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Comparison between Weighted Arithmetic and Canadian Council of Ministers of the Environment Water Quality Indices performance in Amman-Zarqa Area, Jordan

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Abstract

Water Quality Indices (WQI's) are efficient and simplified tools to evaluate the situations of water quality based on the biological, physical, and chemical parameters. National and international institutions and agencies determined the limits of these parameters on a scientific basis. It converts the water quality into a single and simple value, simple enough for the laypeople to understand.

The present study compares the results of the CCME-WQI method with the WA-WQI method for drinking purposes. Fifty-nine groundwater wells were chosen from the Amman Zarqa Area for this purpose. Elevenparameters of water analysis during the period July to November 2020were obtained to determine water quality indices. These parameters are; EC, pH, Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, NO_3^{-}, HCO_3^{-}, $SO_4^{2-}$and Cl^{-}. The results of applying CCME-WQI and WA-WQI for assessing the water suitability in the study area showed that; CCME-WQI classified water samples as "26% Excellent", "49% Good", "8% Fair", "12% Marginal", and "5% Poor" while the WA-WQI classified it as "8% Excellent", "45% Good", "31% Poor", "14% very poor", "2% unsuitable for drinking purpose".By comparing the results of both methods the CCME-WQI with WA-WQI, the results show that the CCME-WQI is more flexible and yielded a higher value of water quality than WA-WQI. Also, the statistical test calculated for both indices showed a strong indication that the differences between the CCME-WQI and the WA-WQI mean values are statistically significant at a significance of (a = 0.05).

Keywords: Water Quality Index, Canadian Water Quality Index, Weighted Arithmetic Index, Amman Zarqa Basin.

1. Introduction

Water is an essential component of the ecosystem and is often found in the form of streams, springs, rivers, lakes, glaciers, rainfall, and groundwater. Over the years, many sources of surface and groundwater have been depleted and large parts of them have been subjected to pollution due to many reasons such as urbanization, growth of population, and industrial development, which contributed to changes in water quality (Imneisi and Aydin, 2016). Nowadays one of the most important issues throughout the world is water quality management and environmental protection. Many countries focused on assessing and monitoring the water situation depending on their physicochemical and biological characteristic for different uses.

Water Quality Index (WQI) concept had recently been innovated to become the most effective tool for evaluating water quality. Based on water characteristics (physical, chemical, and microbiological), the quality of water characterized. Over the years, several national and international organizations applied the water quality index for water quality assessment. Initially, Horton (1965) proposed the first index in the United States in an endeavor to describe the water quality by choosing the most water quality parameters used such as (pH, dissolved oxygen, specific conductance, coliforms, alkalinity and chloride, etc.) and calculated the WQI by using the arithmetic weighted mean technique (Horton, 1965). Brown et al. (1972) modified the Horton index, which is supported by the National Sanitation Foundation.WQI model proposed by Bhargava (1983), to assess the Ganga River in India based on the sensitivity function technique. Canadian Council of Ministers of the Environment (CCME) computed a Canadian WQI using the summation squares of harmonic numbers (CCME, 2001). Over the years, several water quality indices were formulated and used by organizations and researchers such as: a) Index of River Water Quality, b) The Scatter Score Index, c) Chemical Water Quality Index, d) Overall Index of Pollution, e) Universal Water Quality Index-UWQI, f) Iowa Water Quality Index, g) Oregon Water Quality Index, h) Weighted Arithmetic Water Quality Index (Oni and Fasakin, 2016).

Many international and local institutions and agencies sought to transform the huge water quality data into a simple formula or a simple number, simple enough for the laypeople to understand, and studied the water and analyzed all its physical, chemical, and biological elements and their effects to find out the suitability of water for human use and to define permissible standards for each element in drinking water. Among these Institutions are World Health

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Organization (WHO) and Centers for Disease Control (CDC), and Environmental Protection Agency (EPA) (Madalina and Gabriela, 2014).In Jordan, the Jordan Institute for Standards and Metrology has developed permissible standards for drinking water in Jordan (JISM, 2015).

On the other hand, many indices have been commonly used over the last decades, among these are, the Canadian Council of Ministers of the Environment (CCME-WQI), Oregon Water Quality Index (O-WQI), Weighted Arithmetic (WA-WQI), and National Sanitation Foundation (NSF-WQI) are the commonly used (Paun et al., 2016).

The interpretation of the obtained data from monitoring and water quality management improved the accuracy of the applied indices. For this purpose, many statistical methods were utilized such as principal components analysis (PCA), cluster analysis (CA), factor analysis (FA) discriminant analysis (DA), and artificial intelligence (AI) (Bilgin, 2018).

The main objectives of this study are: (1) to assess the water quality of the Amman Zarqa area using two methods of water quality indices (WA-WQI and CCME-WQI), and (2) to compare the results of both indices (WA-WQI and CCME-WQI) by emphasizing the merits and demerits of the two methods and figure out which method is more reliable and concise.

2. Material and Methods

2.1. Canadian Council of Ministers of the Environment (CCME-WQI)

In 1997, the Canadian Council of Ministers of the Environment established the CCME-WQI based on the British Colombia WQI (CCME, 2001). This index is used by many countries to assess water quality with a little modification for their ease to calculate and flexibility to choose the parameters that contribute to the calculation of the index.

In 1997, the Canadian Council of Ministers of the Environment established the CCME-WQI based on the British Colombia WQI (CCME, 2001). This index is used by many countries to assess water quality with a little modification for their ease to calculate and flexibility to choose the parameters that contribute to the calculation of the index.

CCME-WQI consists of three significant factors (Scope, F1; Frequency, F2; and amplitude, F3), denominated to calculate the final CCME Index as a dimensionless single number that describes the water quality condition from 0(poor quality) to 100(High quality) (CCME, 2003; Sutadian et al., 2016; Lopes et al., 2020).

