on irrigated plots: density – 2.51–2.75 g/cm^3, humidity (in mid-August) from 4.1–6.8 to 15.8–19.1%, the lowest moisture content – 7.7– 27.8%, moisture reserve at a depth of 1.5 m ranges from 590-834 to 1580-3328 m^3/ha.

Thus, the observations of different irrigation plots brackish water (up to 2.5 g/l) of the complex chemical composition ($Cl^{Ca}{}_{I}{}^{Na}{}_{IIb}$) proves that the greatest threat (salinity) to soil is primarily exposed by the absence of the outflow from the irrigated site, shallow (above critical) water table, groundwater participation in soil formation. The quality of irrigation water plays a secondary role.

Further studies were carried out on the territory of a large specialized irrigation system in the southern Cis-Urals (Fig. 5), where more than 20 years waste water of pig raising farm (more than 50 thousand heads) was used.

The irrigation plot located on the watershed and slopes of the Belaya and Kuganak river valleys is composed of clay rocks of the Quaternary Neogene age. There are developed water-bearing reservoirs of soil type as well as a confined aquifer in the basal sands and pebbles of the Kinel Suite.

The depth of groundwater (10-20 m depth) in Quaternary and Neogene sediments varies from 0.4–1.0 to 6.0–7.0 m. Hydraulic slopes are 0.004–0.01 and directed to river valleys, drainage module is 0.02...0.40 l/(s•ha). Before irrigation, according to the data of hydro-regime observations, on the slopes of the watershed groundwater levels were 1.0–7.0 m lower than today.

Sands and gravel-pebble deposits are the most water-rich, well flow rates vary from 1.0–5.0 l/s to 30.0–40.0 l/s. Clay sediments of Akchagyl-Absheron deposits have low water availability and low filtration properties (C_f= 0.15–0.5 m/day, water return and water level are 0.06 and 8.0 m^2/day, respectively).

The soil cover of the investigated plot has a capacity of 0.4–0.6 m and is represented by heavy loamy medium-humus leached chernozems. The value of the hydrogen index (pH) is 5.7–6.7, hydrolytic acidity (Ng) – 0.35–2.1 mg-eq/100 g. Before irrigation the soil density was 2.59–2.74, the specific weight was 1.0–1.08 g/cm^3, soil space 60.0–61.5 %. The mineral content of the soil solutions at depths of up to 5.0 m changed in the range of 0.071–0.096%, there were abundant of $Ca(HCO_3)_2$ in the salt composition.

The adsorption ratio being a measure of reactivity of soils and their underlying clay layers had a value of 50 mg-EQ/100 g on average.

Recycled waste water has a complex chemical structure (Komissarov & Kovshov, 2012), depending on the composition of liquid manure, water used for hydraulic washing and disinfectants used. The mineral content of wastewater ~5.6 g/l, the ions ratio is of the soda type: $rHCO_3/(rCa–rMg) \leq 10$. The $NaHCO_3$ soda content reaches 1.5 g/l, the chloride content (Cl) is increased – 0.8 g/l, potassium (K) – 0.35 g/l, especially high (NH_4^+) ammonium content – 0.8–3 g/l. There are significant indicators of silicone acid ($nSiO_2 \cdot mH_2O$.) up to 40 mg/l.

Salt composition can be represented by: Ca $(HCO_3)_2$is 5.5% eq, Mg $(HCO_3)_2$ – 1.3% eq, $NaHCO_3$ – 26.9% eq, $KHCO_3$ – 11.1% eq, NH_4Cl – 23.0 % eq etc.

Discharge is diluted with water of the Belaya River. During the irrigation period it has 0.58–1.65 g/l of mineral components that is determined by the water flow in the river. In the summer low water period (at minimum flow rates 32.0–38.0 m^3/s) there is the highest level of water mineralization (1.38–1.65 g/l). When water flow rises to the values of 127.0–271.0 m^3/s, the salt concentration decreases (Fig. 6a) and irrigation properties of water are improved.

