Development a mathematical model of a water-salt balance on irrigated lands of the Sirdarya area

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Abstract. The article presents the results of field studies and analysis of the parameters of the input and expenditure components of the water-salt balance, which makes it possible to assess the reclamation state of irrigated lands. Directly in the field, using the measurement determined the values of the input and expendable components of the water and salt balance, a tendency to improve or worsen the reclamation state of the irrigated lands of the Shuruzak massif and the Saykhunabad district of the Syrdarya region. The general water balance, the balance in the aeration zone and groundwater was compiled. Determination of water and salt balance in the aeration zone of soil and groundwater leads to the creation of optimal water-air and nutrient regimes for the development of crops and high yields. To determine the water and salt balance on the irrigated lands of the Saykhunabad region, a mathematical model was developed for the first time, based on which it is possible to predict changes in the water, salt regimes and the regime of groundwater in the irrigated massif. Their regulation is very important for determining practical measures to manage this regime in order to save irrigation water and improve the reclamation state of irrigated lands.

1. Introduction
The land of the Shuruzak massif of the Saykhunabad district is a plain located on the left bank of the Syr Darya River. Here, gray-earth meadow soils developed. Meadow bogs (in the floodplain of the Syr Darya River) and various brackish gray soils are also widespread. The mechanical composition of soils is represented by heavy and medium loams and contains a significant amount of nutrients, characterized by high fertility. Due to the proximity of groundwater and poor drainage, these lands are prone to secondary salinization. Reclamation of these soils is often difficult due to the high occurrence of groundwater, their increased mineralization and the backwater by the waters of the Syr Darya River [1]. In this regard, the reclamation of such soils, in many cases, require measures to enhance their drainage, leaching and desalination of groundwater [2]. A. N. Kostyakov proposed the theory of the water balance of reclaimed lands to determine the qualitative and quantitative characteristics of the factors that make up the water balance of irrigated lands, their change and mutual influence [3]. Otherwise, it is difficult to judge when and what waters and in what quantities must be removed or, conversely, retained, and in some cases, additionally filed in order to create soil moisture, which makes it possible to carry out agricultural work and obtain high sustainable crop yields of cultivated crops in variety moisture years. Changes in the moisture content and, correspondingly, the salt content in the aeration zone of soil during the growing season and leaching, the preparation of
equations of water-salt balance have been studied by many scientists, as A. N. Kostyakov, S. F. Averyanov, N. G. Minashina, A.E. Nerozin, A.S. Ovchinnikov, D. M. Katz, V. A. Dukhovny, R.K. Ikramov and others [3],[4],[5],[6],[7],[8],[9]. The studies of these scientists established that the forecast of the water-salt regime is reduced to determining the limit value of the possibilities of natural underground outflow and substantiating the necessity or sufficient supply of irrigated lands with collector-drainage systems.

2. Research methodology

Field studies were carried out on the irrigated lands of the Shuruzak massif and farms in the Saykhunabad district of the Syr Darya region, according to the methods of SANIIRI (NIIIVP at TIIAME), UzNIKh, UzGIP LLC. The total evaporation depending on the evaporation and the position of the groundwater and the drainage rate are determined by the formula S.F. Averyanov[10],[11].

The tasks of predicting water and salt regimes are: taking into account and assessing the factors that determine the water-salt regime of the irrigated area in natural conditions; calculation of the regime of groundwater and salt reserves in the soil under design conditions and establishing on this basis the need for land reclamation measures; calculation of flushing and drainage parameters.

In modern reclamation practice, the following methods for predicting water and salt regimes are used:

1) balance sheet based on the solution of equations, water and salt balances;
2) analytical, which is based on the solution of various differential equations, including the finite difference method;
3) simulations using computers, etc.

Currently, the main of these is the balance method, in which forecasting is based on the solution of the equations of water and salt balances and the equations of motion of moisture and salts in soils. S. F. Averyanov proposed at the same time to determine: the water balance of the irrigated area, taking into account surface and groundwater and aeration zone water; balance of soil and groundwater. The total balance of the irrigated massif represents the sum of the indicated components, in m3/ha [2],[3],[4],[5].