In brief, the above factors are calculated as follows:

$$F_1 = \left(\frac{No.of\ failed\ variables}{Total\ no.of\ variables}\right)*100$$

Where, Scope factor F1= Number of variables, whose objectives are not met.

$$F_2 = \left(\frac{No.of\ failed\ tests}{Total\ no.of\ tests}\right)*100$$

Frequency factor F2 = number of times by which the objectives are not met. Amplitude factorF3= Amount by which the objectives are not met, which is calculated in three steps:

(a) Excursion = $\left(\frac{Failed\ test\ value}{Objective}\right) - 1$

(b) The normalized sum of excursions (nse) $= \frac{\Sigma\ excursions}{No.\ of\ tests}$

(c) F3 $= \frac{nse}{0.01nse + 0.01}$

Finally, calculation the CCME -WQI;

$$WQI = 100 - \frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}$$

According to the final index score (0 to 100), The higher score the better the water quality, WQIiscategorized into the following five classes: "Poor;0–44", "Marginal;45–64", "Fair;65–79", "Good;80–94", "Excellent;95–100" (Table 1, CCME, 2003).

2.2. Weighted Arithmetic Water Quality Index (WA-WQI)

The Weighted Arithmetic WQIis considered one of the widely used method to classify water for drinking purposes. WA-WQI is easy and simple to use; it relies on weighing the water parameters, each according to their importance, let the user choose the water quality parameters incorporated in the process (Iticescu et al., 2019).

WA-WQI is calculated by using the following equation (Zotou et al., 2019):

$$WQI = \frac{\Sigma Q_i W_i}{\Sigma W_i}$$

The quality rating scale (Qi) for each parameter is calculated using this expression:

$$Qi = 100*\left[\frac{V_i - V_o}{S_i - V_o}\right]$$

Where, V_i is the estimated concentration of the i^{th} parameter in the analyzed water

V_o is the ideal value of this parameter in pure water Vo = 0 (except pH =7.0 and DO = 14.6 mg/L)

Si is the recommended standard value of the i^{th} parameter

The unit weight W_i for each water quality parameter is calculated by using the following formula:

$$W_i = \frac{K}{S_i}$$

Where, K = proportionality constant and can be calculated by using the following equation:

$$K = \frac{1}{\Sigma\left(\frac{1}{S_i}\right)}$$

The final rating of WA-WQI is an ascending scale that ranges from 0 to 100 (higher scores indicate higher pollution). The quality of the water body is categorized also into five classes: "Excellent," "Good," "Poor," "Very poor and Unsuitable" for drinking purposes (Table 1, Tyagi et al., 2013).

Table 1. Water Quality Rating for CCME-WQI and WA-WQI.

Rating of Water Quality	Water Quality Value
Canadian Council of Ministers of Environment Water Quality Index (CCME-WQI)	
Excellent water quality	95-100
Good water quality	80-94
Fair water quality	65 -79
Marginal water quality	45 -64
Poor water quality	0-44
Weighted Arithmetic Water Quality Index (WA-WQI)	
Excellent water quality	0-25
Good water quality	26-50
Poor water quality	51-75
Very Poor water quality	76-100
Unsuitable for drinking purpose	Above 100

3. Study Area

Arid and semi-arid regions are characterized by water scarcity. To solve this problem; water conservation and management have become a priority, whether it is surface water or groundwater. Jordan has suffered for a long time from water scarcity because it is considered a semi-arid region. Due to the water shortage, Jordan is highly dependent on underground water sources to cover its water demand. Because of this significance, it is important to preserve and protect groundwater from pollutants, in addition, to reduce over-pumping by factories and farms, which leads to deteriorating the water quality and makes it unfit for drinking purposes. One of the main groundwater sources is the Amman Zarqa Basin (AZB) located in the central of Jordan covers around 4074 Km^2. The study area is representing the southeastern part and including three major cities of Jordan, Amman, Ruseifa, and Zarqa (Figure 1). This portion of the basin is highly developed and urbanized with more than 6 million inhabitants,and represents the home for about 60% of Jordan's population (DOS, 2020).

In the last decades, this area has witnessed a high population growth, which can be related to the sudden fluxes of relatively large numbers of refugees as a result of political instability in the region. This led to huge and instantaneous pressures on the stressed available water resources. Furthermore, the consequence has influenced the per capita share of freshwater resources in Jordan and particularly this area that has been declined to less than 90 m^3/year, which places Jordan way below the poverty limit of 1000 m^3/year (MWI, 2017).

