Mathematical model of the effective use of reclaimed lands in the South of Russia

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Abstract. To assess the state of reclaimed land by purpose and intensity of use, it is necessary to fully apply the following set of indicators: the quality of irrigation water; the depth of groundwater; the salinity of underground water; the degree of salinity of the soil; leaching of the soil; the degree of soil contamination with fluoride, heavy metals and other pollutants; the composition and amount of humus; the density and structural-aggregate composition of the soil; the degree of occurrence of adverse exogenous processes. The main of the indicators is the depth of ground water, which during the growing season is considered relative to the “critical” depth, i.e. the depth at which the optimal water-air regime is determined for growing crops and preventing secondary salinization of the soil. The direction and speed of soil formation processes are also determined by the quality of irrigation water, climatic and hydrogeological conditions of the region, soil topography, natural properties, irrigation techniques and technologies. On reclaimed lands, soil degradation occurs only under certain conditions. The most common degradation processes are: rising groundwater levels; activation of geochemical processes at the local, regional and global levels. Secondary soil salinization is observed on the reclaimed lands. The desalination process is determined by the quality of irrigation water, soil properties, depth and salinity of groundwater; leaching of the soil and an increase in toxic alkalinity, pH; drainage of irrigated soils is formed due to the development of erosional, alkaline and saline processes, the presence of perennial grasses and organic fertilizers in the crop rotation. With soil salinization, the qualitative composition of humus changes, agrophysical degradation of reclaimed lands, modification of mineral soil components and increased hydrophilicity during irrigation. According to the above indicators, the full range of degraded lands in the region is unknown, since it requires regular monitoring of the reclaimed lands. Taking into account the above, studies aimed at increasing the efficiency of the use of reclaimed lands in the South of Russia is an urgent problem.

1. Introduction
The ecological and reclamation state of irrigated lands has not yet been adequately assessed, i.e. dimensional indicators characterizing the environment condition, and their assessment is carried out only at the subjective level, i.e. based on information materials such as soil salinity. That is, there is practically no comprehensive indicator characterizing the ecological and reclamation condition of irrigated agriculture and soil [1-6].

In general, quantitative criteria for assessing the ameliorative state of irrigated lands are often formed depending on the state of the soil, and therefore all natural factors affecting the process of salinization
of the soil system: precipitation, air temperature, wind, speed, filtering properties of the rock, geostructure and much more [7-15].

2. Research results

The development of soil-ecological orientation in the reclamation of irrigated lands in agriculture causes the need for new methodological approaches.

In general terms, the expression for establishing the change in energy has the form:

$$\Delta E = E_i - E_2 = V_i,$$  \hspace{1cm} (1)

$$E_i = m_1 \left(0.5V_i^2 + gH_i\right),$$  \hspace{1cm} (2)

$$E_2 = m_2 \left(0.5V_2^2 + gH_2\right),$$  \hspace{1cm} (3)

where $V_i$ – normal flow of ground water to overcome the friction force on the soil fraction in the study area, m/s; $m_1$ and $m_2$ – average mass of groundwater, respectively, at points in time $t_1$ and $t_2$, kg; $V_i$ and $V_2$ – rate of groundwater, respectively, at the moments of time $t_1$ and $t_2$, m/s; $H_i$ and $H_2$ – groundwater level, respectively, at the moments of time $t_1$ and $t_2$, m.

In the case when the flow obeys Darcy’s law, the friction force of the fluid on the ground is determined as follows:

$$F_i = \frac{\mu \nu V_i \gamma}{K_i \nu} \left[ pf(x) dh \right],$$  \hspace{1cm} (4)

where $\mu$ – absolute liquid viscosity, m$^2$/s; $V_i$ – filtration speed, m/s; $\gamma$ – specific weight, kg/m$^3$; $K_i$ – liquidity ratio, m$^2$; $p$ – porosity; $f(x)$ – cross-sectional area of groundwater flow, m$^2$; $dh$ – elementary section thickness, m.

The work done by the friction force in the area $dx$, is equal $A_i = F_i dx$, since $dx = V_i \Delta t$. Here $\Delta t = t_2 - t_1$, and $\left[ pf(x) dh \right]$ – is the thickness, which means the mass of a liquid of ordinary volume $A_i$, and the value is expressed by the following formula:

$$A_i = \frac{V_i m_i V_i^2 \Delta t}{K_i \nu},$$  \hspace{1cm} (5)

where $K_i$ – filtration coefficient, m/day.

In general, taking into account the sources and flows in the form of evaporation or infiltration, which cause changes in the mass of groundwater flows, $A_i$ is expressed by the formula:

$$A_i = \frac{g V_i^2 \Delta t}{K_i} (m_i + \epsilon_i - q_i),$$  \hspace{1cm} (6)

where $\epsilon_i$ – moisture infiltration rate, m/day; $q_i$ – moisture evaporation rate, equal to:
where \( W \) – moisture amount, kg; \( F \) – surface area, \( m^2 \); \( \tau \) – time, days.

