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A PLATFORM FOR GENETIC-ANALYTIC EVALUATION OF DRINI RIVER FLOW REGULATION IN SHKODRA LAKE ECOLOGY

Përmbledhje: Ky artikull është një përpjekje për paraqitjen e një platforme alternative për masat antropogjenike, që duhen marrë për një rregullim të përgjithshëm të kushteve ekologjike të Liqenit të Shkodrës. Mbi të gjitha, ky rregullim duhet të zgjidhë problemin e reduktimit të luhatjeve të amplitudës së vëllimit të ujit të liqenit nga 2.89.109 m3 në normat optimale. Duke analizuar alternativat e mundshme të rregullimit të regjimit limniologjik të Liqenit të Shkodrës, disiplinimi i rrymës maksimale të formuar në pjesën e sipërme të zonës ujëmbledhëse të Lumit Drin është zgjidhja më e përshtatshme. Në të njëjtën kohë, janë konsideruar gjithashtu dhe alternativa të tjera të mundshme, si kapaciteti transportues i ujit të shtratit të Lumit Buna dhe delta e tij në Detin Adriatik. Gjithashtu janë konsideruar dhe derdhjet e degëve të tjera në Liqenin e Shkodrës. Eshtë hulumtuar dhe një nga metodat e mundshme të vlerësimit të rregullimit të ndikimit të Lumit Drin në ekologjinë e Liqenit të Shkodrës. Në artikull janë paraqitur karakteristikat kryesore të regjimit limniologjik të Liqenit të Shkodrës, si regjimi i nivelit, balanca ujore, shkarkimi maksimal. Njehsimet hidrologjike përkatësisht për vlerësimin e rrjedhjes së lumit, shkarkimin maksimal, vëllimet katastrofike të rrjedhjeve etj. janë pjesë kryesore e studimit.

Fjalë kyçe: *luhatje të amplitudës, balanca ujore, vëllimi i përmbytjeve*

Abstract: This paper is an attempt of an alternative platform presentation of anthropogenic steps (measures) that should be taken for a general regulation of Shkodra Lake ecologic conditions. Above all this regulation must solve the problem of reducing the amplitude oscillations of the lake water volume from2.89.109 m3 to optimal norms. Analyzing the possible alternatives of limniological regime regulation of Shkodra Lake, disciplining the maximal flow formed in the upper part of the catchment area of Drini River is the most proper solution. At the same time other possible alternatives, such as water transport capacity of Buna River bed and its delta in the Adriatic Sea. Shkodra Lake tributaries etc. are also considerate. One of the possible methods to evaluate the regulation of influence of Drini River flow in Shkodra Lake ecology is compiled. The principal characteristics of limniological regime of Shkodra Lake, such as level regime, water balance, maximal discharge are presented in the

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paper. Hydrological calculations respectively for river flow evaluation, maximal discharge, catastrophic flower volumes etc. are important part of the study.

Key words: *amplitude oscillation, water balance, flood volume.*

INTRODUCTION

Drini water discharge into Buna bed, where Buna exits from Shkodra Lake, is not only an obstacle to the free discharge of this lake water but sometimes it forms currents of the opposite direction. This phenomenon is more obvious when Drini River discharge in to Buna is abundant. This restriction and the small water transport capacity of Buna bed (>1800 m^3/s) cause high oscillations in Shkodra Lake levels, respectively from to H_1=4.39 m to H_2=9.97 m ABS, o flooding large territories in Albania and Montenegro with a total surface F>160 km^2.

Buna is one of most important Mediterranean river. Out flow from Shkodra Lake, Buna immediately joins Drini River water and both rivers discharge into SE Adriatic Sea. „Shkodra Lake-Drini River-Buna River" hydrographic complex is very complicated and unique for its hydrographic regime in the World hydrography.

MATERIALS AND METHODS

Levels regime of Shkodra Lake water is determinate by integral indicators such as hydric balance difference $\Delta = \left(y_0 - z_0\right)$ (where: y_0 – water flow; z_0 – real evaporation), etc. (Pano, 1984, 1995, 2009).

