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Evaluation of Zarqa River Water quality on suitability for irrigation using the Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) approach

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Jordan is an arid climate region where the rain is not sufficient for plant growth and crop production that satisfies food demand. About 63% of Jordan's water resources are used for agricultural irrigation to produce food, which is permanently changing with respect to water availability and quality. The present study assessed the suitability of Zarqa River water for irrigation by using the CCME-WQI approach.
Knowing an indicator of the water quality of the Zarqa River is beneficial for both decision makers, farmers, environmentalists and water beneficiaries. This study revealed that even though the water of Zarqa River is unfit for drinking purposes, it is medium to highly suitable for irrigation in compliance with the JS 893/2006. Using the CCME WQI approach, the Zarqa River WQI was calculated as 66.15 and 80.0 and rated as "fair" for green leafy plants that are eaten raw (Class A), and "good" for crop irrigation classes from B to F as defined by JS 893/2006.

Keywords: Water Quality, Zarqa River, Canadian water quality index, arid regions. Irrigation, Jordan.

1. Introduction

Water is an essential natural resource that is vital for human well-being and ecosystem functioning, and for human life activities in homes, industry, trade, agriculture, etc. But today we find most of the surface and underground water bodies unfortunately polluted and under high environmental pressure due to increasing population, urbanization, and the excessive use of chemicals. A special focus should be given to rivers that extend long distances through residential, agricultural, industrial and commercial areas which suffer from the problem of water pollution and make it very difficult to maintain the water quality of those rivers within the standard limits allowed for and drinking, industrial and agricultural purposes.

Providing water of high quality is very important, whether it is used as drinking water, for domestic uses, for food production, or for recreational purposes. According to WHO reports, improving the quality of water by treating wastewater, and the better management of water resources can enhance the economic growth of countries and can contribute significantly to poverty reduction [WHO, 2005]. The lack of water resources in the Middle East region [Frenken 2009; Al-Ansari et al. 2018a, b; Al-Ansari, 2019a, b) is a detrimental factor controlling the stability, peace, and social and economic developments of the region. Expectations indicate that the situation will be bad and more complex in the future [Al-Ansari et al. 2018c].

The unplanned demographic growth of Jordan's cities has led to hasty decisions about water supply regimes and wastewater management systems. This, in turn, has caused the pollution of some of the vital natural water streams, lakes, and other water bodies. One such region, currently highly polluted and far above acceptable limits, is the Zarqa River (ZR) in Jordan.

Nowadays, people's health awareness has increased and they have become more eager to know the quality of the water they want to drink or use. Delivering important information about water quality to the public is a challenge for managers, health experts, and government officials alike. They are looking for a unique, concise, and robust guide to help them monitor, judge, and manage water quality. Water quality is a term used to express the suitability of water for various uses, including agricultural operations, domestic activities, recreational, and industrial purposes. The process of determining water quality requires certain conditions for the physical, chemical, or biological properties of water. However, making a rational and rapid conceptual assessment of water quality is always a challenge for water quality engineers and environmental scientists due to the complexity of the assessment. It is worth noting that traditional water quality description reports that include variable assessments of water properties and statistical summaries, although important to experts, are often useless and not well understood by individuals and non-technical farmers.

Traditionally, the water quality concept can be determined by a set of variables that limit water use by comparing the physical and chemical properties of a water source with water quality guidelines or standards. However, this concept does not easily and clearly provide a comprehensive view of the spatial and temporal changes in the water quality of the water body under study [Debels et al., 2005]. The categorization, modeling, and interpretation of collecting data are the most critical steps in water quality evaluation. In many cases, it is difficult to assess water quality just by taking samples, each has concentrations of many parameters [Almeida et al., 2007]. The meaning of water quality is in many cases confusing and is typically framed by the intended use, as defined by the users. For example, water used for irrigation should be sufficiently low in dissolved minerals to avoid salinization of soils; water used for contact recreation must meet the criteria for fecal coliforms, and potable water must be safe for drinking and cleaning [US EPA, 2000].

