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MODEL FOR QUANTITATIVE ASSESSMENT OF RETURNING COLLECTOR-DRAINAGE WATER FROM IRRIGATED AREAS OF ARID ZONES

F. Kh. Khikmatov[1], G. Kh. Yunusov[2], B. E. Adenbaev[3], R. R. Ziyaev[4], N. B. Erlapasov [5]

National University of Uzbekistan, [1]
National University of Uzbekistan, [2]
National University of Uzbekistan, [3]
National University of Uzbekistan, [4]
National University of Uzbekistan [5]

F. Kh. Khikmatov[1], G. Kh. Yunusov[2], B. E. Adenbaev[3], R. R. Ziyaev[4], N. B. Erlapasov [5]: Model For Quantitative Assessment Of Returning Collector-Drainage Water From Irrigated Areas Of Arid Zones-- Palarch's Journal Of Archaeology Of Egypt/Egyptology 17(6). ISSN 1567-214x
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ABSTRACT

The paper is devoted to study of the dependence of returned collector-drainage water from large irrigated arias on the volume of water withdrawal for irrigation purposes and the total crop areas. The problem was solved on the example of irrigated lands of the Bukhara region. As a result of statistical estimation, equations of normalized regression were obtained. They are characterized by rather high values of the full coefficients of multiple correlation. Based on these equations, the calculated nomogram was expressed. Accuracy of the nomogram was analysed. The results showed that it can be used both for estimation and for forecasting collector-drainage flow from large irrigated areas of arid zones.

Introduction

For the conditions of Central Asia, including for the irrigated areas of Uzbekistan, there are known attempts by MI Getker and his co-authors [1], G.Kh. Ismayilov and his colleagues [2], FE Rubinova [3] and others [4, 5, 6, 7] according to the estimation of return water values using the simplified equation of the water balance of the irrigated area:

$$У_{\text{ВОЗ}}=У_{\text{ВЗ}}-P, \qquad (1)$$

where: $У_{\text{ВОЗ}}$ – potential return flow from the irrigated area, $У_{\text{ВЗ}}$ – total water withdrawal for the irrigated area, P – total costs of runoff for evaporation from irrigated fields and fallows, accumulation of moisture in soil and industrial and communal water consumption.

As can be seen from the above equation (1), the absence of estimates of the quantitative values of the components of the total runoff cost excludes the possibility of using the water balance method for the irrigated territory of the Bukhara region under study.

Taking into account the above, the main goal of this work is to statistically evaluate the dependence of the collector-drainage runoff from the irrigated lands of the Bukhara region on the volume of water intake and the irrigated area and, on its basis, to develop a model for the quantitative assessment of return water from irrigated areas of arid zones.

RESEARCH MATERIALS AND METHODS

When establishing a multifactorial connection of the return collector-drainage flow ($W_{КДС}$) from the irrigated territory of the Bukhara region as the main arguments, we took into account the volume of water intake along the Amu-Bukhara canal ($W_{АБ}$) and areas of irrigated land (F_{03}) Bukhara region. The calculations were carried out on the basis of the use of the objective method of alignment and normalization of correlations proposed by GA Alekseev [8].

A detailed description of this method and its application in hydrological calculations are presented in the works of GA Alekseev [8], VI Babkin [9] and others [10,11,12]. Therefore, in this work, we consider this issue briefly, in the light of establishing a multifactorial dependence of the collector-drainage runoff of the Bukhara region on the volume of water intake and the area of irrigated crops.

Normalization begins by ranking the values of the original variables in ascending order. The rank numbers of the members of the series make it possible to calculate the probability of non-exceeding by the expression:

$$P_m = \frac{m - 0{,}25}{N + 0{,}25}\ , \qquad (2)$$

where, m – the rank numbers of the original variables in ascending order, N – number of members of the hydrological series.

