Establishment of additional norms for irrigation water

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Abstract. Due to the scarcity of water resources, there is a need for an additional source of irrigation. Drainage waters can serve as such sources. To use these waters, it is necessary to develop a number of measures. The aim of the study is to reduce the negative consequences by increasing the norms of preventive irrigation. It is vital to fulfilling the tasks set: calculation of additional water supply rates and irrigation regime when designing the use of drainage water for irrigation. As a result of field studies and according to the methodology of classifications developed by the Central Asian Research Institute of Irrigation (SANIIRI) analysis of the suitability for irrigation of pumped water from vertical drainage wells in the areas of the Fergana region. Studies conducted by scientists in Central Asia have shown that one of the methods to prevent soil salinization in the intra-contour use of collector-drainage water is the requirements with the following conditions: the ratio of total water supply to total evaporation and the ratio of drainage flow to the water supply. Taking into account the established coefficient, the irrigation rate must be increased depending on the mineralization of water and the mechanical composition of the soil.

1 Introduction

When using drainage water for the irrigation of agricultural crops, it is necessary to develop measures to reduce the negative consequences by increasing the norms of preventive irrigation. It should be noted that at present there is no single methodology for calculating additional water supply rates and irrigation regimes when designing the use of drainage water. In contrast, for calculating the irrigation regime and irrigation norms when using (fresh) water, a number of methods are known, such as empirical, water-balance, heat-balance, and others, based on taking into account bioclimatic indicators, as well as methods where evaporation (water consumption) is determined experimentally way.

The aim of the study is to reduce the negative consequences by increasing the norms of preventive irrigation. The objectives of the study include the calculation of additional water supply rates and irrigation regimes when designing the use of drainage water for irrigation. The object of the study is the drainage waters of the Fergana region.

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2 Materials and methods

Research materials include data from field studies, meteorological observation stations, and others. The article uses methods for calculating the water-salt balance, the weight method for measuring soil moisture, computer programming, and other methods.

3. Results

When designing the irrigation regime with fresh water in the conditions of Central Asia, the recommendations of the Institute "Sredagiprovodkhlopok" are widely used. For irrigation with high mineralization waters in order to exclude soil salinization, and reduce the fertility and productivity of agricultural land, it is necessary to provide additional water rates, best of all in the autumn-winter period. They can also be called the washout coefficient [1, 2]. Flushing coefficients can be of two ways:
- based on the generalization of full-scale experiments on the use of collector-drainage waters;
- based on various calculation methods, based on solving the equations of water-salt balances or systems of nonlinear partial differential equations [3].

Table 1. Volume and quality of pumped water in the Ferghana region for 2020.

District name	Number of wells, pieces.	Volume of pumped water, million m3	Mineralization of pumped water, g/l		Suitability for irrigation
			dense residue	Chlorine	
Altyaryk	146	40.6	1.92	0.11	satisfactory
Akhunbabaevsky	52	7.3	1.23	0.08	satisfactory
Baghdad	124	52.5	1.72	0.16	satisfactory
Besharik	109	7.6	1.73	0.14	satisfactory
Dangara	72	7.1	1.89	0.15	satisfactory
Kuva	232	89.2	1.97	0.16	satisfactory
Rishtan	146	70.6	2.2	0.13	satisfactory
Tashlak	114	34.9	1.38	0.08	satisfactory
Uzbekistan	112	20.9	2.09	0.13	satisfactory
Uchkuprik	42	6.3	2.17	0.15	satisfactory
Furkat	56	1.4	1.7	0.15	satisfactory
Yazyavan	10	0.6	1.49	0.06	satisfactory
Kuvasay	26	11.6	1	0.05	good
Total for Fergana region	1264	361	1.48	0.06	satisfactory

Numerous studies that have been conducted in Central Asia have shown that one of the methods to prevent soil salinization during the in-contour use of collector-drainage water is the requirements with the following conditions:
- ratio of total water supply to total evaporation:

$$\frac{\Sigma \quad (B+Oc)}{ET} > (1.2-1.1)Km \qquad (1)$$

- ratio of drainage flow to water supply:

$$\sum \qquad (B + Oc) \geq 0.3 - 0.4 \tag{2}$$

where Km – coefficient, degree of mineralization of water (according to Km can be taken within 1.2-1.4). [5]

For predictive calculations, the established patterns of actual reclamation regimes were calculated during long-term field studies of soil reclamation processes and elements of the water-salt balance.

