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ASSESSMENT OF THE FLOW RATE OF THE ZARAFSHAN RIVER ACCORDING TO CLIMATIC FACTORS

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ABSTRACT--*This article gives a brief natural geographical description of the Zarafshan River Basin and evaluates its hydrometeorological researches. The connections between river flow and meteorological quantities, that are atmospheric precipitation and air temperature, were statistically analyzed. The regression equations representing these connections were taken and on the basis of them, the nomogram for assessing the flow of the river was drawn up. Using this nomogram, the amount of Zarafshan river flow was determined for different climatic scenarios.*

Keywords-- *Zarafshan river, river flow, Meteorological magnitude, atmospheric precipitation, air temperature, multi-level linking, regression equation, nomogram, climate change, quantitative assessment.*

I. INTRODUCTION

Today, as a result of the ongoing process of global climate change, the shortage of water resources on the planet, especially in its arid regions, is becoming more and more noticeable. In this regard, as noted in the V evaluation report of the UN experts group on climate change: "there is such alarming evidence that changes in the planet's ecosystems and climate systems have surpassed the limit and have already become irreversible ... The volume of mountain glaciers is shrinking at a terrible pace, and in the future, as a result of this phenomenon, many generations will experience a decrease in the reserves of drinking water in the dry months of the year"[32]. This situation requires studying the mechanism of formation of river flows in relation to climatic factors and improving methods for assessing the volume of their flow under conditions of climate change.. The formation of river flow and its quantitative assessment in relation to climatic factors were considered in the studies of many foreign scientists.

Researches of scientists of the former Soviet Union and the CIS, including S.S. Abalyan, S.K. Allamanov, M.N. Bolshakov, M.I. Budiko, A.I. Voyeykov, V.G. Glushkov, L.K. Davidov. , N.L. Korjenevsky, E.V. Petryashova, D.P. Sokolov and scientists from abroad, including A.F. van Loon, G.Laaha, C.J.White, D.W.Rycroft, G.Won spent their life studying of these issues.

In Uzbekistan, the first researches on this problem were carried out by E.M. Oldekop, V.L. Schultz, O.P. Shcheglovava and others. Currently researches in this area are being continued by V.E. Chub, B.K.Sarev,

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F.Khikmatov, L.M. Karandaeva, S.A.Haidarov, D.M. Turgunov. These studies are devoted to the influence of natural geographical factors on the formation of river flows in Uzbekistan and surrounding areas, including the state of river basins, exposure of slopes, persistent snow and mountain glaciers. Furthermore, these studies took into account the peculiarities of the natural conditions of river basins, including their geographic location, geological structure and topography, orography, climatic conditions, land cover and hydrographic networks [14, 19, 21, 28].

However, in the above-mentioned studies, the natural conditions of the Zarafshan river basin were not considered separately in connection with the issues of the formation of water resources in the basin. In particular, the conditions for the formation of the Zarafshan River and its main tributaries have not yet been studied in detail in connection with climatic factors, including air temperature and precipitation.

The main goal of this study is a physical and statistical analysis of the influence of seasonal precipitation and summer temperatures on the formation of the Zarafshan River, as well as an assessment of its water resources in the context of climate change, more precisely based on various climatic scenarios.

In order to achieve this goal, the following objectives were set out and found their solution in the research process:

- The gidrometeorological research of the Zarafshan river basin was analyzed;
- Many multi-level linking between the annual flow and the amounts of seasonal precipitation of the Zarafshan river were statistically evaluated;
- The connections between the average monthly, seasonal and annual water costs and the air temperatures of the Zarafshan river during these periods were determined;
- The statistical indicators of multi-level linking, reflecting the combined effect of precipitation and air temperature on the formation of the Zarafshan river flow, were calculated by the method of G.A. Alekseev [3] and their regression equations were taken;
- Through using the nomogram based on this equation, the annual flow of the Zarafshan River was estimated according to various climatic scenarios [15, 21, 24].

