Comparative analysis of weighted arithmetic and CCME Water Quality Index estimation methods, accuracy and representation

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Abstract. This paper aims to investigate and evaluate the difference in the computed WQI using the weighted arithmetic method (WAM) and Canadian Council of Ministers of the Environment (CCME) and the reasons of the exaggeration and permissive of these WQIs. In addition, it also aims to specify the suitable WQI computation method in Iraq. Al-Shula City, Baghdad, Iraq was considered as the case study. The results of estimating the WQI in the Al-Shula City using WA and (CCME) methods for each month fluctuated between 0.103 to 8645 and 8.53 to 58.56, respectively. Hence the WQI fluctuated between excellent for drinking (excellent to poor). However, the range of the computed accumulated WA and CCME WQI was between 8.33 to 3886 and 9 to 59. Consequently, for the two methods, the class of WQ is fluctuated between excellent to unsuitable and excellent to poor. In addition, the calculated CCME WQIs were always lower than the computed WA WQIs. Therefore, the CCME method is permissive or somewhat lenient in contrast to the WA method. Consequently, the WA WQI is more sensitive to presence of toxic contaminants than the CCME WQI. Therefore, the WA WQI is more suitable to use in Iraq because of the high fluctuation in the level and types of pollution sources.

1. Introduction
Water is important all over the world for the survival of mankind. The water scarcity and pollution became a serious challenge threatening the survival of human life. However, many domestic and drinking water resources have become polluted. This contamination from different sources and various types of pollution causes health problems. Hence, monitoring and assessment of water quality (WQ) helps to have an early alarm to decision makers to take the right decision within a suitable time. Therefore, it becomes urgent to use simple applicable methods for evaluating the status of water quality. There are different methods for evaluating water quality. A summary of the WQ estimation approaches are shown in Sivaranjani et al. (2015). One of the most widely used methods is the indices. Water Quality Index (WQI), which is one of the most useful indices, was initially developed by Horton (1965). Since then it has been widely accepted and applied in Asian, African and European countries. Furthermore, Brown (1970) developed a new WQI estimation approach based on assigning weights to individual parameter. Subsequently, many development and modifications have been conducted for WQI estimation approaches (Bhargava et al 1998, Dwivedi et al.1997). However, there are many WQI estimation method such as: Weight Arithmetic (WA), National Sanitation Foundation (NSF), Canadian Council of Ministers of the Environment (CCME), Oregon (O) etc. have been formulated by several national and international organizations. Sivaranjani et al. (2015) presented a summary of these approaches. However, some of the WQI computation methods depend upon weights or variables, but not always give adequate assessment. The WA and CCME are the most...
commonly used WQI. However, there is big difference between the estimated WQI using these two methods.

Chang et. al. (2001) conducted a comparative study to assess the water quality in the Tseng Wen River system in Taiwan. The results of applying the conventional methods of estimating the WQI was compared with those of applying three fuzzy synthetic evaluation techniques. This study showed that the techniques might succeed in coordinating inherent contradictions and interpreting complex conditions. Also, the developed fuzzy approach can be used to verify the maximum daily pollution program of the WQ. Sammen (2013) applied the WA and CCME for calculating WQI in Hemren Lake in Iraq, which is used as a source for drinking and irrigation water. There was big difference between the calculated WQI by using these two methods. In spite of this difference, there was no comparison between the two methods to see which one is much more suitable for Iraq. Many researchers studied the WA, whereas the others studied CCME separately. AlSaqqar et. al. (2013) studied WA to evaluate water quality of Euphrates River for the purposes of drinking. Also, Al Obaidy et. al. (2015) used CCME to evaluate the WQI of Mahrut River for irrigation purposes. Furthermore, Mohammed et. al. (2015) evaluated the quality of potable water of Al-Shuala City in Baghdad, Iraq, by using WA and compared the results with the Standards of World Health Organization (WHO) and Iraqi Standards (IQS) for drinking water.