If we take into account that the effect of evaporation and infiltration of water on the flow of groundwater is not simultaneous, the infiltration time per unit of time is used. Then the effect of evaporation will be in case \((1−t)\). In addition, it should be borne in mind that infiltration leads to an increase in the level of groundwater, which, in turn, leads to increased evaporation. If the infiltration is corrected for the dependence of evaporation on the depth of the groundwater level, then we have:

\[
q_i = Q_0 \left(1 - \frac{H_0}{H_k}\right)^n,
\]

where \( Q_0 \) – evaporation, m; \( H_0 \) – groundwater during the growing season, the average depth of the bed, m; \( H_k \) – the critical depth of groundwater, m.

In view of the foregoing, the work done by the flow of groundwater can be determined by the following formula:

\[
A_i = \frac{gV_i^2}{K_i(B/r)} \left\{ \left[(B/K \cdot r) - V_c\right] - (1-t)Q_0 \left[1 - \left(\frac{H_0}{H_k}\right)^n\right] - It \right\},
\]

where \( B \) – radiation balance, \( W / m^2 \); \( K \) – hydrothermal regime of irrigated lands (hydrothermal coefficient); \( r \) – latent heat of vaporization, J/kg; \( V_c \) – groundwater volume, \( m^3 \); \((1−t)\) – infiltration time, days \((t = T/365)\); \( T \) – duration of the growing season, days; \( I \) – intensity of surface water discharge from irrigated lands, \( m^3 / s \).

This ratio can be used to quantify natural or artificial drainage of irrigated land. From the analysis of the formula that determines the work done by the flow of groundwater, the system in this area can work for a long time.

It should be noted that the actual volume of irrigation or water supply is several times higher than the ecological norm of water consumption. Therefore, this circumstance must be taken into account when determining the work performed by the flow of groundwater.

Water balance components are

\[
Q_i = (1−t)Q_0 \left(1 - \frac{H_0}{H_k}\right)^n \quad \text{– intensity of moisture exchange between soil and groundwater;}
\]

\[
F_i = \frac{gV_i^2}{K_i(B/r)} \quad \text{– frictional force of water absorbed by the soil.}
\]

Then in the system “soil - soil water” we will have:

\[
A_i = F_i \left\{ \left[(B/K \cdot r) - V_c\right] - Q_i - It \right\}.
\]

Considering the work with liquids from the point of view of concentration, this ratio reflects the ability of the system “soil - soil water” to release easily soluble salts, which can be transported to the ionic base of the stream. The average concentration of salts \( (S_i) \) in the “soil - soil water” system is...
determined on the basis of the following assumptions: the initial concentration of salts in the soil \( (S_n) \) increases the input of salts due to irrigation water and atmospheric precipitation. The inflow of these salts can be determined by knowing the concentration of irrigation water \((S_0)\) or precipitation \((S_a)\) in the ratio:

\[
t \varepsilon_0 S_n r / B,
\]

where \( \varepsilon_0 / B \) – intensity of irrigation water inflow.

The increase in concentration due to the loss of the mass of water lost due to evaporation is equal to

\[
(1-t) g S_n r / B,
\]

where \( S_n \) – concentration of salts in groundwater.

Then:

\[
S_i = \left[ S_{ni} + \frac{\varepsilon_0 t g S_{n0}}{B/r} + (1-t) \frac{g S_{nv}}{B/r} \right],
\]

where \( S_{ni} \) – the initial concentration of the soil solution in the soil layer; \( S_{n0} \) – concentration of salts in irrigation water.

In the system “soil - groundwater”, the components of the salt balance are displayed as follows:

\[
\bar{S}_0 = \alpha S_0 / (B/r) \quad \text{– intensity of salinization of irrigation water;}
\]

\[
\bar{S}_{nv} = (1-t) g S_{nv} / (B/r) \quad \text{– intensity of the input of salts into the soil through groundwater.}
\]

Then the equation describing the average concentration of salts in the system “soil - soil water” will have the form:

\[
\bar{S} = \bar{S}_{ni} + \bar{S}_0 + \bar{S}_{nv}.
\]

The reclamation state of irrigated lands can be described by the relation:

\[
\bar{M} = \frac{\overline{A}}{\bar{S}},
\]

where \( \overline{A} \) – work with an infiltrative water flow in the soil layer in a simple volume; \( \bar{S} \) – the average amount of salts in the “surface water - soil - groundwater” system.

Depending on the soil-reclamation conditions of irrigated lands, their condition is characterized as stable, relatively stable, relatively weakly resistant, weakly resistant and unstable to reclamation.

