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Remodeling of the WQI Index for the evaluation of the Shkumbini River's water quality in Albania using the statistical method

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Abstract. Nowadays, assessing the extent of natural water resources and making an accurate assessment of its quality is a task as important as it is urgent. The determination and assessment of the Water Quality Index (WQI) is a method used in our paper to assess the water quality of the Shkumbini River in Albania - one of the main rivers of our country. We used the analysis of the WQI index, because it is the most optimal analysis we can do with the collected data and because it is an easier index to interpret. WQI is considered fundamental information for analyzing and demonstrating the water quality. We have used the data collected during a 4-year period from the Shkumbini River's water (in total 72 sets of data) and through the statistical method of Multiple Linear Regression (MLR) we have defined an equation for the assessment of WQI expressed by three variables: biological oxygen demand, hydrogen carbonate and phosphorus (BOD, HCO_3, P-total). MLR is implemented by interpreting the correlation coefficient R^2, which demonstrates that 99.6% variability of the data is explained by the new regression equation. The t-test was also used, demonstrating the equivalence of the WQI index, calculated from the newly constructed equation, and the values of the first WQI, calculated using nine variables. The reduction of the number of determining variables of WQI has its advantages, both financially, as well as from the way that the water quality of the Shkumbini River is interpreted and monitored.

Key words: Water Quality Index Model, Shkumbini River, Multiple Linear Regression (MLR), Model accuracy.

Introduction

Water is the most precious natural resource that exists on planet Earth. Water is life. To measure and evaluate the quality of water means to evaluate the quality of life or more precisely, to evaluate its existence. Albania is a country full of precious water resources.

The water surface of Albania is a natural asset presented by a wide network of rivers and lakes, and other sources of groundwater. Along its borders, 316 km are comprised of shore borders, 48 km river borders and 73 km lake borders. The hydrographic basin of the rivers of Albania has a surface area of 43305 km^2, of which only 28748 km^2 are located within the territory of Albania. Compared to other European countries, Albania is ranked near the top in terms of water resources. An average of 1485 mm of atmospheric precipitation per year falls on the Albanian territory, of which 891 mm or 25.6 km^3 flows into the sea from the rivers.

With the growth of the population, the daily development of the economy and industry, as well as the modernization of life, people's needs for water are constantly increasing. On the other side, this rapid development and growth of these factors also leads to an increase in the pollution of the water resources.

The existence of residential areas near these water sources is an advantage for the population, but at the same time, it affects the quality of the water, doing these by natural factors or anthropogenic activities (Dantas et al., 2020). Different natural factors that influence water quality as atmospheric, climatic, topographical and lithological (Magesh et al., 2013), accompanied by anthropogenic activities like livestock farming, production and disposal of waste, increased sediment run-off or soil erosion due to land-use change and heavy metal pollution (Uddin et al., 2021).

Since the Shkumbini River flow in the middle of Albania, and a major part of the studied area is an industrial zone where operates different industrial activities, there are a lot of possibilities for it, to be polluted.

The coliforms presence in the study area comes in the water from the agricultural pollution of the area, from the domestic sewage etc. Also, anthropogenic pollution with effluent discharge is the cause of the turbidity of the water. We underlined the significant contribution to river pollution made by sediments originating in industrial zones, as is the area of the Elbasan Metallurgical Combine, where the Shkumbini River flows. This makes the studying of the Shkumbini River's water quality using scientific methods, even more urgent.

Studying the pollution of a water source is a difficult and wide-ranging task and to evaluate this pollution we have to calculate WQI index or we can use other methods (Kumar et al., 2018). Tivar & Mishra (1985) and Bharti & Katyal (2011) concluded that, the study of WQI is an issue that has been widely addressed over the years, considering the WQI value as fundamental information for analyzing and demonstrating the water quality.

The WQI was proposed in 1970 by the National Sanitation Foundation (NSF) in the United States of America (USA), being a tool to simplify the reporting of water quality data and typically as a dimensionless number that combines multiple water quality variables into a single number by standardizing values to the rating curves and allowing for simple data monitoring interpretation (Kachroud et al., 2019). The expression of a WQI model transforms a large number of complex water quality parameter measurements into an easy-to-comprehend information for people to understand and act upon (Syeed et al., 2023).

