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Original Research

Evaluation of Water Quality Index for Drinking Water

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Abstract

The aim of this study is to determine the quality of drinking water in the city of Pogradec, Albania. Daily samples were taken from six fixed points in the city. They were analyzed based on the standard methods for the following parameters: taste, odor, temperature, pH, conductivity (EC), turbidity, NO_3^-, NO_2^-, NH_4^+, chloride, and microbial load. The assessment of water quality was made using the water quality index (WQI) of the Canadian Council of Ministries of the Environment (CCME). The calculated value of CCME WQI by 87.81 indicates that the drinking water quality in the city of Pogradec is "good," and that turbidity is the main problem in quality.

Keywords: drinking water quality, physico-chemical parameters, turbidity, water quality index

Introduction

Fresh water is essential in many spheres of human life [1] and in general it is seen as an essential input to human production and an effective tool of economic development [2, 3]. It plays a significant role in social prosperity [3, 4] and the well-being of all people [5, 6]. Unfortunately, in many countries around the world, including Albania, some drinking water supplies have become contaminated [5, 6] and the deteriorated quality of surface waters is becoming a grave issue in many parts of the globe [1]. Water pollution from diffuse sources [4] and various types of pollution is not only a serious environmental issue but also an economic and human health problem [4-6].

Changes in the physico-chemical characteristics of water quality are influenced not only by anthropogenic factors [3, 7-10], but also by the combined interactive natural processes such as hydrological conditions, topography and lithology, climate [7, 9, 11], precipitation inputs [3, 8, 9, 12], catchment area [9, 11], tectonic [7, 11] and edaphic factors [7], erosion, weathering of crustal materials and bedrock geology [8], in combination with environmental influence [9, 11].

Freshwater sources in Albania exist as natural springs, rivers, lakes, and groundwater aquifers. The water supply for drinking purposes comes mainly from natural springs and underground water sources [13]. Albania has abundant water resources, but the lack of drinking water at the tap is a critical problem [14]. The available average quantity of fresh water is an estimated 8,700 cubic meters per capita per year, which is one of the highest in Europe [13]. However, it is reported an average of 11.1 hours/day continuous water supply service for the year 2010 in Albania [13].

The drinking water at the source is of good quality [14]. However, there are many problems concerning drinking water supply in Albania. Albania has a distribution network problem [14, 15], not a production problem [15]. The situation of water supply infrastructure is critical [14].

During the last years, the water supply service in Albania has achieved substantial and significant improvements; however, these improvements are performing slowly [13]. There are some cities that operate with a new infrastructure (main and distribution networks) that provide a 24-hour-per-day water supply. The city of Pogradec has been one of them since 2007.

Traditionally, including Albania, water quality has been assessed by comparing the values with the local norms.

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However, this technique does not provide any information on the spatial and temporal trends of the overall quality [16]. Therefore, modern techniques such as water quality index (WQI) have been developed. Numerous water quality indices have been formulated all over the world [17]. These indices are based on the comparison of the water quality parameters to the standards and give a single value for the water quality of a certain source [17]. The WQI summarizes a large quantity of water quality data in a comprehensive manner into a single number [3, 16], into a simple term (e.g. excellent, good, bad, etc.) [17], to transmit the information concerning water quality to the public in general [3, 17-19], water distributors, planners, managers, and policy makers [20, 21].

WQI is one of the most effective tools to express water quality [3, 18] and can be used as an important parameter for the assessment and management of the water source [22], giving a good idea of the evolution tendency of water quality to evolve over a period of time [18, 19].

The Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI) is a well-accepted and universally applicable model for evaluating the water quality index [16, 18, 23-25]. The CCME WQI compares observations to a benchmark, where the benchmark can be a water quality standard or a site-specific background concentration [17, 23, 26]. Most applications of the CCME WQI have used the national water quality standard [27]. So, this acts as an advantage of the index, which can be applied in different countries with a few modifications [17].

The main objective of this study is to analyze the drinking water quality to the tap in city of Pogradec using the CCME's WQI model.

Materials and Methods

Study Area

The city of Pogradec, capital of Pogradec District, is situated 135 km southeast of the Albanian capital, Tirana. It is located on the southern shore of Lake Ohrid, close to the Macedonian border. Lake Ohrid (41º01'N, 20º43'E) is a transboundary lake located between the Republics of Albania and Macedonia (Fig. 1) in southeastern Europe. Lake Ohrid is famous for its more than 200 endemic species, and considering its small surface (358 km^2), probably is the most diverse lake in the world [28, 29]. The ecological and cultural importance of this lake and its surroundings was acknowledged by the declaration of Lake Ohrid as a UNESCO World Heritage Site in 1979-80 [28, 29]. There are many sub-lacustrine and surface water springs in Ohrid Basin, particularly on the southeastern and southern sides of Lake Ohrid [30, 31]. The most powerful water springs are the spring complexes of St. Naum (Macedonia) and Tushemisht/Gurras (Albania) in the south [31].