The water balance for the irrigated area in the presence of drainage must be determined from the equations (Fig. 1) [9],[12]:

a) the total water balance is represented by the following formula:
\[ \Delta V = (I_d - O_d) + (I_s - O_s) + P - (I + T_p) \pm V_v + B - C - D \]  
(1)
b) the balance of surface water and moisture in the aeration zone should be determined according to the equation:
\[ \Delta V_a = (I_d - O_d) + P - (I + T_p) \pm V_v + B - F_k - S \]  
(2)
c) groundwater balance:
\[ \Delta V_s = (I_s - O_s) \pm V_v + V_a + F_k - D \]  
(3)
where, \(D\) is the volume of drainage flow (load on the drainage); \(\Delta V\) is the total change in water reserves within the boundaries of the territory under consideration; \(\Delta V_a\) is the change in moisture reserves in the aeration zone within the boundaries of the considered territory; \(\Delta V_s\) is the change in groundwater reserves within the boundaries of the territory under consideration; \(I_d\) is the inflow of surface waters; \(O_d\) is the outflow of surface water outside the territory; \(I_s\) is the groundwater inflow; \(O_s\) is the groundwater outflow; \(P\) is the precipitation; \(I\) is the evaporation from the surface of the soil; \(T_p\) is the transpiration; \(V_v\) is the vertical water exchange of the balance sheet with the underlying aquifers (feeding groundwater with pressurized groundwater or the flow of groundwater into the underlying layers); \(V_a\) is the vertical water exchange between the aeration zone and groundwater; \(B\) is the water intake into the irrigation system from external sources \(B(M + F_k)\); \(S\) is the removal of surface discharges of irrigation water outside the territory; \(F_k\) is the filtration losses of irrigation water from canals; \(M\) is the irrigation rate.
Consider the water-salt balance of the irrigated lands of the Saykhunabad district of the Syr Darya region [1].

Table 1. General water-salt balance of the floodplain of the Saikhunabad region.

| Items of balance | Annual | Growing period | Non-growing period |
|------------------|--------|----------------|-------------------|
|                  | m³/ha  | t/ha           | m³/ha             | t/ha             |
| O_c              | 3615   | 0              | 440               | 0                |
| B                | 7826   | 8.66           | 6524              | 7.38             | 1302            | 1.28           |
| B_{bd}           | 66     | 0              | 45                | 0                | 21              | 0              |
| B_{kds}          | 2397   | 6              | 2397              | 6                | 0               | 0              |
| P                | 114    | 0.46           | 67                | 0.27             | 47              | 0.19           |
| Total coming     | 14018  | 15.3           | 9473              | 13.8             | 4545            | 1.5            |
| E_T              | 9956   | 0              | 8872              | 0                | 1084            | 0              |
| D_B              | 65     | 0.16           | 45                | 0.11             | 20              | 0.05           |
| D_g              | 3386   | 8.43           | 1622              | 4.24             | 1764            | 4.19           |
| C                | 2128   | 2.38           | 1885              | 2.14             | 243             | 0.24           |
| O                | 47     | 0.2            | 27                | 0.11             | 19              | 0.08           |
| Total coming     | 15582  | 11.2           | 12452             | 6.6              | 3130            | 4.6            |
| Balance          | -1564  | 4.12           | -2979             | 7.17             | 1415            | -3.05          |

Where, \( F_{val} = 24.7 \) thousand ha; \( F_{op} = 18.3 \) thousand ha; \( E_{f_{m/x}} = 0.85; E_{f_{v/x}} = 0.70; L_{ud} = 21 \) m / ha.