The problem of analyzing the water quality of rivers in Albania is a problem treated too far in time. In some studies, the calculation of WQI has been done with the data, collected at different points of the river's stretch, while in others the calculation has been done using the degree of pollution of the river's waters.

Damo & Icka (2013) studied the quality of drinking water in Pogradec, Albania, through the value of WQI. Luzati & Jaupaj (2016) brought a study for the assessment of water quality of the Durrësi – Kavaja basin, where eleven chemical parameters have been used to calculate the WQI like pH, general hardness, calcium, magnesium, alkaline cations, iron, bicarbonate, chloride, nitrate, sulphate, and total dissolved solids, confirming the higher amounts of nitrates belong to water samples taken from the shallow wells where the impact of chemical fertilizers is higher. They have concluded that based on the WQI methodology, the groundwater of Durrësi-Kavaja basin, falls into three classes: class I – excellent water, class II – good water and class III – poor water which represents 23%, 72% and 5% of the sampled water wells within the study basin, respectively.

Sulçe et al. (2018) present a general overview of the issues related to the surface and ground water quality in Albania, and discuss about sources and controlling processes. Also Beqiraj & Kumanova (2010) said that the TDS value of groundwater should be less than 1.0 mg/L up to a depth of 400-500 m. Bani et al. (2020) concludes that the recorded values of temperature, pH, dissolved oxygen (DO) and conductivity are within the acceptable limits for the survival, metabolism and physio-logy of aquatic organisms, also Zela et al. (2020) give an assessment of the environmental quality of the Seman River water through 14 parameters, giving a conclusion for the status of the water through the application of WQI.

Marlon et al. (2021) claim that the WQI is considered a mathematical tool that significantly minimizes the complex water quality data sets and provides a single classifying value that describes the water quality status of water bodies or the degree of pollution, and also Abbasi & Abbasi (2012) characterize WQI as a single dimensionless number that describes the overview of the overall water quality status in a simple way by aggregating the measurements of selected parameters.

Given that, the calculation of WQI is a prolonged process in which numerous national and international standards are taken into consideration, we have relied on the standards of Albania for WQI, which are in line with those of Europe. The purpose of this study was to evaluate the application of advanced statistical methods. Those methods extract important information without significant loss of accuracy.

Multiple Linear Regression (MLR) is one of these statistical methods that is used to build a regression equation that connects different statistical determinant variables, and also Marlon et al. (2021) conclude that for linear regression, MLR is a statistical model related to the treatment of time series of data, where its analysis is a forecast of values of one or more response variables to which it uses a set of explanatory variables.

This study succeeds in building a new model for determining the WQI, through an equation with a smaller number of variables, which can be used as a fairly good model to evaluate the water quality of the Shkumbini River, and achieving the study's objectives:

1. Remodeling the calculation of WQI taking into consideration only the variables that really affect the calculation of the WQI of drinking water. This reduction helps simplify the calculation of WQI, both technically and economically.

2. Using the best predictive statistical method, Multiple Linear Regression method (MLR), in analyzing the collected data and explaining the relationship between the studied variables.

3. Calculating the WQI values of Shkumbini River's water that fit the standard (Brown et al., 1972).

4. Concluding the best model of accuracy equation with a reduced number of variables for calculating the WQI index.

This study is organized in four main sections. The first section gives a short summary of the study, emphasizing its objectives. The second part includes materials and methods, giving a view of study area and the theoretical description of the steps for the calculation of WQI. The results and discussion about the new value of WQI are presented in section three. In the four section are presented the conclusions and suggestions for the future.

Materials and Methods

Study Area

The Shkumbini River (Fig. 1) is a river that originates from the Valamar Mountains (Albania) and flows into the Adriatic Sea. The length of the Shkumbini River is 181 km and it is a river with environmental problems (Bani et al., 2020). The water flow reaches the average annual value of 61 m^3/s. The Shkumbini River basin lies entirely in the middle area of Albania. The surface of the drainage basin river is 2445 km^2.

Shkumbini divides Albania into two almost equal parts, and as such, it is one of the most important rivers for the Albanian economy.