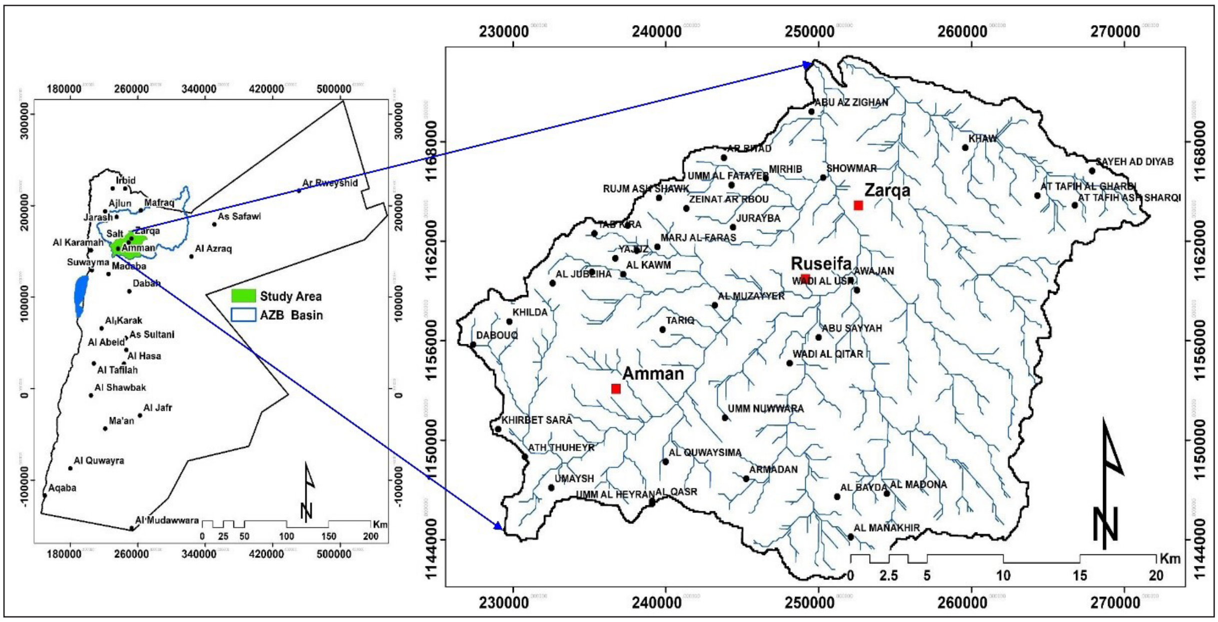


Figure 1. Location of the study area.

3.1. Hydrology and Hydrogeology

The climate of the area is hot and dry in the summer season, cold with rainfall in the winter season. The long term rainfall distribution ranges from around 400mm in the south to 120 mm in the northern parts of the study area. The mean monthly temperature in the area ranges from around 26 °C in summer to 8 °C in winter. The daily temperature ranges from over 30 °C in summer in the southeastern part to 35°C in the north and northeastern makes this area drier and hot (Atashi et al., 2020). The groundwater is exploited from two (shallow and deep) aquifers. The shallow aquifer consists of silicified limestone and limestone beds designated by Amman /Wadi Es Sir Aquifer (B2/A7) and the deep sandstone aquifer designated by the Kurnub Aquifer (K). The groundwater flow direction is from the south-west where recharge occurs along Seil el Zarqa north-west of the study area (Al Kuisi et al, 2014). The aquifer recharge depends on natural (infiltration from the rainfall directly) and artificial (such as leakage from water supply networks and irrigation return flow) sources. Many factors like geology, topographic relief, climate, and land use, affect the groundwater quality(UN-ESCWA and BGR, 2013; Al Kuisi et al., 2014).

Hundred public and private wells were drilled in the area for many purposes, increasing thus the pressure on the aquifers causing degrading the quality of water to become more saline and non-suitable for drinking purposes. The water level is declining in almost all wells in the study area. The Ministry of Water and Irrigation reported that the declines in the water level of the limestone aquifer (B2/A7) range between 0.67 m and 2 m per year (MWI, 2017).

3.2. Primary Data, Determinations, and Data Treatment

This study uses the available data of water quality (59groundwater wells × 11 water quality parameters) collected during 2020 from July to November systematically from the study area. Groundwater wells are distributed over an area of 85km^2. The location and coordinates of all the sample points were recorded using a GPS as present in Figure (2).

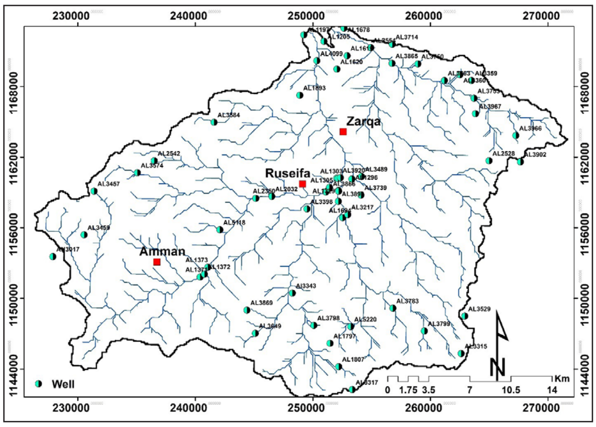


Figure 2. Location of the groundwater wells in the study area.

Before sample collection, the boreholes were pumped for up to 15 min to purge the aquifers and avoid contamination from the water to be sampled. Hydrogen ion concentration (pH), electrical conductivity (EC), and temperature were immediately measured during sampling by using a WTW-portable instrument. In addition, dissolved oxygen (DO) was determined by using calibrated portable DO meter and bicarbonate (HCO_3^-) by titration in the field. The water sample was collected from each well in 1000-mL polyethene bottles, which is rinsed many times before the sample storage and transferred to the laboratory of the Geology Department, at the University of Jordan. Where, different analytical methods and instruments measured Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), Nitrite (NO_3^-), Sulfate (SO_4^{2-}) and Chloride (Cl^-). The accuracy of the analysis was calculated by the charge balance error equation, which resulted in ± 5% concentration of the major cations and anions.

Table 2 shows the selected parameters in CCME-WQI and WA-WQI calculations and their threshold values according to the Jordanian Institute of Standards and Metrology (JISM, 2015). The CCME-WQI and WA-WQI values were calculated for the groundwater samples collected in the Amman Zarqa area, applying the equations mentioned before. JISM Typology established by the Ministry of Water and Irrigation of Jordan was applied to classify the status of groundwater in the area.

Table 2. Statistics of the selected parameters for the classification of groundwater quality.