Water flow depends on run-off discharge. Run-off discharge evaluation $Q_i\left(in\ \ m^3/s\right)$ is calculated for two different categories of Shkodra Lake catchments area, according to different hydrological and hydraulic natural conditions:

a) Zeta River, Moraca River, Cemi River, etc. where the run-off discharge – Q_i is computed as a function: $Q_i = f\left(H_i\right)$, where H_i is attitude of water level river section – *i*.

b) Buna River is part of the water complex: „Shkodra Lake – Drini River – Buna River. This hydrographical complex with a large catchment surface of about 20.000 km^2, is very complicated and unique for its hydraulic regime in the Mediterranean hydrography.

The discharge of Buna River in its exit from Shkodra Lake – Q_2, depends upon the lake level – H_2, and Drini River discharge into Buna River – Q_4. Buna discharge is calculated by the following equation (Pano & Saraçi, 1963):

$$Q_2 = \left\{ 0.025 \cdot \left[H_2 - \frac{Q_4^2}{\left(0.0073 \cdot H_2^{1.61413}\right)^2} \right]^{1.85} - Q_4 \right\}$$

$$Q_2 = f\left(H_2, Q_4\right)$$

Values correspond with the results obtained through the hydraulic calculations (Pano, 1996). The differences of the values of the discharge $-Q_2$, calculated by both methods, are relatively small, about $-\delta Q_2 = \pm 3\%$. Multi-annual average discharge, standard deviation, variation and asymmetry coefficients, representation, homogeneity and independence are calculated. This analysis also includes an investigation of the periodicity of time series. Assemblage of the modeling curves: $Q_2 = f\left(H_2, Q_4\right)$ has been calculated for different levels of Shkodra Lake – H_2 and Drini River discharge – Q_4 equal to 50, 100, 300, 1500 m^3/s.

Correlations between Shkodra water Layer – $H_i\left(in\ km^2\right)$ and respectively: Lake Water surface $-W_i\left(in\ km^2\right)$ and Lake water volume $-W_i\left(in\ m^3\right)$ are determinate $\left[S_i = f\left(H\right); W_i = f\left(H\right)\right]$.

Maximal flow regime in the hydrographical systems „Shkodra Lake-Drini River-Buna River" is calculated by two principal indicators: Maximal discharge Q_oM (in m^3/s) and volume W_oM (in m^3), with different probabilities p% (p=0.01; 0.1; 1; 2; 5; and 10%).

ANALYSES OF THE RESULTS

Water flow of Shkodra Lake catchment area is determined by the correlation of different factors of the geographical land shaft: climate, relative, territory lithological structure, vegetation, etc. As a result of the influence of all these factors of the catchments area, the water flow is different not only during the months, seasons and different periods of the years, but also in the multi-annual cycle.

The principal parameters of the water flow in Shkodra Lake hydrographic system are:

- Water total potential is about $W_0^T = 9.4 \cdot 10^{90}\ m^3 / in\ year$.
- Precipitation in Shkodra Lake basin $-x_0$, ranges from 1600 to 2500 mm in the coastal area, to 3500÷4400 mm in the mountainous area, having a basin area average of about $\overline{x} = 2000mm$.
- The annual module run-off discharge $-q_0$, of Shkodra Lake catchment area varies from: $q_0 = 75 \div 85\ l / s \cdot km^2$, with an average $q_0 = 50 \div 60\ l / s \cdot km^2$.
- The annual coefficient run-off discharge – α_0 of Shkodra Lake catchment area varies from: $\alpha_{0.1} = 0.40 \div 0.50$ to $\alpha_{0.2} = 0.85 \div 0.95$, with an average about $\overline{\alpha_0} = 0.90$.
- Water flow during the wet period of the year (X – V) represents about 75–80% of the annual water flow and 20–25% during the dry period (VI – IX). Considering seasonal distribution, winter is the wettest season with 35–45% of the water flow in Buna River, followed by spring with 25–35%, summer with 10–15% and autumn with 13–17% in the annual water flow. Mediterranean climate influence with a continental climate impact is observed in this annual distribution (Pano & Saraçi., 1984).