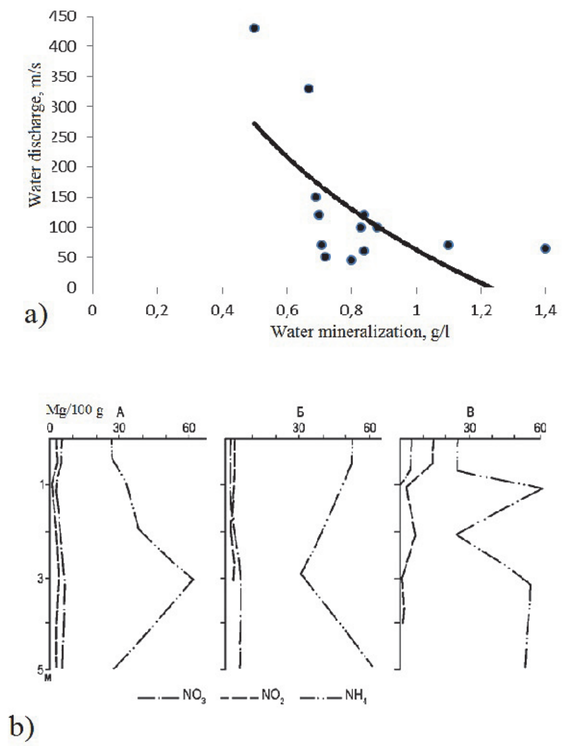

Fig. 6. Irrigation with wastewater of the pig raising farm, Roshchinsky village:
***a*) dependence of water mineralization;**
***b*) content of nitrogen compounds in soil water extracts**

Thus, water diluted 4-5 times, which composed of hydrocarbonate-chloride, chloride calcium-sodium, sodium-calcium and magnesium-sodium-calcium, type – mainly IIIa and IIIb, hydrogen index (pH) of 7.1–8.24 is supplied to the irrigation site with a concentration of 1.5–1.8 g/l.

During the irrigation period (May – August), up to 6 000 m^3 of water averages on 1 hectare of the total area of 450–500 ha (with the volume of diluted waste water 2.6 million m^3 per year). Such intensive use causes significant hydrochemical changes in irrigated lands.

Ammonium (NH_4^+) – up to 200.0-220.0 mg/l, chlorine (Cl) – 550.0 mg/l, sodium (Na) and potassium (K) – 110.0 and 45.0 mg/l, phosphorus (P) – 71.0 mg/l and other components. Ammonium form predominates among nitrogen compounds in soil grounds (Fig. 6b).

Further, when ground waters are close to the ground (up to 2.0–3.0 m), the soil loses ammonium, sodium and potassium ions as a result of their transfer to the groundwater or as a result of their absorption by the exchange complex of soil.

Waste water also contains ammonia (NH_3) which is formed during the decomposition of urea and absorbed by the solid fractions of the soil due to intermolecular forces. In the post-irrigation and autumn-winter periods, the biochemical processes of ammonification, nitrification, denitrification in soil and groundwater lead to a sharp decrease in nitrogen content. Some of it is lost in the gaseous form (N_2, NO_2), the daily loss of nitrogen into the atmosphere reaches 2.0–5.0 mg/m^2 and increases with high humidity and warm weather.

The results of the chemical composition analysis of the soil grounds testify to its significant changes resulting from irrigation with waste water (Fig. 6). The content of mineral components of soil solutions increases from 0.07–0.096 to 0.34–0.45 eq.% (From 2.5–3.2 to 5.0–12.5 mg-eq/100 g) per non-irrigated and irrigated areas respectively. Thus, slightly saline soils are observed (> 0.25%). The excess of hydrocarbonate values of 1.4 mg-eq/100 g (1.5–3.3 mg-eq/100 g) indicates Sodium ions (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}) sulphates (SO^{2-}_4) appear in soils, and chlorine content (Cl^-) increases in some sections. The capacity of the soil-absorbing complex decreases from 48.8 to 13.3 mg-eq/100 g in non-irrigated and irrigated areas, respectively. This is largely due to changes in their density, porosity, permeability and other water-physical parameters, and also, probably, with a decrease in the content of humus in them.