From the general water and salt balances of the floodplain of the Saykhunabad district, it is evident that the incoming part of the balance is mainly precipitation (3615 m³/ha) and water intake from canals (7826 m³/ha), and the evaporation is from the gross area (9956 m³/ha), runoff from closed drains (3386 m³/ha) and operational spillways (2128 m³/ha). The main source of nutrition for groundwater and drainage are losses (discharges, filtration) from inter-farm and on-farm canals. The value of water consumption from the gross area amounted to more than 1564 m³/ha relative to the input and increased from 4.12 tons of salts per hectare (Table 1).

Table 2. Water and salt balance of the aeration zone of irrigated areas of the floodplain of the Saykhunabad region.

| Items of balance | year | vegetation | non-vegetation |
|------------------|------|------------|----------------|
|                  | m³/ha| t/ha       | m³/ha          | t/ha           |
| O_c              | 3327 | 0          | 315            | 0              | 3012            | 0              |
Calculations of water-salt balances of the aeration zone of the irrigated areas of the floodplain of the Saykhunabad district show that during the growing season the amount of evapotranspiration from the irrigated areas became larger relative to the water supply to the field, therefore, groundwater was pulled into the aeration zone by capillaries per hectare of 3389 m$^3$ of water, as a result, into the zone aeration additionally rose 8.8 t/ha of salt. And in the non-growing season, on the contrary, precipitation and water supply from the canals were more relative to evapotranspiration, as a result, 2175 m$^3$ of water and 24.2 t/ha of salt were added to the groundwater from a hectare. And in an annual section, from the aeration zone, 1214 m$^3$/ha of water moved to groundwater and the salt reserve in the aeration zone increased by 0.70 tons (Table 2).

Table 3. The balance of the root layer of agricultural crops in the floodplain of the Saykhunabad region.

| Items of balance | year | vegetation | non-vegetation |
|------------------|------|------------|----------------|
|                  | m$^3$/ha | t/ha | m$^3$/ha | t/ha | m$^3$/ha | t/ha |
| $O_c$            | 3615  | -      | 440        | -    | 3175    | -    |
| $B$              | 8423  | 9.3    | 7022       | 7.9  | 1401    | 1.4  |
| $B_{bd}$         | 90    | 0.1    | 61         | 0.1  | 28      | 0    |
| $B_{kds}$        | 3224  | 8.1    | 3224       | 8.1  | 0       | 0    |
| $C_p$            | 1615  | 1.8    | 1405       | 1.6  | 210     | 0.2  |
| $E_{tp}$         | 15580 | -      | 13989      | -    | 1591    | -    |
| +$g_{ka}$        | -1576 | -15.2  | 4424       | 11.3 | -2848   | -26.6|
| $\Delta C_{ka}$ | -0.9  | -      | 26.2       | -    | -25.3   |      |

From the calculations of the water-salt balance of the root layer of agricultural crops on the irrigated areas of the floodplain of the Saykhunabad district Poyma, it was known that 4424 m$^3$/ha of water rose into the root layer during the growing season, as a result of which 11.3 t/ha of salts rose. And during the year, 1576 m$^3$/ha of water rose into the root layer from the lower layers and 0.90 t/ha of salt increased in the root layer. From these data it is seen that in the root layer of agricultural crops, the salt process is unstable and the degree of salinization is slightly increased (Table 3)[10],[12],[13],[14].

Table 4. Total water and salt balance of the Shuruzyak massif of the Saykhunabad region.

| Items of balance | year | vegetation | non-vegetation |
|------------------|------|------------|----------------|
|                  | m$^3$/ha | t/ha | m$^3$/ha | t/ha | m$^3$/ha | t/ha |
| $O_c$            | 3615  | 0   | 440        | 0    | 3175    | 0    |
| $B$              | 10357 | 11.65  | 8697       | 9.94 | 1660    | 1.72 |
| $B_{bd}$         | 0     | 0   | 0          | 0    | 0       | 0    |
| $B_{kds}$        | 0     | 0   | 0          | 0    | 0       | 0    |
| $P$              | 114   | 0.57 | 67         | 0.33 | 47      | 0.24 |
| Total coming     | 14086 | 12.2 | 9203       | 10.3 | 4882    | 2.0  |
| $E_T$            | 8970  | 0   | 7905       | 0    | 1064    | 0    |
Where, \( F_{\text{val}} = 16.6 \) thousand ha; \( F_{\text{op}} = 13.4 \) thousand ha; \( \text{Eff}_{m/x} = 0.85 \); \( \text{Eff}_{v/x} = 0.70 \); \( L_{\text{ud}} = 25 \text{ m / ha} \).