Points where data and laboratory analyze are collected

Data collection was done in these points: Qukës, Librazhd, Xibrakë, Papër, Bishqem, Rrogozhinë. (Fig. 2).

In these six monitoring points, data has been collected for four consecutive years: 2018, 2019, 2020, 2021, in three different periods of the year: in March, July and October, so in total we have 72 groups of data.

For data collection at each monitoring point, acid-washed plastic holders were used in order to avoid unexplainable changes in water characteristics.

For the analysis of the nine parameters (Table 1) that determine the quality of water, containers with a volume of 2L, 1.5L and 0.5L were used. The methods used for taking samples were determined according to USDA (Musselman, 2012).

The samples taken were sent to be analyzed at the laboratory of the Regional Directorate of Public Health, Elbasan, Albania.

Water quality was evaluated by comparing the obtained values with the values recommended by NIVA classification (Bratli, 2000).

Fig. 1. Flow of the Shkumbini River in Bashtova

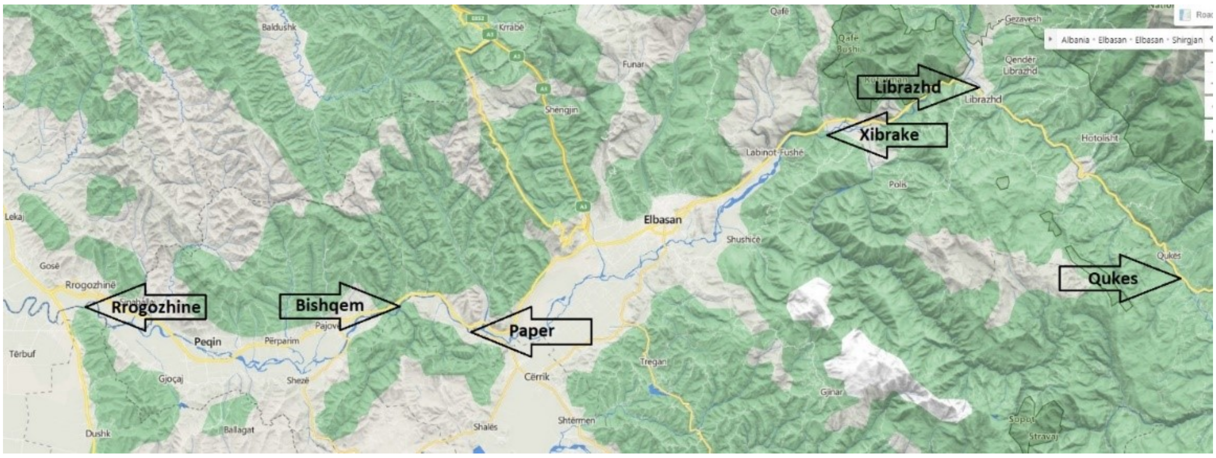

Fig. 2. The points of data collection map

Table 1. Albanian standards that determine the quality of water

Chemical parameters	Units	Albanian standards (w)
TDS	mg/l	6.5
GH	mg/l	20
BOD	mg/l	1.5
pH	mg/l	7.5
DO	mg/l	5.8
Cl	mg/l	20
HCO_3	mg/l	200
P-total	mg/l	0.09
Thermotolerant Coliforms	mg/l	600

The importance and the calculation of WQI

In Albania, the calculation of the WQI is done by taking nine parameters, each with a certain weight, in accordance with the importance that each one has in the quality of water for use as drinking water.

The Albanian Standards for drinking water which fit with those of EU, applied the calculation of the WQI based on nine parameters: pH, Total Dissolved Solids (TDS), General Hardness (GH), BOD, Dissolved Oxygen (DO), Chloride, Total Phosphor (P-total), Thermotolerant Coliforms, HCO_3.

Each of the nine parameters is accompanied with a weight that was shown in the Table 1, according to the relative importance that each parameter has in the quality of drinking water.