The object of the study was the Zarafshan River, which is formed as a result of joining of large streams in the mountainous part of the Zarafshan basin.

Its basin is located in the territory of Uzbekistan and neighboring Tajikistan. The upper part of the basin is bordered by Turkestan in the north and Zarafshon and Gissar ranges in the south (Figure 1).

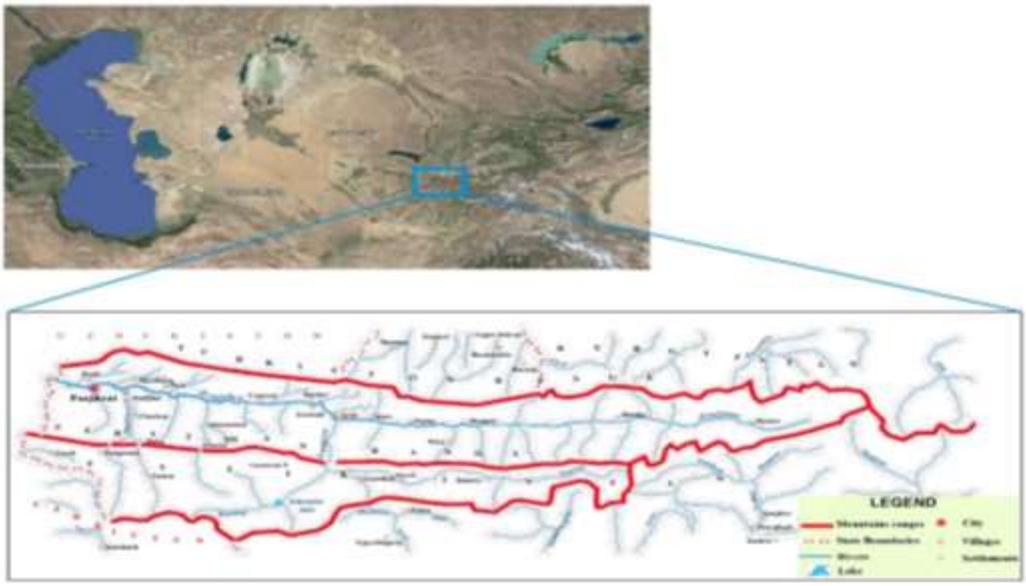

Figure 1: Orogydographic chart of t he mountainous part of the Zarafshan river basin

II. THE MAIN RESULTS AND THEIR DISCUSSION

Natural conditions of the Zarafshan river basin were studied by V.L. Schultz, U.P. Pchecheglova, M.A. Nasirov, D.P. Sokolov, M.I. Getker, G.E. Glazirin, V.E. Chub, V.G. Konovalov, B. K.Tsaryov, L.M. Karandaeva, H. Siddikov and others from a hydrological point of view. They say that current geological structure and relief of the mountainous part of the Zarafshan River basin is the result of complex geological processes of Cambrian, Paleozoic, Mesozoic and Cenozoic eras. On the formation of current relief and its orphograpic and hydrographic networks, the influence of Quaternary geological processes and freezing in this period is also very large. The first meteorological observations in the basin began at the end of the 19th century at the stations of Samarkand (1880) and Panjikent (1882). At the beginning of the 20th century, namely, from the 1914, hydrological observations started at hydrological posts Dupuli on the Zarafshon river, Qushtegirmon on its left side and Payshanba on the Oqdarya.

Over the years, 78 hydrological and 71 meteorological stations have operated in the Zarafshan river basin. Of these, 42 hydrological and 44 meteorological stations and posts are located in the territory of Uzbekistan, and the remaining 36 hydrological and 27 meteorological stations are located in the territory of Tajikistan. Dupuli hydrological station Dehaus, Anzob, Shahristan pass and Iskandarkul meteorological stations on the Zarafshan river were selected as the main hydrometeorological stations in this work. We used data from the “Fedchenko Glacier” meteorological station to solve the issues. All types of hydrometeorological observations and measurements are carried out in accordance with the requirements of the World Meteorological Organization (WMO). In this regard, the reliability of the primary hydrometeorological data used in the study was ensured.