H normalized values of variables, in our case, collector-drainage flow [$U_0(W_{КДС})$], water intake along the Amu-Bukhara canal [$U_1(W_{АБ})$] and areas of irrigated land [$U_2(F_{03})$] were determined by the normalized cumulative distribution function:

$$P_j(X_{ji}) = P_m = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Um} e^{-\frac{U^2}{2}} \cdot dU = \Phi(U_m), \qquad (3)$$

as inverse functions:

$$U_m = F\left[P_m\right] = F\left\lfloor P_j(X_{ji}) \right\rfloor = U_j(X_{ji}), \qquad (4)$$

where: j – the number of the original variables, in our case: j = 0,1,2; i = 1,2,…,N.

The tightness of relationships between pairwise taken initial variables is characterized by paired correlation coefficients. To calculate their values, the sum of the pairwise products of the corresponding normalized values of the variables are determined:

$$U_0(W_{КДС})\cdot U_1(W_{АБ}); \quad U_0(W_{КДС})\cdot U_2(F_{O3});$$
$$U_1(W_{АБ})\cdot U_2(F_{O3}); \qquad (5)$$

The sums of these products were used to calculate the values of the empirical covariance coefficients:

$$\mu_{jj}(N)=\frac{1}{N-1}\sum_{i=1}^{N}U_{ji}(W_{КДС})\cdot U_{ji}(W_{АБ}). \tag{6}$$

The values of the covariance coefficients make it possible to calculate the paired correlation coefficients:

$$r_{jj}=\frac{\mu_{ji}(N)}{\sigma_u^2(N)}, \tag{7}$$

where: σ_u^2 - empirical variance, the value of which is determined by the following formula:

$$\sigma_u^2(N)=\frac{1}{N-1}\sum_{i-1}^{1}U_{ji}(\mathrm{W}). \tag{8}$$

Regression coefficients (α_{01}, α_{02}) are included in the required normalized regression equation. In order to determine α_{01} and α_{02} a system of two linear equations has been compiled:

$$\begin{cases}\alpha_{01}+r_{12}\cdot\alpha_{02}=r_{01}\\ r_{12}\cdot\alpha_{01}+\alpha_{02}=r_{02}\end{cases} \tag{9}$$

By solving this system, expressions are obtained for calculating the regression coefficients:

$$\alpha_{01}=\frac{r_{01}-r_{02}\cdot r_{12}}{1-r_{12}{}^{2}}\quad,\alpha_{02}=\frac{r_{02}-r_{01}\cdot r_{12}}{1-r_{12}{}^{2}}\quad. \tag{10}$$

Calculated values of regression coefficients (α_{01}, α_{02}) allow you to get the equations of normalized regression:

$$U_0(W_{КДС})=\alpha_{01}\cdot \mathrm{U}_1(W_{АБ})+\alpha_{02}\cdot \mathrm{U}_2(\mathrm{F}_{03})$$

(11)

The accuracy of this equation, i.e. the tightness of the relationship between the collector-drainage flow and the variables that determine it are characterized by the values of the total coefficients of multiple correlation (r_0), calculated by the formula:

$$r_0=\sqrt{\left|r_{01}\cdot\alpha_{01}\right|+\left|r_{02}\cdot\alpha_{02}\right|}\;. \tag{12}$$

The root mean square errors of the total correlation coefficients were calculated using the expression.

$$\sigma_{r_0}=\frac{1-r_0^2}{\sqrt{N-\ell}},$$

(13)

where ℓ - the number of arguments, in our case ℓ =2.

As you can see, the normalized regression equation, i.e. equation (11) characterizes the relationship between the collector-drainage flow ($W_{КДС}$) and its determining factors (the volume of water intake along the Amu-Bukhara canal - $W_{АБ}$ and areas of irrigated land - F_{03}). It includes only significant predictors, that is, in our case, both the volume of water withdrawal and the area of irrigated land.

