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Collector-drainage water reuse for crop irrigation: Experiment on saline lands of southern Kazakhstan

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Abstract

As a consequence of global climate change and the resultant recurring periods of drought and water scarcity, the ecological status of irrigated lands in southern Kazakhstan has deteriorated. One of the largest massifs in terms of area is Myrzashol, located in the south of the Turkestan region. Field experimental studies have been conducted on this array over the past 25 years. Experimental work was carried out on saline, abandoned, old-irrigated lands of this massif. As a result of the development of secondary salinization and salinization of soils, the area of irrigated lands with varying degrees of salinity increased from 50.4 to 99.2 thousand hectares or 2 times. In all, the irrigated area under consideration contains approximately 147.0 thousand hectares of land. Of this area, 67% has varying degrees of salinity. An increase in the concentration of salts in the soil not only reduces crop yields, but also disrupts the soil structure and porosity. This, in turn, negatively impacts the soil's water permeability. As a result, the land with such soils is excluded from agricultural production due to low productivity and ineffective irrigation. This article presents the results of field studies to determine the effect of irrigation with mineralised collector-drainage water (CDW) on the yield of cotton and alfalfa using CDW with a mineralisation of 2.4 to 4.0 gram/litre (g/l). A control site was used for comparison, where these crops were irrigated using fresh irrigation water with mineralization levels of up to 0.5 g/l. Additionally, we explored the feasibility of using collected water for the irrigation of agricultural crops. Based on the findings from field experiments, it has been concluded that using CDW with sulphate-type mineralisation levels up to 4.0 g/l to irrigate cotton and salt-resistant alfalfa forage crops on saline soils can lead to production yields of 27.1 centners per hectare (hereinafter – c/ha) and 155.0 c/ha for cotton and alfalfa, respectively, without depleting valuable freshwater resources. These harvests are considered lucrative for this type of land without requiring the use of fresh water.

1. Introduction

The strategy of agricultural drainage water reuse is the most appropriate solution to overcome the irrigation water shortage. It is considered as the fastest effective and economical method to provide accepted water characteristics for irrigation purpose (Ashour et al., 2021; Elshemy, 2017).

Kazakhstan has a limited water supply and is among the lowest-ranking CIS countries in terms of specific water availability, at 37.0 thousand m^3/km^2 and 6.6 thousand m^3 of water per person per year. This deficiency of water resources exacerbates the reliance of over half of the country's regions on neighbouring nations' water policies. Agriculture is the primary consumer of water in Kazakhstan's economy, accounting for more than 70% of usage.

Agriculture accounts for approximately 4.5% of the country's GDP. Over a quarter of the population is employed in the agricultural sector, despite only 7% of the 24.0 million hectares of arable land being irrigated. It is common knowledge that the productivity of irrigated land is dependent on various factors such as fertility, ameliorative state (salinisation and waterlogging) and water availability (Anzelm K.A. and Esanbekov M.Y., 2019).

To date, the area of irrigated land with unsatisfactory land reclamation in the country has doubled compared to 1990. The main reason for the deterioration of their condition is associated with an increase in the level of groundwater occurrence and, accordingly, with secondary salinization of land, which in turn occurs due to the failure of irrigation and drainage systems, directly related to the lack of sufficient funding for its proper operation.

Regarding the level of water availability of irrigated lands, it should be noted that according to the information from the consolidated report of the Food and Agriculture Organization of the United Nations (FAO) «The state of the world's land and water resources for food production and agriculture. Systems at the limit» (FAO, 2021) worldwide over the period 2000–2019, the area of irrigated land increased from 289 to 342 million hectares (+53 million ha), which is undoubtedly primarily associated with population growth and, accordingly, an increase in the demand for agricultural products.

This FAO summary report offers estimates of global freshwater scarcity, with Central Asia experiencing water stress levels exceeding 70%. Such scarcity can be unambiguously connected to climate change and the expansion of irrigated land, which happens to be the largest consumer of freshwater compared to other economic sectors.

To address the challenge of insufficient freshwater resources for crop irrigation, the global research community has dedicated decades to developing and validating water-saving techniques and technologies, including drip irrigation systems (Lu et al., 2022), sprinklers (Yan et al., 2020), and mulch furrow irrigation (Yuan et al., 2019), among others, which has led to successes in reducing water stress during dry periods while preserving soil quality by protecting against irrigation erosion, salinisation, and waterlogging and improving hydrophysical and agrochemical properties of soils (Bronson et al., 2017; Zhu et al., 2022).

In addition, several studies have explored the use of nonconventional water sources in irrigated agriculture, including the reuse and rational management of collected and mineralised wastewater (Shaban et al., 2021), the desalination of discharged wastewater or seawater with high mineral content for crop irrigation (Morote et al., 2017), particularly in view of the global shortage of fresh water.

However, particularly in the arid southern regions of Kazakhstan, where water is scarce and internal local water sources are inadequate, the use of these practices in irrigated agriculture remains limited. Myrzashol irrigation array in Turkestan province faces challenging conditions. The irrigated lands are located in the basins of transboundary rivers with water availability reaching a maximum of 80% in the last decade, dropping to 60% in periods of low water supply. The irrigation areas also discharge significant volumes of collector-discharge and waste water beyond their boundaries, polluting the environment with up to 40% of water supply being affected (Anzelm and Essanbekov, 2019). This evident fact is the primary requirement for selecting this irrigation system as a research subject to explore the effects of irrigating with mineralised CDW on yields of cotton and alfalfa crops, as well as the hydrophysical properties of saline soils.

Our research is aimed at studying the effect of irrigation with saline CDW on the physico-chemical properties of various soils and on the yield of cotton and alfalfa grown on these soils in the period from 1995 to 2022.

1. Study area

The object of the research is irrigated lands of Turkestan province (43°00' N, 68°30' E), located in the southernmost part of Kazakhstan. Total area of the region is 11609,5 thousand ha of which 4190,8 thousand ha (36.1%) is arable lands, including 864.5 thousand ha (20.6%) arable lands, of which 574,4 thousand ha (66.4%) is irrigated. Cotton, vegetables, melons, and fodder crops are mainly cultivated on irrigated lands.

The climate of Turkestan province is sharply continental; winters are mild and short, with frequent thaws; summers are hot and long. Average temperature of January in the north is –12°C, in the south – –2°C, –4°C, in July +26°C – +29°C. The annual amount of precipitation is 150 mm in the north and up to 800 mm in the highlands (RSI 'South Kazakhstan hydrogeological and reclamation expedition', 2020)

The area of the oblast is characterised by a variety of topography and is divided into four distinct parts: northern, southwestern – plains, southern – plains and south-eastern – mountainous. Geographically, the region includes the south-eastern part of the sandy Kyzylkum desert, the middle course valley of the Syr-Darya River, the western edge of the Moyinkum sands, the valley of the lower course of the Shu River, the western part of the clay desert Betpakdala, most of the Karatau ridge and a number of ranges of the western Tien Shan. The Karatau ridge from southeast to northwest divides the region into two parts – northern and southern.