Brown et al. (1972) proposed a method of calculation to increase sensitivity using the formula:

$$\boldsymbol{WQI = \sum W_i q_i} \quad \textbf{(1)}$$

$$\boldsymbol{W_i = \frac{w_i}{\sum w_i}} \textbf{ and } \boldsymbol{Q_i = 100 \times \frac{V_i}{S_i}} \quad \textbf{(2)}$$

where: w_i is the unit weight;

S_i - recommended standard value of i-th parameter;

Q_i- sub quality index of the i-th parameter or the quality rating scale of each parameter, and for the calculation of its numerical value we are based on Brawn et al (1972);

V_i - monitored value of the i-th parameter.

After the calculation of the WQI index (Table 2), the results can represent the quality of the water, in dependence with the quality range presented on Table 3.

Table 2. The calculated values of WQI

N.	Period	The place for taking the samples					
		Qukës	Librazhd	Xibrakë	Papër	Bishqem	Rrogozhinë
1	March 18	66.91	60.09	81.77	75.44	73.82	120.89
2	July 18	58.93	56.50	74.81	73.72	78.77	109.24
3	October 18	68.24	88.57	74.81	87.48	75.31	123.73
4	March 19	67.94	60.97	60.83	92.77	71.82	125.38
5	July 19	90.02	92.84	87.66	79.83	75.60	114.10
6	October 19	61.52	70.74	75.24	81.52	88.49	137.78
7	March 20	87.48	83.58	76.41	56.58	60.60	126.74
8	July 20	81.08	96.99	77.53	78.99	71.67	103.40
9	October 20	68.70	77.51	80.36	76.11	82.07	112.59
10	March 21	88.26	80.83	78.29	74.07	77.54	112.69
11	July 21	71.25	86.55	88.03	88.14	82.84	122.72
12	October 21	67.05	85.48	79.85	91.24	88.33	114.50

Table 3. Water quality classification based on WQI value

WQI value	*Water quality*
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
>300	Unsuitable

Statistical methods

The goal of our work is to find a way to calculate WQI with fewer variables than usual.

For this, the multiple linear regression method helps us. MLR as a statistical technique is a common tool for reducing subjectivity in selecting parameters and accurate the results, and in our study, is a crucial tool in analyzing and reducing the number of variables for the calculation of the new WQI index.

Knowing the conditions for applying a multiple linear regression, it is necessary to take several steps.

We have to determine what kind of distribution the data set has, through the normality test. With the risk of 0.05, using the K-S and Sh-W tests, we verify the hypotheses:

H0 - the distribution of the data set is normal

Ha - the distribution of the data set isn't normal

We use the normality test of Kolmogorov – Smirnov, and also the Shapiro – Wilk test that is the most effective test when testing for a normal distribution, at a significance level of 0.05. Using these tests, for p-value < 0.05 the null hypothesis is rejected.

Depending from the tests mentioned before, in accordance with the kind of their distribution, in order to value the correlation between the chemical and microbiological component of the data, the Pearson and Spearman coefficients are used.

The coefficient

$$\boldsymbol{r} = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(x_i - \bar{x})^2 \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}}} \quad \textbf{(3)}$$

is used to measure the strength of a linear association between variables, and for the variables that don't have a linear relationship, we use the second coefficient

$$\boldsymbol{R_s} = \boldsymbol{1} - \left(\frac{\boldsymbol{6}\sum \boldsymbol{d^2}}{\boldsymbol{n^3} - \boldsymbol{n}}\right) \quad \textbf{(4)}$$

In the equation that will be determined by MLR, the variables with a significant correlation represented as best as possible in this equation, will be used.

We proceed the statistical analysis with the t-test to show if there is any significant difference between the value of the WQI index calculated before (with nine variables), and the new WQI index calculated. This t-test for paired values measures the significance of the variation between dependent pairs of data. The dependent t-test serves to evaluate if the mean difference through pairs of measurements is zero or not. With this test we analyze the hypothesis H0 and Ha, for the difference between the two calculated values of WQI. If the p-value is smaller than 0.05, the basic hypothesis is rejected, showing there is no significant difference between the two calculated values of WQI with 95% confidence, while if the p-value is greater than 0.05, H0 is accepted, so there is no significant difference between the WQI values.

Results and Discussion

The WQI methods provide effective information on the degree of purity and pollution of water, by avoiding an amount quantity of data to demonstrate water quality.

Akhatar et al. (2021) has described the WQI method of calculation in a detailed way, starting from its origins and continuing with the most recent uses today.