RESULTS AND DISCUSSION

Previous researchers have proved that the return flow from the contour of large irrigated areas, concentrated in the collector-drainage network, consists of underground and surface components [1,3,7]. The first, that is, the underground component of the return flow is formed from the natural underground inflow into the irrigated area and filtration losses from irrigated fields, the irrigation system and precipitation falling on this territory. The second, that is, the surface component of return water can be formed from discharges from irrigated fields and from irrigation ditches, as well as from the runoff of melted snow and rainwater.

As F.E. Rubinov, filtration losses from irrigated fields, in the irrigation network and discharges from irrigated fields and from furrows are associated with irrigation and, therefore, they are clearly anthropogenic, while the rest depend on natural conditions. However, the latter are also corrected by human economic activity [3,6].

It should be noted that the contributions of the above factors to the formation of return flow from irrigated areas differ significantly and their values depend on the natural and water management situation. However, in any case, the volume of return collector-drainage water from irrigated areas depends on the surface runoff, i.e. on the volume of water withdrawn for irrigation purposes. This conclusion is confirmed by the results of the regression analysis performed by F.E. Rubinova on the example of the Fergana, Chirchik-Akhangaran-Kelesky and Golodnostepsky irrigation regions. In her studies of multifactorial dependencies for the Fergana irrigation region, she took into account the values of 15 predictors, and for Chirchik-Akhangaran-Kelesky 12 and Golodnostepsky 8 predictors [3].

The main of these predictors are the time index, water withdrawal for the current and previous years, the coefficient of runoff withdrawal, surface inflow, atmospheric precipitation, solar radiation, groundwater level and others. The results of F.E. Rubinova's research showed that in the Fergana and Golodnostep irrigation regions, the return flow from irrigated fields correlates with the water withdrawal of the current (0.91□r□0.81) and previous years (r = 0.74□0.93) ...

As F.E.Rubinova, S.I.Kharchenko and others correctly point out [3, 6], modern hydrometry allows directly measuring only the in-system component of return water, concentrated in the collector-drainage network. In this regard, the total return collector-drainage flow, that is, its channel and intra-system components, are estimated approximately as the residual term of the water balance equation for the irrigated area. Here it is necessary to note the advantages of the first, that is, the hydrometric method over the second - the water balance method.

Calculations to establish the dependence of the collector-drainage runoff from the irrigated fields of the Bukhara region on the determining factors were performed by the method described above in the following three options: 1) for the period of gradual improvement of water supply in the study area (1962-1985); 2) for the period of limited water supply (1986-2015); 3) for the entire period, that is, with the combination of the two previous settlement periods (1962-2015).

As you can see, when highlighting the design options, we took into account the conditions of water supply to irrigated lands and changes in the water management situation in the irrigated areas of the Bukhara region.

The analysis of the calculated values of the paired correlation coefficients and regression coefficients can be performed for each option or for all options as a whole (Table 1).

Table 1
Calculated values of paired correlation coefficients and regression coefficients

Calculation options	Paired Odds correlations			Regression coefficients	
	r_{01}	r_{02}	r_{12}	α_{01}	α_{02}
1- option	0,835	0,581	0,548	0,739	0,176
2- option	0,444	0,248	-0,091	0,469	0,290
3- option	0,745	0,895	0,633	0,297	0,706

As can be seen from Table 1, the second version of the calculation is characterized by the smallest values of both pair correlation coefficients and regression coefficients. Pairwise correlation coefficient between the volume of water intake along the Amu-Bukhor canal ($W_{АБ}$) and the area of irrigated land (F_{03}) is negative (r_{12}=-0,091), which is explained by the decrease in the area of crops during the years of independence of the Republic, due to the elimination of the cotton monoculture since 1991. This may also be associated with errors in the accounting and assessment of collector-drainage waters, and extreme, that is, low-water and high-water conditions of their formation.

For all options, normalized regression equations were obtained, which have a general form as equation (11).

It can be seen from this expression that the normalized regression equations obtained for each calculation option differ only in the values of the regression coefficients (Table 2).