Chemical parameters	Mean	Max.	Min.	Std. Dev.	WHO (2017)*	JISM (2015)**
pH	7.19	8.03	6.5	0.35	8.5	6.5-8.5
EC (µS/cm)	1775.5	5490	372	1211.25	1500	1500
Dissolved Oxygen (DO) mg/L	3.74	8.6	0.10	2.22	5	5
Calcium (Ca^{2+}) mg/L	136.18	331	40	72.44	100	200
Magnesium (Mg^{2+}) mg/L	60.73	193	13	40.24	50	150
Sodium (Na^+) mg/L	148.87	544	3	140.82	200	200
Potassium (K^+) mg/L	5.78	37	0.03	6.70	20	10
Chloride (Cl^-) mg/L	340.96	1251	30	297.07	250	500
Nitrate (NO_3^-) mg/L	31.02	170	0.1	38.24	50	50
Sulfate (SO_4^{2-}) mg/L	146.76	712	14	151.69	250	500
Bicarbonate (HCO_3^-) mg/L	333.74	732	153	110.44	200	250

* WHO (The World Health Organization).
** JISM (Jordanian Institute of Standards and Metrology).

The CCME-WQI and WA-WQI adopts a “five-class” scale, while JISM endorses a “two-class” scale. To make a good comparison between these two WQI’s harmonization terms were used to merge the five classes of CCME-WQI and WA-WQI into two classes similar to JISM (Table 3). Precisely, the “Poor–marginal” CCME ratings and “unsuitable–Very Poor-Poor” WA ratings were both merged into “Class 1” which indicate the “bad” rating, and “Class 2” as given by JISMthe ratings “Excellent–Good–Fair” and “Excellent–Good” of CCME-WQI and WA-WQI, respectively, were harmonized into “Good” rating.

Table 3. Harmonization of WQI’s to JISM classes based on criteria given by WA, CCME, and JISM.

		Classes	**1**	**2**
CCME-WQI		**Rating Range**	**Poor - Marginal 0-64**	**Fair- Good- Excellent 65-100**
WA-WQI		**Rating Range**	**Poor–Very Poor -Unsuitable 51-100**	**Excellent–Good 0-50**
JISM	Units	Rating	Poor	Good
pH			<6.5 or >8.5	6.5–8.5
EC	µS/cm		>1500	<1500
DO	mg/L		<5	>5
Calcium (Ca^{2+})	mg/L	Range	>200	<200
Magnesium(Mg^{2+})	mg/L		>150	<150
Sodium (Na^{+})	mg/L		>200	<200
Potassium (K^{+})	mg/L		>10	<10
Chloride (Cl^{-})	mg/L		>500	<500
Nitrate (NO_3^{-})	mg/L		>50	<50
Sulfate (SO_4^{2-})	mg/L		>500	<500
Bicarbonate (HCO_3^{-})	mg/L		>250	<250

The spatial distributions of water quality parameters across 59 groundwater wells were investigated using the Kriging modules in the ArcGIS 10.8 Software. Kriging is defined as a spatial interpolation technique that uses the measured georeferenced samples to estimates values at unsampled locations based on a statistical model. To test the statistical variations of the water samples, Box-and-Whiskers plots were constructed (Microsoft Excel 2019 version). The plots represent a beneficial way to compare the distributions of the parameter values. It shows the principal statistical attributes such as median, minimum, maximum, upper and lower quartiles.

Paired samples t-test,also called the dependent samples t-test was applied to see if there are two measurements apply to the same samples with the same condition. A T-test is based on comparing the means of the two (pair) samples. The null hypothesis indicates that if the means of the two tests used are equal ($\mu_1 = \mu_2$), there is no statistical significance in the difference between the WA-WQI and CCME-WQI mean values. On the other hand, if the means of the two tests used are not equal ($\mu_1 \neq \mu_2$),this implies that there is a statistical significance in the difference between the WA-WQI and CCME-WQI mean values (Wackerly et al., 2002).

4. Results and Discussion

4.1. Spatial analysis of water quality

The study data set comprises11 water quality parameters (EC, pH, DO, Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, NO_3^{-}, HCO_3^{-}, SO_4^{2-}, Cl^{-}). The statistical variations of every parameter amongst the different groundwater wells were plotted using the Box-and-Whiskers as shown in Figure (3), whereas the spatial distribution maps were constructed using the ArcGIS 10.8 Software and are presented in Figure 4(a) - (k).

The study area is divided depending on the attribute classes of each parameter into four categories; 1-4. The pH values in all groundwater wells ranged between 6.5 and 8.03, which lie in the permissible limits of JISM as shown in Table (2). Most pH values (Figure 4a) were observed in categories 3 and 4 with a range from 7-8. Thus, the groundwater reflects neutral to slightly add pH values in the study region. The EC values of water samples ranged between 372 and 5490 µS/cm, these values are directly proportional to the total dissolved solids. 46 % of the samples show a high concentration of EC greater than the permissible limit set by JISM (2015). These excesses are shown in categories 2, 3, and 4 (Figure 4b). Dissolved oxygen (DO) refers to the amount of free non-compound oxygen dissolved in water. The minimum value of DO in the study area is 0.1 mg/L, while the maximum value equals 8.6 mg/L. Figure 4c shows that most of the DO concentrations occurred in category 3.