The territory of Turkestan oblast is characterized by a variety of soil types and sub-types, which is associated with a variety of relief, climatic conditions, vegetation, the nature of parent rocks. In addition to natural conditions the structure of soil cover was influenced by irrigation-economic factors. The dynamics and current structure of the soil cover of the region are given in Table 1.

Analysis of the soil cover of irrigated lands of the region shows that in 2022 there were some changes in the structure of the soil cover of irrigated lands of the region. It is noteworthy that in comparison with the previous year there is an increase in the areas developing in the conditions of hydromorphic and semi hydromorphic regimes of meadow soil types. Areas of typical meadow soils developing under the hydromorphic regime have especially increased. These soils are considered as ameliorativeley unfavourable for irrigated farming due to close occur-

Table 1
Dynamics of soil cover structure of the irrigated area of Turkestan province (in numerator - ha, in denominator - %) (RSI "South Kazakhstan hydrogeological and reclamation expedition," 2020)

№ n/a	Types and subtypes of soils*	Years:					
		2015	2016	2017	2018	2019	2022
1	Dark, typical and light grey, grey-brown, grey-brown and takyr-like soils	203375 36	197798 34	195049 34	200784 35	192894 34	199992 35
2	Meadow-sierozem and meadow-desert	172267 30	161584 29	163771 28	189185 33	168568 29	172321 30
3	Grey-meadow and alluvial-meadow	130210 23	139979 25	146173 26	139235 24	148954 26	113214 20
4	Typical meadow	60702 11	66536 12	65443 12	43038 8	63529 11	88876 15
	TOTAL	566554	565867	570436	572242	573945	574403

* Soil types and subtypes are classified based on normative documents such as "Systematic list and main diagnostic indicators of soils of the plain territory of the Republic of Kazakhstan" (1995) and "Main diagnostic indicators of soils of mountainous and foothill territories of Kazakhstan" (1989).

rence of mineralised groundwater to the land surface. They are most widespread in Maktaaral, Zhetysay and Shardara districts.

2. Materials and methods

The main results of research are based on field studies conducted jointly with scientists of the Republican State Institution «South Kazakhstan Hydrogeological and Meliorative Expedition» of the Ministry of Agriculture of the Republic of Kazakhstan specialized in conducting reclamation monitoring of irrigated areas. Complex of field research and laboratory work covered all irrigated lands of Turkestan province (1995–2022). Agrochemical analysis of soil samples determined total humus (%), easily hydrolysable (mobile) nitrogen ($mg \cdot kg^{-1}$), soil water extract, water pH and mechanical composition with hygroscopic moisture content.

During the study period (in 2020–2022) a complex of hydrogeological and soil-reclamation surveys was conducted in Maktaaral and Zhetysay districts of Turkestan region (Myrzashol irrigation massif). In particular, 12546 measurements of groundwater levels were made in 558 observation wells and 1466 groundwater samples were taken from observation wells to determine groundwater salinity and chemical composition. At 15 gauging stations located at collector-drainage networks, 562 measurements of discharge water flow and sampling for chemical analysis were made. Laboratory analyses of water samples from all sources were conducted in an accredited laboratory of the RSI «South Kazakhstan Hydrogeological and Meliorative Expedition» of the Ministry of Agriculture of the Republic of Kazakhstan. Based on the results of chemical analyses of water samples using ArcGIS 10.8 software, maps of groundwater level, groundwater salinity and soil salinity composition were drawn up.

For conducting thorough field research works, the lands that were withdrawn from circulation due to unfavourable ameliorative condition with medium degree of salinity and hydromorphic soil formation regime were selected. The field study variants were placed according to the scheme of experience presented in Table 2.

The field experiments consist of 4 variants, in particular two crop species (cotton and alfalfa) were irrigated with fresh and saline water. The field study options presented in Table 2 are identified in Tables 5, 6, 7 and 8 by a number ranging from 1 to 4.

According to presented scheme of field experiment in field and laboratory conditions research on cotton and alfalfa irrigation with CDW with salinity from 2.4 to 4.0 g/l with hydrocarbonate-sulphate chemical composition of salts on agrochemical, hydrophysical properties of soil, as well as on hydrochemical regime of groundwater and on growth development and crop yields were conducted.

In particular, the content of humus, nitrogen, and phosphorus in the soil layers 0–30 and 30–50 cm, as well as the content of salts in soil and water in laboratory conditions by full water extraction by sampling were determined by agrochemical research for each variant. Soil samples of 0–30 and 30–50 cm thickness were selected according to "Rules of state monitoring and assessment of the reclamation status of irrigated lands in

Table 2
Summary table of a field experiment

№ options	Crop types and irrigation water quality
Irrigating cotton	
1	River (freshwater) water
2	CDW with salinity over 2 g/l
Irrigating alfalfa	
3	River (freshwater) water
4	CDW with salinity over 2 g/l

the Republic of Kazakhstan and the information database on the reclamation status of agricultural lands", 2016, according to which sampling for soil-salt survey in scale 1:10000 is carried out from depths: 0–30, 30–70, 70–100 centimetres, and on stationary sites from depths: 0–30, 30–70, 70–100, 100–150, 150–200 centimetres.

Hydrophysical analysis of soil properties were carried out by the method of laying pits on experimental plots and sampling in 50 cm^3 rings, during which the chemical composition and volume weight of the soil were determined according to the following formula:

$$K = P_c \times 100 \div (100 + W) \times V \qquad (1)$$

where: K – volume weight of soil, g·cm^{-3}, Pc – weight of wet soil in the volume of the cylinder, g; W – moisture content of soil, g; V – volume of the cylinder, cm^3.

During hydrogeological and hydrological observations, groundwater table, salinity and chemistry of irrigation, CDW and groundwater were measured by observation wells and gauging stations installed on the field study sites. In addition to agro- and soil-reclamation investigations to determine influence of saline drainage water on agricultural crops development monthly phenological observations of plants growth and development in each experimental variant were conducted, yield accounting on all experimental plots was counted by weighing method and calculated in c/ha.

3. Results

Turkestan oblast, where 1/4 part of irrigated lands of available area in the Republic of Kazakhstan is located, is considered as one of the most perspective regions for continuation of irrigated agriculture development due to its soil and climatic conditions, as well as population number, being both direct labour resource in irrigated agriculture, and direct main consumer of its products. Dynamics of basic agricultural crops sowing area on irrigated lands of Turkestan oblast shows that since 1995 cotton sowing area has increased from 106.7 thousand ha to 125.8 thousand ha, vegetable crops from 80.5 thousand ha to 106.1 thousand ha and fodder crops by 60%.

This region is in the arid zone, where the indicators of meliorative condition of irrigated lands are the main direct diagnostic indicators of crop yields and indirect indicators of the efficiency of the irrigation and drainage system.

Analysis of changing area of irrigated lands with high groundwater salinity shows that since 1995 groundwater salinity up to 1.0 g/l has increased to 170.9 thousand ha, from 1.0 to 3.0 g/l to 351.1 thousand ha, against decrease of areas with groundwater salinity from 3 to 5 and over 5 g/l from 100.0 to 38.6 thousand ha and from 62.0 to 16.2 thousand ha respectively (Fig. 1).

