

Relationships Between Water Discharge And Suspended Sediment Discharge In The Mountain Rivers Basin

Komiljon Rakhmonov¹, Oyjamol Kholtojiyeva¹, Zarina Pulatova¹, Maftuna Abduraimova¹

¹Department of Hydrology and climatology, National University of Uzbekistan, Tashkent 100066, Uzbekistan

Email: oyjamolxoltojiyeva@gmail.com

Abstract. The article evaluates the relationships between the mean annual water discharge and suspended sediment discharge of rivers in the Kashkadarya River Basin using both conventional and artificial neural network (ANN) approaches. For this purpose, data on the mean annual water and suspended sediment discharges observed at hydrological gauging stations located within the basin were collected and analyzed. Based on the collected dataset, the relationships between water discharge and suspended sediment discharge were initially investigated using the conventional approach implemented in Microsoft Excel, as well as an artificial neural network (ANN) model. The pairwise correlation coefficients characterizing the strength of these relationships were subsequently determined.

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Introduction.

Studying and statistically evaluating the relationship between water discharge and suspended sediment discharge in mountain rivers is of great scientific and practical importance. At the same time, this issue is widely used in assessing the sedimentation of reservoirs and canals, estimating the annual sediment volume of rivers, determining the erosion modulus and sediment layer, as well as calculating other indicators of the erosional activity of rivers.

Studying this issue using the rivers of the Kashkadarya River Basin as an example, drawing relevant conclusions from the obtained results, and developing the necessary recommendations based on these findings are currently of particular relevance. This is because the Hisorak, Chimkurgan, and Pachkamar reservoirs are operated within the Kashkadarya River Basin.

At the same time, the regression equations obtained based on the study of such relationships using both conventional methods and artificial neural networks (ANNs) provide a modern approach to reconstructing gaps in suspended sediment discharge series.

State of the Problem.

The issues related to the interrelationship between water discharge and suspended sediment discharge in the rivers of the Kashkadarya River Basin have been studied by researchers such as G.V. Lopatin (1949, 1952), V.L. Shults (1947, 1965), Yu.N. Ivanov (1967), O.P. Sheglova (1972, 1983), and F. Khikmatov (1985, 1998, 2002, 2012). To date, these data require updating and investigation using modern methods. Accordingly, the present study examines this

issue using the rivers of the Kashkadarya River Basin as an example, with an extended observation period, i.e., taking into account new hydrometeorological data, using both conventional methods and an artificial neural network (ANN) approach.

Aim and Objectives of the Study.

The main aim of this study is to investigate the relationships between annual water discharge and suspended sediment discharge in the rivers of the Kashkadarya River Basin using conventional methods and an artificial neural network. To achieve this aim, the following objectives were defined and addressed in the study: 1) to select hydrological gauging stations that enable the investigation of the relationships between suspended sediment discharge and water discharge in the rivers of the Kashkadarya River Basin, and to collect and conduct preliminary processing of the recorded data; 2) to develop an artificial neural network model based on the Python programming environment and to statistically evaluate the accuracy of the model; 3) to construct relationship graphs based on the hydrological data recorded at the selected hydrological gauging stations using conventional methods and an artificial neural network approach; 4) to develop regression equations expressing the relationship between water discharge and suspended sediment discharge in rivers, to evaluate their accuracy, and to compare the obtained results.

The mean annual water discharge and suspended sediment discharge measured in the rivers of the Kashkadarya River Basin were selected **as the object of** the study. The subject of the study is the investigation of the relationship between the mean annual water discharge and suspended sediment

discharge observed at these hydrological gauging stations using conventional and artificial neural network (ANN) methods, as well as the issues related to their practical application.

Main Results and Their Discussion.

The Kashkadarya River Basin is one of the important regions for the water resources and agriculture of Uzbekistan. The relief, geological and lithological structure of the mountainous and foothill areas of the basin, as well as the seasonal variability of river runoff, are among the main factors influencing the formation of erosion processes. Variations in water discharge in the rivers of the basin also cause changes in the amount of suspended sediment. Therefore, this study primarily focuses on investigating the relationships between water discharge and suspended sediment discharge using modern methods and drawing relevant conclusions.