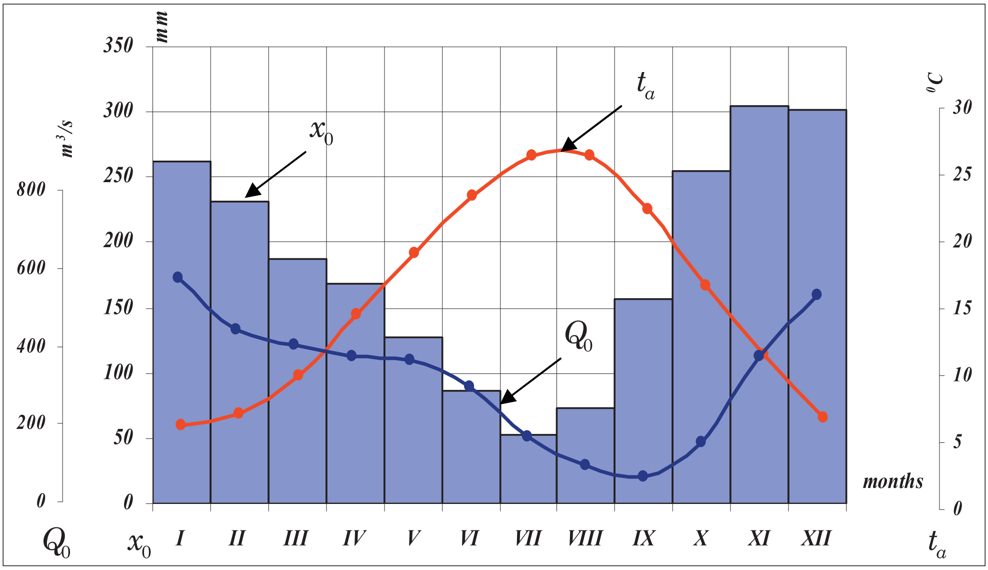


Figure 1. Annual hydro-climate parameters distributions, Shkodra Lake

The annual hydro-climate parameters distribution is presented in Fig. 1.

The underground flow – Q_0^N represents about 70% of the global water potential of Shkodra Lake hydrographic system, that corresponds to a discharge – $Q_0^N = 200 \, {m^3}/{s}$, a layer – $y_0^N = 1300mm$, a module – $q_0^N = 40 \, {l}/{s \cdot km^2}$, and a coefficient run-off discharge $\alpha_0^N = 0.60$.

The surface flow – Q_0^S represents about 30% of the total water potential of Shkodra Lake hydrographic system, that corresponds to a discharge – $Q_0^S = 90 \, {m^3}/{s}$, a layer – $y_0^S = 650mm$, a module – $q_0^S = 20 \, {l}/{s \cdot km^2}$, and a coefficient run-off discharge $\alpha_0^S = 0.30$.

The water supply types of the hydrographic network are presented in Table 1.

Table 1. Water supplying types of the hydrographic network of Shkodra Lake

Nr.	Presentation	Unit	Water Supply types		
			a) Surface	b) Underground	c) Total
1	Water volume – W_1	km²	2.8	6.6	9.4
2	Discharge – Q_0	m³/s	90	210	About 300
3	Layer – y_0	mm	650	1300	1950
4	Module – q0	l/s·km²	15	45	60
5	Percentage – p	%	30	70	100
6	Coefficient – α_0	–	0.30	0.60	0.90

Table 2 presents limnological elements of Shkodra Lake.

Table 2. Liminological elements of Shkodra Lake.