This suggests that, due to the unsustainable use of surface water, there is desalinization of groundwater, which is appropriate for irrigation of crops under conditions of increasing water scarcity.

For this purpose, it is necessary to restore vertical drainage wells in total 1655 units, constructed 50 years ago under irrigated lands development taking into account their hydro-geological conditions for creation of optimal meliorative regimes. As a result of vertical drainage wells system rehabilitation to regulate groundwater table and accordingly water-salt balance of irrigated lands, under which it will be possible to use water pumped from them for irrigation.

As for open collector-drainage networks, their total length is 5941.3 km, including 2982.4 km in state ownership, 2955.6 km in municipal ownership and 3.3 km in ownerless ones. At present, due to siltation of discharge systems and overgrowth of reeds, their capacity has decreased by up to 50%. As a result, the groundwater table in the nearby irrigated land is rising, which contributes to land salinization. For example, according to results of soil-meliorative research in 2022 on irrigated lands of the region slightly saline soils are spread on 77.1 thousand ha (14%), medium saline – 58.4 thousand ha (11%) and highly saline – 40.7 thousand ha (7%) (Fig. 2a). The largest areas of moderately and strongly saline soils (99.2 thousand ha) (Fig. 2b) are in Maktaaral, Zhetysay (Tokbergenova et al., 2022), Shardara and Otyrar districts (Fig. 3, 4, 5).

According to the analyses conducted from 1995 to 2022, there is a clear increase in areas with medium degree of salinity by a factor of 2, strong and very strong degree of salinity by a factor of 3. Moreover, this is happening against the background of decreasing not only slightly saline, but also non-saline lands.

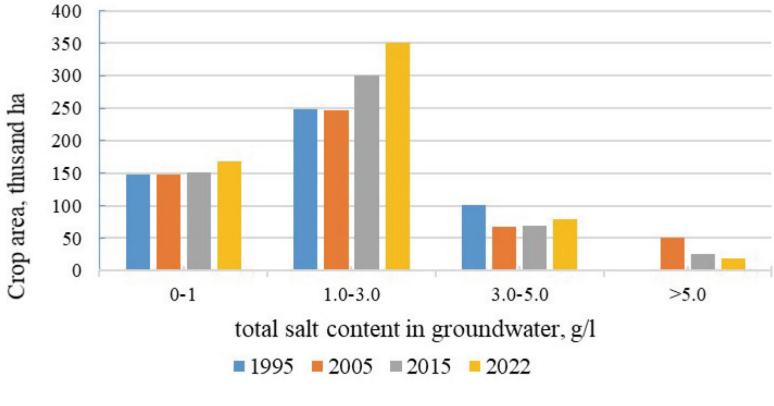

Fig. 1. Evolution of irrigated area with high groundwater salinity over 1995–2022 (thousand ha)

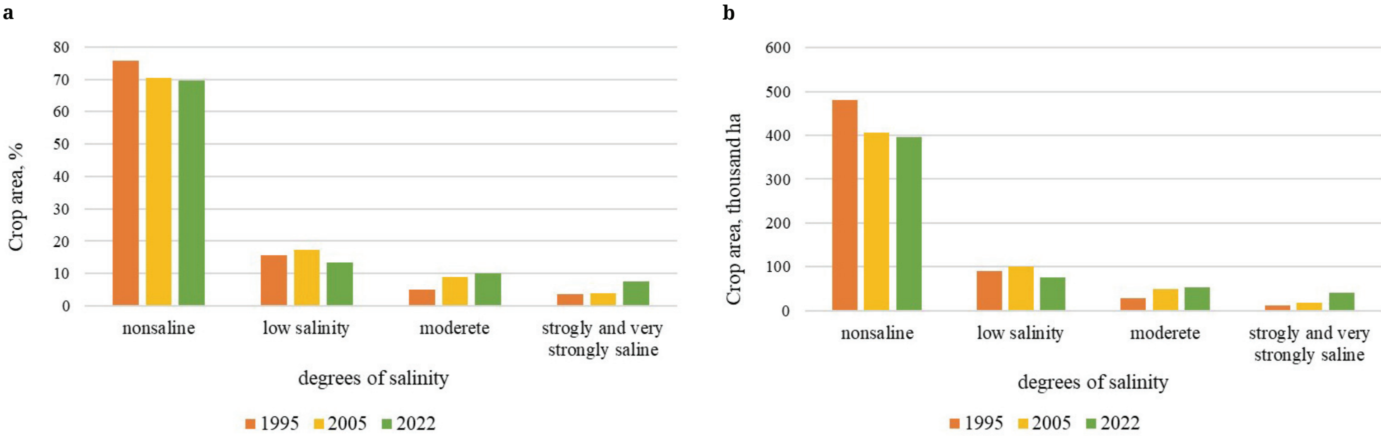

Fig. 2. Evolution of irrigated area with different degree of salinity from 1995 to 2022 (thousand ha and %)