From the general water and salt balances of the Shuruzyak massif of the Saykhunabad district, it can be seen that the incoming part of the balance is mainly precipitation (3615 m\(^3\)/ha) and water intake from the canals (10357 m\(^3\)/ha), and the evapotranspiration from the gross area (8970 m\(^3\)/ha) stock from closed drains (3303 m\(^3\)/ha) and operational spillways (1908 m\(^3\)/ha). The main source of nutrition for groundwater and drainage are losses (discharges, filtration) from inter-farm and on-farm canals. The value of water consumption from the gross area amounted to more than 1001 m\(^3\)/ha relative to the input and from the gross area decreased 2.56 tons of salts per hectare (Table 4).

**Table 5. Water-salt balance of the aeration zone of irrigated areas of the Shuruzyak massif of the Saykhunabad region.**

| Items of balance | \( m^3/\text{ha} \) | \( t/\text{ha} \) | \( m^3/\text{ha} \) | \( t/\text{ha} \) | \( m^3/\text{ha} \) | \( t/\text{ha} \) |
|-----------------|------------------|------------------|------------------|------------------|------------------|------------------|
| \( O_c \)       | 3615             | -440             | -                | 3175             | -                |
| \( B \)         | 9455             | 10.6             | 7940             | 9.1              | 1516             | 1.6              |
| \( B_{bd} \)    | 0                | 0                | 0                | 0                | 0                | 0                |
| \( B_{kds} \)   | 0                | 0                | 0                | 0                | 0                | 0                |
| \( C_p \)       | 1418             | 1.6              | 1191             | 1.4              | 227              | 0.2              |
| \( E_{tp} \)    | 12276            | -                | 10858            | -                | 1418             | -                |
| \( +g_a \)      | 176              | -7.9             | 2561             | 10.8             | -2385            | -18.7            |
| \( \Delta C_a \)| -1.6             | -                | 18.9             | -                | -17.3            |

Calculations of the water-salt balances of the aeration zone of the irrigated areas of the Shuruzyak massif of the Saykhunabad region show that in the growing season the amount of evapotranspiration from the irrigated areas became larger relative to the water supply to the field, therefore, groundwater was pulled into the aeration zone by capillaries per hectare of 2561 m\(^3\)/ha, as a result the aeration zone additionally rose 10.8 t/ha of salt. But in the non-growing season, on the contrary, precipitation and water supply from the canals were more relative to evapotranspiration, as a result of which 2385 m\(^3\) of water and 18.7 t/ha of salt were added to the groundwater from a hectare. And in an annual section, 176 m\(^3\)/ha of water rose into the aeration zone and the salt reserve in the aeration zone increased by 1.6 tons of salts per hectare (Table 5)[1],[10],[11],[12],[13],[14],[15].

**Table 6. The balance of the root layer of agricultural crops of the Shuruzyak massif of the Saykhunabad region.**

| Items of balance | \( m^3/\text{ha} \) | \( t/\text{ha} \) | \( m^3/\text{ha} \) | \( t/\text{ha} \) | \( m^3/\text{ha} \) | \( t/\text{ha} \) |
|-----------------|------------------|------------------|------------------|------------------|------------------|------------------|
| \( O_c \)       | 3615             | -440             | -                | 3175             | -                |
| \( B \)         | 9455             | 10.6             | 7940             | 9.1              | 1516             | 1.6              |
| \( B_{bd} \)    | 0                | 0                | 0                | 0                | 0                | 0                |
| \( B_{kds} \)   | 0                | 0                | 0                | 0                | 0                | 0                |