In the reviewed previous works, it can be noticed that the WA WQI can have high value although all the values and concentrations of the water quality parameter are less than the standard allowable limits. It means that the estimated WA WQI may have exaggerated values. Hence, this confuses the assessment results. Also, all the reviewed studies deals with the evaluation of WQ by using one of the WQIs without comparisons between the WQI estimation methods and consideration of the spatial and temporal fluctuation of WQ and the effect of the amount of deviation or bios of contaminant concentration or values from the acceptable limits on the value of the estimated WQI. Therefore, this issue should be carefully studied in detail. The main purpose of this paper is to study the WA in detail to identify the weakness points in comparison to the CCME method.

2. Methods and Materials
2.1. Methods
The most important drinking water resources all over the world are the surface water and groundwater. Traditionally, drinking water quality status is done by comparing the individual physical, chemical and biological parameters with standard values. The limits of those parameters that are harmful to human health have been established by national or international level by various laws and regulations. The quality of these water sources are usually found unsuitable for use, hence need to be justified. However, WQ assessment commonly becomes complex due to the presence of numerous indicating parameters. On the other hand, assessing WQ on the basis of single statistical analysis concerning individual parameters remains inconvenient. Hence, it is not popular and difficult to understand by many people (Akoteyon et al. 2011, Katyal 2011). The WQI focuses at assessing the quality of water through a single numerical value, computed on the basis of one system which converts all the individual parameters and their concentrations, present into a single value. This is an effective approach that permits to compare the quality of different water samples based on a single numerical value and not only the parameters values of each sample. Any result of WQ measurements can assist as indicator of WQ. Contrary, WQI is an effective tool that combines composite influence of each parameter with a single value indicating the overall quality of water. WQI increases the ability of understanding of definite WQ that is useful to the policy makers, as well as users of the water resource (Nasirian 2007). WQI indicates the quality of water as a single number, which represents all quality of water for any desired uses. It is defined as a rating reflecting the composite influence of different water composite influence of different WQ parameters (Al-Badran, 2013).
There are many different types of WQI, such as, National Sanitation Foundation (NSF), Oregon (O), Bhargava (B), Smith (S), British Columbia (BC), Canadian Council of Ministers of the Environment (CCME), Overall Index of Pollution (OIP), River Ganga RG), Recreational (R), Contamination (C), Weighted Arithmetic (WA), Aquatic Toxicity (AT), Dinius (D), etc. In skilled opinion method, variable selection is the first step in development of WQI. Therefore, collection of water samples is important for raw data generation. Hence, the variables are transformed based on the generated raw data. The transformation process is conducted using various statistical approaches. WQ parameters have different ranges as well as units. According to the transformation process, all the parameters are transformed into a common scale and subindices are generated. Each parameter is assigned a weight according to its potential impact on the WQ. Expert evaluation is required to assign these weights. The weight assignment is not used with some indices, such as aquatic toxicity. Then, a value of cumulative index is generated through assemblage of the subindices to generate a cumulative index value. Subsequently, the WQ is assessed and classified (Ongley and Booty 1999). Because of the large amount of WQ data, extraction of significant information about the WQ condition represents a serious challenge. In indices development, many statistical approaches such as cluster analysis (CA), discriminant analysis (DA), principal components analysis (PCA), factor analysis (FA) and artificial intelligence (AI) are widely used to investigate relationships and structure in multivariate data for aggregation and transformation steps (Kung et al. 1992). Using these approaches improves accuracy of the index through reduction in subjective assumptions. Among various modifications of WQI systems the following two were used in this study:

2.1.1. Weighted Arithmetic Water Quality Index (WA WQI). The weighted arithmetic (WA) method is one of the commonly used methods to study WQI. WA method classifies the WQ according to the degree of purity by using the most commonly measured WQ parameters. This method has been widely used in Iraq to calculate the WQI. The philosophy of this method depends mainly upon the weight of each parameter. This weight varies from numbers less than 0.000667 to numbers more than 330. There is a large variance in the weights. The relative weights are computed by values inversely proportional to the standard of the parameters. WQI is computed by using the following equations (Alsaqqar et al. 2013, Alobaidy et al. 2010).