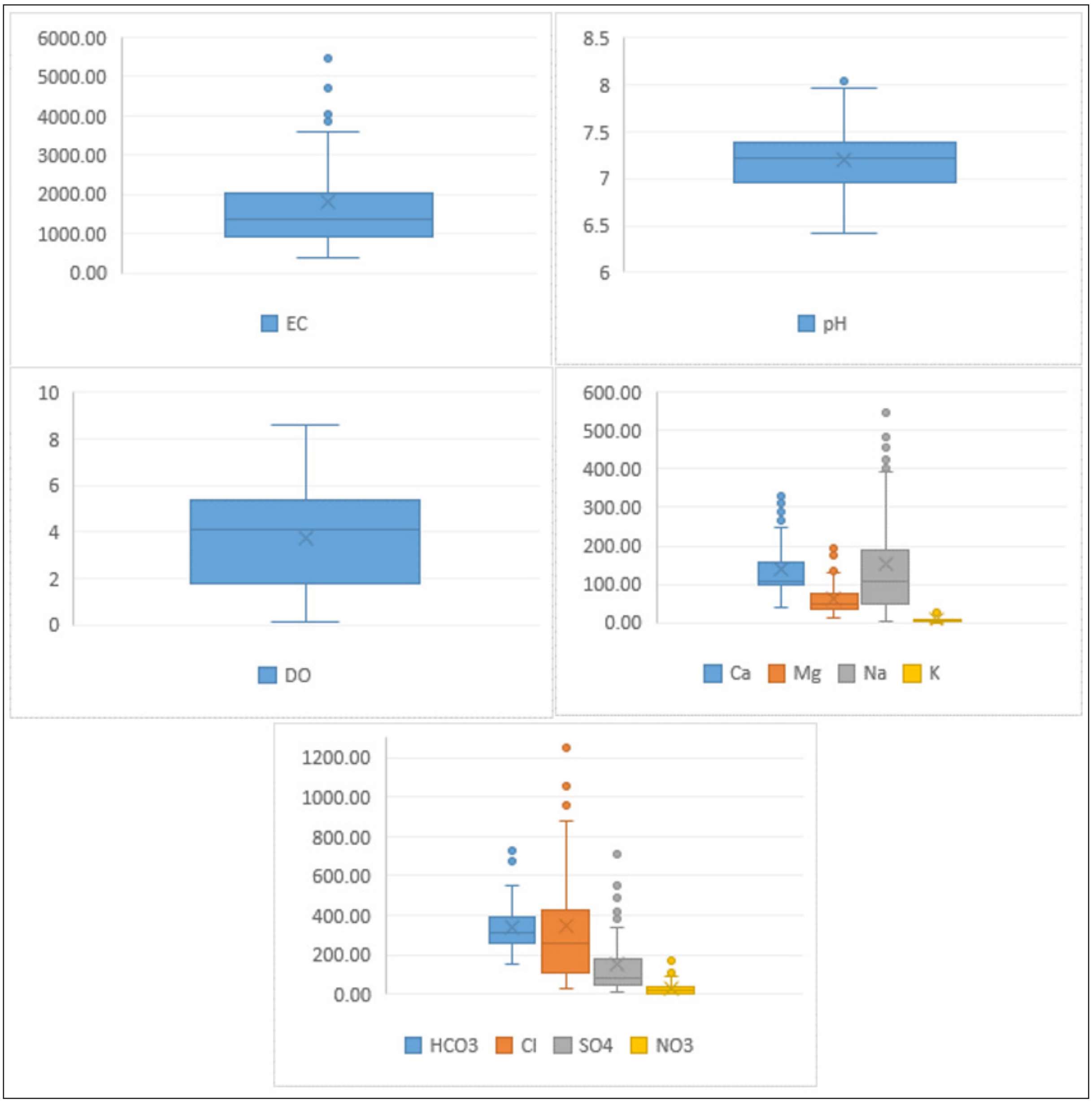
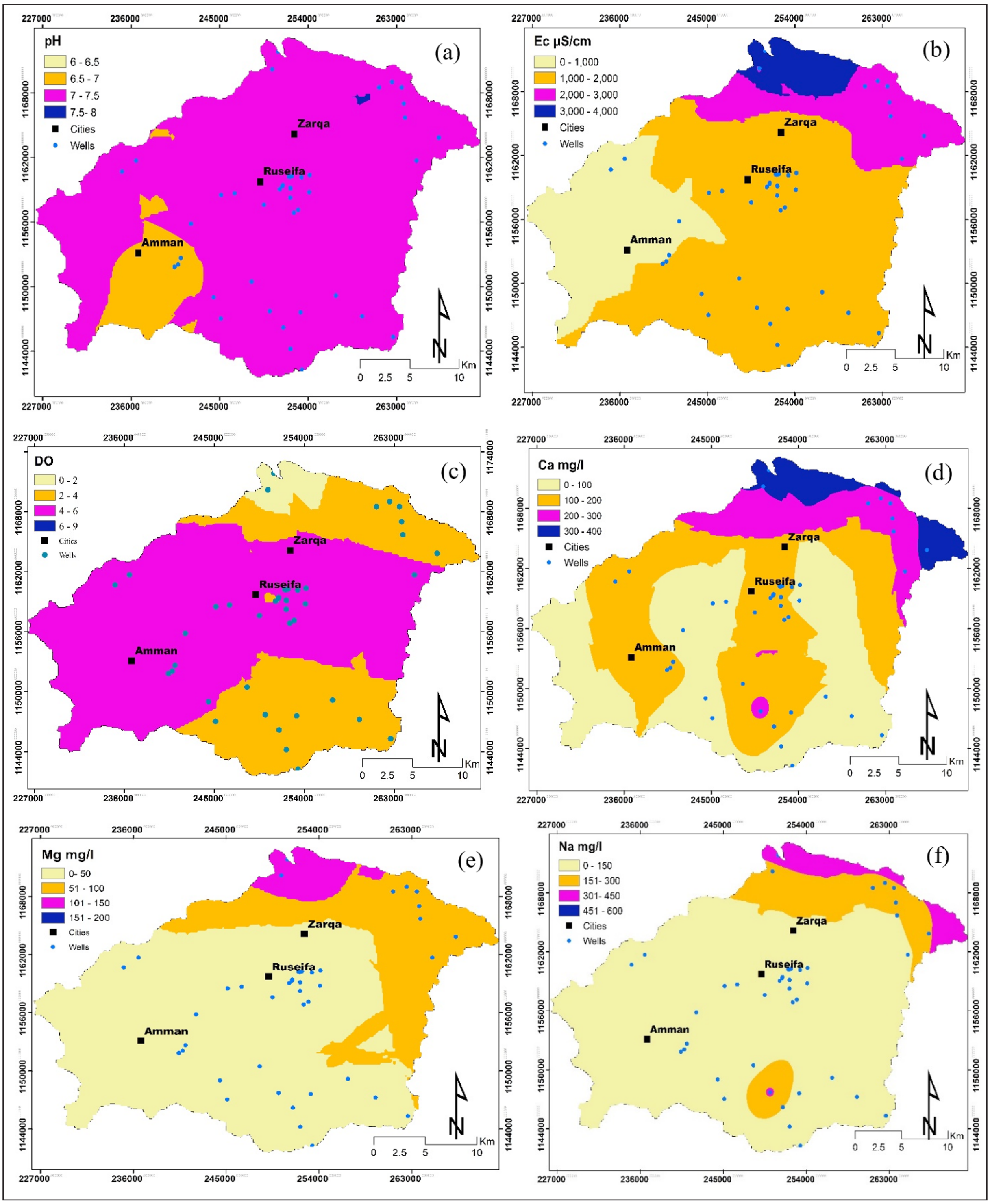