When Lake Ohrid was declared a World Cultural and Natural Heritage Site in 1980, the Environmental Protection Program of Lake Ohrid was launched. The aim of the project was to protect the water quality in the ecologically unique Lake Ohrid and to reduce health risks for the population by ensuring a reliable drinking water provision [32]. The Project "Water Supply and Sewage Disposal in Pogradec" is part of this Program; it is not yet completed. The first phase of the project implementation started in 2005 and it was successfully completed in 2007. It is supplied with drinking water about 24 hours per day

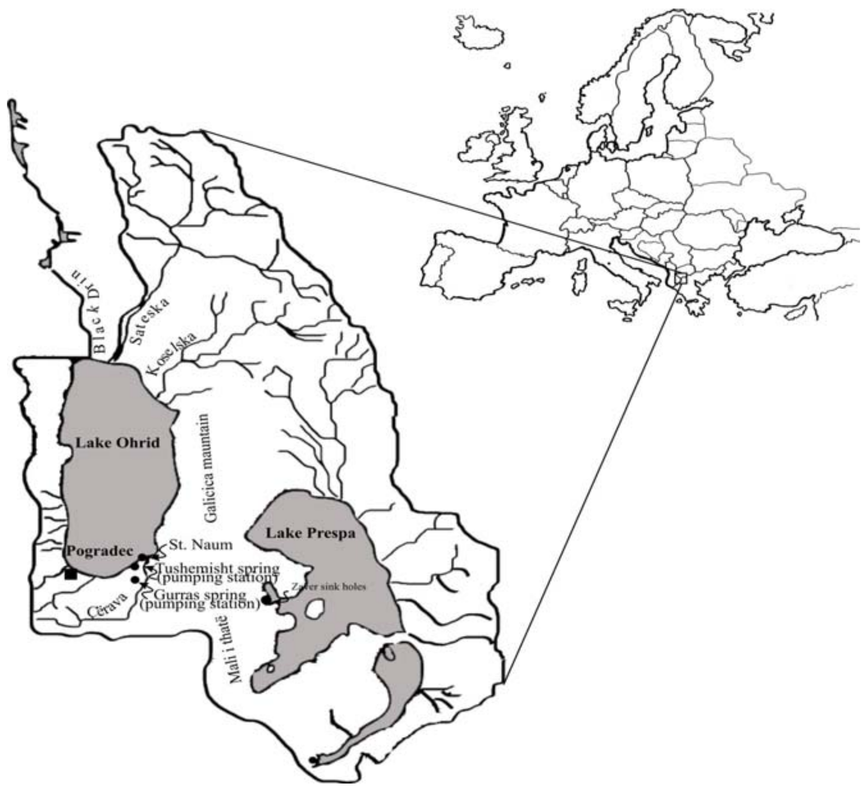

Fig. 1. Locations of Pogradec city, Tushemisht, and Guras surface water springs of Lake Ohrid.

Table 1. CCME WQI index categorization scheme.

Rank	WQI value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment conditions very close to natural or pristine levels.
Very Good	89-94	Water quality is protected with a slight presence of threat or impairment conditions close to natural or pristine levels.
Good	80-88	Water quality is protected with only a minor degree of threat or impairment, conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired conditions, sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired, conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is almost always threatened or impaired, conditions usually depart from natural or desirable levels.

for about 60,000 residents of Pogradec city and the surrounding villages.

The water supply system of Pogradec is using two main pumping stations to supply the system, from natural springs at Tushemisht and Gurras, in the eastern part of Pogradec city. The springs take the water that comes from neighboring Lake Prespa [30, 33], which is located approximately 10 km east and 160 m higher than Lake Ohrid, as well as from mountain range precipitation seeping through the karstic rocks and mixing with the waters originating from Lake Prespa [30]. Lake Prespa is connected hydrologically with Lake Ohrid by a karst system [28, 33] within the Mali Thate and Galicica mountains between the two lakes. The contribution of Lake Prespa to the water supply of the Tushemisht and Gurras springs is very important [34].