Water quality is directly determined by analyzing the physical, chemical, biological, and radiological properties of the water. There are various key parameters that can be employed to evaluate the quality of water but when considering a matrix of all parameters a complexity towards quality may be generated. A Water quality index (WQI) that easily describes the quality of water is the most widely accepted approach to be used as an effective tool to define the level and grade of water pollution status, a fact that is confirmed by [Abbasi and Abbasi, 2012; Alobaidy et al., 2010; Lumb et al., 2011]. The WQI theory reflects the combined influence of different water quality parameters and provides water quality information to the public and legislative decision-makers in an easy, understandable way (e.g., law, fair, moderate, acceptable, excellent, etc.). It is derived from a matrix of several critical water quality parameters calculated by comparing monitored values at a particular location with the adopted regulatory standards at this specific location. At the same time, it easily translates subjective water quality assessments and often eliminates or avoids the bias of individual water quality experts [Ewaid and Abed, 2017].

Initially, a water quality Index, WQI was first proposed by Horton (1965) in the United States by considering 10 critical water quality variables, such as dissolved oxygen (DO), pH, coliforms, specific conductivity, chloride content, alkalinity, which were found wide recognition in several countries. Each selected water quality parameter is given a weight to reflect its significance for a particular use and has a considerable impact on the derivation of the index. A few years later a new WQI index has been developed by the group Brown in 1970 [Brown et al 1970], which focused mainly on weights assigned to the individual parameters and confirmed that a single numerical expression indicating the composite influence of significant parameters impacting water quality was feasible. Since that date, studies have continued about the development of WQI and it has undergone several modifications in terms of its concept and validation by several scientists and experts all over the world [Horton, 1965; Reza and Singh, 2010]. The (NSF-WQI) of the National Sanitation Foundation's Water Quality, the Environment's Water Quality Index (CCME-WQI) of the Canadian Council of Ministers, the Oregon Water Quality Index (OWQI), the British Columbia Water Quality Index (BCWQI), are just well-known examples of water quality assessment indices.

At present, more than 35 WQI models have been identified and used and published by different authors, countries or environmental organizations all aiming to assess surface water quality around the world [Abbasi and Abbasi, 2012]. Although all WQI models were applied to various surface water forms, 82% of the applications were for river water quality assessment. The CCME and NSF models have been used in 50% of the published studies. Common factors among all known WQI models are that each individual and specific application has specific requirements related to the physical, chemical and biological properties of water [Alam et al. 2007]. And when it comes to assessing water quality, each WQI model has a different rating scale. [Tyagi et al. 2013] explained some of the WQI models used in the USA and Canada, and defined the water quality rating for each. Good water quality, for example, has a WQI between 71 and 90 points according to the NSFWQI (National Health Foundation Water Quality Index) in the USA, while according to the Canadian Council of Ministers of Environment (CCME WQI) it is placed on the scale from 80 to 94 points [Lumb et al. 2012]. Comparatively, the Oregon Water Quality Index (OWQI) model places good water quality on a scale from 85 to 89 points [OWQI 2006].

2. Methodology

For this assessment study, a set of nine most commonly used physio-chemical and microbiological water quality parameters were selected to be used for the WQI calculation. These parameters are pH, chemical oxygen demand (COD), total dissolved solids (TDS), Total suspended solids (TSS), total phosphate (as $PO4^{-3}$), total nitrogen (TN), nitrates ($NO3^{-}$), EC and Escherichia coli (E.coli). All sampling procedures, including sample preservation and analysis, were carried out according to standard methods of water and wastewater Examination (APHA, 2005).

For irrigation purposes, the reclaimed wastewater in Jordan is reused either directly (without mixing it with fresh water) and/or indirectly (after mixing it with fresh). The indirect reuse is commonly practiced for unrestricted irrigation which allows irrigation of crops likely to be eaten uncooked, while the direct reuse is practiced for restricted irrigation which is limited to irrigate crops specified in JS 893/2006 standard and categorized as A, B, C, and D. Emphasis will be placed on evaluating the quality of the water flowing in the Zarqa River (ZR) and ensuring its suitability for agricultural use (specifically for options A and D) by applying the quality standards indicated by the Canadian water quality Index (CCME WQI).

3. Hydrology of Zarqa River and its drainage basin

The Zarqa River (ZR) is the third largest river in Jordan after the Jordan River and the Yarmouk River in terms of the annual discharge of bout flow of 63.3 million cubic meters. The ZR basin is considered one of the most vital basins in Jordan with respect to its economic, social, and agricultural value. The basin is located between 213° to 319° E and 140° to 220° N and drains from an area of about 3150 km^2.[Al-Abed et,al., 2005, MWI, 2016]. The Zarqa River (ZR) area is a semi-arid area with an average annual rainfall of about 273 mm. Its basin occupied the most densely populated area in Jordan which is constitutes around 68% of the country's population, 70 % of agricultural activities, and more than 78% of Jordan’s industries.