Figure 3. Box-and-Whisker plot of water quality parameters for the study area in the year 2020.

Calcium and magnesium values ranged from 40 to 331 and 13 to 193 mg/L, respectively. 17 % and 5 % of the calcium and magnesium concentration in the study area lie beyond the documented permissible limits of 200 mg/L for Ca^{2+} and 150 mg/L for Mg^{2+}. From the spatial distribution of calcium (Figure 4d), the higher concentration value was exhibited in the northern and northeast of the region. Figure 4e shows that most of the magnesium concentrations occurred in category 3. This is due to ion exchange in groundwater, dissolution of minerals, agronomic and industrial related activities (Fernandes et al., 2008 and Singh et al., 2011).

Spatial distribution of sodium and potassium concentrations are shown in Figure 4f-g where the high concentration of sodium is clear in categories 2 and 3, whereas the northeast part of the study area is distinguishing with high amounts of potassium values. Sodium and potassium values ranged between 3 and 544 mg/L and 0.03 to 37, respectively.24 % of the samples exceed the permissible limit of JISM (2015) for Na^{+} concentration while 5 % of the samples exceed the permissible limit of JISM (2015) for K^{+} concentration. High K^{+}concentration in water may lead to health concerns for people suffering from hypertension, kidney dysfunction, and diabetes (WHO, 2017). While, Na+ concentrations have a multifunction in the human body to maintain blood pressure, control fluid levels, for nerve and muscle function. However, a high level of Na^{+}isconsidered harmful to the human body (WHO, 2017). Sodium and potassium are present in the water through anthropogenic activities such as industrial discharges, fertilizer, and the release of wastewater around the wells (Al Kuisi et al., 2009).

Figure 4h-k shows the spatial distribution of Chloride, Nitrate, Sulfate, and Bicarbonate in the groundwater samples. Chloride values range from 30 to 1251 mg/L and 24 % of the samples exceed the JISM (2015) allowable limits (Table2). The high Cl^{-} content lies in the category 3 and 4 (Figure 4h). Chloride may get into water from a number of sources including the weathering of soils from industries and municipalities, agricultural activities and overexploitation of the aquifer (Al Kuisi et al, 2009). Nitrate concentrations ranged between 0.1 and 170 mg/L in the study area. Figure 4i indicates that high nitrate concentration is stationed in the northern part of the region. 22 % of the samples exceed the maximum permissible limit of NO_3^- according to JISM (2015).On the other hand,5 % of the samples exceed the permissible limit of sulfate according to JISM (2015). SO_4^{2-} concentrations ranged from 14 to 712 mg/L, and the spatial distribution of $SO_4^{2-}$is shown in Figure 4j. The highest concentration of sulfate is located in the northeast part of the region. Increasing nitrate and sulfate concentrations in the groundwater could be attributed to using chemical and natural fertilizers for agricultural activities and the wastewater effluents (Al Kuisi et al., 2009). Bicarbonate values in the analyzed samples ranged from 153 and 732 mg/L. The TheHCO_3^- content in 59 % of the samples has been found to exceed the maximum permissible limit for HCO_3^- in drinking water guidelines of JISM (2015). This is mostly observed in the northern part of the study area (Figure 4k). The carbon dioxide-charged water infiltrating through the soil zone under the influence of H_2CO_3 commonly encounters dissolvable minerals which are calcite and dolomite which could be dissolved through contact with the CO_2-charged seeping water. This process could be regarded as the major source of HCO_3- input into the groundwater system (Freeze and Cherry, 1979).