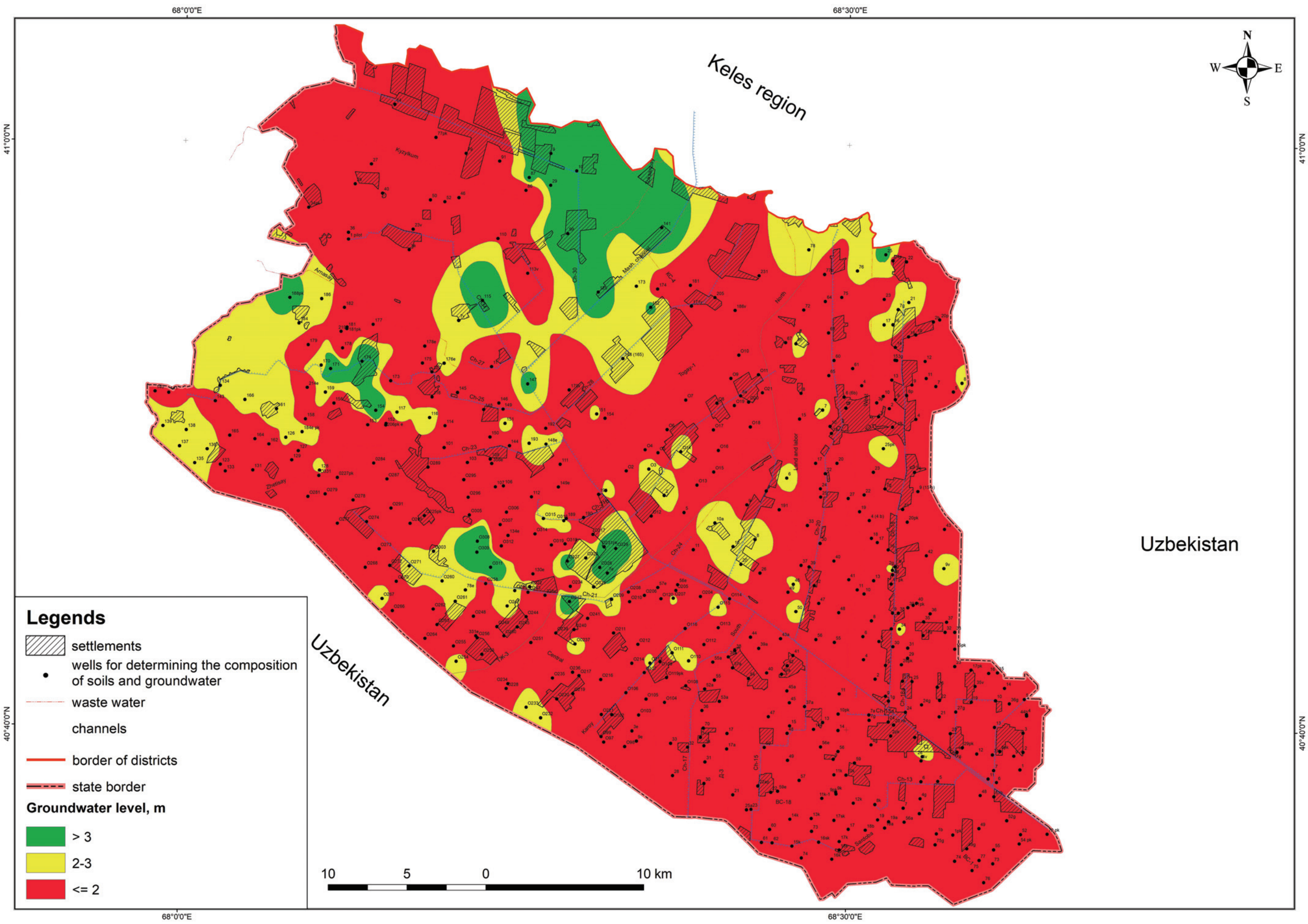

Fig. 3. Map of groundwater level of Myrzashol irrigated massif

Analysis of dynamics of irrigated lands with different degree of salinization during 1995–2022 shows that the area of strongly and very strongly saline lands has increased from 15.1 to 40.7 thousand ha, and the area of slightly saline lands on the contrary has decreased from 90,8 thousand ha to 77.0 thousand ha or by 13.8 thousand ha (Fig. 2b).

The main cause of soil salinisation in the south of Kazakhstan is the ingress of salts into the soil from saline groundwater during evaporation. Groundwater rises to unacceptable levels due to inefficient operation of irrigation and drainage systems, which have been in operation for a long time without proper technical equipment and repair.

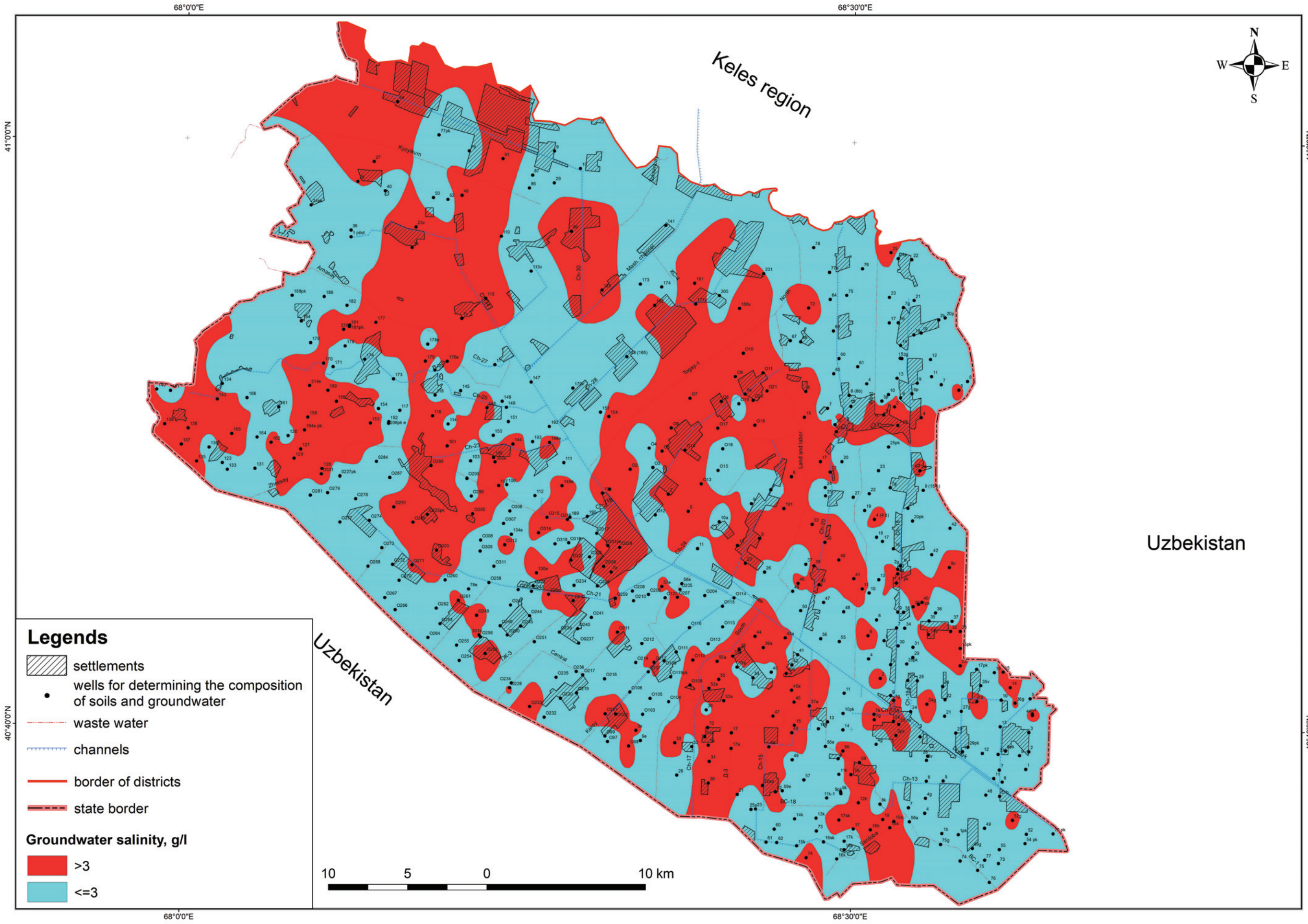

Fig. 4. Groundwater salinity map of Myrzashol irrigated massif

Analysis and assessment of hydrogeological conditions of irrigated lands is based on hydrogeological zoning of the territory, allocation of genetic types of groundwater regime and typification of irrigated lands according to the complexity of meliorative development to justify the need for measures to regulate the groundwater regime.

Under the conditions of Turkestan province, groundwater of the irrigated area is formed by irrigation water, atmospheric precipitation, and groundwater inflow. The groundwater table dynamics is subject to fluctuations by seasons of the year. The lowest groundwater levels are observed in the period after the end of vegetative irrigation and before the beginning of autumn-winter leaching (where they are carried out), and where they are not carried out – practically till the spring field works. The highest groundwater levels are observed on irrigated lands, where summer vegetative irrigation of crops and autumn-winter leaching irrigation are carried out. Here two rises are distinguished – December-March and July-August months, i.e., irrigation type of groundwater regime is observed.