Calculation of Water Quality Index (CCME WQI)

The CCME WQI model consists of three measures of variance from selected water quality objectives (scope, frequency, and amplitude) [16-21, 23, 24, 26, 27]. Scope (F_1) represents the percentage of variables that do not meet their objectives, frequency (F_2) the percentage of individual tests that do not meet objectives, and amplitude (F_3) the amount by which failed test values do not meet their objectives. These three factors combine to produce a value between 0 and 100 that represents the overall water quality, where 0 represents the "worst" water quality and 100 represents the "best" water quality [18, 20, 21, 23, 24]. The CCME WQI values are then converted into rankings by using the index categorization scheme [20, 21, 23, 24, 27] modified from Khan et al. [25], presented in Table 1.

The detailed formulation of the WQI, as described in [17-21, 23, 24, 27], is as follows:

Water quality index (CCME WQI) was determined by equation:

$$CCME - WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (1)$$

The divisor 1.732 normalizes the resultant values to a range between 0-100.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} x100 \quad (2)$$

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} x100 \quad (3)$$

F_3 (Amplitude) is calculated in three steps.

1) The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is called "excursion" and where the test value must not exceed the objective is expressed as follows:

$$Excursion_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_j} \right) - 1 \quad (4)$$

2) The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions, or *nse*, is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{\sum \text{ of tests}} \quad (5)$$

3) F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01\, nse + 0.01} \right) \quad (6)$$

Sampling protocol requires at least four parameters (sampled at least four times) and no maximum parameters have been set [18, 25]. Different parameters can be monitored depending on the type of aquatic surface quality [18].

Table 2. Physico-chemical parameters in drinking water of Pogradec.

Months	Parameters										
	Odor ODN	Taste TDN	Turb NTU	Temp ºC	pH	EC µS/cm	NO_3 mg/L	NO_2 mg/L	NH_4 mg/L	Cl mg/L	TC N/100 ml
January	0	0	**0.67**	11.8	7.5	318	2.56	0.001	0.002	0.1-0.3	0
February	0	0	0.861	12.6	-	308	2.41	0.002	0.001	0.1-0.3	0
March	0	0	**0.57**	13.5	7.45	316	2.24	0.002	0.002	0.1-0.3	0
April	0	0	**0.47**	13.5	7.55	299	1.91	0.001	0.001	0.1-0.3	0
May	0	0	**0.78**	13.8	7.40	306	2.32	0.001	0.002	0.1-0.3	0
June	0	0	**0.42**	14.2	7.50	304	2.36	0.001	0.001	0.1-0.3	0
July	0	0	**0.74**	**15.1**	7.65	298	2.43	0.001	0.002	0.1-0.3	0
August	0	0	**0.68**	**15.3**	7.45	300	1.89	0.001	0.001	0.1-0.3	0
September	0	0	**0.56**	14.8	7.50	289	2.13	0.001	0.002	0.1-0.3	0
October	0	0	**0.82**	13.2	7.62	278	2.36	0.003	0.001	0.1-0.3	0
November	0	0	**0.72**	12.9	7.45	302	1.87	0.001	0.001	0.1-0.3	0
December	0	0	**0.98**	12.5	7.43	316	2.34	0.001	0.003	0.1-0.3	0
Objective	0.0	0.0	0.4	15-sie	6.5-8.5	400	25	0,05	0.05	0,3	0.0

The values in bold do not meet the objective.
Objective values as per standards given by [35].

Data for WQI Calculation

The following physical, chemical, and bacteriological parameters were determined according to standard methods [35]: taste (TDN – taste dilution number), odor (ODN – odor dilution number), temperature (ºC), pH – value, conductivity (EC; µS/cm), turbidity (NTU), nitrate (mg/L NO_3^-), nitrite (mg/L NO_2^-), ammonia (mg/L NH_4^+), chloride (mg/L Cl^-), and microbial load (total bacteria count, N/100 ml). According to the Albanian standard [35], the unit of measure for taste and odor is taste/odor dilution number (T/O DN). For the original (undiluted) sample, where the taste/odor is deemed taste- and odor-free T/O DN = 0 [36]. The data (from laboratory of Water Supply and Sewerage Enterprise Pogradec) used in this study for all parameters are monthly averages collected from six fixed points in the city, every day during the year 2011. The data of these variables are used in the calculation of CCME WQI model using sets of Albanian standard (objectives) values of drinking water quality (Table 2). Water quality is ranked by comparing it to one of the categories listed in Table 1.

Results and Discussion

The data of physical, chemical, and bacteriological properties given in Table 2 indicate that the average values of all parameters are below the maximum permissible limits indicated in the Albania Official Standard [35] for drinking water.