Where, \( D_B = 858 \) m\(^3\)/ha; \( D_g = 3303 \) m\(^3\)/ha; \( \alpha = 2.69 \); \( \beta = 558 \); \( \gamma = 1.81 \); \( \delta = 300 \); \( \varepsilon = 0.89 \);

\( C = 1908 \) m\(^3\)/ha; \( \alpha = 2.15 \); \( \beta = 1602 \); \( \gamma = 1.83 \); \( \delta = 366 \); \( \varepsilon = 0.32 \);

\( O = 47 \) m\(^3\)/ha; \( \alpha = 0.2 \); \( \beta = 27 \); \( \gamma = 0.14 \); \( \delta = 19 \); \( \varepsilon = 0.10 \).

\[
\begin{align*}
D_B & = 858 & 2.69 & 558 & 1.81 & 300 & 0.89 \\
D_g & = 3303 & 9.71 & 1532 & 4.40 & 1772 & 5.32 \\
C & = 1908 & 2.15 & 1602 & 1.83 & 306 & 0.32 \\
O & = 47 & 0.2 & 27 & 0.14 & 19 & 0.10 \\
\text{Total coming} & = 15087 & 14.8 & 11625 & 8.2 & 3461 & 6.6 \\
\text{Balance} & = -1001 & -2.56 & -2422 & 2.10 & 1421 & -4.66
\end{align*}
\]
3. Results and discussion

From calculations of the water-salt balance of the root layer of crops in the irrigated areas of the Shuruzyak massif of the Saykhunabad region, it was known that 3374 m³/ha of water rose into the root layer during the growing season, as a result of which 11.5 t/ha of salts rose. And during the year, 272 m³/ha of water rose into the root layer from the lower layers and 0.3 t/ha of salt increased in the root layer. From these data it is seen that in the root layer of agricultural crops, the salt process is unstable and the degree of salinization is slightly increased (Table 6) [16],[17],[18],[19],[20].

The program for calculating the change in groundwater reserves is as follows:

```pascal
uses vcl;
var
Form1: Form;
Button1, Button2, Button3, Button4, Button5, Button6, Button7, Button8, Button9: Button10,
Button11, Button12, Button13, Button14, Button15, Button16, Button17, Button18: Button;
Edit1, Edit2, Edit3, Edit4, Edit5, Edit6, Edit7, Edit8, Edit9: Edit;
Edit10, Edit11, Edit12, Edit13, Edit14, Edit15, Edit16: Edit;
bitmap1: bitmap;
paintbox1: paintbox;
id,od,p,i,tp,va,b,fk,s,os,vv,d,dva,dvs,dv,iss: real;
sdva,sdvs,sdv: string;
cod: integer;
procedure Button17OnClick;
begin
val(edit1.text,id,cod);
val(edit2.text,od,cod);
val(edit3.text,p,cod);
val(edit4.text,i,cod);
val(edit5.text,tp,cod);
val(edit6.text,va,cod);
val(edit7.text,b,cod);
val(edit8.text,fk,cod);
val(edit9.text,s,cod);
val(edit10.text,iss,cod);
val(edit11.text,os,cod);
val(edit12.text,vv,cod);
val(edit13.text,d,cod);
dva: = id-od+p+i-tp-va-b-fk-s;
dvs: = iss-os+vv+va+fk-d;
dv: = dva+dvs;
str(dva,sdva);
str(dvs,sdvs);
str(dv,sdv);
edit14. text: = sdva;
edit15. text: = sdvs;
edit16. Text: = sdv;
end;
procedure Button18OnClick;
```

| Cp   | 1418 | 1.6 | 1191 | 1.4 | 227 | 0.2 |
|------|------|-----|------|-----|-----|-----|
| Etip | 12276| -   | 10858| -   | 1418| -   |
| + gkc | 272  | -9.1| 3374 | 11.5| -3102| -20.6|
| ∆Ckc | -    | 0.3 | -    | 19.5| -   | -19.2|
begin
Form1.close;
end;

Program result is shown in Fig. 2.

Figure 2. The result of the calculation.