According to agromelioration survey data most of existing today vertical drainage wells are idle during vegetation period, and on working wells coefficient of useful operation does not reach design one (0.75–0.85). Horizontal drains due to long operation, lack of repair and maintenance are also ineffective on large area of irrigated lands.

The main method of soil salinization control is leaching, efficiency of which depends on timing of leaching, chosen norm and quality of land preparation. For conditions of Turkestan oblast, the most optimal term of leaching of middle, strong and very strong saline lands is autumn-winter (November-December) period.

The leaching of slightly saline soils can be combined with spring rewetting. The recommended dates (November-December) are determined by the peculiarities of soil chemistry in the region. According to chemical analyses the salt composition of water extract of saline soils is dominated by sulphates, the solubility of which is in direct dependence on soil temperature. In November-December the soils have not yet had time to cool down and retain the heat accumulated during the summer. In addition, during this period the greatest depth of groundwater and low evaporation are observed. The recommended flushing rates for saline soils in the region are shown in Table 3.

In addition to the optimal timing and norms of flushing, the effectiveness of flushing depends on the preparation of the site – layout, optimal dimensions. The position and size of the checks is determined by the slope of the earth's surface and the terrain.

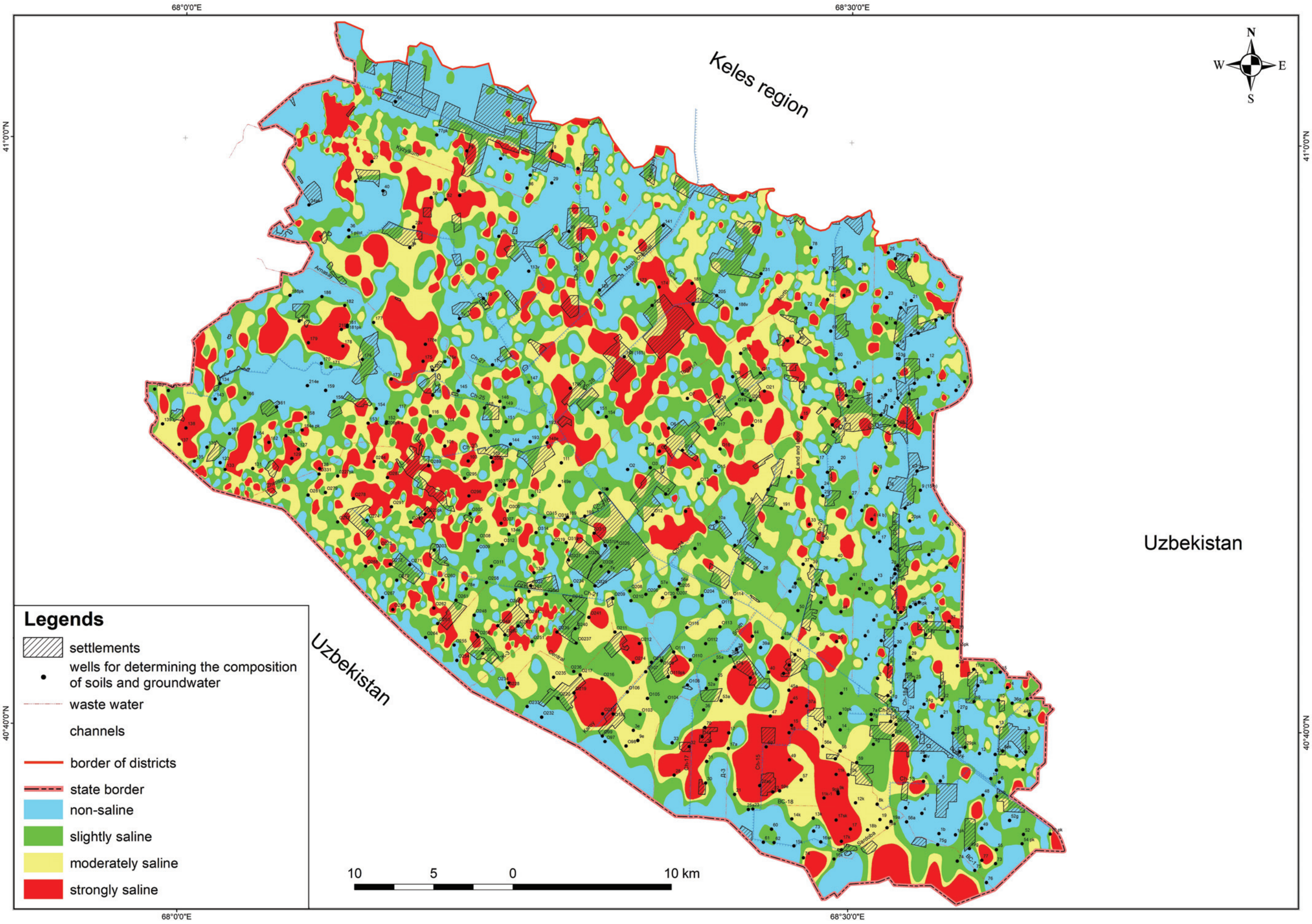

Fig. 5. Soil salinity map of Myrzashol irrigated massif

Table 3
Leaching rates for soils with different degrees of salinity

Degree of salinity, %	Mechanical composition of soils	Flush rates, thousand m^3/ha
Low salinity (0.15–0.3)	light loams medium loams heavy loams	2.5–3.0 3.5–4.0 4.0–5.0
Medium salinity (0.3–0.6)	light loams medium loams heavy loams	5.0–7.0 7.0–8.0 8.0–9.0
Highly salinity (0.6–1.4)	light loams medium loams heavy loams	9.0–10.0 10.0–11.0 11.0–12.0
Very highly salinity (more than 1.4)	loams	more than 12.0

Note – Soil salinity is classified according to Kiryushin and Ivanova, 2005*)*.

As the slope increases, the terrain becomes more difficult and the permeability of the soil increases, the dimensions of the checks are made smaller. Checks are as rectangular as possible on terrain with a surface slope of less than 0.005. The size of the checks also depends on the way of water supply to the checks, the size of a single leaching rate.

The role of groundwater, as the most important component of the biosphere, is especially great in arid zones and is the main factor in determining the reclamation status of irrigated lands. Underestimation of groundwater importance during design and operation of irrigation systems in difficult hydrogeological conditions can worsen hydrological and engineering-geological conditions of irrigated lands. The analysis of the groundwater regime and balance is of particular importance.

By results of observations of 2022 the areas of irrigated lands with critical mark (0–2 meters) of groundwater table amounted to 139.5 thousand ha or 24% of the total area of irrigated lands of the oblast. The basic area of such unfavourable irrigated lands is situated in Maktaaral and Zhetysay (106.7 thousand ha), Shardara (23.1 thousand ha) and Otyrar (5.7 thousand ha) districts. In these districts by hydrogeological conditions irrigation type of groundwater regime is characteristic, where winter-spring leaching of saline lands, spring watering and seasonal vegetative irrigation of crops are made. Unfortunately, these reclamation measures in most cases are carried out without vertical drainage wells, which regulate the hydrogeological regime of irrigated lands subject to waterlogging.