It should be noted that man-made factors have a significant impact on the chemical composition of groundwater plots irrigated with waste water. Before irrigation, they had a mineral content (hydrocarbonate, sulphate-hydrocarbonate magnesium-calcium, water type II), mostly 0.4–0.6 g/l.

As a result of irrigation with waste water, the chemical composition and salinity of groundwater changed significantly: the sulphate content (from 20.0–40.0 to 150.0–350.0 mg/l), chlorine (from 10.0–20.0 to 100.0–200.0 mg/l), sodium (from 10.0–50.0 to 70.0–100.0 mg/l) and other ions. The content of mineral components increased to 1.4–2.7 g/l. Water type II (sulphate-sodium) is metamorphosed into types IIIa (chlorine-magnesium) and I (sodium bicarbonate). The increase in the groundwater of HCO^{3-} ions contributed to the formation of an alkaline reaction of the medium with a pH of 7.5–8.4.

The following observations are important – in groundwater, especially in summer, NO^{3-} and NH^{+4} accumulate, the chlorine content in water extracts remains almost unchanged in non-irrigated and irrigated areas (Fig. 7), while in groundwater it increases dramatically in irrigated areas. This indicates a high migration ability of Cl^-.

Experiments show that the use of treated waste water for irrigation on specialized irrigation systems (Komissarov & Kovshov, 2012) can be considered as an important water protection measure, as due to sorption, biochemical and physicomechanical absorption during migration through the soil layers and clay soils, treated wastewater is subjected to additional cleaning. However, with irrigation rates exceeding the self-cleaning capacity of soils, there is a danger of

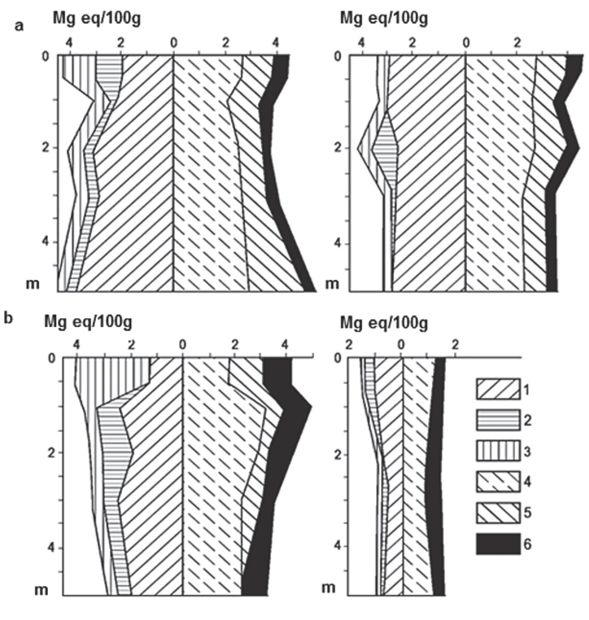

Fig. 7. Soil salt profiles: *1-6* – ions: *1* – calcium, *2* – magnesium, *3* – sodium and potassium, *4* – hydro-carbonate, *5* – sulphate, *6* – chloride; *a*) irrigated lands *b*) non-irrigated lands

contamination of groundwater with the ingredients contained in the effluent (nitrogen, chlorine, phosphorus, potassium, sodium, etc.). Particularly dangerous are heavy metals – Cu, Zn, Ni, Mn, etc.).

