METHODOLOGY FOR CALCULATION OF THE MULTI-FACTORY RELATIONSHIP OF RIVERS SUSPENDED SEDIMENT RUNOFF WITH CLIMATIC FACTORS

G.U.Jumabayeva, D.V.Nazaraliyev, Mkhanna Aaed Ismail Nazir

Abstract

The paper considers a method for calculating a multifactorial relationship with climatic factors of suspended sediment runoff (SSR) factors. The calculations are based on the use of an objective method of alignment and normalization of correlations proposed by G.A. Alekseev. Climatic factors were used as the main arguments - atmospheric precipitation of winter and summer period and air temperature for the summer period. The technique made it possible to evaluate the contributions of each argument to the formation of the SSR.

Key words: *river, river load, climatic factors, winter precipitation, multifactor relationship, summer precipitation equation, air temperature, regressions, contributions of arguments.*

Introduction. The problem of the formation of suspended sediment runoff (SSR) has long attracted the attention of G.I. Shamov, G.V. Lopatin, V.L. Schultz, O.P. Rasulov and other authors, the complexity of studying the process of formation of river sediments lies in the abundance of simultaneously acting factors that make it difficult toµ identify common patterns [3,7].

As O.P. Shcheglova rightly noted, the study of any process in nature, including hydrological, should begin with the identification of its genesis or origination. This is due to the fact that the development of new methods of hydrological calculations and forecasts requires a reliable genetic foundation. The stated position also fully applies to SSR [7].

The study of the genesis of SSR is not an ultimate purpose in itself, but serves as a reliable foundation for solving a number of scientific and practical issues. The division of SSR into genetic components is rational for a number of reasons. First of all, it should be noted that, depending on the genesis, each type of water erosion has its own specific altitudinal distribution area. Taking into account this circumstance, the genetic analysis of the SSR is the key to understanding the altitudinal zonality of the manifestation of water erosion [6,7].

Results and discussion. When establishing a multifactorial relationship between the annual SSR and climatic indicators, as the main arguments for the washout from the watersheds of the mountain rivers of Uzbekistan and surrounding territories, the sums of atmospheric precipitation of different seasons (winter -X_w and summer -X_s) and the average values of air temperature for the warm half-year - ts were applied. Their values will be derived from data selected from representative meteorological stations operating within the studied basins or in their immediate vicinity. The method of joint processing of the main climatic arguments with SSR for the aims of their genetic analysis is based on the use of an objective method of normalizing correlations proposed by G.A. Alekseev [1].

A detailed description of the objective method of alignment and normalization of correlations and its application in various areas of hydrometeorology with specific examples are quite sufficiently set out in the works of G.A. Alekseev [1], V.I. Babkin, N.N. Bobrovitskaya and others. Therefore, we will consider this issue very briefly, in the light of its application to establish a multifactorial relationship between the SSR of the mountain rivers of Uzbekistan and surrounded territories with climatic factors.

According to G.A. Alekseev, normalization begins with the ranking of the observed values of the initial variables in ascending order [1]. In accordance with the rank numbers of the members of the series, the probability of non-exceeding is calculated using the following formula:

$$P_m = \frac{m-0,25}{N+0,25} \quad (1)$$

where: m – rank numbers of initial variables in ascending order: N – number of variables.

The empirical values of the normalized variables, in our case SSR - $U_0(R)$, air precipitation - $U_1(Xw)$ and summer - $U_2(Xs)$, although air temperature - $U_3(ts)$ are determined as the known normalized integral distribution function:

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

as inverse functions or quantiles

$$U_m = F[P_m] = F[P_j(X_{ji})] = U_j(X_{ji}) \quad (3)$$

where j – number of initial variables, in this case j = 0,1,2,3; i = 1,2,..., N.

The tightness of the links between the pairwise taken initial variables, with the exclusion of the influence of all other considered variables, is characterized by pairwise correlation coefficients. To calculate their value, you first need to determine the sums of pairwise products of the corresponding values, normalized variables:

$$U_0(R) \cdot U_1(X_w); \quad U_0(R) \cdot U_2(X_s); \quad U_0(R) \cdot U_3(t_s);$$

$$U_1(X_w) \cdot U_2(X_s); \quad U_1(X_w) \cdot U_w(t_s); \quad U_2(X_s) \cdot U_3(t_s)$$

Based on the sums of pairwise products, the values of the corresponding empirical covariance coefficients are calculated (μ_{01}, μ_{02}, μ_{03}, μ_{12}, μ_{13}, μ_{23}):

$$\mu_{jj}(N) = \frac{1}{N-1} \sum_{i=1}^{N} U_{ji}(R) \cdot U_{ji}(X_ç) \quad (4)$$