According to the river basin water balance equation ($U_0 = X_0 - Z_0$), the main climatic factors affecting any river flow (U_0) are atmospheric precipitation (X_0) and evaporation (Z_0). This conclusion is also consistent with the Zarafshan river basin. In the first half of the 20th century, scientists put forward the following two views on the influence of climatic factors on the course of mountain rivers in Central Asia: 1) The degree of influence of climatic factors on the annual change in the volume of river flow depends on their sources of saturation [14]; 2)

The change in the amount of annual river flow, regardless of their type, depends on the amount of precipitation in the basin. [9, 22].

Later, in the 70s of the last century, M.N. Bolshakov and E.V. Petryashova's research clarified the dilemma on this issue. Based on the results of their research, they divided the West Tienshan rivers into three groups: 1) rivers whose annual variation in flow is mainly associated with the annual amount of atmospheric precipitation; 2) rivers whose annual flow fluctuations are under the joint influence of annual precipitation and changes in the thermal regime;3) rivers whose annual flow fluctuations are mainly associated with changes in air temperature during the melting of snow and glaciers. [4, 16].

Taking into account the above, we tried to consider the type of precipitation in the river basin that is being studied in the research. For this purpose, annual precipitation is divided into winter and summer precipitation. Average annual water costs (Q_{Dup}) measured at the Dupuli post of the Zarafshan river and multi-level linking density between winter ($\Sigma X_{X\text{-}III}$) and summer ($\Sigma X_{IV\text{-}IX}$) precipitation in the basin were statistically analyzed based on the application of the objective equation and normalization method. The calculations were carried out on the basis of the information about the amount of precipation of 3 meteorological stations (Dehaus, Anzob and Shahristan pass). Moreover, the calculations were also repeated based on their average values. (Table 1).

Table 1: Statistical indicators showing the relationship between seasonal precipation and average annual water consumption of the Zarafshan River

№	Connection type	$R_0 \pm \sigma_{R_0}$	$R_{01} \pm \sigma_{R_{01}}$	$R_{02} \pm \sigma_{R_{02}}$
1	$Q_{Dup} = f\,(\Sigma X_{X\text{-}III}, (\Sigma X_{IV\text{-}IX})_{Deh}$	0,65±0,107	0,62±0,114	0,21±0,178
2	$Q_{Dup} = f\,(\Sigma X_{X\text{-}III}, (\Sigma X_{IV\text{-}IX})_{Anz}$	0,46±0,146	0,33±0,165	0,21±0,178
3	$Q_{Dup} = f\,(\Sigma X_{X\text{-}III}, (\Sigma X_{IV\text{-}IX})_{Shah}$	0,68±0,103	0,56±0,156	0,03±0,186
4	$Q_{Dup} = f\,(\Sigma \bar{X}_{X\text{-}III}, (\Sigma \bar{X}_{IV\text{-}IX})$	0,63±0,111	0,65±0,107	0,15±0,182

Note: Q_{Dup} - average annual water consumption, m^3/c; $\Sigma X_{X\text{-}III}$, $\Sigma X_{IV\text{-}IX}$ - winter and summer precipitation, mm; *Deh* - Dehaus; *Anz* - Anzob; *Shah* - Shahristan; σ_{R_0}, $\sigma_{R_{01}}$ *ва* $\sigma_{R_{02}}$ - the errors of the complete *(*R_0*))* and double *(*R_{01}, R_{02}*)* correlation coefficients, respectively.