Table 2: Normalized regression equations and their total multiple correlation coefficients

Calculation options	Equations normalized regression	$r_0 \pm \sigma_{r0}$
1- option	$U_0(W_{КДС})=0,739 \cdot U_1(W_{АБ})+0,176 \cdot U_2(F_{03})$	0,846±0,061
2- option	$U_0(W_{КДС})=0,469 \cdot U_1(W_{АБ})+0,290 \cdot U_2(F_{03})$	0,529±0,141
3- option	$U_0(W_{КДС})=0,297 \cdot U_1(W_{АБ})+0,706 \cdot U_2(F_{03})$	0,923±0,021

Note: r_0 – total multiple correlation coefficient, σ_{r0} – total correlation coefficient error.

The normalized regression equations obtained for various design options and shown in Table 2 are characterized by rather high values of the full multiple correlation coefficients (r_0). Their values range from 0,529±0,141 before

0,923±0,021. At the same time, the discrepancies in the estimates of the correlation coefficients (even in the 2nd variant of the calculation) turned out to be within the errors of their calculation.

This result shows that the normalized regression equations calculated by us have the same order as the above-mentioned regression equations obtained by F.E.Rubinova for various irrigation regions of the Syrdarya basin [3,19,20]. On this basis, the normalized regression equations obtained by us are recommended for calculating and forecasting return collector-drainage waters from large irrigated areas of the Bukhara region. It is assumed that in the near future the conditions for their formation will not change significantly.

For the convenience of performing calculations and forecasts of collector-drainage runoff, we have proposed a graphical interpretation of the normalized regression equation obtained for the 3rd option. It, that is, a graphical interpretation, is carried out using the relationship between the initial and normalized variables, in the form of a nomogram, which is shown in Figure 1. We accept this nomogram as a model for quantitative assessment of return water from irrigated areas of arid zones. It can be used both for design and forecasting purposes of collector-drainage flow.