The study indicates that the information obtained from the WQI can usually be utilized for the specified purposes, such as (1) to assist the community and the policymakers in avoiding subsequent biased views and subjective assessment, (2) to compare water quality from multiple sources and locations without a highly rigorous evaluation of water quality data, (3) to provide water authorities and the wider community with an overall water quality status and (4) to study the environmental quality impacts of administrative policies and environmental programs (Akhtar et al., 2021).

From the analyses of the correlation, by Spearman's coefficient, we can see from the Table 4 of the coefficients that the three variables which have a significant correlation are: BDO, HCO_3 and P-total. In this way, we can say that the variables will have a significant value in the linear regression models. These variables reflect all the changes that happened in the water flow from the anthropogenic and natural factors.

All the important correlation coefficients in the table (with an absolute value greater than 0.05) are positive, so with the increase of the BOD, HCO_3 and P-total, the final result of WQI also increases.

Above, we demonstrate the most influenced variables in the value of WQI, which are the variables used to build the equation of the linear regression.

We have established four models of linear regression especially with two, three, four and five variables, respectively:

1. WQI (dependent variable) with BOD (independent variable)
2. WQI (dependent variable) with BOD, HCO3 (independent variable)
3. WQI (dependent variable) with BOD, HCO_3, P-total (independent variable)
4. WQI (dependent variable) with BOD, HCO_3, P-total and thermotolerant coliform (independent variable).

Table 4. Correlation coefficients and their p-values

WQI parameter	**Coefficient value**	**p-value**
TDS	0.163	0.172
GH	-0.017	0.888
BOD	0.536	0.000
pH	0.053	0.657
DO	-0.229	0.054
Cl	0.143	0.229
HCO_3	0.294	0.012
P-total	0.588	0.000
Thermotolerant Coliform	0.429	0.000

In Table 5, the values of R^2 are used as a way to measure the total variation. We can conclude that in model 3 the value of R^2 is 0.99. This model of linear regression with one dependent variable and three independent variables, explains 99.6% of the WQI variation.

From the ANOVA table of the regression (Table 6), we can note the values of residuals and mean squares for all the models. The third model has the lowest residue.

In Table 7 in bold are the significant values for those variables that had significance according to the statistical test we have performed.

The new linear equation that determines the formula for the calculation of the WQI (Table 7) is:

$$\boldsymbol{Y = 1.76 + 3.63x_1 + 0.02x_2 + 988.24x_3} \quad \textbf{(5)}$$

where: x_1 is the amount of BOD, x_2 is the amount of HCO_3 and x_3 is the amount of P-total, Y represents the value of the new WQI.

Table 5. All the coefficients model in the linear regression analysis

Model	**R**	**R^2**	**Adjusted R^2**	**Sig. change of F**
WQI → BOD	0.85	0.73	0.72	0.00
WQI → BOD, HCO_3	0.86	0.74	0.73	0.00
WQI → BOD, HCO_3, P-total	0.99	0.99	0.99	0.00
WQI → BOD, HCO_3, P-total, coliform	0.99	0.99	0.99	0.00

Table 6. ANOVA table for the regression models

Model		**Sum of squares**	**Mean squares**	**Sig.**
WQI → BOD	*Regression*	17423.30	17423.30	0.00
	Residual	6445.68	92.08	
	Total	23868.98		
WQI →BOD, HCO_3	*Regression*	17669.12	8834.56	0.00
	Residual	61999.86	89.85	
	Total	23868.98		
WQI → BOD, HCO_3, P-total	*Regression*	23767.03	7922.34	0.00
	Residual	101.94	1.49	
	Total	23868.98		
WQI → BOD, HCO_3, P-total, coliform	*Regression*	23767.03	5941.76	0.00
	Residual	101.95	1.52	
	Total	23868.98		

Table 7. The regression coefficients

Model		Coefficient	Standard Error	Sig.
WQI → BOD	Constant	69.36	1.57	0.00
	BOD	3.38	0.25	0.00
WQI → BOD → BOD, HCO_3	Constant	54.27	9.26	0.00
	BOD	3.30	0.25	0.00
	HCO_3	0.07	0.04	0.10
WQI → BOD, HCO_3, P-total	Constant	1.76	1.45	0.00
	BOD	3.63	0.03	0.00
	HCO_3	0.02	0.01	0.00
	P-total	988.22	15.50	0.00
WQI → BOD, HCO_3, P-total, coliform	Constant	1.76	1.47	0.04
	BOD	3.63	0.09	**0.00**
	HCO_3	0.02	0.01	**0.00**
	P-total	988.24	15.62	**0.00**
	Coliform	3.83 E-5	0.00	0.97

The values of new WQI calculated by the equation (5), are presented in Table 8.

