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PRELIMINARY WATER QUALITY ASSESSMENT USING CANADIAN WATER QUALITY INDEX OF RAS EL-AIN PONDS, SOUTH LEBANON

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1. INTRODUCTION

Today, water quality in many regions of the world especially in developing countries is facing severe deterioration caused by extensive human activities such as wastewater disposal, waste damping, unsustainable agricultural practices, and industrial processes among others (*Anja du Plessis, 2022; UN Water, 2018*). Besides, water quality is also subject to the indirect impact of climate change as increased temperatures lead to increase in the levels of contaminants and in the associated risks (*Kundzewicz et al., 2007; Bates et al., 2008*). Water quality deterioration has serious effects on human health, agriculture, food production, environmental health and economic growth constraining socioeconomic security and human wellbeing (*UNEP, 2016; Bashir et al., 2020*). For example, lack of safe and clean water is a major contributing factor to more than 80% of human diseases with around 300,000 children under the age of five dying each year from diarrhea caused by tainted drinking water, inadequate sanitation, and poor hand hygiene (*Waddington et al., 2009*). Nitrate, arsenic, chromium, and other hazardous contaminants show strong correlations with different types of cancers (*Marmot et al., 2007*). Water contaminants also stand a serious threat to agricultural productivity and food quality. Research shows that poor water quality negatively effects crop, animal, and soil productivity (*Temesgen et al., 2020*). In addition, research also reports many cases of the destruction effect of water quality degradation on aquatic life (*Woo et al., 2009; Ayandiran et al., 2009*). The mass killing of fish is one of the earliest and most dramatic effects of poor water quality. Such serious consequences have urged the United Nations to set the Sustainable Development Goal (SDG) 6 on water and sanitation with the respective target on improving water quality by 2030 (*Hering et al., 2016*). There are eight targets for the SDG 6 that goes beyond drinking water, sanitation and hygiene to also address the quality and sustainability of water resources, which are critical to survival of people and the planet (www.un.org/). Although meeting the future needs of safe and clean water in a sustainable manner is highly challenging, but the water quality assessment and monitoring plans continue to exhibit critical issues in water resources management (*Vasistha et al., 2020*).

In Lebanon, water quality deterioration has become one of the major challenges facing the country in recent decades. High levels of contaminants are found in many water bodies in the country. Litani River, the most important Lebanese river, stands as a stark example of the sever water quality deterioration and the nation's many heavily contaminated water bodies *(Darwish et al., 2021*). High levels of nutrients, biological oxygen demand measured after 5 days (BOD_5), chemical oxygen demand (COD), total dissolved solids (TDS) and some trace metals with extremely increased levels of bacteriological contamination are reported by numerous studies (*Darwish et al., 2021; Nehme & Haidar., 2018; Shaban & Hamzé., 2018*). Intensive land use, unsustainable practices, population surge of recent years due to the high number of Syrian refugees and lack of appropriate management of the river basin were reported among the main causes of this severe water quality degradation *(Darwish et al., 2021; Nehme & Haidar., 2018; Shaban & Hamzé., 2018*). Other rivers and water bodies are also exposed to different levels of various pollutants confirming the severity and complexity of the water quality issues in Lebanon ultimately affecting human wellbeing and constraining socioeconomic security and sustainable development of the country (*El Najjar et al., 2019*). Thus, it becomes imperative to regularly assess and monitor the water quality of other water bodies.

In this context, Ras El-Ain Ponds located in Tyre district South of Lebanon, stand as one of the most important water resources in the southern part of the country currently under high contamination risk. Population growth together with increased food demands and climate change are bringing new demands for water and food, further putting more stress on water availability and its quality in Lebanon. In a very recent study by Khatib et al. (2023). using PhreeQC software, a geochemical modeling tool, the quality of one of Ras El-Ain Ponds was assessed. Findings showed high levels of pollution emphasizing the need for more future studies and the development of a monitoring program.