The exact correlation coefficients (R_0) of connections between the flow of the Zarafshan River and the amounts of seasonal precipitation are almost the same in 1, 3 and 4-type connections, and vary in the range of 0,63÷0,68. However, in the 2nd type connection, its value decreased and became equal to R_0 = 0,46. This result shows that the data of the Anzob pass meteorological station are not representative when examining the connections between the Zarafshan River runoff and precipitation. As shown data in the table, the impact of winter ($\Sigma X_{X\text{-}III}$) precipitation on the annual flow of the Zarafshan River is significantly higher than that of summer ($\Sigma X_{IV\text{-}IX}$) precipitation. Consequently, changes in the amount of winter precipitation have a greater effect on the annual flow fluctuations of the Zarafshan river.

Another feature of the Zarafshan river basin is the presence of modern mountain glaciers in the river basin. This indicates the need to take into account the influence of air temperature in addition to precipitation when studying the dependence of river runoff on climatic factors.

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To study the effect of air temperature on the Zarafshan river, double correlation coefficients were calculated to represent the density of the conncetion between the average monthly water consumption in the river and the average air temperatures measured during these months at weather stations in the basin (table 2).

Table 2: Double correlation coefficients of the connection between monthly average water consumption and air temperature

Meteorological station, height, m	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Iskandarkul, 2204	-0,08	-0,03	0,19	0,21	0,59	0,62	0,36	0,60	0,56	0,32	0,26	0,44
Dehaus, 2561	-0,07	0,05	0,28	0,22	0,55	0,63	0,34	0,61	0,54	0,32	0,26	0,33
Shahriston, 3143	0,00	-0,07	0,25	0,47	0,70	0,73	0,40	0,70	0,46	0,31	0,36	0,21
Anzob., 3373	0,00	0,06	0,27	0,30	0,62	0,66	0,35	0,69	0,56	0,30	0,34	0,29
Fedchenko 4169	0,02	-0,03	0,34	0,42	0,54	0,72	0,44	0,61	0,67	0,27	0,26	0,37

The results of the analysis of the table data allowed us to identify representative weather stations where air temperature data could be used in subsequent calculations. Among the meteorological stations used in the calculations, the values of the double correlation coefficients calculated using the data of the Shahristan pass are distinguished from others by their magnitude. Taking into account this situation, we used the values of the air temperature measured in the meteorology of Shahristan pass in the subsequent calculations.

In the next phase of the study, double correlation coefficients were calculated for the connection between average water consumption of the Zarafshan river determined for annual (Q_y) and different periods of the year (Q_{IV-IX}, Q_{V-IX},Q_{VI-IX}, Q_{VII-IX} ва Q_{V-X}) and air temperatures recorded at the Shahristan Pass meteorological station during the same period. (Table 3)

Table 3: Double correlation coefficients of the connection between the average water connection and air temperature, determined for different periods

Air temperature	Average water consumption					
	Q_y	Q_{IV-IX}	Q_{V-IX}	Q_{VI-IX}	Q_{VII-IX}	Q_{V-X}
T_y	0,60	0,60	0,59	0,57	0,48	0,61
T_{IV-IX}	0,53	0,54	0,56	0,53	0,49	0,55
T_{V-IX}	0,50	0,51	0,51	0,52	0,49	0,53
T_{VI-IX}	0,47	0,47	0,48	0,52	0,50	0,49

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T_{VII-IX}	0,38	0,38	0,40	0,43	0,48	0,40
T_{V-X}	0,52	0,52	0,54	0,53	0,49	0,54

Note: the determinations are listed in the text.

The analysis shows that average water consumption of the river for annual (Q_y) and different periods (Q_{IV-IX}, Q_{V-IX}, Q_{VI-IX}, Q_{VII-IX}, Q_{V-X}) and values of correlation coefficients, which represent the density of connections between average annual air temperature (T_y) are larger than other pairs. Their largest value (R = 0.61) refers to the T_y = f (QV-X) connection. In total, 21 of the 36 double correlation coefficients (58.3%) accept values in the range 0,50÷0,60. Consequently, the average temperature of the Zarafshan river for the different periods of the year and the hottest periods of the year is influenced by the temperatures at that time. We analyzed the correlations between the average monthly water consumption and the average annual temperatures for the Zarafshan River during the long-term period of April-September. These connections have been studied for extreme wet years throughout the basal period (1961–1990) (1973-multi-water; 1981-medium-water and 1982-low-water) (Figure 2).