The area of irrigated land with high groundwater salinity in 2022 was 54,600 ha or about 10% of the total irrigated area of the region.

Irrigated lands with high groundwater salinity are mainly located in Maktaaral, Zhetysay (41.5 thousand ha) and Otyrar (7.7 thousand ha) districts. According to laboratory analyses, these waters vary from sulphate-hydrocarbonate-calcium to sulphate-chloride-sodium in chemical composition. In the Oblast, the area of irrigated land with unacceptable depth of groundwater has almost doubled between 1995 and 2022. Comparing the areas of irrigated land with high groundwater salinity over the past 25 years, one can see a reduction of up to 40% since 2010. This is primarily due to the abundant leaching of saline land, against which the area of wetlands is increasing. Based on the results of the distribution of irrigated land by groundwater level and salinity, digital cartographic materials have been prepared. Table 4 provides data on the zoning of the irrigated area of the province in terms of groundwater recharge and outflow conditions, i.e. the formation of the groundwater regime.

According to the results of observations, the total volume of CDW from all large irrigation arrays of the region amounted to 634.6 million m^3, which is 11.2 million m^3 more than in 2020. This is since last 2020, compared to 2022, was arid and low-water, and less irrigation water was discharged, respectively.

According to laboratory analyses, the mineralization of wastewater in 2022 ranges from 1.5 to 5 g/l or more, which are confirmed by the results of previous years of research. By chemical composition from (by anions) sulphate-chloride type to (by cations) – sodium-magnesium.

It is necessary to note that especially in dry and low-water years, when there is a large deficit of irrigation water in the peak of water consumption, it is recommended to use these drainage waters for repeated irrigation that will allow saving crops and obtaining high yield of cultivated crops. At that, it is necessary to take into account that drainage water including pumped from vertical drainage wells at salinity level up to 2.0 g/l can be used without mixing with fresh water, and at increased salinity from 2 to 5.0 g/l only after mixing with fresh water in proportions 1:1, 1:2, 1:3. At higher salinity values, drainage water should only be used for flushing saline soils.

The irrigation water limit for crop irrigation for the province in 2022 was 4,239.5 million m^3. Water withdrawal and delivery are 3494.8 million m^3 and 2670.1 million m^3 respectively.

Compared to 2021, water withdrawal increased by 171.1 million m^3, accordingly water supply increased by 230.7 million m^3. At the same time, specific water supply amounted to 5187 m^3/ha and increased by 443 m^3/ha compared to the previous year (4744 m^3/ha).

The highest specific water supply of 13442 m^3/ha in 2022 is in Saryagash district and the lowest in Tulkubas district.

As of today, furrow irrigation remains the main method of irrigation on all irrigated areas. Increasing shortage of irrigation water on the land of Turkestan province leads to the search and introduction of water-saving technologies, such as: drip, drip-jet, furrow irrigation, mulch furrow irrigation, sprinkler irrigation, in-soil irrigation, and others.

Table 4
Rezoning the irrigated area of the province according to (natural) groundwater recharge and outflow conditions

Hydrogeological areas	Administration-active areas	Weighted average depth groundwater table, m	Land catechism	Square, ha %
a – area of assured outflow of hydrocarbons under deep ground conditions	Arys (part), Kazygurt, Otyrar (part), Sairam, Saryagash, Keles, Tolebi, Sauran (part), Tulkubas, Sozak (part), r. Shymkent	> 5	I	207.4 35.9
b – area of intense external inflow and obstructed outflow of HS	Arys (part), Baidibeksky (part), Maktaaral (part), Zhetysay (part), Ordabasy (part) Baidibek (part), Otyrar (part), Sozak (part), Sauran (part), Shardara (part)	3–5	II	218.2 37.8
c – an area of hindered external inflow and outflow of hydrocarbons with an unstable depth, and a regime dependent on local conditions	Shardara (part), Maktaaral (part), Zhetysay (part), Ordabasy (part)	<3	III	151.9 26.3

Table 5
Agrochemical soil parameters on the experimental plots

Options	Sampling depth, cm	At the start of the growing season			At the end of the growing season		
		Humus content, %	Movable		Humus content, %	movable	
			Nitrogen	Phosphorus		Nitrogen	Phosphorus
			mg·kg^{-1}			mg·kg^{-1}	
Cottonwood							
1	0–30 30–50	1.31 0.91	23.3 12.3	20.3 11.8	0.84 0.56	16.6 8.8	26.4 21.8
2	0–30 30–50	1.28 0.88	23.1 12.2	19.6 13.1	0.76 0.45	17.8 9.6	24.3 19.9
Alfalfa (First year of sowing)							
3	0–30 30–50	1.33 0.93	22.9 11.9	19.4 12.1	1.37 1.11	19.5 14.5	29.3 22.8
4	0–30 30–50	1.32 0.90	23.1 12.6	20.1 13.8	1.36 1.14	18.9 14.9	28.2 23.3

Based on the set objectives, every year at the beginning of the growing season in each variant of experiment we selected soil samples from layers 0–30 and 30–50 cm for agrochemical analyses. And at the end of the irrigation season, we determined the content of humus, mobile forms of nitrogen and phosphorus on the same reference points, which gives an opportunity to judge about the dynamics of nutrients in the soil.

Analysing data of Table 5 we can say that at the beginning of vegetation in the arable soil layer 0–30 cm the average humus content was 1.31%, the content of mobile forms of nitrogen and phosphorus was 21.9 and 19.8 mg·kg^{-1} respectively.

Autumn humus content in arable root of 0–30 cm layer in variants 1 and 2 with cotton crops was 0.84 and 0.76% respectively, and in variants 3 and 4 with alfalfa crops was 1.37 and 1.36% respectively. It is obvious that in variants 3 and 4 with alfalfa cropping humus content (1.37–1.36%) by the end of irrigation season was higher than in variants 1 and 2 (0.84–0.76%) with cotton cropping by 0.53–0.6%.

The Fig. 6a shows dynamics of humus content change in (2 and 4) variants with irrigation with mineralised water and cultivation of cotton and alfalfa. As it is seen, at alfalfa sowing in the most fertile soil layer 0–30 cm by the end of vegetation period