In view of the above mentioned, water quality indices (WQIs) present an important tool for water quality monitoring changes in water quality over time and contribute to informed decision-making. Numerous strategies and various water quality indices based on datasets of water quality characteristics have been created globally to attain this goal *(Adelagun et al., 2021; Casillas-García et al., 2021; Uddin et al., 2021*). The concept of WQI is based on the use of different techniques that allow the conversion of extensive water quality datasets into a single value or index. Since its development in the 1960s, WQI has become a popular tool due to its generalized structure and straightforward easy use. Among the globally well-recognized WQIs is the Canadian Water Quality Index (CCME WQI) used by the Canadian Council of Ministers of the Environment as a tool for informing the public and governments about water quality issues. This index has been used in several studies in different regions. The index was used to monitor changes in water quality at five sites in the Mackenzie-Great Bear sub-basin in Canada (*Sharma et al., 2002; Lumb et al., 2002*). For general, drinking, and aquatic water applications, the CCME WQIs model rated the raw water quality in the Mackenzie River watershed as marginal to fair. The CCME WQI values were lowered by physical water quality factors such as turbidity, true color, suspended particles, and total (mainly particulate) trace metals. In a very recent study by *Alaa et al., (2023*) on the quality of the Hilla River in Iraq, the CCME WQI was adopted for assessing the water quality based on several parameters. Water quality was observed on five sites of the river and the CCME WQI values were rated marginal almost in four stations with one site recoding good water quality. More recently, *Panagopoulos et al. (2023)*, CCME WQI and its modified version were calculated with the aim to implement the index for the evaluation of the physicochemical quality of Greek Rivers based on a larger dataset. Findings revealed the conservative behavior of the CCME WQI and identified the limiting factors for its successful implementation in Greek rivers. In all these studies, the employment of the CCME WQI was straightforward and recommended its potential use with case studies of different climatic, geologic, and hydrological conditions and human impacts. This pressing research concern has served as a significant stimulus for the commencement of the present study.

The aims of this study are to assess the physicochemical and microbiological properties of water quality of Ras El-Ain Ponds using CCME WQI based on assessed parameters. and the permissible levels of Lebanese Standards Institution, World Health Organization, and CCME. To the best of our knowledge, this is a unique effort to provide a preliminary application of the CCME WQI on a water body scale in Lebanon and serve for more comprehensive future studies on Ras El-Ain Ponds and other water bodies across the country.

2. STUDY AREA

This study has been conducted on one of the Ras El-Ain Ponds which are located in Tyre district, South Governorate of Lebanon. This water body consists of four Ponds, in addition to a reservoir established by South Lebanon Water Establishment (SLWE). They are located in a green and fertile plain about 77 kilometers from south Beirut and one kilometer from the sea coastline (Figure 1). Through history, Ras El-Ain Ponds have been the main source of water for Ancient Tyre since the Phoenician days reflecting the importance of this water body in meeting water demands. The Ponds are mainly fed by Ras El-Ain artesian spring with a flow discharge of about 0. 88 m^3/s (*Meinzer., 1923*). Through the SLWE water network, the Pond provides water supplies to 9,985 households and 28,3057 capita distributed over 10 Villages as recorded by the SLWE station.

3. MATERIALS AND METHODS

3.1. Sampling

Water samples from the several locations of Al-Asrawi Pond, one of the Ras El-Ain Ponds were collected in replicates during February-March 2023. Sampling procedure followed the collection, handling and preservation principles enunciated by the French standards AFNOR (Association Française de la Normalisation, NF T90-100). Water samples were collected in 1L polypropylene clean bottles for physico-chemical tests and in 500 mL sterile amber glass bottles for microbiological tests. All bottles were labeled with the sampling date and time, and kept at 4°C in a portable refrigerator for transportation to the laboratory. All microbiological analysis tests were initiated within 24 hours of the sampling at the laboratories of Debbieh campus, Beirut Arab University, Lebanon.