The irrigation rate of effluents and the concentration of the elements contained in them determine the flow of pollutants into groundwater. Their consumption is expressed by losses for evaporation, absorption by plants and soil grounds, as well as removal by surface and drainage waters. In irrigated areas, where the supply of nitrogen compounds exceeds their digestibility by plants and the processing capacity of the soil, ammonia is oxidized to nitrates, and there is the accumulation of the latter and their entry into the groundwater. This multi-stage oxidation process in general form is expressed by the scheme:

$$NH_3 \rightarrow NH_2OH \rightarrow [NOH \rightarrow ONOOH] \rightarrow NO_2 \rightarrow NO_3$$

Thus, there is a progressive increase in groundwater salinity. The absence of nitrate consumers in groundwater leads to the fact that they become predominant at a considerable depth. The content of nitrogenous compounds in groundwater in irrigated areas with treated waste water is: nitrate – 2.2–189.6, ammonium – 1.5–49.5 mg/l.

These observations indicate a significant change in the underground hydrosphere in the areas of waste water disposal of large livestock farms.

Conclusions

The use of groundwater of increased mineralization for the purposes of irrigation under the conditions of an acute shortage of freshwater resources will make it possible to a certain extent to solve the problem of irrigation agriculture water supply.

Assessment of saline waters, widespread in Western Bashkortostan, showed their fundamental difference in irrigation.

Sulphate and bicarbonate-sulphate slightly saline waters (1-3 g/l) with a predominance of alkaline earth components (calcium and magnesium) in the cation composition have good qualities in all indicators and are certainly suitable for irrigation. Compared with fresh water, they contain high concentrations of a number of trace elements (copper, cobalt, manganese, molybdenum, iodine, bromine, etc.), which are necessary for normal plant life.

Sulphate sodium and sulphate-chloride calcium-sodium highly saline (5-10 g/l and more) waters are not suitable for irrigation without dilution with fresh water, as they are potentially dangerous for soil salinization.

Sulphate, chloride-sulphate and sulphate-chloride medium saline (3-5 g/l) water with approximately equal content of alkaline-earth and alkaline elements and the predominance of the latter among cations occupy an intermediate position. The solution to the issue of their suitability for irrigation purposes depends on the specific conditions of the irrigated area and should be based on the results of field trials.

To prevent negative impacts, it is necessary to assess the hydrogeological and ameliorative state of the land, which shows the orientation of hydrogeological processes and delimits the areas requiring the use of various ameliorative measures. At the same time, one of the most important issues is the assessment of the natural drainage of the territory, the intensity of feeding and discharge.

The irrigation with low-mineralized (0.2–0.5 g/l) waters of rivers and ponds of calcium carbonate composition with high irrigation indices in favourable hydrogeological-reclamation conditions (drainage or deep groundwater) does not cause abrupt changes in the water-salt and absorbed rock complex. The accumulation of nitrates exceeding digestibility by plants is observed only with increased application of fertilizers in the soil solution. However, the close occurrence of groundwater and the absence of natural outflow does not guarantee against soil salinization even when irrigated with fresh water.

At the same time, the depth of groundwater without taking into account the underground outflow cannot be a criterion of land reclamation for irrigation purposes, because over time (8-10 years) groundwater can rise to a level at which they will begin to participate directly in the soil-forming process.

Significant changes in the underground hydrosphere are observed in the areas of disposal of waste from large livestock farms (agricultural filtration fields, specialized irrigation systems), irrigation with treated waste water can be considered as an important water protection measure.

The research on the use of saline water for irrigation needs to be expanded, since the problem is complex and covers issues of hydrogeology, soil science, agricultural engineering, land reclamation and other industries.

References

Abdrakhmanov, R. F., (2005). *Hydrogeoecology of Bashkortostan*. Informreklama Publ., Ufa.

Abdrakhmanov, R. F., & Khasanova, L. M. (2018). Irrigation of perennial grasses and vegetables with waters of increased mineralization. *Bulletin of Bashkir State Agrarian University*, *2*(46), 7-16.

Batanov, B. N. (2004). Melioration in Bashkiria: development stages, new targets. *Melioration and Water Management*, *3*, 3-4.