It is well known that although conventional methods allow the quantitative assessment of relationships between water discharge and suspended sediment discharge, they do not fully represent the complex and nonlinear characteristics of hydrological processes. Initially, conventional regression equations and the sediment-rating curve method were used to investigate the relationships between water discharge and suspended sediment discharge. Currently, the use of artificial intelligence methods that allow the complex and nonlinear characteristics of hydrological processes to be taken into account is becoming increasingly widespread.

The Turkish scientist H.K. Cigizoglu investigated the forecasting of daily suspended sediment discharge using the MLP (Multi-Layer

Perceptron) method [Cigizoglu, 2004]. Ö. Kisi achieved the modeling of suspended sediment discharge using ANN models based on hydrometeorological data [Kisi, 2007]. In their study of the Longchuanjiang River, Yun-Mei Zhu, X.X. Lu, and Yue Zhou found that modeling suspended sediment flow using ANN based on hydrometeorological factors such as precipitation, air temperature, and water discharge produced effective results [Mei Zhu et al., 2007]. Melesse et al. investigated the potential for forecasting suspended sediment flow using ANN based on water discharge and suspended sediment discharge data from the Mississippi, Missouri, and Rio Grande rivers, as well as atmospheric precipitation over the basin [Melesse et al., 2011].

In general, foreign researchers have achieved significant results in modeling the relationships between water discharge and suspended sediment discharge using artificial neural networks. Therefore, the present study focuses primarily on investigating the relationships between water discharge and suspended sediment discharge using ANN, taking the rivers of the Kashkadarya River Basin as an example. The model was developed in the Python programming environment based on the MLPRegressor algorithm. In this model, water discharge (Q) was selected as the input parameter, while suspended sediment discharge (R) was selected as the target, i.e., output parameter. The model was developed using MLPRegressor. The performance of the model can be evaluated by comparing the observed and modeled suspended sediment discharge values (Table 1).

Table 1. Information on the Studied Rivers

No	River – Observation Station	F, km ²	H, m	Observation period			
				Q, m ³ /sek	R, kg/sek	Number of observations	
						Q	R
1	Kashkadarya - Varganza v.	511	1800	1951-2024	1951-2024	74	74
2	Kashkadarya - Chirakchi v.	1970	1720	1951-2024	1951-2024	74	74
3	Kichik Uradarya-Kumbulak v.	1570	1420	1969-2024	1969-2024	56	56
4	Uradarya - Bozortepa v.	1250	1750	1961-2024	1961-2024	64	64
5	Yakkabogdarya - Tatar v.	504	2730	1951-2024	1951-2024	74	74

Note: F – catchment area; H – mean elevation; Q – water discharge; R – suspended sediment discharge.

Based on the above, the relationship between water discharge and suspended sediment discharge was initially investigated in the study using the **conventional correlation-regression method** implemented in Microsoft Excel. The graphs obtained using the conventional method indicate that, with an

increase in water discharge, suspended sediment discharge also increases accordingly. However, the strength of this relationship differs substantially among the selected hydrological gauging stations (Figure 1).