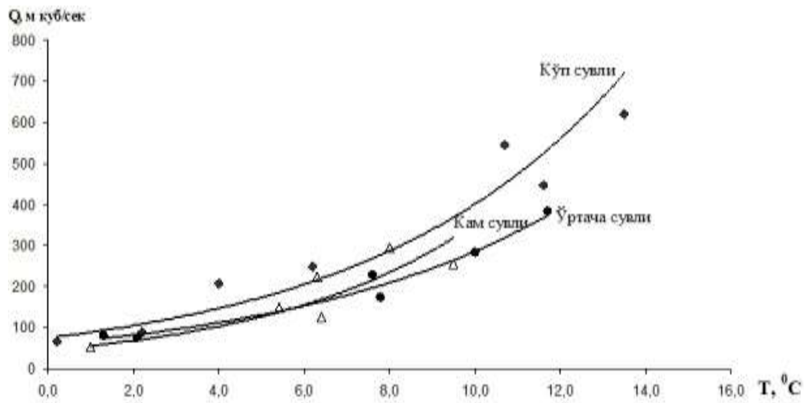

Figure 2: Connection between average monthly water consumption and air temperatures in extreme wet years

This series of connection indicates that a specific year's water level in the Zarafshan river is largely dependent on the July and August temperatures. From this perspective, these connections have practical value. For the practical use of the graph, the representative equations of connections were recommended and their accuracy was evaluated. (Table 4).

Table 4: Equations and correlation coefficients determined for extreme wet years

T/p	Extreme wet years	Regression equations	$R\pm\sigma_R$
1	multi-water in 1973	$Q_i = 75{,}402e^{0{,}1671 \cdot Ti}$	0,97±0,015
2	medium-water in 1981	$Q_i = 60{,}226e^{0{,}1558 \cdot Ti}$	0,98±0,011
3	low-water in 1982	$Q_i = 60{,}226e^{0{,}1558 \cdot Ti}$	0,93±0,037

Note: Q_i is the average monthly water consumption and represents the months of IV, V, VI, VII, VIII, IX, X; T_i - average monthly air temperatures; $R \pm \sigma_R$ - double correlation coefficient and its error.

In the next phase of the study, the correlation between the average water consumption in April-October and the average monthly temperatures in the months during the vegetation period of the Zarafshan river was considered. This connection covers all months in the base period of 30 years (1961-1990) (Figure 3).

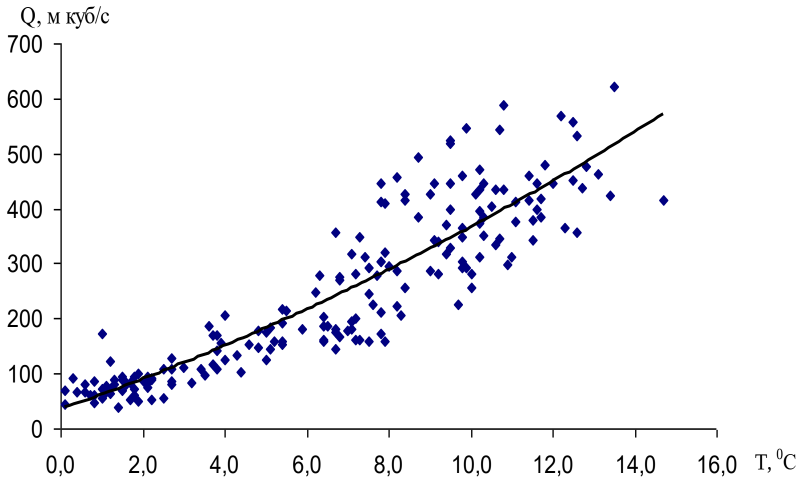

Figure 3: The graph of the connection between the water consumption and the temperatures of the Zarafshan river in April and October