\[
WQI = \frac{\sum_{i=1}^{n} q_i \cdot W_i}{\sum_{i=1}^{n} W_i} \tag{1}
\]

The quality rating scale (Qi) is calculated by using the following expression:

\[
Q_i = 100 \left[ \frac{V_i - V_o}{S_i - V_o} \right] \tag{2}
\]

Where, \(V_i\) is estimated concentration of \(i^{th}\) parameter in the analyzed water; \(V_o\) is the ideal value of this parameter in pure water \(V_o= 0\) (except pH =7.0 and DO = 14.6 mg/l) and \(S_i\) is recommended standard value of \(i^{th}\) parameter. The unit weight (Wi) for each WQ parameter is calculated by using the following formula:

\[
W = \frac{K}{S_i} \tag{3}
\]

Where, \(K\) = proportionality constant. It can be calculated by using the following equation:

\[
K = \frac{1}{\Sigma \left( \frac{1}{S_i} \right)} \tag{4}
\]
In this method, the output ranges from 0 to 100, and sometime exceed 100, see Table 1. The 0 to 50 value represents excellent WQ condition, while 50-100 is good WQ, 100-200 is poor WQ, 200-300 is very poor WQ and it is unsuitable for drinking if WQI is greater than 300 (Bhaven et al., 2011).

2.1.2. Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI). CCME WQI is established based on the British Columbia Water Quality Index (Canadian Council of Ministers of the Environment 2001b). CCME WQI comprises 3 factors in calculation: scope (F1), frequency (F2) and amplitude (F3), which represent the percentage of parameters that do not meet their objectives at least once (failed parameters), the percentage of individual tests that do not meet their objectives (failed tests), and the amount by which failed tests do not meet their objectives, respectively (Canadian Council of Ministers of the Environment 2001b, Mostafaei 2009, Terrado et al. 2010, Selvam et al. 2014).

(i) Calculation method of scope (F1).

\[ F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \]  

(ii) Calculation method of frequency (F2).

\[ F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \]  

(iii) Calculation method of amplitude (F3).

For the parameter which is the larger the better, such as dissolved oxygen,

\[ \text{excursion}_i = \frac{\text{objecti ve}_i}{\text{failed test value}_i} - 1 \]  

For the parameter which is the smaller the better, such as COD,

\[ \text{excursion}_i = \frac{\text{failed test value}_i}{\text{objecti ve}_i} - 1 \]  

Then the Canadian Council of Ministers of the Environment defines a subfactor “nse”, which represents the normalized sum of all the excursions (Mostafaei 2009, Terrado et al. 2010).

\[ nse = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Total number of tests}} \]  

and the amplitude (F3) is generated by

\[ F_3 = \frac{nse}{0.01 \times nse + 0.01} \]  

(iv) Calculation method of CCME WQI.

\[ \text{CCME WQI} = 100 - \sqrt{\frac{F_1^2 + F_2^2 + F_3^2}{1.732}} \]  

CCME WQI is a dimensionless number between 0 and 100, which describes the WQ from poor to high quality (Dede et al. 2013). According to the score of CCME WQI, the WQ condition is classified into 5 categories, which are: excellent if WQI is 94 to 100, good if WQI is 79-94, fair if WQI is 64-
79, marginal if WQI is 44-64 and poor if WQI is 0-44  (Canadian Council of Ministers of the Environment 2001a, Feng 2016).

It is seen that the CCME gives one value for each station all over the period of study. For the WA, it is found that there is a value of WQI for each (=specific) date (=reading) in each (=particular) station.

The merits of both methods represent measurements of different parameters in a single number of WQI; both methods are easy to compute and use; give a good description the suitability of surface and groundwater sources for human consumption, for drinking and irrigation.