Knowing the values of the covariance coefficients, it is possible to calculate the pairwise correlation coefficients:

$$r_{jj} = \frac{\mu_{ji}(N)}{\sigma_u^2(N)} \quad (5)$$

where σ_u^2 (N) - empirical dispersion, which determines with the following formula:

$$\sigma_u^2(N) = \frac{1}{N-1} \sum_{i-1}^{1} U_{ji}(R) \quad (6)$$

An analysis of the values of paired correlation coefficients calculated according to the above formula between the annual values of the SSR of the studied rivers and three climatic indicators - precipitation in winter, summer and average summer air temperature can be made

Table 1

Limits of change in the values of pair correlation coefficients annual SSR with winter (r01), summer (r02) precipitation and average summer temperature (r03)

Type of nourishment	Number of stations	Limits of change		
		r_{01}	r_{02}	r_{03}
Amudarya River basin				
Snow-rain	17	0,55 ÷ 0,57	0,50 ÷ 0,70	-0,36 ÷-0,10
snow	11	0,60 ÷ 0,81	0,42 ÷ 0,71	-0,32 ÷0,20
Snow-glaciar	7	0,18÷ 0,60	-0,12 ÷ 0,35	0,48÷0,58
glaciar	13	-0,32 ÷ 0,31	-0,39 ÷ 0,29	0,56 ÷ 0,88
Syrdarya River basin				
Snow-rain	19	0,61 ÷ 0,78	0,50 ÷ 0,59	-0,31 ÷ -0,08
snow	17	0,63 ÷ 0,78	0,45 ÷0,59	-0,29 ÷ -0,20
Snow-glaciar	12	0,22 ÷ 0,51	-0,08 ÷ 0,37	0,47 ÷ 0,64
glaciar	2	-0,23 ÷ 0,24	-0,28 ÷ -0,26	0,59 ÷ 0,67

for groups of rivers similar in terms of feeding conditions according to the classification of V.L. Schulz (table. 1). For rivers of snow-rain and snow types of feeding, the pair correlation coefficients of SSR with both winter and summer precipitation have a positive sign and fluctuate, respectively, in the range of 0.337÷0.811 and 0.419÷0.712. It should be noted that for the rivers fed by snow and rain, the annual SSR is more closely related to summer precipitation than to winter precipitation. For snow-fed rivers, in most cases, correlation coefficients with summer precipitation are inferior to correlation coefficients with winter precipitation. For the rivers of both types of feeding, the influence of the summer temperature regime on the SSR is weak, and in most cases it has the opposite character. The values of pair correlation coefficients of SSR with air temperature range from -355 to 0.304.

On the contrary, for rivers of snow-glacial and glacial nourishment types, the values of pair correlation coefficients with precipitation in winter and summer are low, and varying within -0.322 ÷ 0.596 and -0.385 ÷ 0.368, respectively, they are always inferior in absolute value to the values of pair correlation coefficients with air temperature, varying from 0.384 to 0.878. The highest values of pair correlation coefficients correspond to glacier-fed rivers. α

Determining the regression coefficients is one of the main steps in the calculation. Regression coefficients (α_{01}, α_{02}, α_{03}) are calculated by solving a system of three linear (normal) equations:

$$\begin{cases} \alpha_{01} + r_{12}\cdot\alpha_{02} + r_{13}\cdot\alpha_{03} = r_{01} \\ r_{12}\cdot\alpha_{01} + \alpha_{02} + r_{23}\cdot\alpha_{03} = r_{02} \\ r_{13}\cdot\alpha_{01} + r_{23}\cdot\alpha_{02} + \alpha_{03} = r_{03} \end{cases} \quad (7)$$

The solution of the system of equations, in order to determine the regression coefficients, is performed based on the application of the Cramer's method in the following sequence. First, the main minor is determined:

$$\Delta_{00} = \begin{vmatrix} 1 & r_{12} & r_{13} \\ r_{21} & 1 & r_{23} \\ r_{31} & r_{32} & 1 \end{vmatrix} \quad (8)$$

The determinants of the system of linear equations are calculated by the expressions:

$$\Delta_{01} = \begin{vmatrix} r_{01} & r_{12} & r_{13} \\ r_{02} & 1 & r_{23} \\ r_{03} & r_{32} & 1 \end{vmatrix}, \quad \Delta_{02} = \begin{vmatrix} 1 & r_{01} & r_{13} \\ r_{21} & r_{02} & r_{23} \\ r_{31} & r_{03} & 1 \end{vmatrix}, \quad \Delta_{03} = \begin{vmatrix} 1 & r_{12} & r_{01} \\ r_{21} & 1 & r_{02} \\ r_{31} & r_{32} & r_{03} \end{vmatrix} \quad (9)$$