The regression equation for this connection is represented by the second polynomial:

$$Q_i = 0{,}71 \bullet T_i^2 + 26{,}01 \bullet T_i + 35{,}18,$$

Here, Q_i is the average monthly water consumption and represents i = IV, V, VI, VII, VIII, IX, X; Ti - average monthly air temperature.

This equation has both scientific and practical significance. Its scientific significance is that this curve-line connection was expressed by a correlation ratio of η=0,91 value, and it is statistically substantiated that the flow of the Zarafshan river during the vegetation months depends on air temperature.. It is recommended to use it in the practice of hydrological calculations related to determining the amount of monthly flow of the Zarafshan river.

Taking into account the goals and objectives of the study, the combined effects of various seasonal atmospheric precipitation and summer air temperature on the Zarafshan River flow were statistically evaluated by G. A. Alekseev method [3].

III. RESULTS

As a result of the calculations, the following normalized regression equation was taken, which represents a multi-level linking between four hydrometeorological variables:

$$U_0(Q_{Dup}) = 0{,}500 \cdot U_1(\Sigma X_{X\text{-}III}) + 0{,}351 \cdot U_2(\Sigma X_{IV\text{-}IX}) + 0{,}450 \cdot U_3(\bar{t}_{VI\text{-}IX}), \qquad (2)$$

Here, respectively, $U_0(Q_{Dup})$, $U_1(\Sigma X_{X-III})$, $U_2(\Sigma X_{IV-IX})$ ва $U_3(\bar{t}_{VI-IX})$ - normalized values of water consumption, winter precipitation, summer precipitation and summer air temperatures; α_{01}, α_{02} and α_{03} - regression coefficients.

Only winter precipitation and summer air temperatures were taken into account when developing a method for quantifying the annual flow of the Zarafshan River depending on climatic factors. This is due to the fact that the contribution of these arguments to the above expression (1) was 56.1% and 41.9%, respectively. The proportion of summer precipitation did not exceed 2% and did not meet the criteria of efficiency. . Therefore, the calculations were repeated for 3 variables (Q_{Dup}, ΣX_{X-III}, ва $\bar{t}_{VI-IX}$,). The following regression equation was taken:

$$U_0 (Q_{Dup}) = 0{,}512 \cdot U_1 (\Sigma X_{X-IV}) + 0{,}402 \cdot U_2 (\bar{t}_{IV-IX}), \qquad (3)$$

The determinations in the expression are given above.

Equation (3) includes values of all hydrometeorological variables that are normalized, that is, do not have units of measurement. Therefore, to facilitate the quantitative assessment of the water consumption of the Zarafshan river, a special nomogram was developed based on this equation, which takes into account variables such as water consumption, atmospheric precipitation, and air temperature (Figure 4).