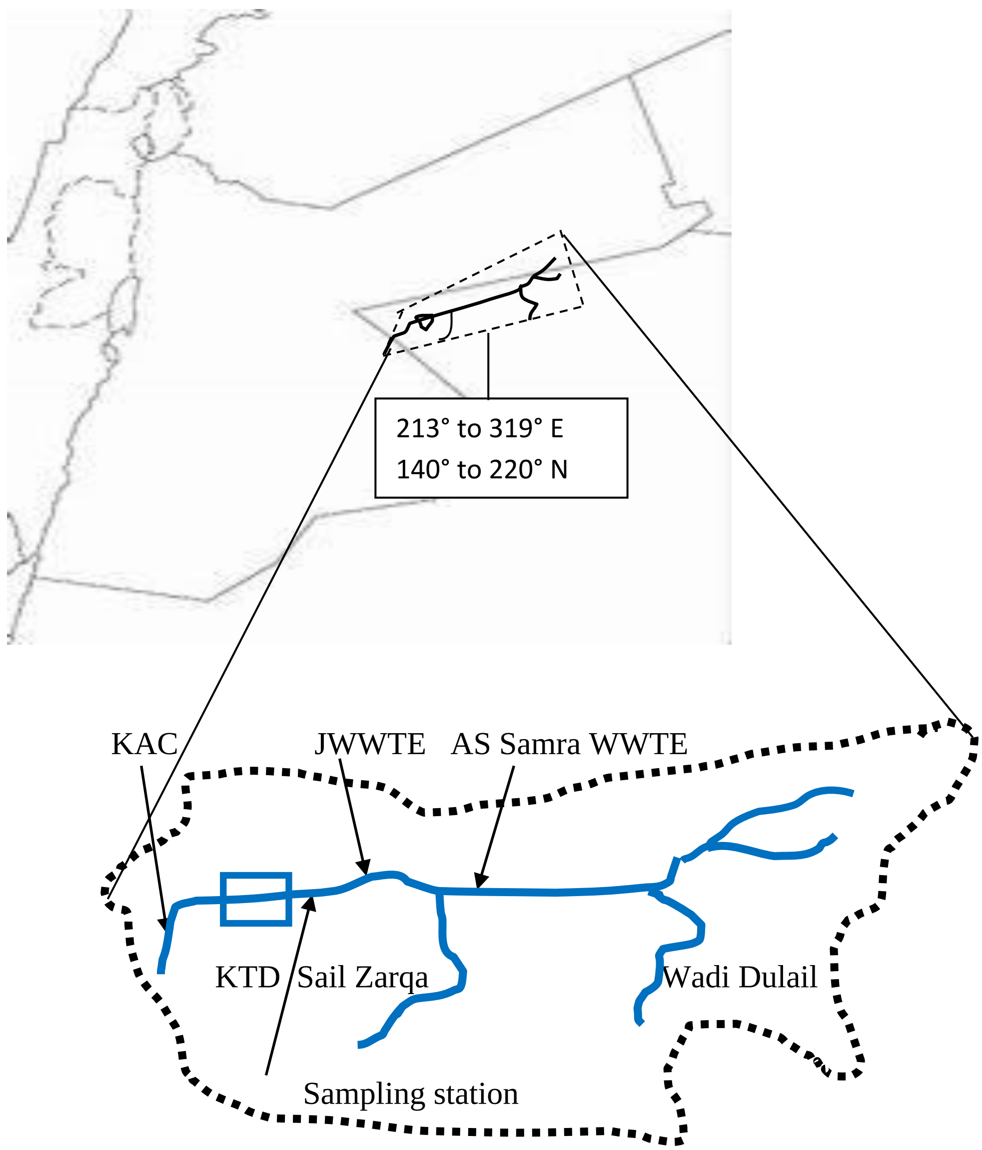

Fig. 1: Map of Jordan showing location and course of Zarqa River (ZR) and tributaries