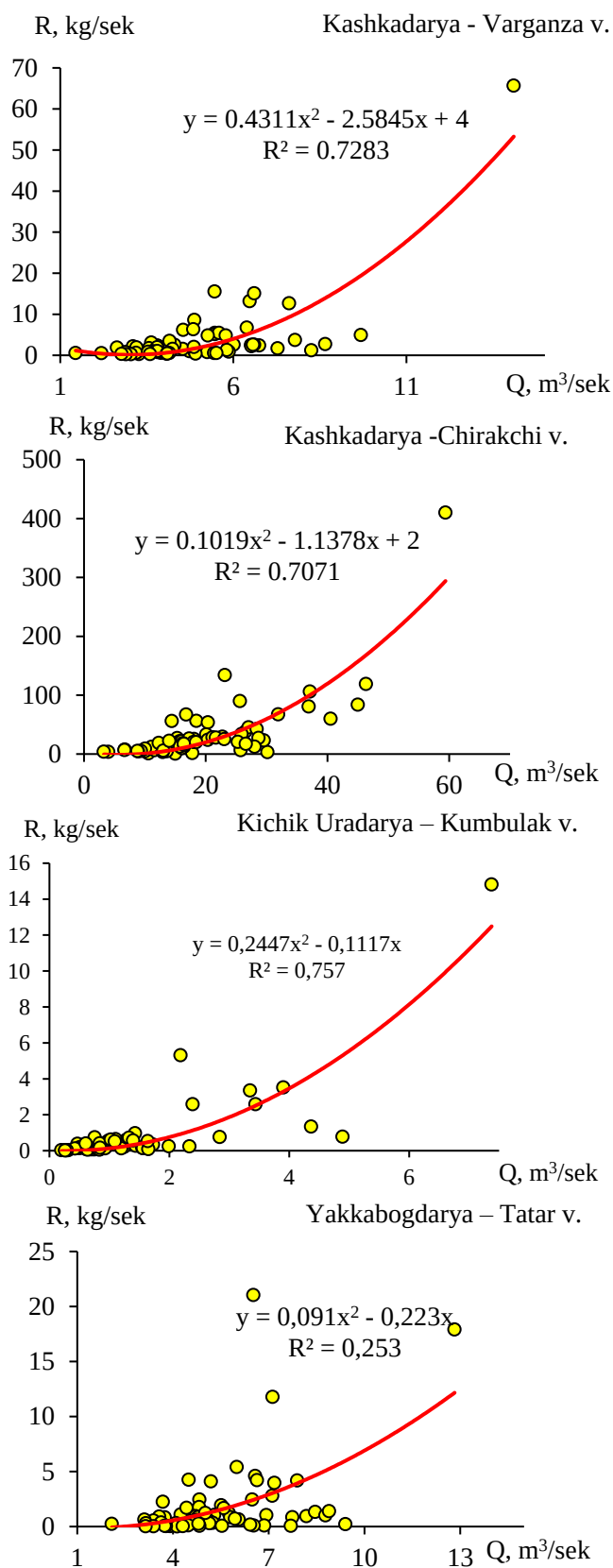


Figure 1. Graphs illustrating the relationship between water discharge and suspended sediment discharge

As can be seen from the above figures, the correlation coefficient characterizing the strength of the relationship between water discharge and suspended sediment discharge, together with its error, was 0.853 ± 0.012 at the Varganza hydrological gauging station on the Kashkadarya River, while at the Chirakchi gauging station it was 0.841 ± 0.013 .

At the next stage of the study, the main focus was placed on investigating the graphs illustrating the relationship between water discharge and suspended sediment discharge using an artificial neural network (ANN) approach. The theoretical foundations of artificial neural networks are closely associated with the mathematical neuron model proposed by W. McCulloch and W. Pitts. Subsequently, the perceptron model was developed by F. Rosenblatt [McCulloch et al., 1943]. The development of the error backpropagation algorithm by D.E. Rumelhart, G.E. Hinton, and R.J. Williams further expanded the possibilities for the wider application of multilayer neural networks [Rumelhart et al., 1986].

In hydrological studies, ANNs were initially used to model relationships between precipitation and river runoff and to forecast water discharge. By the late 1990s, ANN methods began to be investigated as an alternative approach to conventional statistical and regression models for river flow forecasting. Researchers Tokar and Johnson conducted studies on forecasting the flow of the Little Patuxent River using artificial neural networks and investigated the possibility of comparing ANN results with those obtained from statistical regression and conceptual models [Tokar et al., 1999]. Subsequently, these methods also began to be applied to the modeling of erosion processes. Due to the relationship between suspended sediment discharge observed in rivers and factors such as water discharge, precipitation, basin-specific characteristics, and other variables, ANNs have been considered an effective tool for identifying these nonlinear relationships. In this field, particular attention has been devoted to studies aimed at estimating and forecasting suspended sediment transport using artificial neural networks [Alp et al., 2007].