Knowing the values of the main minor and determinants, it is possible to calculate the corresponding regression coefficients taken in pairs of the original variables:

$$\alpha_{0j} = \frac{\Delta_{0j}}{\Delta_{00}} \quad (10)$$

The errors of the regression coefficients are determined by the formula:

$$\sigma_{0j} = \sqrt{\frac{1-r_0^2}{N-\ell}} \cdot \frac{\Delta_{0j}}{\Delta_{00}} \quad (11)$$

where: j=1, 2, 3; - number of arguments; Δ_{00} - determinative minor Δ_{0j}, corresponding to its element of r_{jj} =1.

The limits of change in the calculated values of the regression coefficients for different types of river feeding are presented in Table 2. They are included in the desired normalized regression equation, which has the general form (12).

Using the method described above, for all the studied rivers, normalized regression equations were obtained, which have the general form:

$$U_0(R) = \alpha_{01}\cdot U_1(X_з) + \alpha_{02}\cdot U_2(X_л) + \alpha_{03}U_3(t_л) \quad (12)$$

As can be seen from this expression, the resulting equations differ for different rivers only in the values of the regression coefficients.

The tightness of the relationship between the SSR and the variables that determine it is characterized by the values of the total (or summary) multiple correlation coefficients (r_0). Their values are calculated using the following formula:

$$r_0 = \sqrt{|r_{01}\cdot\alpha_{01}| + |r_{02}\cdot\alpha_{02}| + |r_{03}\cdot\alpha_{03}|} \quad (13)$$

The root mean square errors of the total multiple correlation coefficients are calculated by the expression:

$$\sigma_{r_0} = \frac{1 - r_0^2}{\sqrt{N - \ell}} \quad (14)$$

where l - number of arguments, in our case l= 3.

The normalized regression equations obtained for various rivers are characterized by rather high values of the total correlation coefficients, which range from 0,56±0,12 до 0,94±0,03.

Table 2

Parameters of Normalized Regression Equations

Type of nourishment	The limits of the change			
	Regression coefficient			Full coefficients of correlation, r_0
	α_{01}	α_{02}	α_{03}	
Amudarya River basin				
S – R**	0,52 ÷0,67	0,28 ÷0,70	-0,22 ÷-0,06	0,78 ÷ 0,89
S	0,40 ÷ 0,64	0,25 ÷ 0,51	-0,15 ÷ 0,25	0,71 ÷ 0,84
S – G	0,30 ÷ 0,64	-0,24 ÷ 0,43	0,37 ÷ 0,71	0,69 ÷ 0,77
G	-0,37 ÷ 0,44	-0,30 ÷ 0,38	0,63 ÷ 0,95	0,71 ÷0,94
Syrdarya River basin				
S – R	0,52 ÷ 0,68	0,30 ÷ 0,46	-0,34 ÷ -0,03	0,72 ÷ 0,85
S	0,52 ÷0,68	0,24 ÷ 0,34	-0,10 ÷ -0,03	0,74 ÷ 0,82
S – G	0,22 ÷ 0,45	-0,20 ÷ 0,28	0,56 ÷ 0,72	0,54 ÷0,69
G	0,22 ÷ 0,24	-0,23 ÷-0,16	0,59 ÷0,62	0,68 ÷ 0,72

Conclusions.

1. For rivers of snow-rain and snow types of nourishment, the pair correlation coefficients of SSR with both winter and summer precipitation have a positive sign and fluctuate, respectively, in the interval 0,337-0,811 and 0,419-0,712. It should be noted that for the rivers fed by snow and rain, the annual SSR is more closely related to summer precipitation than to winter precipitation;

2. Primary processing, systematization and generalization of both scientific and source materials on atmospheric precipitation, water runoff, river sediments of the rivers of the study area over a long period have been carried out. A specialized data bank on water runoff, river sediment, atmospheric precipitation and air temperature has been created;

3. A method has been developed for calculating a multifactorial relationship between the water erosion index - SSR of the studied rivers and climatic factors - atmospheric precipitation of different seasons (winter and summer) and air temperature. Here, river sediments are considered as an integral indicator of the intensity of water erosion occurring in river basins as a result of the influence of surface waters formed due to liquid atmospheric precipitation, melted snow and glacial waters.

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