Identified pollution sources to the Zarqa River are wastewater treatment plants, overflow of wastewater pumping stations, and leaks from sewer lines and manholes that pass through the riverbed, in addition to industrial, commercial, domestic, and agricultural activities along the river course. The main pollutants released to the river from these sources are organics, nutrients, heavy metals, raw wastewater, solids, and solid waste. Identified pollution sources to the Zarqa River are wastewater treatment plants, overflow of wastewater pumping stations, and leaks from sewer lines and manholes that pass through the riverbed, in addition to industrial, commercial, domestic, and agricultural activities along the river course. The main pollutants released to the river from these sources are organics, nutrients, heavy metals, raw wastewater, solids, and solid waste.

The basic flow of ZR is formed from two tributaries, the first is Wadi Dhulail and the second is Sail Al-Zarqa. In the year 1970, King Talal Dam (KTD) was built at the lowest point of (ZR) with a lake having a capacity of 55 MCM, which was upgraded later to be able to store 86 MCM. The effluents from industrial and municipal wastewater treatment plants form about 50% of the water reaching (KTD). The main sources of water in (ZR) are from annual precipitation runoffs, discharge of small springs, and effluents from wastewater treatment plants including Al-Samra, Jerash, Abu Nusair, and Baqa'a WWTPs). Overflow from wastewater pumping stations, leaks from sewer lines and manholes passing through the river bed, and commercial, domestic, and agricultural activities along the river, all contribute to massive pollution of the river. Because of this, pollution in the lake has reached a level that makes the water unfit for human consumption and is currently used for restricted irrigation purposes only [Al-Omary et, al., 2019]. Currently, The ZR has an average annual base flow of around 113 MCM. [Al-sharifa et, al., 2018].

Table 1: Average values of water quality parameters of ZR during five consecutive seasons from 2019 to 2020.

Parameter	**Unit**	**Monitoring seasons in years 2019 -2020**				
		Spring	**Summer**	**Fall**	**Winter**	**Spring 2020**
pH	**-**	**7.7**	**7.86**	**7.52**	**7.64**	**7.73**
E.coli	**MPN/ 100 ml**	**45.2**	**784.7**	**456**	**490.4**	**1302.6**
T-P as PO4	**mg/l**	**23.7**	**17.94**	**15.77**	**18.75**	**21.53**
NO3	**mg/l**	**0.71**	**31.44**	**38.0**	**8.76**	**6.58**
T-N	**mg/l**	**55.8**	**36.1**	**14.88**	**12.33**	**104.1**
TDS	**mg/l**	**1138.4**	**1031.7**	**972.33**	**1118.0**	**1116.1**
TSS filt.	**mg/l**	**48.5**	**23.75**	**27.71**	**18.50**	**47.60**
COD	**mg/l**	**244.2**	**75.3**	**58.00**	**166.0**	**63.7**
BOD5	**mg/l**	**80.0**	**28.3**	**38.4**	**7.75**	**9.7**
EC	**µS/cm**	**1253**	**1753**	**1266**	**2322**	**1482**

Table 2: The Jordanian standards for treated wastewater reuse in irrigation (JS 893/2006)

Parameter	**Unit**	**Maximum allowable limits (JS* 893/2006)**
pH	**-**	**6 -9**
E.coli	**MPN/ 100 ml**	100^{A}, 1000^{B}, 1000^{D}, 5000^{C}, $\leq 1.1^{E}$, $\leq 2.2^{F}$
T-P as PO4	**mg/l**	$30^{A,B, C,,D,E}$, 15^{F}
NO3	**mg/l**	$30^{A,F}$, 45^{E}, $70^{B,C,D}$
T-N	**mg/l**	$45^{A,F}$, $70^{B, C, D, F}$
TDS	**mg/l**	$1500^{A, B, C, D, E, F}$
TSS filt.	**mg/l**	15^{E}, $50^{A,F}$, 60^{D}, $150^{B,C}$
COD	**mg/l**	100^{A}, 150^{D}, $500^{B,}$C, $50^{E,F}$
BOD5	**mg/l**	30^{A}, 60^{D}, 200^{B}, 300^{C}, $15^{E,F}$
EC	**µS/cm**	**700 -2000**

JS* 893/2006: Jordanian Standard for agricultural irrigation with treated wastewater. (A,B,C,D,E,F): Irrigation Categories. (A): cooked vegetables, parks and playgrounds, (B): Fruit trees, side of roads and landscape, (C): Field crops, forests, and industrial crops, (D):

Discharges to Wadis, streams and surface water bodies, E: cut flowers, F: recharge of groundwater and springs.