No	Elements	Unit	Minimal (RMin)	Mean (RMea)	Maximal (RMax)	Difference R= RMax- RMin
1	Layer – H	m. Abs	4.39	6.52	9.40	5.0
2	Surface – S	m^2	377	476	524	150
3	Water volume – V	m^3	$1.62 \cdot 10^9$	2.6	$4.06 \cdot 10^9$	$2.44 \cdot 10^9$

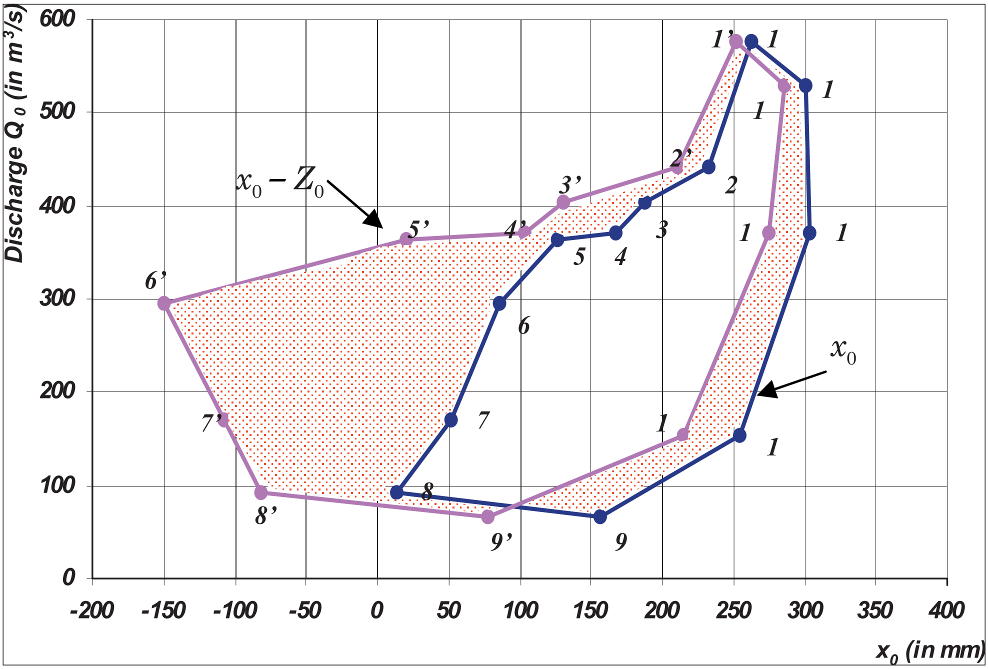


Figure 2. Correlation between monthly water discharge – $Q_0\left(in\ {m^3}/{s}\right)$, and respectively: precipitation – $x_0\left(in\ mm\right)$; and precipitation difference – $\Delta x_0 = \left(x_0 - E_P\right)\left(in\ \text{mm}\right)$.

Correlation between annual water discharge – $Q_{0.p\%}\left(in\ \ m^3/s\right)$ and annual precipitation – $x_{0.p\%}\left(in\ \ \text{mm}\right)$ of the same probability (p%) is presented in Fig. 2.

The Potential Evotranspiration – E_p in Shkodra Lake catchments area varies from $E_{p,1}$=*15 mm* in January to $E_{p,2}$=*190 mm* in August, having an annual average E_p=*1000 mm*

Real Evotranspiration is $E_R = 650\, {mm}/{year}$.

Deficit Evotranspiration is $\Delta E = 350\, {mm}/{year}$

Deficit Pluviometric is $\Delta x_0 = 1000mm$

Evotranspiration on the Shkodra Lake water surface (in m³/s), varies from $Q_{A1} = 8\, m^3/s$ in January to $Q_{A2} = 25\, m^3/s$ in August, having an annual average $\overline{Q}_A = 12\, m^3/s$.

The correlation between water discharge – $Q_0 \left(in \quad m^3/s \right)$, precipitation – $x_0 \left(in \quad \text{mm} \right)$; and respectively pluviometric difference – $\Delta x_0 = \left(x_0 - E_p \right)$ in mm is presented in Fig. 3.