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Fig.1: Map of study area showing Villages and Location of Ras El-Ain Ponds (within the circle).

3.2. Physio-Chemical Analysis

Water quality tests under study were conducted by standardized methods. These were: Electrical Conductivity (EC) and pH by MH51 Bench Meter and MI 170 Bench Meter, respectively. Total hardness, magnesium (Mg) hardness, and calcium (Ca) hardness by Ethylene diamine tetra acetic acid (EDTA) titrimetric method (ISO 7980, 1986). Sulfate (SO_2^{-4}) and orthophosphate by spectrophotometric method AOAC 973.57 and ISO 6878, 2004, respectively, using UV-VIS spectrophotometer JASCO V630. Nitrite (NO_2^-) and Nitrate (NO_3^-) by EPA 354.1 and ammonia (NH_3) by ISO 5664 spectrophotometric methods using UV-VIS JASCO V630. Total Organic Carbon (TOC) by a method that involves digestion with an oxidizing agent and assessment of Chemical Oxygen Demand (COD) followed by conversion to TOC by the following equation (TOC value = value COD x 0.375). Alkalinity can be measured by a standard method, Titration Standard Methods, 21st Edition (2005), Chloride by Argentometric method (ISO 9297, 1989) and fluoride by calorimetry. Whereas turbidity by Paqualab Turbidity Meter.

3.3. Microbiological Analysis

According to the APHA method (APHA, 1999), samples for bacteriological analysis were first filtered using 0.45 µm sterilized cellulose nitrate membrane filters (Whatman 10401170). Membranes were then placed on suitable agar plates and incubated for 24-48 hours at 44˚C. After incubation, grown colonies were counted as CFU/100 ml.

3.4. Canadian Water Quality Index

This is the detailed formulation mentioned below of the CCME WQI is documented by CCME (*CCME, 2001*). The CCME comprises three factors which include the following:

Scope: The measure for scope F1 representing the extent of water quality guideline non-compliance over the time period of interest. F1 is calculated by formula 1.

$$F1= \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) \times 100 \quad (1)$$

Frequency: The measure for frequency F2 represents the percentage of individual tests that do not meet objectives (failed tests).

$$F2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right) \times 100 \quad (2)$$

Amplitude: The Amplitude is F3 represents the amount by which failed test values do not meet their objectives. This measure is calculated in three steps:

First step: Calculation of Excursion

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows.

When the test value must not exceed the objective:

$$Excursion = \left(\frac{Failed\ \ Test\ Value\ i}{Objective\ j}\right) - 1 \quad (3)$$

When the test value must not fall below the objective:

$$Excursion = \left(\frac{Objective\ j}{Failed\ \ Test\ Value\ i}\right) - 1 \quad (4)$$

Second step: Calculation of Normalized Sum of Excursions

The normalized sum of excursions (nse) is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and dividing them by the total number of tests (both those meeting objectives and those not meeting objectives).

$$nse= \frac{\sum_{i=1}^{n} excursion}{Number\ of\ Tests} \quad (5)$$

Third step: Calculation of amplitude

F3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100.

$$F3 = \left(\frac{nse}{0.01nse+0.01}\right) \quad (6)$$

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The CCME WQI is then calculated as:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

This score is then ranked by a scale of five categories presented in Table 1.

Table 1. Canadian Water Quality Index scale.

CCME WQI Value	Water Status	Water Description
100 - 95	Excellent	Water quality is protected with a virtual absence of impairment; Conditions very close to natural or pristine levels.
94 - 80	Good	Water quality is protected with only a minor degree of impairment; conditions rarely depart from desirable levels.
79 - 65	Fair	Water quality is usually protected but occasionally impaired; conditions sometimes depart from desirable levels.
64 - 45	Marginal	Water quality is frequently impaired; conditions often depart from desirable levels.
44 - 0	Poor	Water quality is almost always impaired; conditions usually depart from desirable levels.