4. Analysis of Zarqa River (ZR) water quality in accordance of JS 893/2006.

Table 1 shows that, according to JS 893/2006 (Table 2), all the pH values monitored for ZR water are within acceptable limits (between 6.0 and 9.0) for all specified irrigation classes (A, B, C, D, E and F). As for the TDS values, it was found that they fall within the range of 972.33 mg / l - 1138.4 mg / l, which means that all values are within the permissible limits for all irrigation classes (A, B, C. D, E and F). For TSS, JS893/2006 define 15 mg/L for class E, 50 mg/L for A and F, 60 mg/L for class (D), and 150 mg/L as the maximum allowable for irrigation classes (B and C). Average concentrations of total soluble solids range from 18.5 mg/L to 48.5 mg/L. Among the studied five seasons, the mean TDS concentration was lower than the maximum allowable for irrigation classes (A, B, C, D, and F), but higher than what is required for irrigation class €.

The average COD values were found to be in the range of 58 mg/L to 244.2 mg/L. The maximum allowable COD for irrigation of Class A crops is set as 100 mg/L, 50 mg/L for Class E and F, 150 mg/L for Class D, and 500 mg/L for irrigation of Class B and C crops. As required by JS893/2006. Of the five samples, all have an average COD that exceeds the permissible limit for irrigation classes E and F, two have an average COD concentration that exceeds the permissible limit for class A. All COD values are within the permissible limit for classes B and C. Laboratory analyses showed that the average concentration of PO4−3 in the river water is between 17.94 mg/l and 23.7 mg/l. Thus, the average PO4−3 values in all studied samples are below the permissible limit of 30 mg/L, according to JS893/2006 standard for the five major irrigation classes A, B, C, D, and E except for class F, where the required average concentration of PO4− 3 in water is 15 mg /L.

The laboratory results showed that the average concentration of nitrate (NO3-) in the water ranged from 0.71 mg/L to 38.0 mg/L in the observed samples. Thus, the average values of NO3− in all studied seasons are less than the permissible limits of 45 mg/L required for class E and 70 mg/L permitted for the three major classes (B, C and D) according to JS893/2006. In two samples, it was noted that the average Nitrate concentration exceeds the permissible limit of 30 mg/L required for classes (A) and (F) according to JS893/2006. In regard to the maximum allowable limits of the total nitrogen (TN) concentration to irrigate crops in categories A and F, the JS893/2006 specified 45 mg/L and 70 mg/L for all other categories (B), (C), (D), and € respectively. The mean effluent value of TN in the studied plants ranges from 12.33 mg/L to 104.1 mg/.

The mean value for E.coli level is found to vary between 45.2 MPN/100 mL and 1302.6 MPN/100 mL. The reference guide line (JS893/2006) allows for E.coli levels a limit value of 100/ 100 mL as maximum to irrigate crops in category A, and allows 1000/100 mL to irrigate crops in category ©, and, 5000/100 mL to irrigate crops in categories (B and D), ≤ 1.1 and ≤ 2.2 per 100 mL to irrigate crops in category (E and F) respectively. Most of the found E.coli counts in the studied samples exceeded the maximum allowable limit for the categories A, E, and F. The average number of Escherichia coli exceeded the maximum allowable limit in 4 out of five studied samples for class (A), and one sample out of every five studied samples exceeded the maximum allowed for irrigation of classes (B) and (D).

The physio-chemical analysis of water samples showed that while some of the parameters are within permissible limits, many exceeded the stipulated guidelines values. Therefore, it is clear that it is not possible to evaluate water and assess its suitability for any purpose of reuse only by comparing the monitored concentrations of selected quality parameters with what is stipulated in the guidelines for those parameters. Hence the need to derive a quality indicator that takes into account the impact of all these parameters combined in one term which determines the suitability of the water for planned use quickly and easily.