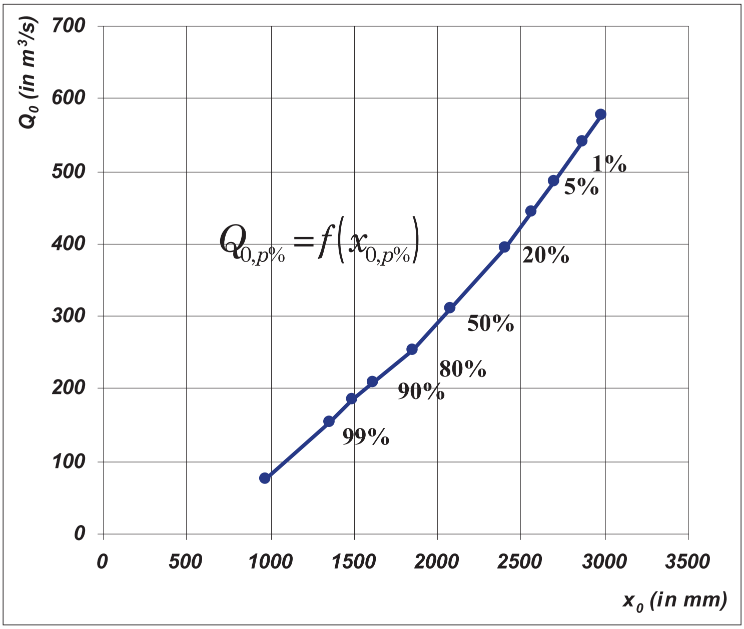


Figure 3. Correlation between annual water discharge $Q_{0,P\%} \left(in \ m^3/s \right)$, and annual precipitation $x_{0.P\%} \left(in \ mm \right)$ of the same probability $\left(p\% \right)$.

The multi-annual data supports the arguments that in Shkodra Lake the water layer varies within very wide limits. Minimal layer is $H_{Min} = 4.39m.Abs$ for the hydrological dry years of low precipitation up to maximal values $H_{Max} = 9.40m.Abs$ of the hydrological wet years of high precipitation. In these conditions in Shkodra Lake the multi-annual water layer amplitude is $\Delta A = \left(9.40 - 4.39\right) = 5.0m$, that corresponds a changeable surface – $\Delta F = \left(F_{Max} - F_{Min} \right)$, $\Delta F = \left(524 - 476\right) = 150km^2$ and an active water volume – $\Delta W = \left(W_{Max} - W_{Min} \right)$, $\Delta W = \left(4.06 \cdot 10^9 - 1.62 \cdot 10^9\right) = 2.44 \cdot 10^9 m^3$.

High values of the changes in time of the corresponding surface and water volumes of Shkodra Lake are determining factors of the natural conditions for the powerful wetland habitat of this lake. The climate in Western plain areas of Albania was warmer 3.5 century ago (Frashëri & Pano, 2002, 2003). Later a cooling of 1 °C did until one century ago. During the last half of the 20th century an increase of 1 °C is observed. Climate changes have an impact on country hydrographical system (Shkodra Lake, Buna River and Drini River system and area habitat).

The maximal flow for Shkodra hydrographical system: (Respectively: discharge – Q_0^M and volume – W_0) with probabilities – p% (p = 0.01; 0.1; 1; 2; 5 and 10%) is presented on Table 4.

Table 4. Discharge – Q_0 (in m^3/s); Volume (in 106 m^3)