The demerits of both methods are: WQI in CCME and WA cannot carry enough information about the real quality situation of the water body, a single number may not give the all indication about WQ and there are many other parameters that are not included in the index.

In the WA, to examine the equation if it works correctly or not, it was assumed that all the parameters is equal to 0, except pH = 7, and DO = 14.6. After calculations, the WQI is equal to 0, that means WQ is excellent. The other assumption adopted another idea by scanning each parameter separately. This scan is done by increasing the value of each parameter from 0 to the less value of the allowable standard of this parameter. Some parameters show higher values of WQ even the value itself is less than the permitted value of the standard. This examination leads to think for other method more appropriate than this method.

The CCME contains a table, the x-axis represents the 10 parameters, while the y-axis represents the sampling date. For each station (site) there is one value represented in the WQI in this site. In the WA, in each site there are values of WQI in each sampling date. It means that the WA gives more details than CCME. It is difficult to compare between the CCME, which gives one value in each site during the period of study, with the WA, which gives a value in each date in each site. To make a comparison between these two methods, there are two assumptions.

The first assumption, in the CCME computes WQI in each date by ignoring the other dates in this site to find one value for this date and compares it with the same date in the WA. In other words, in the CCME table, take only one row to compute WQI for this date, and then take the second row to calculate the WQI for this date, and so on. The second assumption is computing accumulative value for each index. For example, in the CCME, taking the first row (first date) to compute WQI and compare it with the WA, then taking the first and second rows (first and second date) in the CCME to compute WQI and compare it with the first and second values of parameters in the WA to compute one value of WQI.

2.2. Materials:
To implement the evaluation and application for the cases, and studying the diffraction may occur in WQI values, and making the necessary comparisons. Al–Shula City, which is located in Baghdad, Iraq, was chosen to be the case study. In Al-Shula City there is a big canal for drainage of salinity water, which passes through the East of the city to the West. This city is suffering from deficiency of general services and accumulation of waste products that make it important to compute and evaluate WQI in this city. Figure 1 shows Al–Shula city which is characterized by high population density is the study area of this research. It is located in North – West zone of Baghdad, the capital city of Iraq. The water quality data of the study area were taken from Mohammed et al. (2015). Ten parameters were chosen to evaluate WQI. These parameters are pH, Chlorides (Cl), total hardness (TH), turbidity, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), and heavy metals: lead (Pb), cadmium (Cd), and iron (Fe).
3. Results and Discussion

3.1. Computation of WA WQI

The computed WQIs at each station per each month and neglecting other months using the WA method, based on equations (1) to (4), at the considered ten were shown in Figure 2. The computed WQI fluctuated and dispersed within a range of 0.103 to 8645. The high values of WQI was at station S9. At this station, the maximum WQI was 8645 on 22 February while the minimum was 0.103 on 1 February. Hence, the class of water quality at this station fluctuated from excellent to unsuitable for drinking. However, low values of WQI were at station S1. At this station, the maximum WQI was 136 on 19 April while the minimum was 0.103 on 1 February.

3.2. Computation of CCME WQI
Based on equations (5) to (11), which concern applying the CCME for computing the WQI, the monthly WQI was computed at each station per each month and neglecting other months, see Figure 3. The computed WQI ranged between 8.53 to 58.56. The high values of WQI was at station S9. At this station, the maximum WQI was 58.56 on 22 February while the minimum was 30.33 on 12 April. Hence, the water quality at this station is classified as good to poor. However, there were low values of WQI at station S3. At this station, the maximum WQI was 58.03 on 22 February while the minimum was 8.53 on 12 April. Consequently, the class of water quality at this station is poor to excellent.

**Figure 3.** Monthly WQI using CCME.

In General, the comparison between the WA WQI and CCME WQI, Figures 2 and 3, show that the WQI at station 9 was always has the highest value, while the lowest value was in station 1.