The main advantage of artificial neural networks (ANNs) is their ability to accurately learn and model complex, nonlinear relationships between hydrological variables and time series based on available observational data. This approach is

particularly important for forecasting complex processes such as water discharge, water level, suspended sediment discharge, and snowmelt, compared with conventional linear models. Artificial neural networks (ANNs) differ from conventional regression methods in their ability to learn complex and nonlinear relationships, process long-term datasets, and model variations in unpredictable hydrological data with high accuracy. In conventional computational methods, the relationship between water discharge and suspended sediment discharge is established using a preselected mathematical expression. In this case, the functional form of the relationship and its parameters are determined. In an artificial neural network, however, it is not necessary to specify the exact mathematical form of such a relationship in advance. The model takes water discharge as the input data and suspended sediment discharge (R) as the output data, thereby enabling the relationship between them to be learned directly from the data. Another important advantage of ANN is its ability to model complex and nonlinear relationships between water discharge and suspended sediment discharge. In addition, the model can be retrained using new data and adapted to the changing characteristics of the process under investigation.

In this study, the relationship between water discharge and suspended sediment discharge in the rivers of the Kashkadarya River Basin was investigated using the MLPRegressor model from the *scikit-learn* library in the Python programming environment. MLPRegressor is a regression model based on a multilayer perceptron that enables the learning of nonlinear relationships between input and output data. The model architecture consisted of two hidden layers. The ReLU (Rectified Linear Unit) activation function was used to represent nonlinear relationships between neurons in the layers. The ADAM (Adaptive Moment Estimation) algorithm was used to optimize the model parameters. The maximum number of iterations for the training process (the specified limit for the number of times the model processes the dataset) was set to 5,000. In addition, the computational parameter `random_state = 42` was used to ensure the reproducibility of the results. The performance of the ANN model was quantitatively evaluated based on the correlation coefficients representing the relationships between water discharge and suspended sediment discharge (Figure 2).

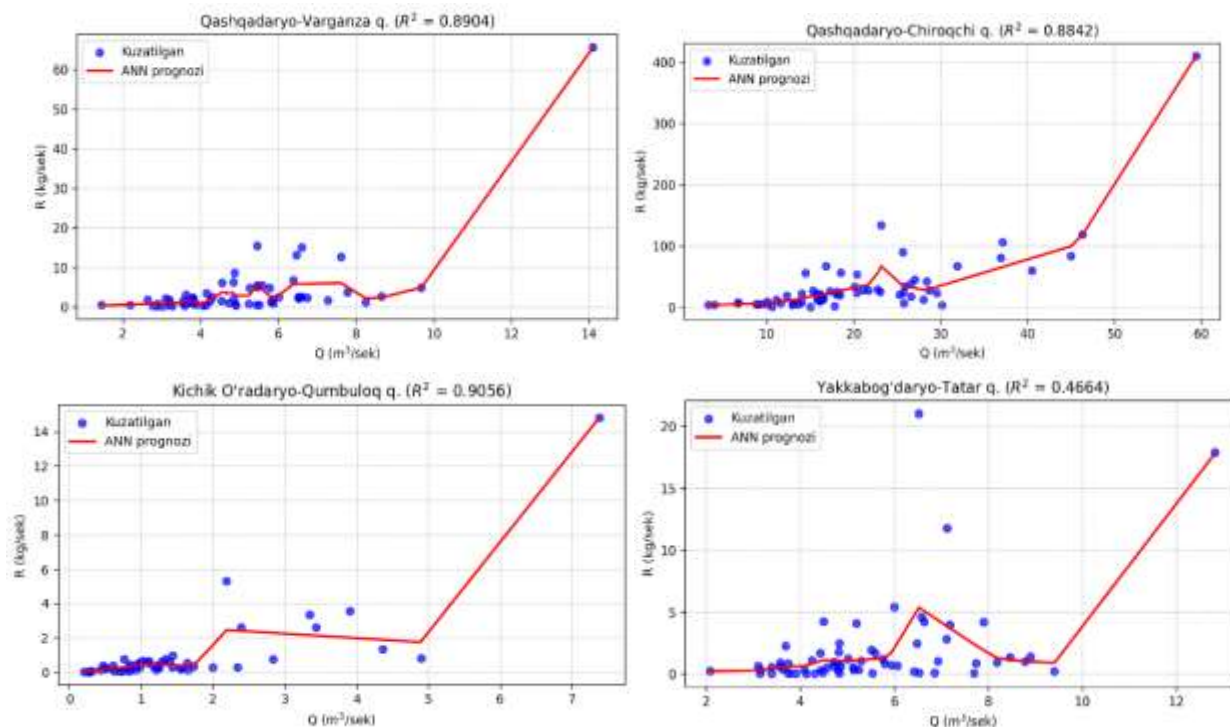


Figure 1.4. Relationships between water discharge and suspended sediment discharge investigated using the ANN model

At the next stage of the study, the correlation coefficients and their errors determined based on the regression equations obtained using the conventional

and ANN models were compared with each other (Table 2).