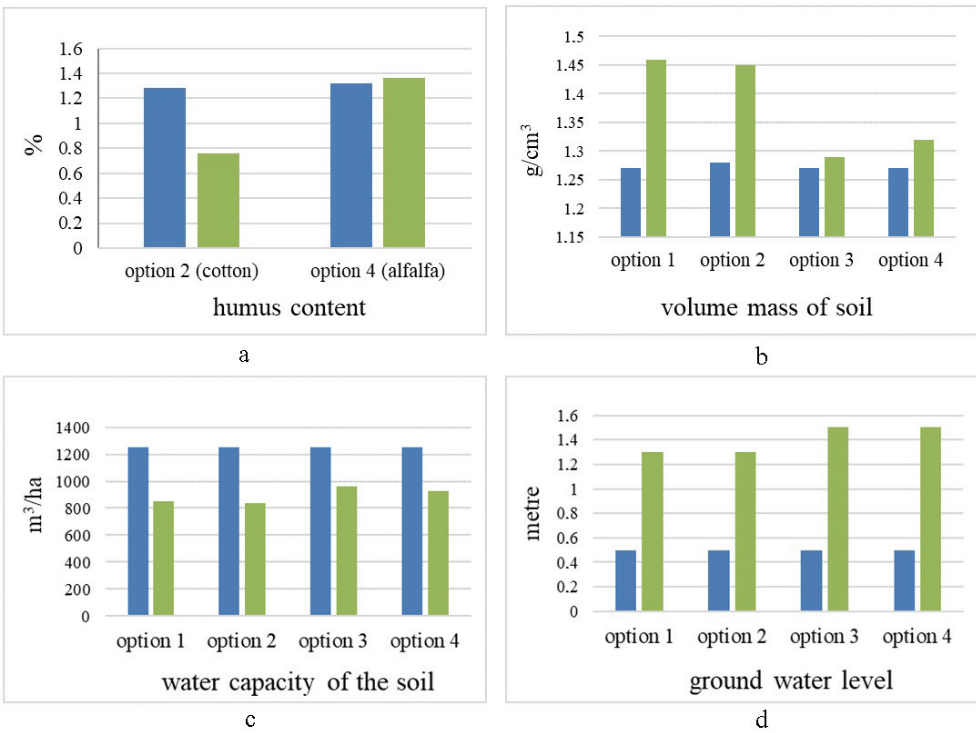

Fig. 6. a) Dynamics of humus content change in 2 and 4 variants with irrigation by mineralized water, %, b) Dynamics of volume mass of soil, g·cm^{-3} (2021), c) Dynamics of water permeability of soil, m^3/ha (2021), d) Dynamics of groundwater table change by seasons, m (2021) (blue – *at the beginning of the growing season*; green – *at the end of the growing season*)

humus content increases by 0.04%, and at cotton sowing from initial content by the end of irrigation season it decreases by 0.52%.

Comparing the content of mobile forms of nitrogen and phosphorus, we can confidently argue that in 3 and 4 variants with alfalfa sowing, both when watering with river fresh water and when watering with mineralized CDW, by the end of the irrigation season, their increase turned out to be greater than in the variants with cotton sowing. In the sub-arable layer (30–50 cm) of the soil, also on alfalfa crops, this pattern persists, where the content of all chemical indicators 3 and 4 variants exceeds the first two variants with cotton sowing.

This is because alfalfa with its deep and strong root system has a multifaceted effect on soil fertility, i.e., their strong tap roots penetrate the dense subsoil layers and leave a tubular network filled with loose organic matter and thereby drain the soil, improving soil fertility, which naturally contributes to favourable crop growth and development.

This pattern confirms that under conditions of freshwater scarcity, the use of CDW with increased salinity as an alternative source of irrigation water is quite possible for irrigating forage crops such as alfalfa, whereby soil fertility is maintained at least at baseline.

This once again proves that alfalfa in reclamation science can be classified as a phytomeliorant, which in conditions of saline lands with irrigation with saline water allows to obtain a highly profitable crop and thus rationally use the scarce water and land resources of the country (Cui et al., 2021).

To determine the mechanical composition of soils of the experimental plot in the first year of research, soil sections were dug, on which the mechanical composition of soil was determined by soil profile description and by pipetting with sodium hexametaphosphate in soil samples. According to the results of the research the mechanical composition of the soil of the experimental plot belongs to the light grey-meadow belt of light grey soils of old irrigation.

The volumetric mass of the experimental plot was determined at the beginning and end of the growing season by 10 cm layers to a depth of 100 cm. Table 6 shows the initial data of soil density 2021 of the research year, measured at the beginning and the end of the growing season.

Analyzing dynamics of changes in soil volume mass (Fig. 6 b) from spring to autumn for 2021, we can conclude that because of irrigation and inter-row tillage on plots with cotton crop (variants 1 and 2) soil volume mass has increased significantly by the end of vegetation in the middle layer of soil 0–100 cm compared to plots with alfalfa crop.

For example, in all variants of experience initial index of volume mass of soil was the same – 1.27 g·cm^{-3}, which by the end of irrigation period in first two variants was 1.46–1.45 g·cm^{-3}, and in 3–4 variants with alfalfa cropping it was 1.29–1.32 g·cm^{-3}

Table 6
Volumetric mass of soil in the sample plot, g·cm^{-3}

Options for experience	Soil layers, cm				Average
	0–15	15–30	30–60	60–100	
May, 2021					
1	1.23	1.25	1.28	1.31	1.27
2	1.24	1.26	1.28	1.32	1.28
3	1.23	1.27	1.27	1.31	1.27
4	1.23	1.25	1.28	1.32	1.27
October, 2021					
1	1.41	1.45	1.48	1.51	1.46
2	1.39	1.43	1.47	1.50	1.45
3	1.26	1.29	1.30	1.32	1.29
4	1.27	1.31	1.32	1.38	1.32
May, 2022					
1	1.26	1.29	1.31	1.35	1.30
2	1.29	1.32	1.33	1.36	1.33
3	1.26	1.30	1.28	1.31	1.29
4	1.28	1.30	1.34	1.39	1.33
October, 2022					
1	1.42	1.47	1.50	1.54	1.48
2	1.41	1.45	1.48	1.51	1.46
3	1.28	1.32	1.31	1.34	1.31
4	1.26	1.33	1.36	1.37	1.33

or on the average 0.15 g·cm^{-3} less than cotton cropping. This is directly related to the fact that on the plots with cotton crops the soil is tilled before and after irrigation and thus the soil is compacted more than on the background of alfalfa planting.

This positive fact, as well as the agrochemical properties of soils should be explained by the fact that in alfalfa crops, despite the increased salinity of irrigation water, alfalfa with a deep and powerful root system has a positive impact on soil structure, This means that their strong core roots penetrate the dense subsoil layers and leave a tubular network filled with loose organic matter, thus draining the soil, improving soil structure and porosity, which in general also contributes to favourable growth and development of crops.

The hydrophysical properties of soils depend not only on the mechanical composition and bulk weight of soils, but also on the water permeability of the soil. To determine this indicator on all variants of the pilot plot, the relevant studies were carried out by the frame and ring method, the results of which are shown in Table 7.

The dynamics of water absorption into the soil is normal, characterized by a decrease in the intensity of water absorption into the soil from the first hour to the sixth (duration of the experiment is 6 hours). Absorption rate at 6 hours, close to steady state, varies from 0.13 mm/min to 0.39 mm/min and depends on mechanical composition and volume mass of soil, as well as the nature of soil profile composition, water, and soil temperature.

Based on data of Table 7 the dynamics (Fig. 6c) of soil water permeability change is plotted, by which it is seen that at the beginning of irrigation period 2021 the volume of water absorbed during 6 hours of study averaged 1250 m^3/ha. In autumn in variants with cotton sowing with freshwater irrigation (variant 1) amount of water absorbed into soil was 850 m^3/ha, and in variant with irrigation with mineralized CDW (variant 2) amount of water absorbed was 840 m^3/ha. These indicators in variants 3 and 4 with alfalfa sowing were 960 and 930 m^3/ha respectively or 110–90 m^3/ha more.