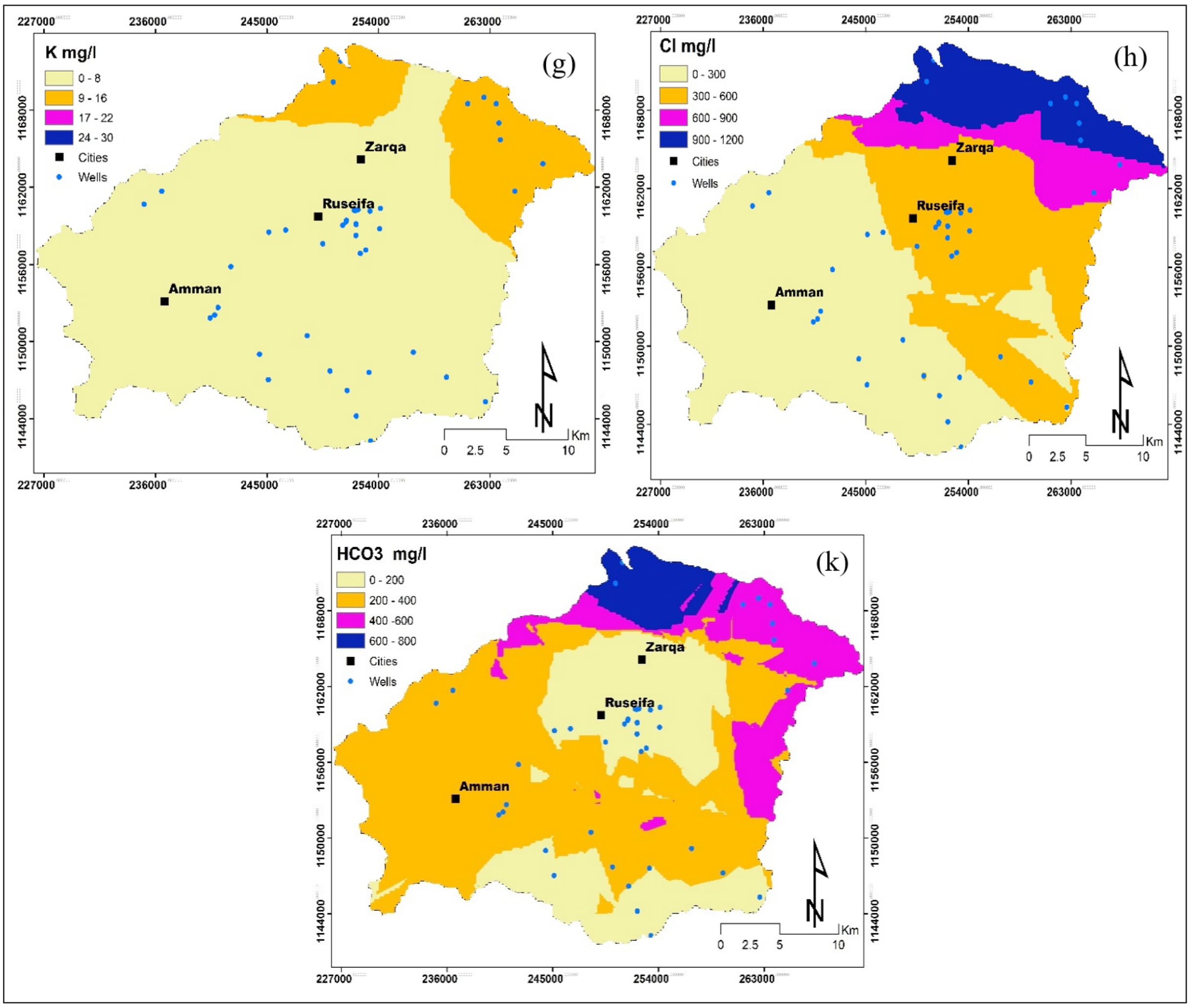


Figure 4. Spatial distribution for water quality parameters in the study area.

4.2. Comparison between CCME and WA water quality indices

Generally, most of the WQI's work is focused on the comparative performance of the various quality indices in surface water bodies rather than groundwater because the surface water is more vulnerable to pollution. Many researchers have discussed results related to the performance of WQI's in surface water bodies (Alexakis et al., 2016; Darvishi et al., 2016; Hamlat et al., 2017; Majeed, 2018; Noori, 2020).

Several researchers showed a clear interest in the WA-WQI, whereas the others, widespread overall the world, applied the CCME-WQI separately (Bilgin, 2018; Ewaid, 2016; Uddin et al., 2017; Ama et al., 2018; Dutta et al., 2018) and just a few of them focused on comparing indices performance for water quality management purpose such as Lopes et al., 2020; Wong et al., 2020; Ebraheim et al., 2020; Zotou et al., 2019. The lack of comprehensive and comparative studies of the performance of Water Quality Indices in the area under consideration prompted this study.

The first comparison made was carried out to check whether the two indices would yield similar results. The t-test rejected the null hypothesis regarding similarity at the 95% significance level. This means that the produced means using the two indices exhibit a significant statistical difference.

Figure 5 shows the calculations made using the WA and CCME indices. Both indices include 11 water quality variables (EC, pH, DO, Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, NO_3^{-}, HCO_3^{-}, SO_4^{2-}, Cl^{-}). Results observed show that CCME-WQI classify the groundwater samples as follows: "26% Excellent", "49% Good", "8% Fair", "12% Marginal", and "5% Poor" on the other hand, the WA-WQI classify the sample in the following manner: "8% Excellent", "45% Good", "31% Poor", "14% very poor", "2% unsuitable for drinking purpose". The results indicate that there is a minor disparity in rating groundwater by these two indices. The reason for this minor difference is related to weights, assignments, quality scales, and aggregation formulae. After reviewing the results of the analyzed parameters for the dissimilar samples between the two indices, it is clear that they are not exceeding the limits recommended by the JISM (2015). Although the Weighted Average water quality index classifies it as very bad to not suitable for drinking purposes.

Figure 5. Variations in water quality values obtained at the groundwater monitoring stations of the study area using the above mentioned indices.

In general, the comparison between the WA -WQI and CCME -WQI considering their merits and demerits is shown in Table 4 (Terrado et al., 2010; Abbasi and Abbasi, 2012;Yogendra and Puttaiah, 2008; Akoteyon et al., 2011).

Table 4. Merits and demerits of the selected water quality indices (Terrado et al., 2010; Abbasi and Abbasi, 2012;Yogendra and Puttaiah, 2008; Akoteyon et al., 2011).