The last step of the statistical analysis is the t-test for the paired dependent samples (two values of the WQI: the value with nine parameters and the new value).

Two new hypotheses for the changes between the WQI indexes are:

H0: there is no significant difference between the two WQI indexes;

Ha: there is a significant difference between the two WQI indexes.

The p-value of this t-test is greater of 0.05 (Table 9) showing that there is no significant difference between the two WQI indexes (the first index is calculated with nine variables and the new index is calculated with three variables).

The new equation, which is a new way of calculating the WQI index depending on three variables, is what we wanted to find.

The new WQI index is a function of BOD, HCO_3 and total phosphorus, and this is justifiable, considering the pivotal role of those parameters in the quality of the surface waters.

Table 8. New WQI values calculated by the regression equation

N	Period	The place for taking the samples					
		Qukës	**Librazhd**	**Xibrakë**	**Papër**	**Bishqem**	**Rrogozhinë**
1	March 18	67.54	59.96	81.82	75.35	74.28	121.70
2	July 18	58.73	55.80	73.96	72.49	78.31	107.87
3	October 18	67.84	87.80	73.96	86.24	73.97	122.23
4	March 19	67.55	61.59	61.82	92.95	71.13	125.98
5	July 19	88.56	91.23	85.87	78.48	70.72	111.46
6	October 19	61.36	71.46	76.21	81.45	86.46	135.61
7	March 20	87.19	83.45	75.94	57.62	60.82	127.31
8	July 20	80.66	96.79	77.72	79.76	71.96	103.11
9	October 20	68.64	77.28	81.56	76.64	83.25	113.11
10	March 21	89.17	82.74	79.39	74.50	78.61	114.08
11	July 21	71.91	87.06	89.22	89.50	84.40	123.96
12	October 21	67.71	86.52	80.80	92.33	89.82	116.90

Table 9. Paired Samples Test

Paired Samples Test

		Paired Differences		
		Mean	Std. Deviation	Std. Error Mean
Pair 1	Original WQI - New WQI	-9.99 E-3	1.20 E0	1.41 E-1

Paired Samples Test

		Paired Differences				
		95% Confidence Interval of the Difference				
		Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Original WQI - New WQI	-2.92 E-1	2.72 E-1	-0.07	71	0.94

Syeed et al. (2023) confirmed that there are 23 Water Quality Index models, that are used in research for water quality assessment and pollution measurement, and alongside several statistical methods are applied for predictive analysis of the water quality. Our scope of the study in the future is to prove if our model of calculation of the WQI index with three parameters is also applicable for the other models of WQI index different from the model with nine parameters approved by the National Sanitation Foundation Water Quality Index.

Also, we will propose the use of our method in the evaluation and calculation of the WQI index for other surface waters of rivers in Albania

Conclusions

Having in mind that the Shkumbini River is one of the largest rivers in Albania, and its deep water after processing is used as drinking water for the inhabitants of Central Albania, several studies have been done to calculate the WQI, as an index of characterization of water quality.

This study is the first of its kind in Albania. The aim of this study was achieved, making it possible to discover the way to calculate the value of the WQI index with only three variables. The use of statistical analysis is a very important tool in monitoring water quality. The benefits of this new way of calculation of the WQI index, for the water of Shkumbini River, are financial and time saving. Also, the reduction of the parameters number in calculation, brings the reduction in the eclipse effect, characterized by the reduction of the impact of the variation of one of the parameters due to the stability of the others. Those benefits make possible for this method to potentially be used. But in order to declare our method as an efficient and simple way to calculate the WQI index, with financial and time-saving benefits, we must first use it to evaluate the water quality in other Albanian rivers.

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