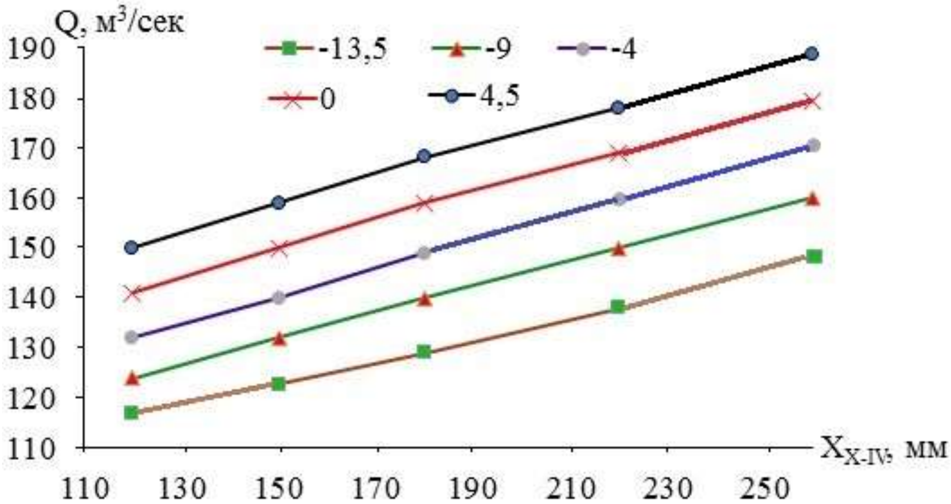

Figure 4: Nomogram of estimation of Zarafshan river flow depending on meteorological factors

The accuracy of the nomogram was evaluated in two ways. In the first method, its accuracy was evaluated for predictive purposes according to the "Prediction Service Manual" [24]. As a result of the calculations, it was found that the efficiency scale of the forecasting method based on the nomogram equals to $\frac{S}{\sigma} = 0{,}69$.

Therefore, the quality of this forecasting method can be evaluated as "satisfactory".

In Method 2 of the accuracy evaluation, the connection between the observed (Q_k) and nomogram-based (Q_x) values of the average annual water consumption of the Zarafshan river was studied (Figure 5).

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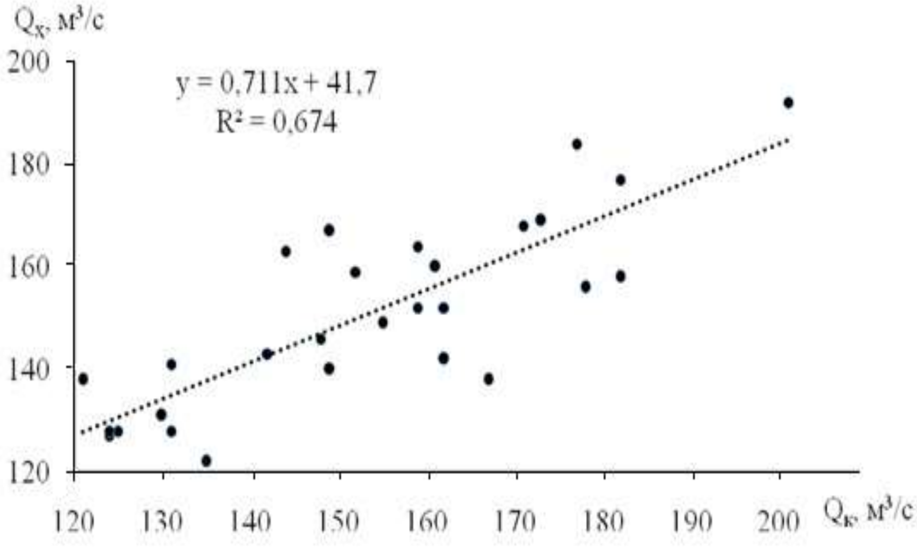

Figure 5: Dependence graph of calculated (Q_x) and observed (Q_k) values of the Zarafshan river flow.

As can be seen from the graph, the connection between the values of average annual water consumption determined from the nomogram and observed in practice, is represented by the statistical indicator R0 ± sR0 = 0.821 ± 0.040. , This value of the correlation coefficient fully meets the accuracy requirements of the empirical expressions used in hydrological calculations.

Thus, the nomogram allows calculating and forecasting the flow of the Zarafshan River based on climatic factors, namely, atmospheric precipitation and summer air temperature. It is recommended to use it in practice for hydrological calculations and forecasts.

Based on the above nomogram, quantitative indicators of the Zarafshan river flow were estimated based on scenarios (CCCM – Model of the Canadian Climate Centre; UKMO–Modelof the Canadian Climate Centre U.K. Meteorological Office; GFDL– Geophysical Fluid Dinamics Laborotory; GISS – Model of the Goddard Institute for Space Sciences) recommended by the World Meteorological Organization for climate change. (Table 4).