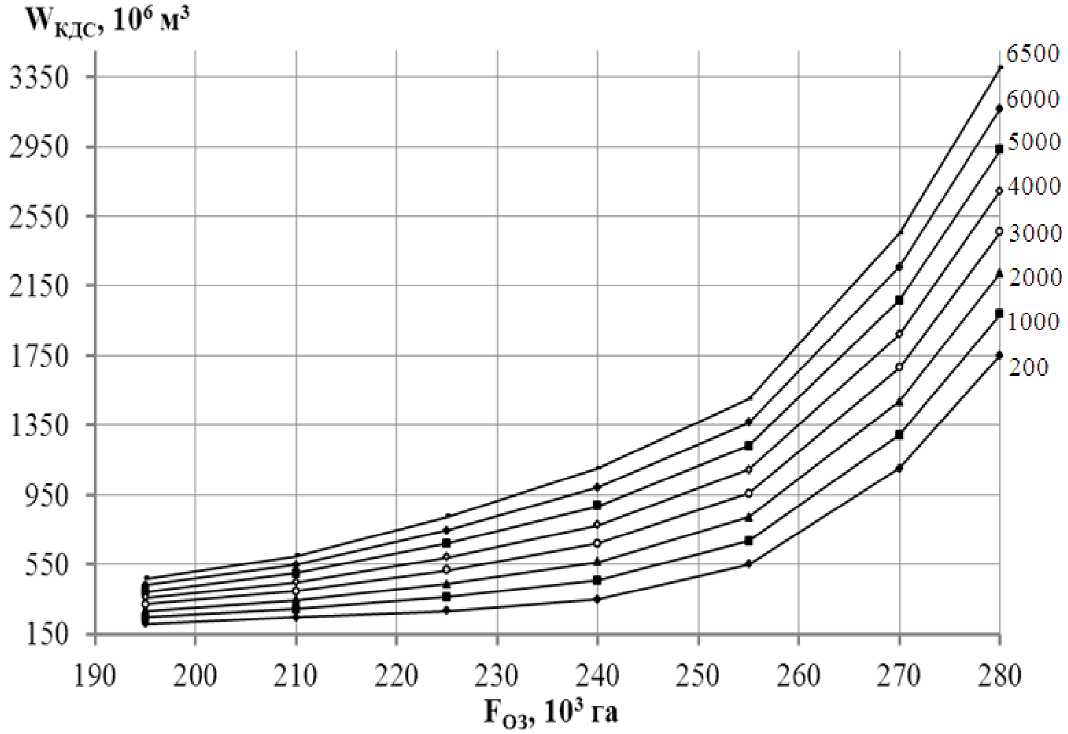

Fig. 1. Nomogram for calculation and forecast collector-drainage flow

The assessment of the reliability of the constructed nomogram for design purposes was made by comparing the actually observed ($W_{КДС}^{ф}$)and calculated () according to the nomogram of the collector-drainage flow values. The calculation results showed their good convergence. The correlation coefficient between them, that is, calculated according to the nomogram ($W_{КДС}^{p}$)and actually observed ($W_{КДС}^{Ф}$)the values of the collector-drainage flow is equal to 0,775±0,037 (fig. 2).

The analysis of the comparison results showed that of the 54 cases considered, in 31 cases the absolute error is less than 30%, in 12 cases - up to 40%, and in the remaining 11 cases it is about 50% or more. On average, the error of the collector-drainage flow values calculated from the nomogram is 28%.

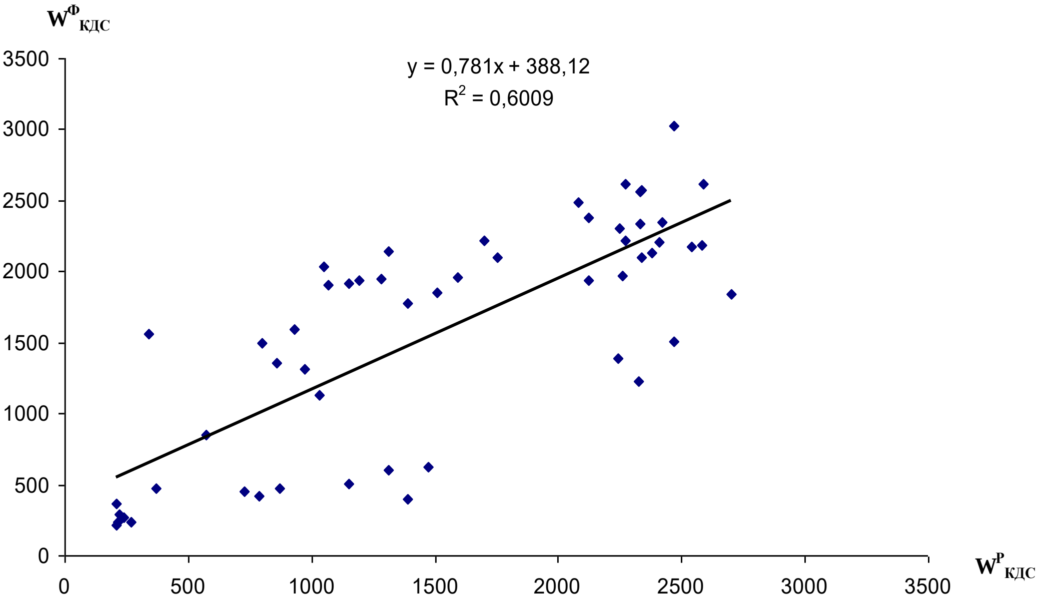

Fig. 2. A graph of the relationship between the calculated according to the nomogram) and actually observed () values of the collector-drainage flow

As can be seen from Figure 2, the greatest deviations from the midline are high-water (1969) and low-water (1974) and subsequent 1975, 1976, 1977 years. In this regard, in the second version, 1969 is excluded from the calculation, a high-water year, when atmospheric precipitation in the entire Central Asian region fell in 1,5÷2,0 times more than the norm. As a result, the share of atmospheric precipitation in the formation of collector-drainage runoff from irrigated fields has sharply increased, which has led to large errors. The exclusion of the high-water year 1969 in the calculations provided an increase in the value of the correlation coefficient (0,791±0,035), characterizing the relationship between the actually observed and calculated values of the collector-drainage flow (Table 3).