To establish the leaching regime of soils according to the above method, the conditions of the association of water users for the operational period in the annual and long-term context were used. The above equations were taken as a basis based on many years of research in the Fergana region. For the implementation of predictive indicators of the ameliorative state of irrigated lands during long-term use for irrigation of mineralized waters and flushing. The irrigation regime was as follows: pre-irrigation humidity during the growing season was 70% of the field moisture capacity, and after irrigation 100%. Mineralization of irrigation and washing water was taken according to field studies of 1.5-2.5 g/l. The water-salt balance during the growing season is positive, and the total annual is negative, which means a flush irrigation regime is created. The calculations were performed according to the method developed at SANIIRI [15]. In predictive calculations for large irrigated areas, with different types of drainage, it is effective to use the balance method [6]. The calculation of the balance must be carried out in the context of the month since the data of the operational services are used as the initial ones. They are established on the basis of average monthly values with the elements included for them. Predicted groundwater depths are calculated using the general balance equations according to S.F. Averyanov [15]:

$$\Delta W = W_{н} - W_{k} = \\ = O_c + V_{v/d} + F_{mk} + F_{mg} + F_{m/x} + P - ET_m - С - О \pm Р - D_g - D_w \tag{3}$$

where ΔW is total changes in the stock of moisture in the territory of the balance contour; Fmk is the filtration from the main channel; Vv/d is the water supply by groundwater from vertical drainage wells; ETm is the evapotranspiration of the irrigated area; C is the discharge from irrigation fields; Dg is wedging out of groundwater into horizontal drainage; Dw is the volume of pumped water; Fmk, Fmg, and Fm/x are filtration losses. Moisture reserves in the balance layer can be calculated by using the formula obtained using the empirical dependence:

$$W = \left(4.5n - hA\sqrt{n}\right)10000 \ \ [m^3/ga] \tag{4}$$

where n is porosity; h is the depth of groundwater; A is a parameter characterizing the permeability of the soil (for homogeneous loamy soils A = 0.11 m2, for heavy soils it is 0.12 m2; for layered ones, it is 0.15 m2).

Groundwater balance:

$$\Delta W = \Delta h0 * 104 = Fmk + Fmg + \alpha\, Fm/x \pm g + P - О \pm R - Dg - Dw \tag{5}$$

Water and salt balance of the aeration zone:

$$\Delta W_{ak} - \Delta W_{an} = O_c + B_{\frac{v}{d}} + (1 - \alpha)F_{vx} \pm g + P \pm R - D_g - D_v \tag{6}$$

$$S_{ak} - S_{an} = S_{Op} + S(1-\alpha)\,F_{vx} - S_s \pm S_g \tag{7}$$

Salt balance of the surface layer of groundwater:

$$S_{gk} - S_{gh} = S\,\alpha\frac{Fv}{x} \pm S_g - S_q \pm S_d \pm S_z \tag{8}$$

where Fvx - seepage losses from on-farm canals; Wak,Wan - moisture reserves in the aeration zone at the beginning and end of the calculation period; Oc is the outflow of groundwater from the calculated surface layer of groundwater to the underlying ones; Sak and San are salt content in the aeration zone at the beginning and end of the calculation period; Cg and Cq describe the salt content in the corresponding elements of water balances; Sd and Sz are diffusion and sorption salt exchange, between the calculated and neighbouring layers of groundwater.

$$S_{ah} = h * \text{н} * R * S_{an} * \xi * 100 \tag{9}$$

where Sah is the salt content in the soils of the aeration zone, % of the weight of dry soil; R is the volumetric mass of the soil zone of aeration, in t/m3 unit; ξ is the coefficient of transition from water extracts to the initial estimated salt reserves, which is for chloride soils 1.17 g/l, and for chloride-sulfate, it is 1.41 g/l. The removal of salts in the soils of the aeration zone and seepage waters ($+g$) is determined in our scheme according to the formula [15]:

$$S_g = S^a\lfloor 1 - \frac{1}{(\text{a}\frac{K_a}{\gamma}\_)}\rfloor \tag{10}$$

where γ is the salt leaching constant, which is for chloride soils 1.5, and for chloride-sulfate it is 4.25; K_a-fold rate of water exchange in the soils of the aeration zone

$$K_a = g/(hm_a) \tag{11}$$

where ma is the active porosity. For the case of feeding the aeration zone with groundwater:

$$S_g = 10^{-30} g\mu^{pv} \tag{12}$$

where μ^{pv} is the average mineralization of groundwater for the calculation period, g/l (determined from the water-salt balances of the surface layer of groundwater). Under conditions of close occurrence of groundwater, the role of Sq and Sf in their mineralization is not great. In this case, the hydrochemical regime is formed mainly due to the consumption of groundwater for evapotranspiration and infiltration from irrigated fields. The salt content in the aeration zone at the end of the calculated time interval

$$S_{ak} = S_{\text{an}} \pm Sg + S_{op} + S(1-\alpha)O_a + N_a - N_1 \tag{13}$$

Due to the fact that in the intra-annual section, the mineralization and depth of groundwater are subject to significant fluctuations, the calculated thickness of the surface layer h_Q is lower: with the rise and fall of the groundwater level, respectively

$$\xi = (\alpha F_{vx} \pm g)(1 - \frac{\Delta W}{(\alpha O + O \pm g)})$$
$$\text{at} \quad \alpha F v x < | - q|, \xi = 0 \tag{14}$$