4. Conclusions
1. From the general water-salt balances of the floodplain of the Saikhunabad region, it is evident that the incoming part of the balance is mainly precipitation and water intake from the canals, and the evapotranspiration from the gross area, runoff from closed drains and operational spillways are the expense part.

2. The main source of nutrition for groundwater and drainage are losses (discharges, filtration) from inter-farm and on-farm canals.

3. The magnitude of the water flow from the gross area was greater than the arrival and increased from 4.12 tons of salts per hectare on the gross area.

4. The water-salt balance of the Shuruzyak massif also shows that the incoming part of the balance is precipitation and water intake from the canals, and the evapotranspiration from the gross area, runoff from closed drains and operational spillways are the expenditure part.

5. The main source of nutrition for groundwater and drainage are losses (discharges, filtration) from inter-farm and on-farm canals.

6. The value of water consumption from the gross area was more relative to the income and from the gross area 2.56 tons of salts per hectare decreased, which indicates an improvement in the technical condition of on-farm irrigation networks and the prevention of operational discharges.

References
[1] Savosku O S, Chevnina E V, Perziger F I, Vasilina L Y, Baburin V L, Danshin A I and Matyakubov B 2003 Water, Climate, Food, and Environment in the Syr Darya Basin
[2] Bogomolov YG, Baron V A, Katz D M and Kozlov M F 1982 Prediction of underground water regime and balance in lands under reclamation Improvements of Methods of Long Term Prediction-of Variations in Groundwater Resources and Regimes Due to Human Activity 136,
[3] Kostyakov A N 1960 Fundamentals of Land Reclamation (Moscow)
[4] Minashina N G 1978 Reclamation of saline soils (Moscow)
[5] Nerozin A E 1980 Agricultural land reclamation (Tashkent)
[6] Ovchinnikov A S, Borodychev V V, Lytov M N, Bocharnikov V S, Fomin S D, Bocharnikova O V and Vorontsova E S 2018 Optimum control model of soil water regime under irrigation Bulg. J. Agric. Sci. 5 909–13
[7] Katz D M 1963 Groundwater regime in irrigated areas and its regulation (Moscow: Selkhozizdat)
[8] Dukhovny V A and Baklushin M B 1979 Horizontal drainage on irrigated lands (Moscov)
[9] Ikramov R K 2001 Principles of managing the water-salt regime of irrigated lands in Central Asia under conditions of water scarcity (Tashkent: Hydroingeo) p 190
[10] Kasimbetova S, Ergashova D, Akmedjanova G, Mardiez S and Malikov E 2020 Application of magnetized water on the washing of salted lands under the conditions of the low village of the Amudarya River J. Adv. Res. Dyn. Control Syst. 12 127–130
[11] Serikbaev B S, Baraev F A and Kasymbetova S 1996 Workshop on the operation of irrigation and drainage systems (Tashkent: Mehnat)
[12] Shukurlaev Kh I, Baraev A A and Mamataliev A B 2007 Agricultural hydrotechnical land reclamation (Tashkent)
[13] Sujitha E, Selvaperumal A and Senthivel S 2019 Validation of Surge Model Using Furrow Gradient and Flow Retardance Curr. J. Appl. Sci. Technol. 8 1–8
[14] Anon Methods of field experience (the basics of static processing of research results) 1985
[15] Reshetov G G 1988 Soil leaching on furrows (Tashkent: Mehnat, Institute "Sredazgiprovdokhlopop" im. A.A.Sarkisova) p 24
[16] Marchuk G I 1980 Methods of Computational Mathematics Science
[17] Abdullayev Z S, Mirzayev S S, Shodmonova G and Shamsiddinov N B 2012 Informatics and Information Technology (Tashkent)
[18] Eshmatov H, Verlan A F and Lukyanenko S A 2008 Numerical methods in modeling
[19] Eshmatov H, Yusupov M, Aynaqulov Sh and Khadjaev D 2008 Mathematical modeling
[20] Bakhvalov N S 1975 Numerical methods