It is noted that in the WA method, presence of pH and DO is very necessary. In the absence of these two elements errors appear in the calculations and in the equation itself. Hence, the correct results cannot be obtained (showing negative water quality index). However, in the CCME method, calculation of WQI does not base on the pH and DO. It passed on the values of all the WQ parameters, if they exceed the permissible limits it failures, and it is required to calculate F1, F2.

### 3.3. Computation of Accumulated WA and CCME WQI

The monthly WA and CCME WQI, considering the entire monitoring period, was computed at each station using equations (1) to (4) and (4) to (11), respectively, based on the water quality data, see Figures 4 and 5.

The range of the computed accumulated WA and CCME WQI was between 0.13175 to 3886 and 8.7 to 59), respectively. The high values of WA WQI were at station S9 where the maximum WQI was 3886 on 22 February while the minimum was 1837 on 26 April. Consequently, the class of water quality at this station is unsuitable. Moreover, the low values of WQI was at station S1 where the maximum WQI was 11.48 on 19 April while the minimum was 0.131 on 8 March. Hence, the water quality at this station is excellent. However, the high values of CCME WQI was at station S9 where the maximum WQI was 59.01 on 22 March while the minimum was 54.9 on 1 February. Consequently, the class of water quality at this station is poor. Moreover, the low values of WQI was at station S1 where the maximum WQI was 13.14 on 19 April while the minimum was 8.705 on 12 April. The water quality at this is excellent. Figure 6 shows a comparison between the accumulated WA and CCME WQI. It is observed that the computed WQI at station 9 has higher values than those at other stations. This is because it contains some toxic impurities (such as lead) that has heavy weight compared to other parameters.
Figure 4. Accumulated WA WQI.

Figure 5. Accumulated CCME WQI.

Figure 6. Comparison between Accumulated WA and CCME WQI.

The results illustrated in figures 2 to 6 show that the computed CCME WQI are always lower than the computed WA WQI. This indicated that the CCME method is permissive or somewhat lenient in contrast to the WA method. In WA WQI, it can be noted that when the lead is present in water, even if it is within or below the permissible limits, the WA WQI will give an indication that the water is not suitable for drinking or poor. This is because in the WA method weights are taken into consideration. For example, the weight allowed by WHO for lead is 0.01 and when the value is reversed, the number
turns to 100, so large and exaggerated WQI value will obtain when using the WA method. The same is true for cadmium where the permissible limits are 0.003, according to WHO, and when reversing the value it becomes 333.33 i.e. the value of the WQI is high and exaggerated. Whereas, in the CCME WQI method, weights are not taken into consideration. Here the important factors are F1 and F2. Forasmuch, F1 represents the percentage of water contaminants that failed to meet the drinking water quality criteria at least once during the relevant time for the total number of measured pollutants. F2 represents the percentage of tests that did not meet the criteria for water quality. Consequently, the CCME WQI is always permissive and somewhat lenient. However, if there is a high toxicity but does not exceed the permissible limits, the CCME WQI indicates excellent water quality. While the for the same contaminant condition, the WA WQI indicates unfit for drinking or poor water quality.

4. Conclusions
Based on the results and analysis of the comparison between the WA and CCME WQI estimation methods, the following conclusions could be extracted:

• In the study area (Al Shuala City), the computed WQI using WA method for each month fluctuated between 0.103 and 8645. Hence, the WQ is fluctuated between excellent to unsuitable for drinking. While, the computed WQI using CCME method for each month ranged between 8.53 and 58.56. Hence the WQ is fluctuated between excellent and poor. However, the range of the computed accumulated WA and CCME WQI was between 0.131 to 3886 and 8.705 to 59.01. Consequently, for the two method, the class of WQ fluctuated between excellent to unsuitable and excellent to poor.

• The computed CCME WQI is always lower than the computed WA WQI. Therefore, the CCME method is permissive or somewhat lenient in contrast to the WA method.

• The WA WQI is more sensitive to presence of toxic contaminants than the CCME WQI.

• The WA WQI is more suitable to use in Iraq because of the high fluctuation in the level and types of pollution sources.

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