N	Elements		Units	Probability – p (in %)						
				20	10	5	2	1	0.1	0.01
1	WHITE DRINI (Kukes F= 4965 km^2)	Q_0	m^3/s	960	1220	1490	1830	2150	3428	4706
		W_0	$m^3\text{-}10^6$	156	198	245	295	350	470	601
2	BLACK DRINI (Skavica F = 5562 km^2)	Q_0	m^3/s	944	1200	1410	1630	1850	2950	4050
		W_0	$m^3\text{-}10^6$	202	258	304	352	400	540	690
3	DRINI (Fierza F = 11829 km^2)	Q0	m3/s	1490	2620	3210	3900	4360	6952	9540
		W_0	$m^3\text{-}10^6$	273	480	560	670	800	1080	1360
4	DRINI (Vau Dejes F = 13650 km^2)	Q_0	m^3/s	2870	3400	3920	4610	5800	6680	8250
		W_0	$m^3\text{-}10^6$	679	804	923	1080	1190	1550	1910
5	SHKODRA LAKE (Pellgu F = 5179 km^2)	Q0	m^3/s	2650	2940	3220	3570	3840	4670	5470
		W_0	$m^3\text{-}10^6$	600	711	811	958	1060	1400	1740
6	BUNA (Ura F = 5179 km^2)	Q_0	m^3/s	947	1104	1265	1455	1600	1882	2160
		W_0	$m^3\text{-}10^6$	406	473	543	626	687	808	1801
7	BUNA + DRINI (Dajç F = 19582 km^2)	Q_0	m^3/s	4960	5210	5680	6220	6680	7860	9020
		W_0	$m^3\text{-}10^6$	1700	1980	2270	2610	2870	3700	4520

The regulation platform of the ecological regime of Shkodra Lake would include following alternatives:

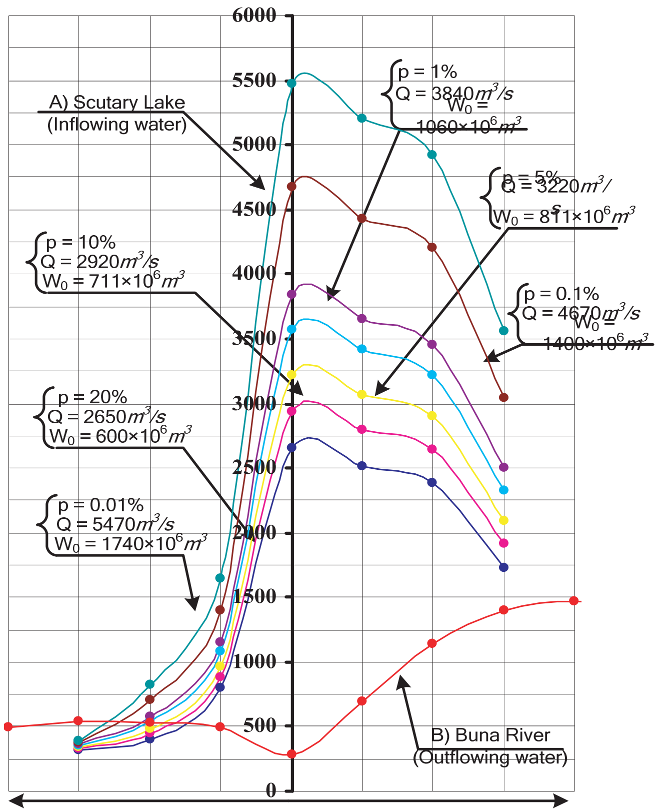
1) Water flow regulation of Shkodra Lake catchment area,
2) Water transport capacity increase of Buna River bed,
3) Maximal flow reduction of Drini River.

This regulation first of all, must reduce the oscillations amplitude of the active water volume of Shkodra Lake in optimal quotas.

Analyzing the possible alternatives of regulating the ecological regime of Shkodra Lake it results that Skavica reservoir construction in Black Drini River catchment area is the only possible real alternative for this regulation.

The maximal flow of Black Drini River-Skavica (F=5562 km^2) with probability once in 100 year (p=1%) has a discharge $QM_{1\%}$=1850 m^3/s and volume $W_{1\%}$=400.10^6 m^3.

The maximal flow of Buna-Shkoder is presented in Fig. 4. Maximal flow with probability once in 100 year (p=1%) that is formed in Shkodra Lake catchment area (F=5179 km^2) and inflows in this lake has the discharge $QM_{1\%}$=3840 m^3/s and a volume $W_{1\%}$=1060.10^6 m^3. At the same time reduced maximal discharge $QM_{1\%}$=1400 m^3/s and volume $WM_{1\%}$=687.10^6 m^3 outflow from Shkodra Lake through the Buna River bed (Fig. 5). Such situation caused growing of the lake water level in very high quotas, about 10.0 m ABS, so flooding wide territories in Albania, including the historical city Shkodra, and Montenegro.