Table 4: Changes in the basic parameters of the Zarafshan river flow in different climatic scenarios

Flow indicators	The norm in the base period	Climate scenarios			
		CCCM	UKMO	GFDL	GISS
Q, $\frac{m^3/c}{\%}$	$\frac{153,4}{100}$	$\frac{158,0}{102,9}$	$\frac{161,0}{104,9}$	$\frac{159,0}{103,7}$	$\frac{163,0}{106,3}$
W,10^9 m^3	4,838	4,978	5,205	5,108	5,302
M, л/sec·km²	15,0	15,5	15,8	15,6	16,0
h, mm	974	488	510	501	520

Note: Q - water consumption; W - flow volume; M - flow module; h - flow layer.

The normal flow rate of the Zarafshan river during the basal climatic period is $4{,}838 \cdot 10^9$ m^3. This annual flow value can be increased by $4{,}978 \cdot 10^9$ m^3 over the next 15-20 years, according to the SSSM model. In general,

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in all climatic models, river flow is expected to increase between 2.9÷ 6.3%. But, it should be noted that all of the above models do not take into account the fact that as the area and volume of glaciers in the Zarafshan river basin decrease due to climate change, river flow will decrease accordingly. Future researches should focus on these issues.

IV. CONCLUSION

1. Peculiarities of natural conditions of the Zarafshan river basin are reflected in its geographical location, geological structure, relief, orography, climatic conditions, soil and vegetation cover, hydrographic network. There are 78 hydrological and 71 meteorological observation points in the basin. Of these, 42 hydrological and 44 meteorological sites are located in Uzbekistan, 36 hydrological and 27 meteorological stations are located in the territory of the Republic of Tajikistan;

2. The influence of seasonal (winter, summer) atmospheric precipitation on the formation of the annual flow of the Zarafshan river was evaluated statistically. The complete correlation of these connections varies in the range of 0,63÷0,68. In all computational options, the double correlation coefficients representing the degree of dependence of river flow and winter precipitation varies between 0,56÷0,65, which is 3–4 times greater than summer precipitation with 0,15÷0,21 intervals;

3. The influence of air temperature on the formation of the Zarafshan river flow was studied. The connections between average monthly water consumption and air temperatures were statistically evaluated. The largest values of the correlation coefficients of these connections are ($r \geq 0,70$), which corresponds to the months of May, June and August. The connection between the annual water consumption of the river and the average water consumption at different times of the year and air temperature during these periods was studied.. 21 of the 36 double correlation coefficients (58.3%) varied in the range 0,50÷0,60;

4. The combined effect of seasonal precipitation and summer air temperature on the formation of the annual flow of the Zarafshan river was statistically evaluated. The full correlation coefficient, which represents the accuracy of the normalized regression equation for this multi-level linking is expressed by value of $R_0 = 0.685 \pm 0.098$. . The nomogram accuracy based on this equation was evaluated in two ways and obtained a positive result: The efficiency criterion in method 1 equals to $\frac{S}{\sigma} = 0,69$, in method 2, that is, the double correlation coefficient between the calculated and practically observed water consumption based on the nomogram of the Zarafshan river equals to $0,821 \pm 0,040$. Therefore, the nomogram can be recommended for use in practice of special hydrological calculations and forecasts;

5. A method has been developed for assessing quantitative changes in river flow in the context of climate change using the example of the Zarafshan river. According to the climatic scenarios used in the study, river flow is expected to increase by 2.9 to 6.3 percent over the next 15-20 years compared to the norm. However, not all of these models take into account the fact that if the climate changes, that is, air temperature rises, the area and volume of glaciers in the Zarafshan river basin decrease, and as a result, river flow will also decrease. In future research, the main focus should be on the solution of these issues.

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