Merits	Demerits
Weighted Arithmetic Water Quality Index	
1. Uses several parameters in a mathematical equation to obtain a rating of water quality. 2. Water quality is represented by one number, which facilitates the delivery of information to decision-makers and citizens. 3. It helps to describe the suitability of surface and groundwater sources for human use. 4. It requires fewer parameters compared to other water quality parameters for a specific use. 5. Several parameters and their composition can be used to assess and manage water quality.	1. The final water quality indicator number may not be a true description of water quality. 2. There are many parameters that are not taken into account in calculating the water quality index. 3. A bad value of any parameter may affect the calculation of the water quality index. 4. A water quality index based on important parameters can provide a simple water quality indicator.
Canadian Council Ministry of Environment Water Quality Index	
1. Convert the measure of the variable to a single number. 2. Flexibility to choose the parameters that contribute to the calculation of the index. 3. Adaptability to changing legal requirements and different uses of water. 4. Simplify the multivariate data statistically. 5. Understandable and clear diagnosis for decision-makers and the public. 6. An appropriate tool to assess the water quality at a specific location. 7. Easy to calculate. 8. Tolerance for lost data.	1. Loss of information of single variables. 2. Loss of information about the particular objectives for each location and specific utilizing of water. 3. Results are influenced by the formulation of the index. 4. Missing a lot of information about the interactions between variables. 5. The index is difficult to adapt to different ecosystem types. 6. Equal importance is given to all variables. 7. It cannot be used in combination with other indicators or biological data. 8. When few variables are considered or there is an excessive amount of covariance between them, F1 cannot work properly. 9. Gives a partial diagnosis of water quality.

Figure 6. shows the spatial variation of WQI's values in the studied wells within the study area. The CCME-WQI values range from 22 to 100, while the WA-WQI values range from 5 to 157.

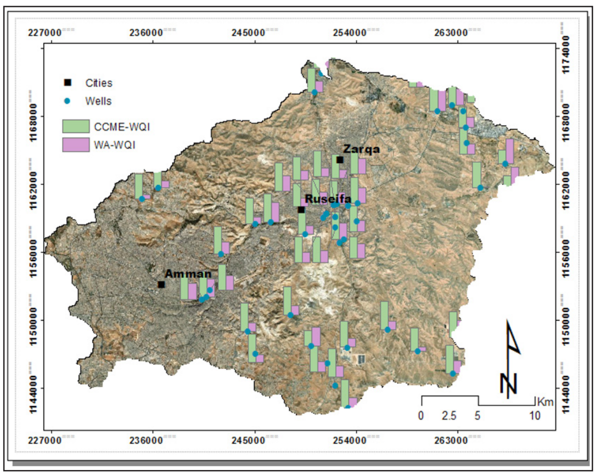


Figure 6. Spatial variation of CCME and WA-WQI values.

WQI's spatial distribution maps were constructed using kriging technique (Figures 7 and 8). The high CCME index value corresponds to excellent groundwater while the low value indicates poor water quality. On the other hand, the low WA index value corresponds to excellent groundwater while the high value indicates very poor and unsuitable water. A careful inspection of both figures 7 and 8 shows that there is a great similarity between both figures. Both indices characterized the northern part of the study area similarly, whereas the southern part differs slightly, in such a manner where the CCME-WQI index yielded more precise and detailed characterization. This reflects its superiority to WA-WQI especially in pinpointing specific areas of deteriorating water quality.

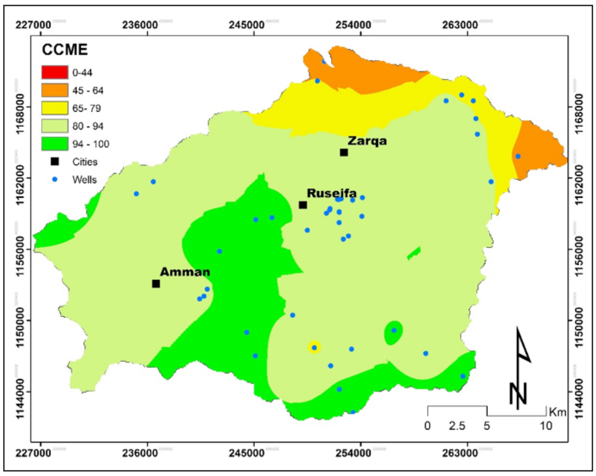


Figure 7. CCME-WQI prediction map for the study area.

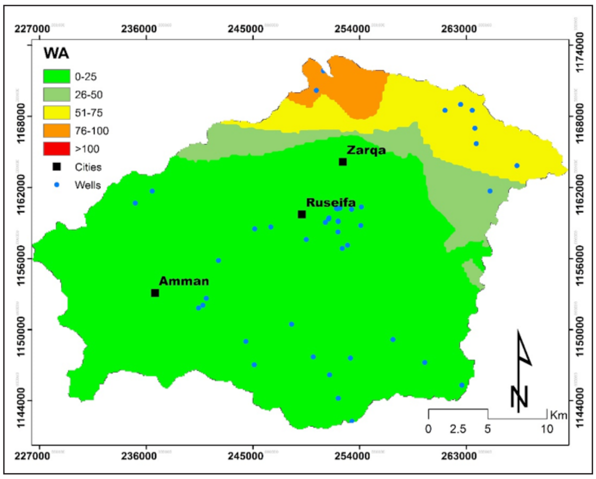


Figure 8. WA-WQI prediction map for the study area.

5. Conclusions

Water quality monitoring and evaluation indices based on water quality parameters are useful tools. They can reflect the water quality status and give an impression about the suitability of water for drinking purposes. Spatial and Statistical analyses were conducted to analyze 11 water quality parameters (EC, pH, DO, Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, NO_3^-, HCO_3^-, SO_4^{2-}, Cl^-) across the study area. The paired (two tail) t-test for the WQI values of the study area at a significance level (a = 0.05) shows that there is a strong indication that the difference between CCME-WQI and WA-WQI mean values are statistically significant. The grading of the study area quality varied due to the difference in the numbers and types of selected parameters, mathematical structures, weights, assignments, quality scales, and aggregation formulae in each index. The CCME-WQI proved to be a more accurate tool in characterizing the groundwater of the study area. The CCME-WQI has flexibility in the selection of parameters and simplicity in the calculation and pinpoints specific areas of deteriorating water quality.WA-WQI ranked 15% of the samples as "very bad" and "not suitable for drinking purposes" thoughthe parameters used in determining the water quality indices did not exceed the values allowed by the JISM.

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