According to the hydrogeological observations the groundwater in the pilot plot is identified by two increases – December-March and July-August months, i.e., an irrigation type of groundwater regime is observed. The dynamics of groundwater level-salt regime was established by observation wells located around the pilot plot, where measurements were made every ten days during the whole period of research.

The hydro chemical regime of groundwater is monitored by taking water samples and determining their chemical composition. A total of 12 water samples were taken during the years of study, 6 samples each year, including 2 before the irrigation period, during the irrigation period and after the irrigation period (Table 8).

The depth of groundwater table in 2021 averaged 1.3 m during the vegetation period in variants with cotton crops, which was higher than in variants with alfalfa crops by 0.2 m. Details on the dynamics of changes in groundwater table levels by seasons and variants can be seen in Fig. 6d.

In studies that differ in irrigation water quality and crops (cotton and alfalfa), with the same soil fertility and the same agronomic practices, different yields were obtained (Table 9).

In variant 1 of research, where cotton was watered with fresh water, average yield of raw cotton was 32.3 c/ha, and in variant 2 with irrigation with mineralized water yield was equal to 27.1 c/ha. Yield increase in comparison with the second variant was on the average 3.5 c/ha. In this case fresh water had great influence on cotton yield increase under equal agrotechnical conditions. However, it is necessary to note that raw cotton

Table 7
Soil permeability of the experimental plot, m^3/ha

Definition periods	Field experience options	2021	2022
Spring	general	1250	1330
Autumn	1	850	840
	2	840	845
	3	960	980
	4	930	1010

Table 8
Groundwater table of the test site

Definition periods	Groundwater level by experiment variant, metres			
	1	2	3	4
2021				
Spring	0.5	0.5	0.5	0.5
Summer	1.6	1.6	1.9	1.9
Autumn	1.8	1.8	2.2	2.2
Mid-vegetation	1.3	1.3	1.5	1.5
2022				
Spring	0.4	0.4	0.7	0.8
Summer	1.3	1.4	2.1	2.1
Autumn	1.8	1.7	2.5	2.5
Mid-vegetation	1.2	1.2	1.8	1.8

Table 9
Cotton and alfalfa yield change under CDW use, c/ha

Options	2021	2022	Average yield, kg/ha	Yield increase, c/ha
Cotton (raw cotton)				
1	30.3	34.3	32.3	+ 4.0
2	25.6	28.6	27.1	+ 3.0
Alfalfa (dry hay)				
3	154	160	157.0	+ 6.0
4	152	158	155.0	+ 6.0

yield of 27.1 c/ha obtained in saline soil and irrigation water conditions is considered higher than average yield obtained in all irrigation array, cultivated on non-saline lands with freshwater irrigation.

In variants 3 and 4 of research, where alfalfa was grown with irrigation as well as in plots with cotton with fresh and mineralized water, dry hay yield slightly differed (+6.0 c/ha). The average alfalfa yield in these variants was 155.0–157.0 c/ha and was higher separately by 2.0–3.0 c/ha in the study years. The maximum yield in the second year of the study was 158.0–160.0 c/ha. The salt tolerance of alfalfa, both to soil salinity and to saline water, attracts particular attention here.

4. Discussion

Problems of using CDW from irrigated lands, one of the ways to fill the irrigation water shortage in the conditions of the Turkestan region. As indicated in the results of the study, over the period 1995–2022, the area of land with high groundwater mineralization decreased (Fig. 4), and the area of irrigated land with low groundwater mineralization, on the contrary, increased by about 40%. This situation, as noted above, is associated with large volumes of water for washing the soil, as a result of which partial desalination of groundwater is observed.

According to the results of this work, the use of CDW for irrigation of agricultural crops shows an ambiguous answer. According to the assessment of the irrigation quality of CDW in the region, except for CDW, “Shaulder” in the Otyrar district and “Arnasai” in the Maktaaral district are suitable for reuse without mixing in the amount of about 500 million m^3. This volume of water at an irrigation rate of 8 thousand m^3/ha will increase the water supply of 60.0 thousand hectares of irrigated lands.

The results of chemical analysis of soils using CDW in fields with cotton and alfalfa in the Myrzashol irrigation massif (Table 5) show minor changes in the content of humus, mobile nitrogen and phosphorus. Soil samples from the alfalfa field had a slight positive effect. Also, when growing alfalfa, despite the mineralized water, the water permeability of the soil is preserved by autumn better than when sowing cotton with row-to-row treatments before and after watering.

This positive fact suggests that when sowing alfalfa and growing it under irrigation with mineralized water, the soil was less affected by certain agrotechnical measures that contribute to soil compaction, which are confirmed by data on the volume mass of the soil.

Based on these positive results, it can be concluded that the use of lands with varying degrees of salinity for the cultivation of feed alfalfa and irrigation with mineralized water in conditions of shortage of fresh irrigation water is advisable in terms of preserving the fertility and reclamation condition of lands with a harvest on such low-fertile lands.

Analyzing the diagram shown in the Fig. 6d, it can be concluded that when cultivating alfalfa with irrigation with mineralized water, the level of groundwater occurrence relative to the site with cotton sowing is marked lower from the ground surface. This positive fact contributes to a more favourable creation of the water-air and thermal regime of soils, which is considered optimal for the normal growth and development of crops.

Based on the results of many years of research, as well as according to the above sections, according to this positive effect, it can be concluded that when sowing alfalfa with irrigation with mineralized water, with the help of a deep and powerful alfalfa root system, a positive effect is also exerted on the groundwater regime, in particular their strong tap roots penetrate dense subsurface layers and they leave a tubular network filled with loose organic matter and thereby improves the drainage of the irrigated area, which affected crop yields.

In general, in conditions of low level of operation of irrigation and drainage systems, an increase in the area of irrigated lands with a critical level of groundwater with high mineralization is observed. In this regard, it is especially necessary to pay great attention to the operation of drainage systems. Here, it should be noted that due to climate change, an increase in the intensity of groundwater consumption in the aeration zone is expected, which will lead to an increase in secondary salinization, further land degradation and a decrease in the productivity of irrigated lands.

5. Conclusions

Research has shown that irrigating cotton and alfalfa with mineralized CDW can be a viable alternative for irrigation in areas with low water availability. This can have a positive impact on soil properties in saline lands.

High yields of cotton and alfalfa can be achieved by recycling CDW with a sulphate mineralisation of up to 4.0 g/l on saline irrigated lands in southern Kazakhstan.

Besides, great advantages are created in ameliorative aspect:

- water withdrawal into irrigation systems of river water is reduced, which contributes to reduction of water losses for filtration from canals and lowering of groundwater table;
- groundwater table is lowered directly under the influence of groundwater abstraction;
- when using drainage water, water horizons in collectors and drains are lowered, which increases their working depth and drainage effect;
- against the background of lowered groundwater table the leaching effect of atmospheric precipitation, leaching and vegetation irrigation increases and thus soils are better desalinised and easily cultivated.

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