Tastes and odors in water may be derived from a variety of conditions and sources [37]. They may originate as a result of water treatment (e.g., chlorination) [38]. In this study all the water samples were odorless and tasteless.

The pH measurement reflects a change in the quality of the source [38]. Very acidic or very alkaline water produce sour or alkaline tastes [39]. Also, higher values of pH reduce germicidal potential of chlorine [40]. In this study, the average values for pH ranged from 7.43 to 7.65. They are within the objective range of 6.5-8.5 for drinking water.

The EC value is an index that represents the concentration of soluble salts in water [10, 38-40]. A high concentration of dissolved solids greatly affects the taste of the drinking water [10, 12]. The EC values for the investigated period show that tap water samples have similar values (278-318 µS/m) and are lower than the objective of 400 µs/cm.

The high levels of nitrate and nitrite in drinking water may cause serious illnesses such as methemoglobinemia or "blue baby syndrome" [4, 12, 40, 41], cancer risks [4, 38, 41], increased starchy deposits, and hemorrhaging of the spleen [12]. Nitrate and nitrite in the water samples are found to be in a range of 1.87 to 2.56 mg/L and 0.001 to 0.003, respectively. All the data satisfy the objective values for drinking water.

Ammonia is an indicator for elevated pollution from organic substances [42]. The measured values for this parameter are within the recommended objectives of 0.05 mg/L. Chlorides occur in all natural waters in varying concentrations [38, 43]. They are responsible for the salty taste in water [38, 40]. The measured values for the chloride con-

Table 3. Calculated values of WQI in Pogradec drinking water.

No.	Term of index	Value	Rating of water quality
1	Scope – F_1	18.18	Rank: Good Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
2	Frequency – F_2	10.69	
3	*nse*	0.07	
4	Amplitude – F_3	0.86	
5	WQI	87.81	

centrations in this study are within the recommended objectives of 0.3 mg/l.

Water may be contaminated with microorganisms at the source, but contamination may also occur during distribution or transportation. The microbiological analyses of the water indicate that the microbial loads do not exist. The zero values of the microbial load in the water are indicators for an effective disinfection process during treatment.

The temperature was found to be in the range of 11.8 to 15.3ºC and exceeds the objective in July and August. The water temperatures vary seasonally in the normal range within the objective. The exceeded values probably are due to non adequate depth of water supply network pipes.

Turbidity is a measure of the relative clarity or cloudiness of water [5, 6, 44]. The occurrence of turbidity may be permanent or seasonal [43]. Turbidity may result from insufficient filtration during water treatment [43, 45] or mobilization of sediments, mineral precipitates, or biomass within the water supply network [45]. Changes in turbidity following rainfall may indicate contamination with untreated water [45].

Turbidity is the main problem in the supply system during all analyzed periods. The observed values of turbidity are between 0.42 in June to 0.98 in December. All the samples have turbidity values greater than the objective value of 0.4 NTU, but values are less than the maximum permissible limits for drinking water by 4 NTU [35], indicated in the standard. The turbidity comes from the source and probably is a consequence of inert clay and chalk particles or of insoluble precipitations that can be related with its karstic origin, human activity in this region, and amortized water supply network of Gurras spring. The high turbidity values observed in this study are an indication of the absence of the filtration process of water spring. Improvement of turbidity can be achieved by adding the water filtration process (actually only the chlorination process is used) and rehabilitation of Gurras spring capture and pumping station, planned for the next phase of the project.

According to the total values of parameters examined, Table 2 calculates overall water quality CCME WQI. The total numbers of parameters examined are 11, and the total numbers of individual tests are 131. The number of parameters not meeting objectives are 2 (turbidity, temperature), and the number of tests not meeting objectives are 14. The calculated values and ratings of WQI are presented in Table 3.

The WQI of 87.81 indicates that drinking water quality for Pogradec city tap water is ranked 'good.' The "good" quality can be attributed to the measured turbidity that exceeds the objective and to its large excursion. It reflects the intervention between natural effects and those of anthropogenic activities.

Conclusion

The CCME WQI is an effective tool to evaluate water quality for water supply systems. The WQI model used for rating of drinking water quality in Pogradec city indicates that the quality is "good" (CCMEWQI is 87.81) for the year 2011. Turbidity is the most important parameter that determinates the rating of water quality, exceeding the standards (objective) of drinking water. To modify this parameter and to increase water quality, during the treatment process water should be implemented, even the filtration process. The information provided by CCME-WQI is a useful tool for describing the state of the drinking water quality and can be of great value for water users, suppliers, and planners, etc.

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