4. RESULTS AND DISCUSSIONS

Table 2 presents the results of the water quality analysis and Figure 2 shows CCME WQIs scores calculated based on these analyses and standard codes of Lebanese Standards Institution (LIBNOR), World Health Organization (WHO) and CCME.

4.1. Physiochemical and Microbiological Parameters

The results of physiochemical parameters revealed that mean values of Temperature, turbidity, pH, alkalinity, ammonia, nitrate, nitrite, chloride, hardness, sulfate, orthophosphate, and fluoride are all within the acceptable levels according to the LIBNOR, WHO, and CCEM (Table 2). Exceedance of the permissible levels results from water exposure to contamination risks from agricultural, industrial, and domestic activities, which may discharge a wide range of pollutants rendering water unsuitable for use. pH parameter is among the most important parameters of water quality. Extremely high and low pH can be detrimental to the use of water and damage the aquatic environment, soil, crops, animals, and human wellbeing. High pH affects the taste of water and reduces the effectiveness of the chlorine usually used for disinfection in domestic water, thereby resulting in the need for higher chlorine amounts (*US EPA, 2015*). Low pH corrodes or affects metals and other substances (*US EPA, 2015*). Another example is high sulfate; it is often caused by water moving on a sulfate rich surface and may cause corrosion of the plumbing pipes and health issues (*Man et al., 2014; Liu et al., 2008; Otero et al., 2007*). Orthophosphate is usually attributed to surface run-off and bank erosion (*Spellman, 2014)*. Fluoride also presents a good example as moderate amounts in drinking water can be good for dental health but excessive amounts can cause serious health effects. Like many other water parameters, the level of fluoride is influenced by temperature. In the current study the mean value of fluoride was recorded as 0.08±0.01 mg/l falling within the acceptable range set by LIBNOR below 1.5 mg/l in temperatures of 8-12 ^{0}C, and below 0.7 mg/l in higher temperatures (25 - 30 ^{0}C). Overall, the generally desirable values of the above-mentioned water physicochemical quality parameters might be due to the lower extent of land use and human activities surrounding the Pond under study, which may not be the case with other Ponds.

On the contrary, EC and TDS recording the mean values of 867.8±39.24 mS/cm and 563.9±25.28 mg/l, respectively, represented marginal scores of permissible levels of WHO and CCME. Although these values were below the permissible levels of LIBNOR, they may still be considered moderately high in view of international standards. They can be mostly attributed to the karstic geological formation characterizing the main aquifers of the country.

This can also explain the relatively high total hardness mean value of 323±1.41 mg/l though it is still within the acceptable levels of LIBNOR. Water with more than 300 mg/l of hardness is generally considered to be hard and hardness level above 500 mg/l affects health and causes scale deposits in hot water pipes, home appliances and industrial machineries (*Rand et al., 2013*). Electrical conductivity is the measure of the water capacity to convey electric current and is directly proportional to TDS. These two parameters are indicators of salinity level, which make them very useful as one way in studying seawater intrusion in the coastal area. Any measurement higher than 1000 mg/l of TDS is considered unsafe for human consumption (WHO, 2017). In addition, water with high EC is unsuitable for irrigation, thus, considered an important criterion of irrigation water. Importantly, the EC and TDS values of tested samples are greater than those of SLWE Laboratories (personal communication) and Khatib et al. (2023) assessed around the same time of year 2022. The sources of these higher value TDS and EC could be natural, i.e. geological formation and seawater intrusion, and anthropogenic such as domestic wastewater and agricultural runoff **(***Gupta et al., 2010; APHA, 2005)*. Moreover, TOC also recorded a mean value of 2.21 mg/l slightly exceeding the permissible level set by LIBNOR at 2 mg/l. This reflects a relatively high organic content creating unfavorable quality conditions that may be accentuated in the dry summer season. High TOC levels may result from decaying natural organic matter such plants, other vegetation, and domestic and agricultural pollution in the water body. TOC is generally one of the important parameters of water quality and raw water with high TOC requires additional treatment before it is acceptable for domestic use. Thus, a more comprehensive assessment of spatio-temporal dynamics of TOC and monitoring of TOC levels in Al-Asrawi Pond can contribute to the identification of the causes of the observed moderately high levels and provide a reference of water quality and protection of the Pond (Jiang et al., 2022).