5. Selection of parameters for calculation of water quality index

The expectation and declaration of high levels of organic pollution in the Zarqa River Basin is the basis for selecting critical water quality criteria for this evaluation study. COD, BOD, electrical conductivity (EC), nitrate-nitrogen, total P, E.coli, TDS, pH, and TSS are significant indicator parameters of surface water quality. The raw values of each quality parameter is being compared with the standard threshold values that are taken into account for the computation of the index (for this study JS: 893/2006). This Jordanian specification includes the upper limits allowed for each of the water quality parameters and the appropriateness of the water quality for the crops being irrigated, irrigation categories A, B, C, D, E, and F). Next, the focus will be on calculating the water quality index and assessing its suitability for agricultural irrigation, especially for classifications A and D, as the Jordanian Standard stipulates the highest and most stringent quality requirements for these two options.

For this study, The CCME-WQI approach is tested in evaluating the Zarqa River water quality for agricultural irrigation. The CCME-WQI model was initially conceptualized by the Canadian Water Quality Index (CWQI), having several benefits over other methods, including compliance with different legal requirements and multiple water uses, suitability for water quality assessment in specific areas, flexibility in selection criteria, and ease of bypassing missing data [Mohebbi et al. 2013; Yan et al. 2016]. In addition, this is the most effective approach to accurately assessing water quality and determining its suitability for an intended use [Zotou et al. 2019; Ochuko

2014]. It provides an easy-to-understand mathematical aggregation of the final index value without the need for sub-indices and weights estimations as by other conventional methods. As mentioned by CCME, the CCME WQI calculation is based on three significant terms (the scope, the frequency, and the amplitude) to produce a single unitless number that represents an overall water quality based on the selected benchmark value [CCME, 2014]. The result is a single unitless number ranging from 0-to 100, where 100 indicates that the parameters were is similar to the selected benchmark or below it [Tirkey et al., 2013]. The formulation of the Canadian Water Quality Index (CCM WQI) varies from other conventional derived indices, for each date, it calculates values over an index period, typically a season or a year. Thus it is directed to evaluate average water quality over a specified time period rather than to be used as a tool for identifying actual water quality problems at a specified time or location.

6. The mathematical structure of the CCM WQI

After determining the body of water for which the water quality index is to be calculated, the time period and all associated variables and objectives must be fixed with taking into account the factors that make up the index. The detailed formulation of the WQI, as described in the Canadian Water Quality Index 1.0 – Technical Report [Gebrehiwot, 2010], is based on selecting parameters and setting objectives (benchmarks) for each parameter. The index calculates three terms relative to these objectives. The combination of these factors together gives a mathematic rating that is related to common descriptors. The three terms to use combined together are: The scope, defined as (F1), represents the percentage of variables that do not meet their guideline values at least once during the time period under consideration and are announced as failed variables relative to the total number of variables measured. The frequency, (F2), communicates the percentage of individual tests that do not meet guideline values and are announced as failed tests. F1 and F2 are calculated directly and can be expressed as follows:

$$\mathrm{F1} = \frac{number\ of\ failed\ variables}{total\ number\ of\ measured\ variables} x\ 100 \qquad \text{Eq. 1}$$

$$\mathrm{F2} = \frac{number\ of\ failed\ tests}{total\ number\ of\ tests} x\ 100 \qquad \text{Eq. 2}$$

The third term (F3) is the Amplitude, which represents the value of the deviation of the failed test from the required value. The number of times by which an individual parameter value is greater than or less than the standard is termed “Deviation” and can be expressed through such equations:

When the test value must not exceed the objective:

$$\text{Deviation} = \left\{\frac{\text{failed tests value}}{\text{Guideline value}}\right\} - 1 \qquad \text{Eq.3}$$

For the cases in which the test value must not fall below the objective:

$$\text{Deviation} = \left\{\frac{\text{Guideline value}}{\text{failed tests value}}\right\} - 1 \qquad \text{Eq.4}$$

The cumulative amount by which all the individual tests are out of compliance is calculated by summation of all deviations of individual tests from their guideline values and dividing by the total number of tests. This variable, referred to as the normalized sum of deviations, or NSD, is mathematically structured as:

$$\text{NSD} = \frac{\sum_i^n \text{Deviations}}{\text{number of tests}} \qquad \text{Eq.5}$$