In the third variant of the calculation, in addition to the high-water year 1969, the low-water years 1975 and 1976, when the largest errors were observed between the actually observed and calculated values of the collector-drainage runoff, were excluded from the calculation. In this version of the calculation, the correlation coefficient and its error are 0,813±0,032, that is, the tightness of communication has increased in comparison with the previous two options (table 3).

Table 3: Statistical characteristics of various communication calculation options between the actually observed and calculated values collector-drainage flow

Calculation options	Years	Regression equations	Correlation coefficient and its

			error, $r \pm \delta_r$
1- option	54	$W_{КДС}^{ф}=0{,}781 \cdot W_{КДС}^{P}+388{,}12$	0,775±0,037
2- option	53	$W_{КДС}^{ф}=0{,}814 \cdot W_{КДС}^{P}+319{,}56$	0,791±0,035
3- option	51	$W_{КДС}^{ф}=0{,}808 \cdot W_{КДС}^{P}+368{,}31$	0,813±0,032

In the future, in order to improve the accuracy of calculations, on the communication graph $W_{КДС}^{ф}=f(W_{КДС}^{P})$,shown in Figure 2, two lines can be drawn, that is, this graph can be divided into two parts. The first part, that is, the points located below the straight line, characterize low-water years on the source river (Amudarya river), and the second part, that is, points located above the straight line, characterize high-water years.

Taking into account the above comparison results, the constructed nomogram - the model is recommended for assessing the amount of collector-drainage runoff from irrigated fields of Bukhara region The advantage of this model is that the calculations of the collector-drainage runoff for it can be carried out on the basis of a minimum of information - the volume of water intake and the area of irrigated land. This makes it possible to apply this model to assess the collector-drainage runoff from irrigated lands in unexplored areas of other arid territories.

As noted above, the nomogram shown in Figure 1 can also be used to predict collector-drainage runoff from irrigated fields. The assessment of its reliability for forecasting purposes was carried out on the basis of the "Manual for the Forecast Service" [21], approved by Uzhydromet under the Cabinet of Ministers of the Republic of Uzbekistan (now under the Ministry of Emergencies of the Republic of Uzbekistan).

According to this Manual, the absolute error of the forecasting method is calculated by the following formula:

$$\delta = W_{КДС}^{П} - W_{КДС}^{Ф}, \tag{13}$$

where: $W_{КДС}^{П}$ - predicted collector-drainage flow; $W_{КДС}^{Ф}$ - actually observed value.

The standard deviation of the forecast error (S) is calculated by the expression:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(W_{КДСi}^{П} - W_{КДСi}^{Ф})^2}{n-\ell}}, \tag{14}$$

where: n - number of members in a series or number of test predictions; ℓ - the number of predictors (arguments).

Mean square deviation of the predicted value from the norm (σ)calculated by the formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(W^{\Phi}_{КДСi} - \overline{W}^{\Phi}_{КДСi})^2}{n-\ell}}\ , \qquad (15)$$

where: $\overline{W}^{\phi}_{КДС}$ - the arithmetic mean of the statistical series, which is calculated by the formula:

$$\overline{W}^{\Phi}_{КДСi} = \frac{\sum_{i=n}^{n} W^{\Phi}_{КДС}}{n}\ . \qquad (16)$$

For the permissible error of the developed forecasting technique ($\delta_{доп}$) the probable deviation of the predicted value from the norm is taken and it was calculated by the formula:

$$\delta_{доп} = \pm\, 0{,}674 \cdot \sigma\ . \qquad (17)$$

The effectiveness of the developed forecasting technique is characterized by the ratio S/σ. The recommended forecasting technique is considered effective, that is, you can apply it in practice if the condition S/σ≤0,80.