With respect to microbiological quality, results revealed a total absence of the *E. coli* confirming the potential of water of the tested Pond for domestic and agricultural use. *E. coli* in the water is a strong indicator of sewage and animal waste contamination that can lead to severe illness, especially in vulnerable populations. These results show some disagreement with the previously conducted study on Ras El-Ain Ponds by Khatib et al. (2023). The later study showed some counts ranging between 0-86 CFU/ml that entails high variations between sampling sites, which could explain the discrepancy with the current study emphasizing the need for more comprehensive future studies. Moreover, the importance of quality changes while water is distributed in networks is evidently shown in epidemiological studies and outbreaks. Thus, water entering distribution networks must be protected against microbiological contamination and maintained as safe as the water is transported to users.

4.2. CCME Water Quality Index

Figure 2 presents the values of CCME WQI calculated to describe the overall quality based on the water quality parameters assessed in the present study in view of the set standards CCME WQI ratings qualifying as “Good” according to three sets of national and international codes used i.e. LIBNOR, WHO, and CCME scoring the values of 94.42%, 92.379%, 90.73%, respectively. These values indicate that water quality of Ras El-Ain Ponds is generally protected and only exposed to a minor degree of threat or impairment. These conditions are considered close to natural or desirable levels resulting in high suitability for domestic use and other purposes. The CCME WQI used presents an easy understanding of water quality and points towards the requirement of urgent plans for the protection of the quality of the water body and prevention of any possible pollution. Despite the consensus that no single index is ideal for all situations, the CCME WQI is believed to offer reasonable relatability and high simplicity in reporting. It offers an effective communication tool about the general state of water quality. The validity of the index was recently confirmed by extensive statistical analysis in a study conducted by Dao et al. (2020). Nevertheless, the investigators encountered certain cases that were classified as “Bad water quality” according to CCME WQI, but analysis that is more detailed showed that the water was good. Accordingly, a modification of CCME WQI, the authors of the mentioned study proposed Modified Canadian Water Quality Index (MCWQI). This modified index is still at an early stage of its development before it is confirmed and recommended for wide use.

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Table 2. Mean values ± SD of physico-chemical and microbiological water quality parameters of Ras El-Ain Ponds.

Parameters	Min	Max	Mean Value ± SD	LIBNOR	WHO	CCME
Temperature (ºC)	19.45	19.7	19.58 ± 0.11	15-25	N.A	15
Turbidity (NTU)	1.9	3	2.5 ± 0.71	10	5	5
Electrical Conductivity (mS/cm)	838	902	867.8 ± 39.24	200-1500	800	800
Total Dissolved Solids (mg/l)	544.7	585.65	563.9 ± 25.28	100 -750	500	500
pH	6.95	7.18	7.1 ± 0.02	6.5 - 8.5	7.5- 8.5	7.5 - 8.5
Alkalinity (mg/l)	298	304	300.5 ± 0.71	350	30 - 400	30 - 400
Ammonia (mg/l)	0	0.001	0	0.5	0.2	1.37
Nitrite (mg/l)	0	0.004	0	0.5	3	3
Nitrate (mg/l)	14.79	16.1	15.4 ± 0.82	45	50	48.5
Chloride (mg/l)	53.9	98	75.97 ± 31.14	200	200	250
Total Hardness (mg/l)	312	336	323 ± 1.41	350	350	N.R
Calcium Hardness (mg/l)	111.2	116.8	114 ± 3.96	250	200	N.R
Magnesium Hardness (mg/l)	74.88	80.64	77.52 ± 0.34	100	150	N.R
Sulfate (mg/l)	12.06	12.42	12.52 ± 0.21	250	400	500
Orthophosphate (mg/l)	0.65	0.68	0.67 ± 0.01	1	1	1
Fluoride (mg/l)	0.1	0.06	0.08 ± 0.01	1.5	1.5	1.5
Total Organic Carbon (mg/l)	-	-	2.21	2	N.A	N.A
E.coli (CFU/100ml)	-	-	Absence	N.D	N.D	N.D