F3 is then calculated by a mathematical function that scales the normalized sum of the deviations from objectives (NSD) to produce a number between [0 to100]. The NSD involves both terms those meeting objectives and those failing to meet objectives. This is expressed mathematically as:

$$\text{F3} = \left\{\frac{\text{NSD}}{0.01\ \text{NSD}+0.01}\right\} = \frac{\text{NSD}}{\text{NSD}+1}\ x\ 100 \qquad \text{Eq.6}$$

Once the factors are obtained, the index itself can be calculated by:

$$\text{CCME WQI} = \frac{\sqrt{\text{F1}^2+\text{F2}^2+F3^2}}{(\sqrt{3}\,)} = \left\{\frac{\sqrt{\text{F1}^2+\text{F2}^2+F3^2}}{1.732}\right\} \qquad \text{Eq.7}$$

Where: $[(100)^2 + (100)^2 + (100)^2]^{1/2} = (30000)^{1/2} = 173.2$ Eq.8

The number ($\sqrt{3} = 1.732$) normalizes the obtained values to a range between 0 and 100, where (0) represents the worst water quality and (100) represents the best water quality.

7. Applying the Canadian Water quality Index approach to estimate the water quality of Zarqa River (ZR).

In this study, the adopted calculation of CCME WQI is as suggested by the CCME model, which proposed four principle values (number of failed variables, number of failed tests, total variables considered, and total number of tests performed) as basis for the calculation of WQI [CCM, 2001]. These terms are derived from data in table 1 and presented in table 3 and will be used for the calculation of the terms F1, F2 and F3. These three terms of deviation incorporate to generate a single value between 0 and 100 that describes the overall water quality. The CCME WQI values are then transformed into ratings using the index rating scale presented in Table 3.

To calculate the scope (F1) there are 9 water quality variables (TP as PO_4, TN, NO_3, TDS, TSS, COD, EC, pH, and E.coli) to consider (Table 1). During the monitoring period, four of them namely, (E.coli, NO_3, TN, and COD) failed their respective objectives when considering the water for irrigation category (A), while only three of them (E.coli, TN, and COD) failed their objectives if the water is to be used for irrigation category (D). The calculation of the frequency (F2) needs to define the number of individual tests performed and to fix the number of failed tests among them.

Table 3: Summary of the four principle values needed to calculate F1 and F2 in accordance to CCME WQI.

Irrigation category	Nr. of variables tagged as failed	Nr. of failed tests	Nr. of total variables tested	Nr. of total tests
A	**4**	**10**	**9**	**45**
D	**3**	**4**	**9**	**45**

The Amplitude (F3) is calculated based on the deviation of each failed test in relation to its objective value. The equation used for calculating the normalized sum of deviations NSD is:

The normalized sum of deviations NSD= $\frac{\sum_i^n \text{Deviations}}{\text{number of tests}}$

Table 4: Computation of NSD and the amplitude (F3) applied to Zarqa River water.

Irrig. Cat.	**NSD** Eq. 5	**F3** Eq.6
(A)	$\frac{\left(\frac{784.6}{100}-1\right)+\left(\frac{456}{100}-1\right)+\left(\frac{490.4}{100}-1\right)+\left(\frac{13026}{100}-1\right)+\left(\frac{38.4}{30}-1\right)+\left(\frac{55.8}{45}-1\right)+\left(\frac{104.1}{45}-1\right)+\left(\frac{244.2}{100}-1\right)}{45}$ $= 0.4512$	$\left\{\frac{0.4512}{0.01 \times 0.4512 + 0.0}\right.$ $= 31.10$
(D)	$\frac{\left(\frac{13026}{1000}-1\right)+\left(\frac{104.1}{70}-1\right)+\left(\frac{244.2}{150}-1\right)+\left(\frac{166}{150}-1\right)}{45}$ $= 0.034$	$\left\{\frac{0.034}{0.01 \times 0.034 + 0.01}\right\}$ $= 3.29$

Table 5: The aggregation of WQI for Zarqa River based on the CCME WQI approach [CCM, 2001].