Table 2. Regression Equations and Their Accuracy for the Relationship Between Water Discharge and Suspended Sediment Discharge in the Rivers of the Kashkadarya River Basin

No	River – Observation Station	Equation	$r \pm \sigma_{ro}$	
			Conventional	ANN
1	Kashkadarya – Varganiza v.	1 $\bar{R} = 0,431 \cdot Q^2 - 2,585 \cdot Q + 4$	$0,853 \pm 0,012$	$0,943 \pm 0,005$
		2 $\bar{R} = 0,577 \cdot Q^2 - 4,866 \cdot Q + 11,5$		
2	Kashkadarya – Chirakchi v.	1 $\bar{R} = 0,102 \cdot Q^2 - 1,138 \cdot Q + 2$	$0,841 \pm 0,013$	$0,940 \pm 0,005$
		2 $\bar{R} = 0,153 \cdot Q^2 - 4,36 \cdot Q + 43,7$		
3	Katta Uradya – Bozortepa v.	1 $\bar{R} = 0,05 \cdot Q^2 + 0,325 \cdot Q$	$0,616 \pm 0,052$	$0,865 \pm 0,011$
		2 $\bar{R} = 0,026 \cdot Q^2 + 0,493 \cdot Q - 0,866$		
4	Kichik Uradya – Kumbulak v.	1 $\bar{R} = 0,245 \cdot Q^2 - 0,112 \cdot Q$	$0,870 \pm 0,022$	$0,951 \pm 0,004$
		2 $\bar{R} = 0,43 \cdot Q^2 - 1,97 \cdot Q + 3,91$		
5	Yakkabog'darya – Tatar v.	1 $\bar{R} = 0,091 \cdot Q^2 - 0,223 \cdot Q$	$0,503 \pm 0,042$	$0,683 \pm 0,026$
		2 $\bar{R} = 0,145 \cdot Q^2 - 1,0 \cdot Q + 2,532$		

Note: 1 – conventional method; 2 – artificial intelligence (ANN model); $r \pm \sigma_r$ – correlation coefficient and its standard error.

The table data show that the correlation coefficients determined using the conventional method range from 0.503 to 0.870. The highest correlation coefficient was obtained for the Kichik

Uradya–Kumbulak gauging station ($r = 0.870$), whereas the minimum value, $r = 0.503 \pm 0.042$, was recorded for the hydrological data from the Yakkabog'darya–Tatar gauging station. It should be

noted that the higher correlation coefficients obtained using the ANN model indicate its greater capability to represent the relationship between the observed water discharge and suspended sediment discharge values. In the conventional approach, the relationship is represented by a preselected quadratic equation, whereas in the ANN approach, the relationship is determined through the model parameters and hidden layers. As a result, the relationship graphs obtained using the ANN model exhibit a higher degree of fit, which leads to comparatively higher values of the correlation coefficients.

Conclusion.

The study investigated the relationship between water discharge and suspended sediment discharge recorded in the rivers of the Kashkadarya River Basin using both conventional methods and an artificial neural network (ANN). The correlation coefficients determined using the conventional method ranged from 0.503 to 0.870. For the rivers selected as the study objects, the correlation coefficients determined using the ANN model were 0.683 and higher. These results demonstrate that the artificial neural network provides effective results in modeling the relationships between water discharge and suspended sediment discharge. A comparative analysis of the conventional regression and ANN results indicates that the ANN model has a greater capability to represent complex and nonlinear relationships. On this basis, the ANN model can be considered appropriate for the quantitative assessment of the intensity of soil and sediment erosion within river basins. The obtained results are recommended for use as an additional source in the development of measures for water resource protection, the investigation of suspended sediment transport, and the quantitative assessment of water erosion processes.

Corresponding author:

Oyjamol Kholtojiyeva,
Department of Surface hydrology and meteorology
National University of Uzbekistan Tashkent, 100066,
Uzbekistan

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