Gorev, L. N., & Peleshenko, V. I. (1991). *Fundamentals of hydro-*

chemistry and reclamation. Vyscha Shkola Publ., Kiev.

Katz, D. M., & Pashkovsky, I. S. (1988). *Reclamation hydrogeology*. Agropromizdat Publ., Moscow.

Komissarov, A. V., & Kovshov, Y. A. (2012). Ecological condition of the lands irrigated by livestock waste waters in the Republic of Bashkortostan. *Water: Chemistry and Ecology, 2*(44), 83-86.

Kostyakov, A. N. (1951). *Fundamentals of reclamation*. Selkhozgiz Publ., Moscow.

Minigazimov, N. S. (2017). *Oil microelements in the environment*. Bashkir Encyclopaedia, Ufa.

Mustafin, R., Ryzhkov, I., Sultanova, R., Khabirov, I., Khasanova, L., Zagitova, L., Asylbaev, I., Kutliyarov, D., Zubairov, R., & Rajanova, A. (2018). Assessment of slope stability in coastal water protection zones. *Journal of Engineering and Applied Sciences*, *13*, 8331-8337.

Nachshon, U. (2018). Cropland soil salinization and associated hydrology: Trends, processes and examples. *Water*, *10*(8), 1030.

Ozturk, O. F., Shukla, M. K., Stringam, B., Picchioni, G. A., & Gard, C. (2018). Irrigation with brackish water changes evapotranspiration, growth and ion uptake of halophytes. *Agricultural Water Management*, *195*, 142-153.

Pang, G. B., Xu, Z. H., & Zhang, S. (2015). Optimization of irrigation mode with brackish water for winter wheat in shallow groundwater areas based on the FEFLOW model. In: *Kim, Y. H. (ed.), Progress in Civil, Architectural and Hydraulic Engineering: Proceedings of the 4th International Conference on Civil, Architectural and Hydraulic Engineering (ICCAHE 2015), Guangzhou, China, June 20-21, 2015*. CRC Press, 659-664.

Posokhov, E. V. (1985). *Ionic composition of natural waters.* Genesis and evolution. Gidrometeoizdat Publ., Leningrad.

Rashed, A. A. (2016). Vegetable production on rice bales using brackish treated drainage water. *Irrigation and Drainage*, *65*(5), 664-672.

Ronco, P., Zennaro, F., Torresan, S., Critto, A., Santini, M., Trabucco, A., Zollo, A. L., Galluccio, G., & Marcomini, A. (2017). A risk assessment framework for irrigated agriculture under climate change. *Advances in Water Resources*, *110*, 562-578.

Sivakumar, D., Pavithra, S. L., Vasuki, K., & Lavanya, B. (2015). Groundwater suitability for irrigation around Perungalathur, Chennai, Tamil Nadu. *International Journal of Applied Engineering Research*, *10*(53), 37-42.

Sultanova, R. R., Gabdrahimov, K. M., Khayretdinov, A. F., Konashova, S. I., Konovalov, V. F., Blonskaya, L. N., Sabirzyanov, I. G., Martynova, M. V., Isyanyulova, R. R., & Gabdelkhakov, A. K. (2018). Evaluation of ecological potential of forests. *Journal of Engineering and Applied Sciences*, *13*(S8), 6590-6596.

Tahtouh, J., Mohtar, R., Assi, A., Schwab, P., Jantrania, A., Deng, Y., & Munster, C. (2019). Impact of brackish groundwater and treated wastewater on soil chemical and mineralogical properties. *Science of the Total Environment*, *647*, 99-109.

Wang, Z., Li, J., & Li, Y. (2017). Using reclaimed water for agricultural and landscape irrigation in China: a review. *Irrigation and Drainage*, *66*(5), 672-686.

Zanosova, V. I., & Molchanova, T. Y. (2017). Assessment of groundwater quality and the degree of their suitability for irrigation. *Bulletin of the Altai State University*, *6*(152), 49-53.