Salt balance elements of the surface layer of groundwater are defined as follows:

$$S^{pgv} = h_o C_{pgv} R \xi 100 \tag{15}$$

$$E_1 = \frac{\xi}{h_0 \ m_0 \ 10^4} \tag{16}$$

$$S_e^{IAN} = (N_i^{IAA} + \text{N}\alpha O_{AO}) \pm Ng - C \tag{17}$$

$$C_e^{1AA} == \frac{N_E^{1Aa}}{h_0 R \xi 100} \tag{18}$$

$$\mu^{1AA} = \frac{S^{1AA}}{\theta} \tag{19}$$

where Se1AA is the salt content in soils of the calculated groundwater layer, (%) of the weight of dry soil; θ is the fresh factor from the salt content in soils (%) to express the mineralization of groundwater, in g/l unit [6]. R is the volumetric mass of the soil zone of aeration, C is the discharge from irrigation fields, and μ is the average mineralization of groundwater for the calculation period

The salt balance of the aeration zone of an irrigated field is calculated according to the formulas and specific values for the "net" area. When determining the water-salt balances of the root layer, the following assumptions were made: the root layer during the entire growing season is assumed to be 0.8 m; change in moisture reserves in the root layer ΔWak for monthly intervals; the salinity of the ascending groundwater flow feeding the root zone is equal to the average mineralization of the aeration zone layer between the groundwater level and the root zone; salts coming from groundwater into the aeration zone with an upward current from their surface are completely deposited in the root zone. The estimated irrigation norm net, established for a complex hectare according to fresh water was 5200 m3/ha. Taking into consideration the coefficient established above, the irrigation rate must be increased depending on the mineralization of water and the mechanical composition of the soil [10]. At the same time, the irrigation rate in the Fergana region will be from 5750 m3/ha to 6250 m3/ha for permeable soils per year with mineralization of 1.5-2.5 g/l. To consider the efficiency of irrigation equipment equal to 0.70, the calculated irrigation norms should be 8210-8925 m3/ha (gross). Additional norms of preventive irrigation are recommended to be applied in the autumn-winter period. The results of calculations for predicting the total water balance, water and salt balance of the aeration zone, the content of easily soluble salts in the aeration zone and the root layer, as well as the salinity of groundwater and the root layer according to the above method, are given in Table 2. The presented data show that the calculated rates of additional irrigation (i.e., flushing regime coefficients) are quite sufficient to ensure the required reclamation state of lands when using pumped groundwater [7,8,12].

Table 2. Total water balance of the field when using pumped water for different leaching regime coefficients (Kpr).

Kpr	Income, m3/ha				Receipt amount	Receipt amount, m3/ha			Amount of expense	Balance ±ΔWот
	Bbr	A	Fк	P		ETп	Dr	Cbr		
Kpr = 1.15	8210	1680	810	2000	12700	6710	3110	620	10440	+2260
Kpr = 1.25	8925	1680	880	2000	13485	6710	3380	710	10800	+2685

Table 3. Salt balance of the aeration zone.

Elements		At Mot = 1.5 g/l	At Mot = 2.5 g/l
		salt, t/ha	salt, t/ha
	SA	7.5	1.15
	$S_{0_p}^{veg}$	7.5	12.5
Coming:	SNnov	2.18	2.67
	S(1-α)Fк	0.61	1.1
Total		11.44	17.42
Consumption:	S±q	14.85	18.13
	Ssbr	1.06	1.78
Total		15.91	19,91
Difference		-4.48	Δ= -2.49

Table 4. Forecast of the main indicators of the ameliorative state of irrigated lands when using pumped water.

Period	Indicators				
	Sa, %	S^{gr},%	M^{gr},g/l	$S^{кс}$, %	M^{kc}, g/l
Initial	0.350	0,289	5,000	0,275	3,920
Final	0,250	0,270	4,271	0,264	3,777

4 Discussion

The water balance of a territory is a quantitative expression of its water regime, which determines the ratio of irretrievable water consumption and return water runoff. It is this ratio in each specific area and at each level of water management construction that determines the intensity of flow change in the process of its use. Researchers have developed a methodology for assessing the conditions for the use of vertical drainage, on the basis of which scientists found that on the territory of Uzbekistan on the total area in need of drainage of 4.5 million hectares, the land the possible use of vertical drainage is 2.68 million hectares, including in the Fergana Valley, respectively, from 0.706 million hectares to 0.53 million hectares [11]. Despite the large volumes of research work performed, issues related to the use of drainage water need to be addressed. Their solution is connected with conducting deep theoretical and long-term field studies on typical pilot production sites [9,13].

5 Conclusions

The results of chemical analyzes showed that the salinity of pumped water from the vertical drainage wells varies from 1 (Kuvasoy town) to 1.99 g/l (Altyaryk district) in terms of solid residue, and from 0.05 g/l to 0.17 g/l in terms of chlorine. The quality of these waters is satisfactory and can be recommended for irrigation.

The results of calculations for predicting the overall water and salt balance of the aeration zone, as well as the salinity of groundwater and the root layer, show that the calculated rates of additional irrigation (i.e, flushing regime coefficients) are quite sufficient to ensure the required reclamation state of the land when using pumped groundwater. The established values of the flushing regime coefficient are generally close to the data of other scientists, and their comparison showed that they differ by no more than 10-15%.

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