The quality of the developed forecasting technique is also established by the value of the ratio S/σ: a) if S/σ≤0,50 – the quality of the forecasting method is rated as "good"; b) provided 0,51≤S/σ≤0,80 - the forecasting technique is considered satisfactory.

The security of the forecasting technique was calculated by the formula:

$$P = \frac{m}{n} \cdot 100\ \%\ , \qquad (18)$$

where: n - number of test predictions; m - the number of correct predictions. The forecast is considered correct if the absolute error is less than or equal to the permissible, that is $\delta \le \delta_{доп}$.

The assessment of the developed methodology for forecasting the annual volume of collector-drainage runoff was made, according to the above sequence, in three versions. The evaluation results are presented in Table 4.

Table 4: Assessment of the accuracy and efficiency of the developed methods for forecasting collector-drainage flow

Evaluation options	Correlation coefficient and its error, $r \pm \delta_r$	Criteria for assessing the quality and effectiveness of the forecast				
		σ	$\delta_м$	S	S/δ	P,%
1- option	0,775±0,037	801,1	±539,3	537,6	0,67	66,7
2- option	0,791±0,035	807,6	±544,3	515,8	0,64	69,8
3- option	0,813±0,032	794,6	±535,6	492,9	0,62	72,5

Note: $r \pm \sigma_r$ - correlation coefficient and its error; S - mean square error of test predictions, $10^6 м^3$; σ - standard deviation of the predicted value, $10^6 м^3$; P – provision of forecasting methods, в %.

As you can see from this table, the relationship S/σ in different variants of calculation fluctuate within 0,62÷0,67, that is, for all design options, the prognostic dependence proposed by us and the prognostic nomogram based on it satisfy the requirements for hydrological forecasts.

Conclusion

1. A correlation has been established between the return collector-drainage runoff from the irrigated areas of the Bukhara region and the volume of water intake and the total area of crops. An assessment of their accuracy showed that the normalized regression equations obtained by us are of the same order as the above-mentioned regression equations obtained by F.E. Rubinova for various irrigation areas of the Syrdarya basin.
2. A normalized regression equation was obtained, which characterizes the relationship between the collector-drainage flow and its determining factors - the volume of water intake and the area of irrigated land. A graphical interpretation of the normalized regression equation in the form of a nomogram is proposed, which can be used both for design and prognostic purposes of collector-drainage runoff from irrigated lands of Bukhara region.
3. In the future, methods and approaches to establishing a multifactorial dependence of the collector-drainage flow on the volume of water intake and the area of irrigated land can be tested on the example of other large irrigated areas of Uzbekistan and adjacent territories.
4. The assessment of the reliability of the constructed nomogram for design purposes was made by comparing the actually observed and calculated values of the collector-drainage runoff from the nomogram. The correlation coefficient between them is 0,775±0,037. On average, the absolute error of the collector-drainage runoff values calculated from the nomogram is 28%.
5. The assessment of the reliability of the nomogram for forecasting purposes was carried out on the basis of the "Manual for the Forecast Service" approved by Uzhydromet, in three design options. It should be noted that in some cases the forecasts did not come true, that is, the absolute error (δ)more than the permissible error (δ_M). The greatest errors were noted in years when atmospheric precipitation was higher than normal, that is, in extremely high-water or, conversely, extremely low-water years.
6. The values of the quality criterion of the developed forecasting method, that is, the relationship S/σ in different variants of calculation fluctuate within 0,62÷0,67. Thus, the prognostic dependence proposed by us and the prognostic nomogram constructed on its basis satisfy the requirements for hydrological forecasts.
7. The advantage of the nomogram we propose is that calculations and forecasts of collector-drainage runoff can be carried out on the basis of a minimum of information - the volume of water intake and the area of irrigated land. This makes it possible to apply this technique to assess the collector-drainage runoff from irrigated lands in unexplored areas of other arid territories.

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