Days	3	2	1	0	1	2	3	4	5
Ordinate	0.10	0.15	0.30	1.0	0.95	0.90	0.65	0.50	0.30

Figure 4. Characteristic Hydrograph (Buna River-Shkoder)

Table 5. Maximal discharge – Q_0 and maximal volume – W_0

N	Elements		Units	Probability – %						
				20	10	5	2	1	0.1	0.01
1	Discharge	Q_0	m^3/s	2650	2940	3220	3570	3840	4670	5470
	Volume	W_0	$m^3 \cdot 10^6$	600	711	811	958	1060	1400	1740

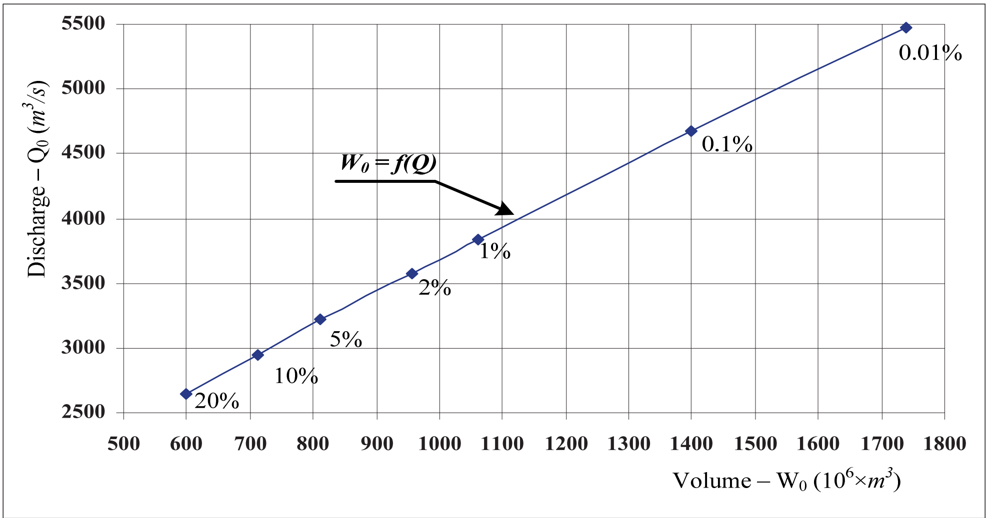


Figure 5. Correlation between maximal discharge (Q_0) and maximal volume (W_0) Ordinates

a) Shkodra Lake (Inflowing water)

Days	γ	Probability – p%						
		20	10	5	2	1	0.1	0.01
3	0	320	330	340	350	360	380	390
2	0.15	397	447	487	535	576	700	820
1	0.30	795	882	966	1077	1152	1400	1640
0	1.00	2650	2940	3220	3570	3840	4670	5470
1	0.95	2517	2793	3059	3415	3648	4430	5196
2	0.90	2385	2646	2899	3213	3456	4203	4923
3	0.65	1722	1917	2093	2321	2496	3036	3555

b) Buna River (Out flowing water)

Day	5	4	3	2	1	0	1	2	3	4	5
Ordinate	456	495	536	527	497	287	693	1140	1400	1470	1409

CONCLUSIONS

1. Shkodra Lake, Buna River and the Drini River represent a complicated hydrographical system. Buna is one of the biggest and most important rivers of the Med-

iterranean Sea. After getting out of the Shkodra Lake, this river joins the Drini River, forming this particular hydrographical system;

2. The discharge of the Buna River away from the Shkodra Lake depends upon the lake water level and the Drini River discharge into Buna River. Discharge of the Buna River has been calculated by equation system proposed by Pano N.;

3. Global warning during the last half of the 20 th century have an impact on country hydrographical system, includes and on Shkodra Lake, Buna River and Drini River system and area habitat.

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