Irrig. Categ.	**F1** $\frac{\textbf{Nr. of failed var.}}{\textbf{tot. measured var.}} \textbf{x 100}$	**F2** $\frac{\textbf{Nr. of failed var.}}{\textbf{total tests}} \textbf{x 100}$	**F3**	**WQI** $\{\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\}$
(A)	F1: $\frac{4}{9} x\ 100 = 44.44$	F2: $\frac{10}{45} x\ 100 = 22.22$	31.10	**WQI: 66.15**
(D)	F1: $\frac{3}{9} x\ 100 = 33.33$	F2: $\frac{4}{45} x\ 100 = 8.89$	3.29	**WQI: 80**

Using the aggregation function used by the CCME to expressed WQI, results (Table 5):

$$\mathrm{WQI, A} = 100 - \left\{\frac{\sqrt{44.44^2 + 22.22^2 + 31.1^2}}{1.732}\right\} = 100 - \frac{58.6}{1.732} = 66.15$$

$$\mathrm{WQI, D} = 100 - \left\{\frac{\sqrt{33.33^2 + 8.89^2 + 3.29^2}}{1.732}\right\} = 100 - \frac{34.65}{1.732} \approx 80$$

Basis for the evaluation of water quality of Zarqa River on suitability for agricultural irrigation is by considering the categorization rating proposed by CCME water quality models as shown in table 6:

Table 6.: Canadian Water Quality Index (CCME WQI) categorization scheme as stated in [CCME, 2005b].

Rating CCMWQI	WQI value	Description
Excellent	95 - 100	All measurements are within objectives virtually all of the time, conditions very close to natural or pristine levels
Good	80 - 94	Conditions rarely depart from natural or desirable levels
Fair	60 - 79	conditions sometimes depart from natural or desirable levels
Marginal	45 - 59	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels, usage is with restricts.
Poor	0 -- 44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels and couldn't be used.

8. Results and Discussion

The CCME WQI approach integrates three terms: Scope, F1, gives the number of water quality parameters failed in meeting water quality objectives; Frequency F2, shows the number of times, when the objectives are not met; and Amplitude F3, which indicates the extent to which the objectives are not met. The aggregation of the index produces a single number between 0 (as theworst scenario) to 100 (best scenario) to describe the water quality.

The water of the Zarqa River was evaluated for both alternatives (A) and (D), which require the highest and most stringent specifications of irrigation water quality, according to the Jordanian standard. Calculations related to quality indicators and based on the water quality rating proposed by CCME WQI approach showed that the water of the Zarqa River (ZR) is of fair quality when considering it to irrigate green crops that are eaten without cooking (category A), and of an acceptable quality for irrigating the rest of the crops (categories B to F).

Table 7: Final values of CCEM WQI as calculated for Zarqa River water.

CCME WQI	
Irrigation Category (A)	**Irrigation category (D)**
66.15	**80**
fair	**good**

As per table 7, for all seasons during 2019-2020, WQI values for ZR fluctuated between good, fair, with differences between seasons. With the exception of winter 2019 and spring 2020, where the largest differences between the average WQI values are observed, probably due to the effect of untreated sewage and industrial discharges from Zarqa- city, the second largest city in Jordan. Both are rainy seasons in which the transport of urban and industrial waste and farmland residuals to the river, especially agricultural residuals, E. coli, TN, and TP, is increased.

9. Conclusions

The CCME WQI approach has been proven to be a multi-purpose tool for better water resource management with many potential environmental applications. It provides reasonable flexibility in assessment and ease of reporting that can be used as an effective communication tool for describing the general state of water quality and rating its suitability for use. It can be used effectively in all cases where the data is compared with the corresponding guidelines or standards.

The WQI was found in the waters of the Zarqa River with greater inter-seasonal differences, while these seasonal variations were significantly higher in winter 2019 and spring 2020 compared to other observational periods. The reason for this could be that runoffs in these rainy seasons increase the likelihood of domestic and industrial wastewater being discharged into the river without treatment.

This study presented a mathematical application in assessing the suitability of water flow in the Zarqa River for irrigation purposes. On the basis of WQI calculations, the following specific conclusions were drawn: According to the classification of the WQI scale, the water quality of the Zarqa River does not fully comply with the Jordanian Standards for Reclaimed Domestic Wastewater (JS 893/2006). It was found that the water is only suitable for restricted cultivation and cannot be used in direct watering of green leafy plants that can be eaten raw (class A).

Based on the observations and results of studies, there is an urgent need for regular monitoring programs to control the water quality in the Zarqa River and to identify temporal and spatial changes in water quality, and also to obtain the information necessary to design specific monitoring programs aimed at identifying the causes, times and locations of pollution, in order to help prevent pollution and the possibility of mitigating its effects.

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