If the amount of salts in the water tends to zero, then the reclamation index has the greatest value, i.e.

\[
\left[ S_{ni} + \frac{tg S_{n0}}{r} + (1-t) \frac{g S_{nv}}{B/r} \right] \to 0, \ \text{to} \ \bar{R} \to \infty.
\]

And if the difference between the inflow and outflow of the water balance tends to zero, then the melioration indicator \( \bar{R} \) has the smallest value, i.e.:
\[
\left\{(B/K \cdot r) - V_i \right\} - (1-r)Q_0 \left[ 1 - \left( \frac{H_0}{H_i} \right)^n \right] - Ir \right\} \to 0, \text{ to } R \to 0. \tag{17}
\]

When determining the melioration indicator, it is necessary to take into account the hydrogeochemical diversity of irrigated lands, in connection with which a complex melioration indicator is determined:

\[
R = \sum_{i=1}^{n} R f_i,
\]

where \( f_i \) – area of the \( i \)-th element of irrigated land, ha.

3. Conclusion
The developed mathematical model of the effective use of reclaimed lands takes into account the entire set of natural and climatic factors: climatic indicators, which are included in the amount of evaporation; hydrological regime of irrigated lands, which is determined by the values of the filtration coefficient, groundwater flow rate, groundwater depth; soil indicators of infiltration of irrigated lands, which are reflected in the concentration of soil solution; hydro geochemical conditions of irrigated lands, which affect the salinity of irrigated and soil waters.

References
[1] Shekikhachev Yu A and Bzheumykhov V S 2017 Main directions of rational use, protection and improvement of soil resources in the Kabardino-Balkarian Republic AgroEcoInfo 4 URL: http://agroecoinfo.narod.ru/journal/STATYI/2017/4/st_412.doc
[2] Kyul E V, Apazhev A K, Kudzaev A B and Borisova N A 2017 Influence of anthropogenic activity on transformation of landscapes by natural hazards Indian Journal of Ecology 44 (2) 239-43
[3] Apazhev A K, Shekikhachev Yu A, Pazova T Kh, Shekikhacheva L Z and Kurmanova M K 2020 Mathematical modeling of water erosion process AgroEcoInfo 2 URL: http://agroecoinfo.narod.ru/journal/ STATYI/2020/2/st_222.pdf
[4] Abdefattakh A Kh, Ivanov B L and Ziganshin B G 2019 Research of some parameters of drip irrigation by hydraulic assessment of droppers Kazan State Agrarian University Bulletin 14 2 (53) 72-6
[5] Shekikhacheva L Z, Zotov R A and Shorov AZ 2020 System analysis of environmental factors of agroecosystems Energy Saving and Energy Efficiency: Problems and Solutions (Nalchik: Kabardino-Balkarian State Agrarian University) pp 327-31
[6] Balkizov A B and Sasikov A S 2018 Issues of regulating the water regime of soils and the pecularities of its formation for southern chernozems Engineering Support of Innovative Development of the Agro-Industrial complex of Russia (Nalchik: Kabardino-Balkarian State Agrarian University) pp 35-7
[7] Vasiliev S M, Shkura V N and Shtanko A S 2020 Local contours of soil drip moistening formed on slope lands Bulletin of the Nizhnevolsky Agricultural University Complex: Science and Higher Professional Education 1 (57) 279-89
[8] Vasiliev S M, Babichev A N, Monastyrskiy V A and Olgarenko V I 2020 Strategy for the successful development of melioration - precision irrigation Scientific Journal of the Russian Research Institute of Land Reclamation 3 (39) 1-22
[9] Vasiliev S M, Shkura V N and Shtanko A S 2020 Form and parameters of contours of drip soil moistening on slope lands Agrarian Scientific Journal 3 70-5
[10] Vasiliev S M and Shtanko A S 2019 Geometric and moisture parameters of the contours of drip moistening of loamy chernozems Melioration and Water Management 1 16-9
[11] Shchedrin V N and Vasiliev S M 2019 Conceptual and methodological principles (foundations) of a strategy for the development of land reclamation as a national treasure of Russia Scientific Journal of the Russian Research Institute of Land Reclamation 1 1 (33) 1-11
[12] Vasiliev S M, Shkura V N and Shtanko A S 2019 Outline of local zones of moistening of sub-drip soil space Agrarian Scientific Journal 3 65-71
[13] Vasiliev S M, Shkura V N and Shtanko A S 2018 Determination of moisture parameters of the intra-contour drip-moistened soil space Bulletin of the Nizhnevolzhsky Agricultural University Complex: Science and Higher Professional Education 4 (52) 316-23
[14] Golovina N A, Domashenko Yu E and Vasiliev S M 2017 Development of an environmentally friendly filter element for drip irrigation Scientific Journal of the Russian Research Institute of Land Reclamation 2 (26) 144-55
[15] Vasiliev S M and Mityaeva L A 2016 Assessment of the processes of degradation of irrigated lands as part of the calibration of agricultural land monitoring services Scientific Journal of the Russian Research Institute of Land Reclamation 4 (24) 70-85