Notes: N.A means Not-Available and N.D means Non-Detectable/100ml.

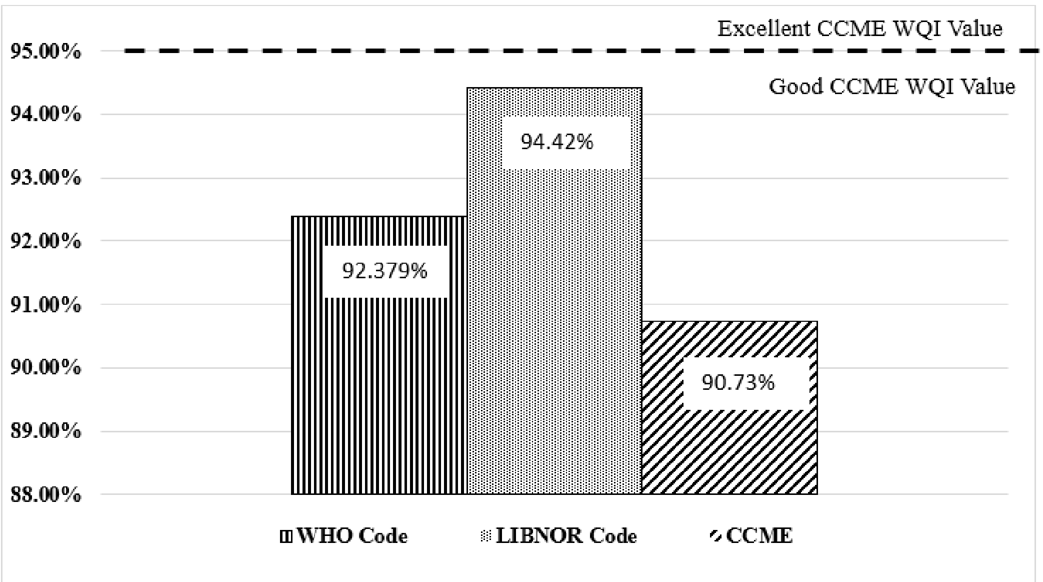

Fig.2: The mean values of CCME WQI valued based on LIBNOR, WHO, CCME standards.

5. CONCLUSION AND RECOMMENDATION

The current study has been conducted to evaluate the quality of Ras El-Ain based on several physico-chemical and microbiological parameters using CCME WQI. With the exception of EC, and TDS, the quality level was found to fall within the permissible limits set by LIBNOR, but exceeds acceptable levels by WHO and CCME. TOC has exceeded the acceptable level stated by the LIBNOR code. Based on the rating of CCME WQI, the water quality of Ras El-Ain Natural is qualified as Good. These results indicate that water quality conditions rarely depart from the acceptable levels with a minor degree of impairments confirming its suitability to meet domestic demands and other needs. However, the moderately higher levels of EC, TDS and TOC may necessitate some treatment processes. In addition, authorities and local community should together participate in the development of a policy and management program to protect Ras El-Ain Ponds against a water pollution integrated approach. Examples include rationalization of the exploitation of fertilizers and pesticides in agriculture and developing waste and wastewater management strategies. In addition, the validation of CCME WQI for regular water quality evaluation and monitoring is required to facilitate easy information that is understandable and usable by decision makers and the public.

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